Marine Engineering

I get a lot of questions, at least two a week, from people looking at becoming a marine engineer but unsure what qualifications they require, can get and what jobs they can do after this. This page hopefully goes someway to explain.

Marine engineering comes in two families

- Sea Going Marine Engineering- These are the people this sight is specifically aimed at although there are some parts equally of interest to both
- Shore Based Marine Engineering - These are people who do not study for certificate of competencies but instead follow an accademic route which leads them to the research and development side

Sea Going Marine Engineering

Entry qualifications are very much dependent on the root you follow. This can range from none to a degree. No qualifications are required when you first start as a member of the crew gaining experience and knowledge whilst working on a vessel. An increaseing level of qualification is required as the curse which leads to the first certificate of competency is condensed.

Traditionally you will start as a cadet having 5 or more high school qualifications. Hopefully this will be under sponsorship from an employer. Completion of the cadetship should give a qualification of a higher diploma or Degree. These qualifications are very important as they contin units which do not have to be retaken when you try for the higher levels of certificates in later years.

Having obtained your first certificate you will now be qualified to sail as a watchkeeping engineer on a variety of vessels. You wil be expected to have at least a rudimentary knowledge of large diesel engines, air compressors, fridge systems, pumps, boilers and amny other anciliary equipment. You will also have some knowledge on electrical, electronic and control engineering. You will have some ability in the workshop including machining and welding.

In future years you can chose to move into the many shore based industries that are currently crying out for experienced engineers such as technical superintendency, Accident investigations, damage assessor and surveying

Shore Based Marine Engineering

There are degree and above qualifications in marine engineering and naval architecture which allow entry into the various design and development side of vessels. There are in addition qualifications specifically for sea going personel that are looking to come ashore

Corrosion found in the Boiler and feed systems

Corrosion and tube failure caused by water chemistry

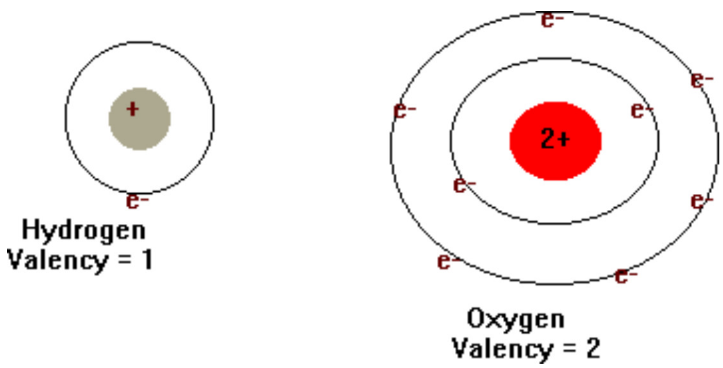
Metals obtained from their oxide ores will tend to revert to that state. However , if on exposure to oxygen the oxide layer is stable , no further oxidation will occur. If it is porous or unstable then no protection is afforded.

Iron+O_2 --- magnetite(stable and protective) + O_2----ferrous oxide (porous)

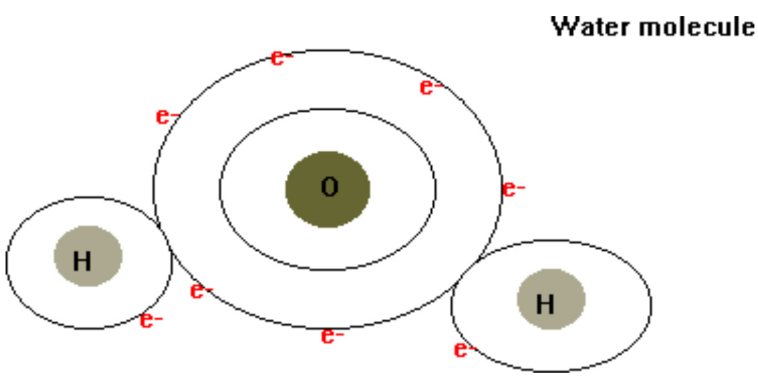
Two principle types of corrosion

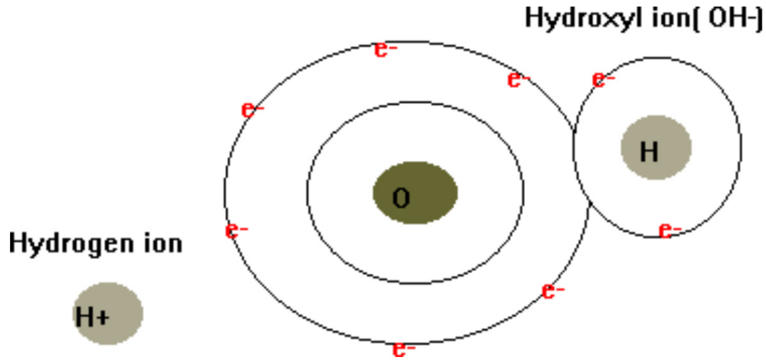
Direct chemical-higher temperature metal comes into contact with air or other gasses (oxidation, Sulphurisation) **Electrochemical**-e.g. Galvanic action , hydrogen evolution , oxygen absorption

Hydrogen Evolution (low pH attack)

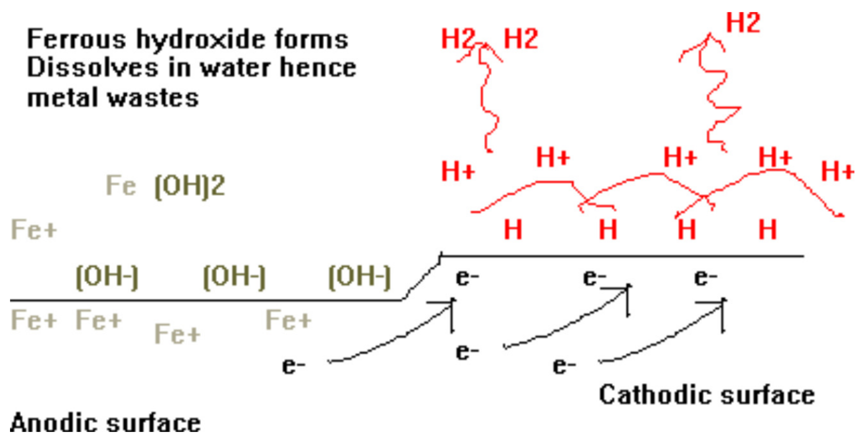


Valency = No of electrons required to fill outer shell



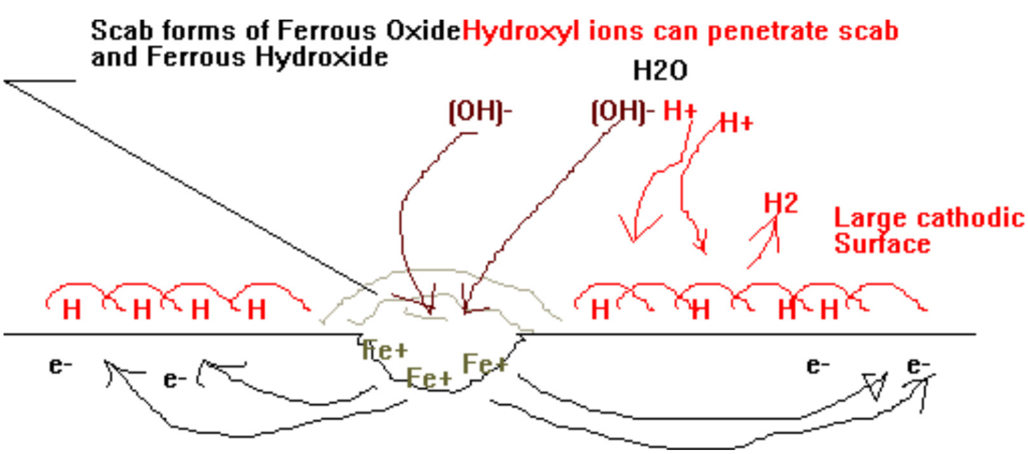


Pure water contains equal amounts of hydrogen and hydroxyl ions . Impurities change the balance . Acidic water has an excess of hydrogen ions which leads to hydrogen evolution



For hydrogen absorption to occur no oxygen needs to be present, a pH of less than 6.5 and so an excess of free hydrogen ions is required.
The Protective film of hydrogen gas on the cathodic surface breaks down as the hydrogen combines and bubbles off as diatomic hydrogen gas.

Oxygen Absorption(high O_2 corrosion)



pH between 6- 10, Oxygen present. Leads to pitting. Very troublesome and can be due to ineffective feed treatment prevalent in idle boilers. Once started this type of corrosion cannot be stopped until the rust scab is removed , either by mechanical means or by acid cleaning. One special type is called deposit attack, the area under a deposit being deprived of oxygen become anodic. More common in horizontal than vertical tubing and often associated with condensers.

Boiler corrosion

General Wastage	Common in boilers having an open feed system.
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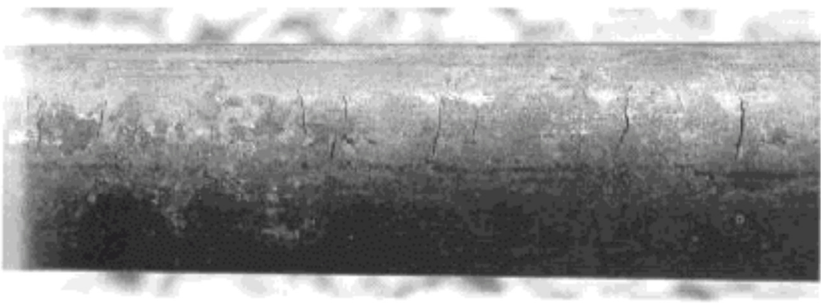
Pitting	-Most serious form of corrosion on the waterside -Often found in boiler shell at w.l. -Usually due to poor shape -In HP blrs found also in screen and generating tubes and in suphtr tubes after priming.

Corrosion fatigue cracking



Cases found in water tube blrs where due to alternating cyclic stresses set up in tube material leading to a series of fine cracks in wall. Corrosive environment aggravates. Trans crystalline

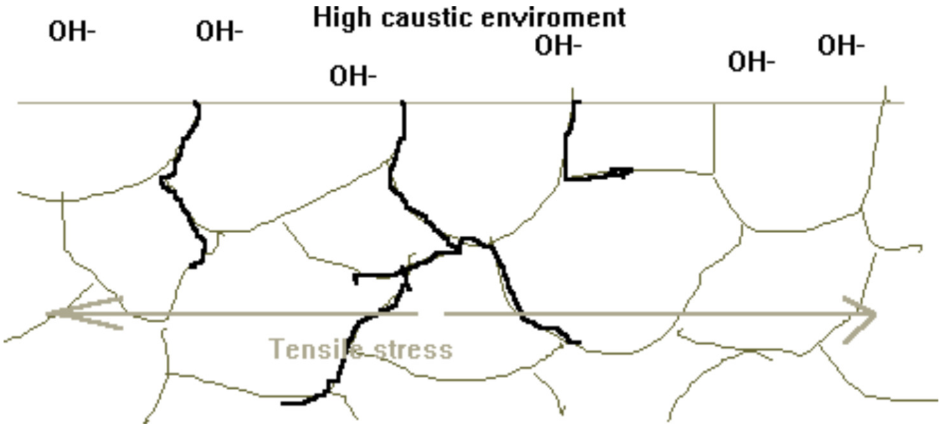
more in depth: Occurs in any location where cyclic stressing of sufficient magnitude are present

Rapid start up and shut down can greatly increase susceptibility.

Common in wall and supht tubes, end of the membrane on waterwall tubes, economisers, deaerators . Also common on areas of rigid constraint such as connections to inlet and outlet headers

Other possible locations and causes are in grooves along partially full boiler tubes (cracks normally lie at right angle to groove), at points of intermittent stm blanketing within generating tubes, at oxygen pits in waterline or feed water lines, in welds at slag pockets or points of incomplete fusion , in sootblower lines where vibration stresses are developed , and in blowdown lines.

Caustic cracking (embrittlement) or stress corrosion cracking



Pure iron grains bound by cementite (iron carbide).

Occurs when a specific corrodent and sufficient tensile stress exists

Due to improved water treatment caustic stress- Corrosion cracking (or caustic embrittlement) has all but been eliminated.

It can however be found in water tubes , suphtr and reheat tubes and in stressed components of the water drum.
The required stress may be applied (e.g. thermal, bending etc.) or residual (e.g. welding)
Boiler steel is sensitive to Na OH , stainless steel is sensitive to NaOH and chlorides
A large scale attack on the material is not normal and indeed uncommon. The combination of NaOH , some soluble silica and a tensile stress is all that is required to form the characteristic intergranular cracks in carbon steel.

Concentrations of the corrodent may build up in a similar way to those caustic corrosion i.e.

- DNB
- Deposition
- Evaporation at water line
- And also by small leakage

Caustic corrosion at temperatures less than 149^{o}C are rare

NaOH concentration may be as low as 5% but increased susceptibility occurs in the range 20- 40 %

Failure is of the thick walled type regardless of ductility.

Whitish highly alkaline deposits or sparkling magnetite may indicate a corrosion sight.

To eliminate this problem either the stresses can be removed or the corrodent. The stresses may be hoop stress(temp', pressure) which cannot be avoided bending or residual weld stresses which must be removed in the design/ manufacturing stage.

Avoidance of the concentrations of the corrodents is generally the most successful. Avoid DNB , avoid undue deposits prevent leakage of corrodents, prevent carryover.

Proper water treatment is essential.

Caustic corrosion

- Takes place at high pressure due to excessive NaOH
- In high temperature, high evaporation rates leading to local concentrations nearly coming out of solution and form a thin film near heating surface.
- Magnetite layer broken down
- Soluble compound formed which deposits on metal as a porous oxide
- Local concentrations may cause a significant overall reduction in alkalinity.
- If evaporation rate reduced alkalinity restored.

More in depth:

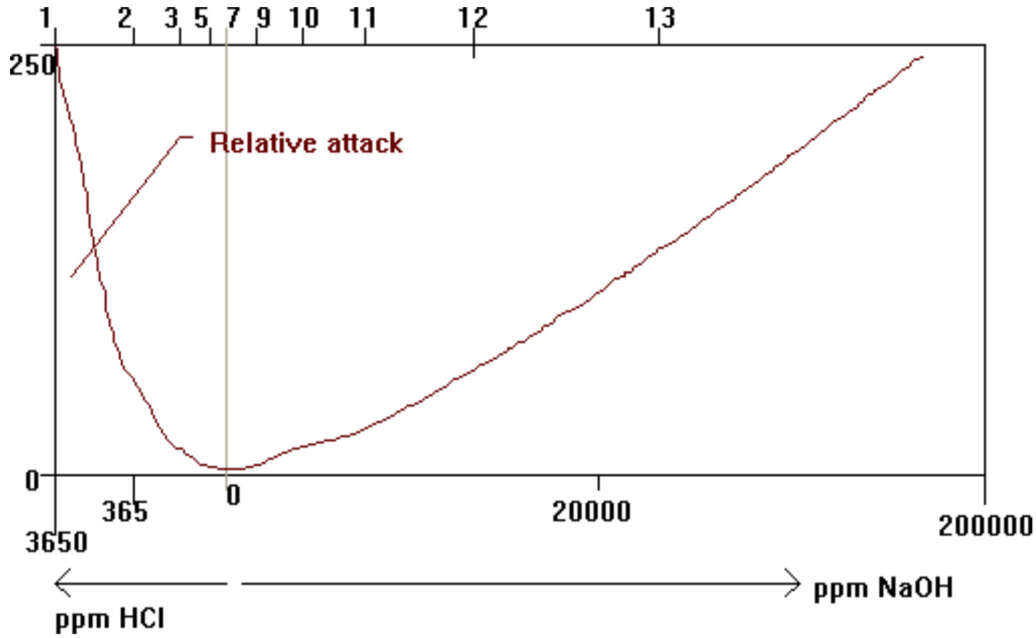
Generally confined to

1. **Water cooled in regions of high heat flux**
2. **Slanted or horizontal tubes**
3. **Beneath heavy deposits**
4. **Adjacent to devices that disrupt flow (e.g. backing rings)**

Caustic (or ductile) gouging refers to the corrosive interaction of concentrated NaOH with a metal to produce distinct hemispherical or elliptical depressions.

Depression are often filled with corrosion products that sometimes contain sparkling crystals of magnetite.

Iron oxides being amphoteric are susceptible to corrosion by both high and low pH enviroments.



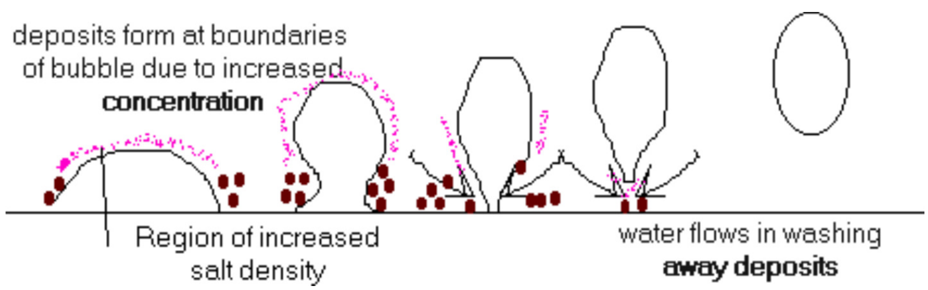
High pH substances such as NaOH dissolve the magnetite then attack the iron.

The two factors required to cause caustic corrosion are;

- the availability of NaOH or of alkaline producing salts. (e.g. intentional by water treatment or unintentional by ion exchange resin regeneration.)
- Method of concentration, i.e. one of the following;
    - *i. Departure form nucleate boiling (DNB)*
    - *ii. Deposition*
    - *iii. Evapouration*

i)Departure form nucleate boiling (DNB)

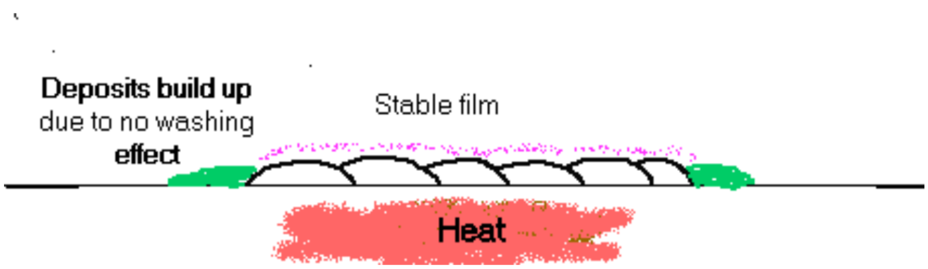
Under normal conditions steam bubbles are formed in discrete parts. Boiler water solids develop near the surface . However on departure of the bubble rinsing water flows in and redissolves the soluble solids



However at increased rates the rate of bubble formation may exceed the flow of rinsing water , and at higher still rate, a stable film may occur with corrosion concentrations at the edge of this blanket.

The magnetite layer is then attacked leading to metal loss.

The area under the film may be relatively intact.

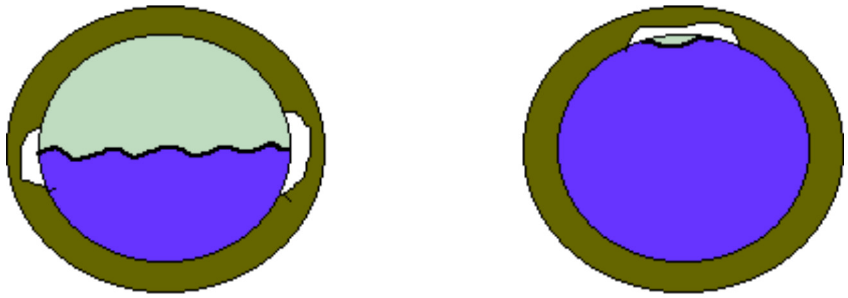


ii), Deposition

A similar situation can occur beneath layers of heavy deposition where bubbles formation occur but the corrosive residue is protected from the bulk water

iii), Evaporation at waterline

Where a waterline exists corrosives may concentrate at this point by evaporation and corrosion occurs.



prevention's

- Rifling is sometimes fitted to prevent DNB by inducing water swirl.
- Reduce free NaOH by correct water treatment
- Prevent inadvertent release of NaOH into system (say from an ion exchange column regenerator)
- Prevent leakage of alkaline salts via condenser
- Prevent DNB
- Prevent excessive waterside deposits
- Prevent creation of waterlines in tubes- slanted or horizontal tubes are particularly susceptible to this at light loads were low water flows allow stm water stratification.

Hydrogen attack

If the magnetite layer is broken down by corrosive action, high temperature hydrogen atoms diffuse into the metal, combine with the carbon and form methane. Large CH-3 molecules causes internal stress and cracking along crystal boundaries and sharp sided pits or cracks in tubes appear.

more in depth: Generally confined to internal surfaces of water carrying tubes that are actively corroding. Usually occurs in regions of high heat flux, beneath heavy deposits, in slanted and horizontal tubes and in heat regions at or adjacent to backing rings at welds or near devices that disrupt flow .

Uncommon in boilers with a W.P.of less than 70 bar

A typical sequence would be ;

- NaOH removes the magnetite

- free hydrogen is formed (hydrogen in its atomic rather than diatomic state) by either the reaction of water with the iron reforming the magnetite or by NaOH reacting with the iron
- This free hydrogen can diffuse into the steel where it combines at the grain boundaries to form molecular hydrogen or reacts with the iron carbide to form methane
- As neither molecular hydrogen or methane can diffuse through the steel the gasses build up , increasing pressure and leading to failure at the grain boundaries
- These micro cracks accumulate reducing tensile stress and leading to a thick walled failure. Sections may be blown out.
- This form of damage may also occur in regions of low pH
- For boilers operating above 70 bar , where high pH corrosion has occurred the possibility of hydrogen damage should be considered

High temperature corrosion.

Loss of circulation , high temperature in steam atmosphere, or externally on suphtr tubes

Chelant corrosion

Concentrated chelants (i,e. amines and other protecting chemicals) can attack magnetite , stm drum internals most susceptible.
A surface under attack is free of deposits and corrosion products , it may be very smooth and coated with a glassy black like substance
Horse shoe shaped contours with comet tails in the direction of the flow may be present.

Alternately deep discrete isolated pits may occur depending on the flow and turbulence

The main concentrating mechanism is evaporation and hence DNB should be avoided

Careful watch on reserves and O_2 prescience should be maintained

Low pH attack

Pure water contains equal amounts of hydrogen and hydroxyl ions . Impurities change the balance . Acidic water has an excess of hydrogen ions which leads to hydrogen evolution.See previous notes on Hydrogen Evolution

For hydrogen absorption to occur no oxygen needs to be present, a pH of less than 6.5 and so an excess of free hydrogen ions is required.
The Protective film of hydrogen gas on the cathodic surface breaks down as the hydrogen combines and bubbles off as diatomic hydrogen gas.
May occur due to heavy salt water contamination or by acids leaching into the system from a demineralisation regeneration.

Localised attack may occur however where evaporation causes the concentration of acid forming salts . The mechanism are the same as for caustic attack. The corrosion is of a similar appearance to caustic gouging

Prevention is the same as for caustic attack . Proper maintenance of boiler water chemicals is essential

Vigorous acid attack may occur following chemical cleaning . Distinguished from other forms of pitting by its being found on all exposed areas
Very careful monitoring whilst chemical cleaning with the temperature being maintained below the inhibitor breakdown point. Constant testing of dissolved iron and non ferrous content in the cleaning solution should be carried out.

After acid cleaning a chelating agent such as phosphoric acid as sometimes used . This helps to prevent surface rusting , The boiler is then flushed with warm water until a neutral solution is obtained.

Oxygen corrosion

Uncommon in operating boilers but may be found in idle boilers.
Entire boiler susceptible , but most common in the superheater tubes (reheater tubes especially where water accumulates in bends and sags)

In an operating boiler firstly the economiser and feed heater are effected.

In the event of severe contamination of oxygen areas such as the stm drum water line and the stm separation equipment

In all cases considerable damage can occur even if the period of oxygen contamination is short

Bare steel coming into contact with oxygenated water will tend to form magnetite with a sound chemical water treatment program.
However , in areas where water may accumulate then any trace oxygen is dissolved into the water and corrosion by oxygen absorption occurs(see previous explanation)

Oxygen Absorption

in addition to notes above pH between 6- 10, Oxygen present.
Leads to pitting. Very troublesome and can be due to ineffective feed treatment prevalent in idle boilers. Once started this type of corrosion cannot be stopped until the rust scab is removed , either by mechanical means or by acid cleaning.

One special type is called pitting were metal below deposits being deprived of oxygen become anodic . More common in horizontal than vertical tubing and often associated with condensers.

The ensuing pitting not only causes trouble due to the material loss but also acts as a stress raiser

The three critical factors are

i. *the prescience of water or moisture*
ii. *prescience of dissolved oxygen*
iii. *unprotected metal surface*

The corrosiveness of the water increases with temperature and dissolved solids and decreases with increased pH
Aggressiveness generally increases with increased O_2

The three causes of unprotected metal surfaces are

i. *following acid cleaning*
ii. *surface covered by a marginally or non protective iron oxide such as Hematite (Fe_2O_3)*
iii. *The metal surface is covered with a protective iron oxide such as magnetite (Fe_3O_4 , black) But holidays or cracks exist in the coating, this may be due to mechanical or thermal stressing.*

During normal operation the environment favours rapid repair of these cracks. However, with high O_2 prescience then corrosion may commence before the crack is adequately repaired.

FEED SYSTEM CORROSION.

Graphitization

Cast iron , ferrous materials corrode leaving a soft matrix structur of carbon flakes

Dezincification

Brass with a high zinc content in contact with sea water , corrodes and the copper is redeposited. Inhibitors such as arsenic , antimony or phosphorus can be used , but are ineffective at higher temperatures.
Tin has some improving effects

Exfoliation (denickelfication)

Normally occurs in feed heaters with a cupro-nickel tubing (temp 205^{o}C or higher)
Very low sea water flow condensers also susceptible.
Nickel oxidised forming layers of copper and nickel oxide

Ammonium corrosion

Ammonium formed by the decompositin of hydrazine
Dissolve cupric oxide formed on copper or copper alloy tubes
Does not attack copper, hence oxygen required to provide corrosion,Hence only possibel at the lower temperature regions where the hydrazine is less effective or inactive,
The copper travels to the boiler and leads to piting.

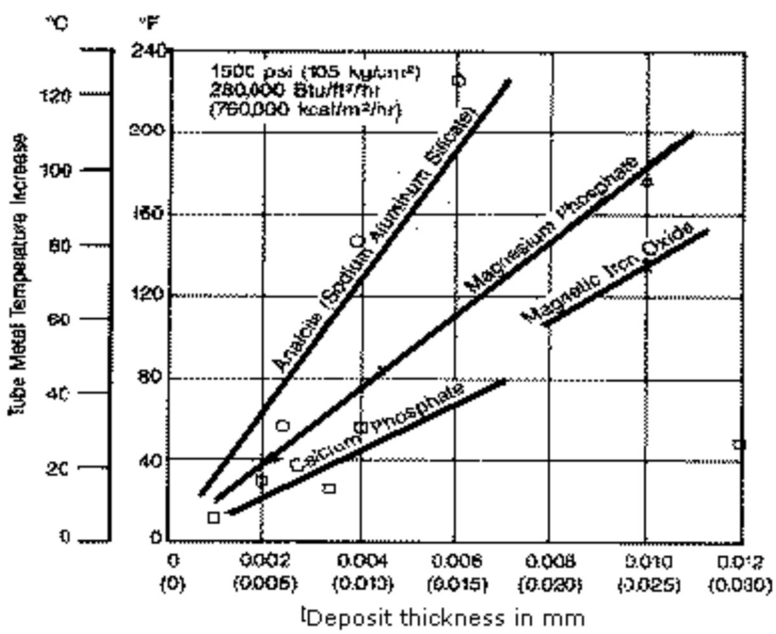
Deposits and scales found in boilers

Definition: material originating elsewhere and conveyed to deposition site; Oxides formed at the site are not deposits.

Water formed and steam formed deposits

- **May occur anywhere**
- **Wall and screen tubes most heavily fouled , superhtr has deposits formed elsewhere and carried with the steam or carryover. Economisers (non-steaming) contain deposits moved from there original site.**
- **Tube orientation can influence location and amount of deposition.**
- **Deposits usually heaviest on the hot side of the steam generating tubes. Because of steam channelling, deposition is often heavier on the top portion of horizontal or slanting tubes**
- **Deposition occurs immediately downstream of horizontal backing rings.**
- **Water and steam drums can contain deposits, as these are readily accessed then inspection of the deposition can indicate types of corrosion. e.g. Sparkling black magnetite can precipitate in stm drums when iron is released by decomposition of organic complexing agents.**
- **Superhtr deposits (normally associated with high water levels and foaming) tend to concentrate near the inlet header or in nearby pendant U-tubes**
- **Contaminated attemperating spray water leads to deposits immediately down stream with the possibility of chip scale carried to the turbines.**
- **At high heat transfer rates a stable thin film boiling can occur, the surface is not washed (as it is during bubble formation) and deposits may form**
- **Thermal stressing can lead to oxide spalling (the exfoliation of oxide layers in areas such as the suphtr). These chips can pass on to the turbine with severe results. Steam soluble forms can be deposited on the turbine blades , If chlorides and sulphates are present , Hydration can cause severe corrosion due to hydrolysis.**
- **As deposits form on the inside of waterwall the temperature increases. This leads to steam blanketing which in turn leads to reduced heat transfer rate , long term overheating and tube failure.**

Effects on tube temperature of scale deposit



DEPOSITS

Iron oxides

Magnetite (Fe_3O_4)

A smooth black tenacious , dense magnetite layer normally grows on boiler water side surfaces.taken to indicate good corrosion protection as it forms in low oxygen levels and is susceptible to acidic attack

Heamatite (Fe_2O_3)

is favoured at low temperatures and high oxygen levels can be red and is a binding agent and tends to hold over materials in deposition. This is an indication of active corrosion occuring within the boiler/feed system

Other metals

Copper and Copper oxide is deposited by direct exchange with iron or by reduction of copper oxide by hydrogen evolved during corrosion . Reddish stains of copper are common at or near areas of caustic corrosion. Copper Oxide appears as a black depositi. It is considered very serious corrosion risk because of the initiation of galvanic corrosion mechanisms.

Galvanic corrosion associated with copper deposition is very rare in a well passivated boiler. **Zinc** and **nickel** are very often found near copper deposition , nickel being a particularly tenacious binder

Rapid loss of boiler metals can occur. Copper can appear in various forms as a deposit in the boiler. As a copper coloured metallic deposit, usually in a corrosion pit, as a bright red/orange tubercules on the boiler metal surface or as a brown tear drop shaped formation.

Copper is generally an indicator of corrosion (or possible wear) occuring in the feed pump whether in the condensate lines or in the parts of a feed pump. A possoble cause of this is the excessive treatement of hydrazine which decompose to ammonia carrying over with the steam to attack suc areas as the air ejectors on condensers.

Copper oxide formed in boiler conditions is black and non- metallic.

SALTS

The least soluble salts deposit first

Calcium carbonate-effervesces when exposed to HCl acid

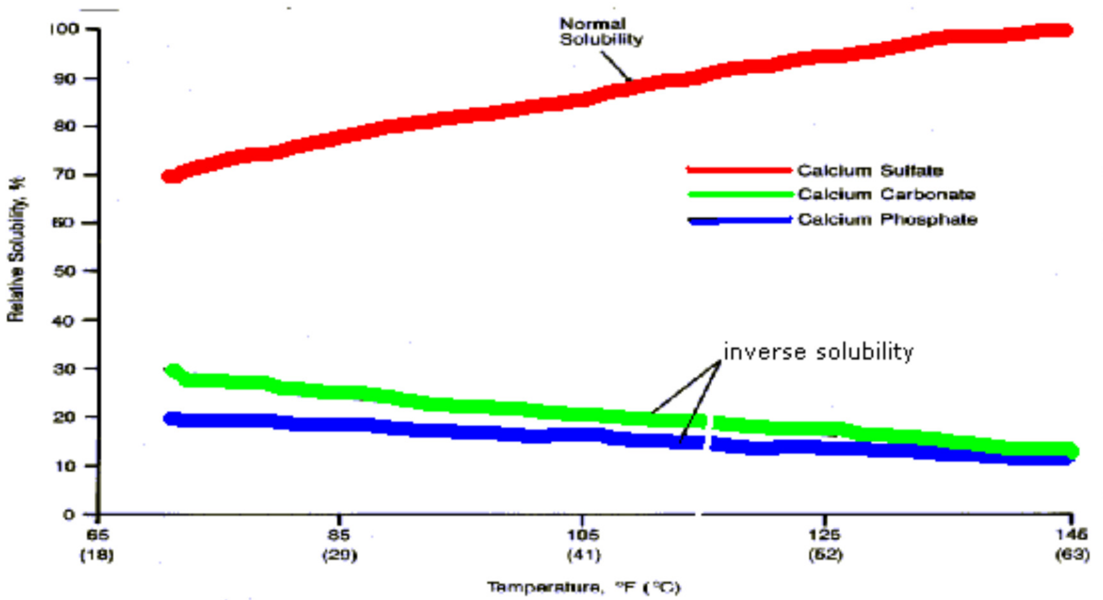
Calcium sulphate-Slightly less friable then $CaCO_3$

Magnesium Phosphate-Tenacious binder, discoloured by contaminants

Silicates-Insoluble except in hydroflouric acid E.G. Analcite

Water soluble deposits can only be retained if local concentration mechanism is severe. Prescence of NaOH , $NaPO_3$ Na_2SO_3 should be considered proof of vapouration to dryness.

Calcium and magnessium salts exhibit inverse solubility. As the water temperature rises their solubility reduces, at a temperature of 70'C and above they come out of solution and begin to deposit. Feed water must be condition to remove the hardness salts before the water enters the boiler. The purity of the water is related to the steam conditions required of the boiler.



Hydrolyzable salts such as MgCl can concentrate in porous deposits and hydrolyze to hydrochloric acid

Scaling mechanism examples

Calcium Carbonate
Cacium Carbonate is formed by the thermal decomposition of Calcium BiCarbonate and apperas as a pale cream to yellow scale

$Ca(HCO_3)_2$ + Heat = $CaCO_3 + H_2O + CO_2$

Magnessium Silicate
Tor form requires sufficient amounts of magnessium and silicate ions coupled with a deficiency in OH^- alkalinity

$Mg^{2+} + OH- = MgOH^+$

$H_2SiO_3 = H^+ + HSiO_3^-$

$MgOH^- + HSiO_3^- = MgSiO_3 + H_2SO_4$

Thus this rough tan scale can be prevented by the maintenace of alkalinity levels

Calcium Phosphate (hydroxyapatite)
$Ca_{10}(PO_4)_6(OH)_2$

Found in biolers using the phosphate cycle treatment method this is a tan/cream deposit. This is generally associated with overdosing a boiler but can occur where insufficient disperseing agent reduces the effects of blow down.

In anouther form $Ca_3(PO_4)_2Ca(OH)_2$ it is associated with correct treatment control

Scales forming salts found in the boiler

Calcium Bi-Carbonate 180ppm

- Slightly soluble
- >65^{o}C breaks down to form $CaCO_3$ +CO_2, remaining Calcium carbonate insoluble in water
- Forms a soft white scale

Magnesium BiCarbonate 150 ppm

- Soluble in water
- at more than 90^{o}C breaks down to form $MgCO_3$ and CO_2 and then $Mg(OH)_2$ and CO_2
- Forms a soft scale

Calcium Sulphate 1200 ppm

- Worst scale forming salt
- > 140oC (sat. press 2.5bar) or >96000ppm will precipitate out
- Forms a thin hard grey scale

Magnesium Sulphate 1900ppm

- Precipitates at high temperatures and about 8 bar
- Forms sludge

Magnesium Chloride 3200ppm

- Breaks down in boiler conditions to form MgOH and HCl
- forms a soft white scale Rapidly lowers pH in the event of sea water contamination of the boiler initiating rapid corrosion MgCl2 + 2H2O---> Mg(OH)2 + 2HCl HCl + Fe --->FeCl + H 2FeCl + Mg(OH)2 ---> MgCl2 + 2FeOH This series is then repeated. Effective feed treatment ensuring alkaline conditions controls this problem

Sodium Chloride 32230 to 25600 ppm

- Soluble <225000ppm
- forms a soft encrustation
- Free irons promote galvanic action

Other deposits-

Amorphous Silicon dioxide (SiO_2) - trace

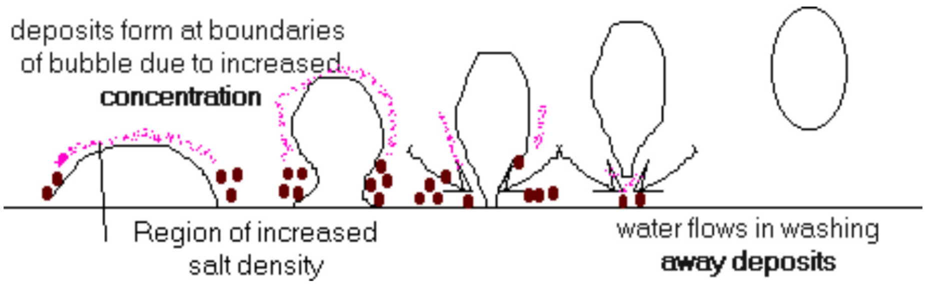
- at high tempos and pressures (>40bar) silica can distill from the bioler as Silicic acid and can sublime and pass over into the steam system as a gas. Here it glazes surfaces with a smooth layer, which due to thermal expansion crack and roughen the surface. Troublesome on HP blading. Can be removed only by washing with Hydroflouric acid.

Magnessium Silicate $3MgO.2SiO_2.2H_2O$ (Serpentine) is formed in water with proper treatment control

SCALE FORMATION

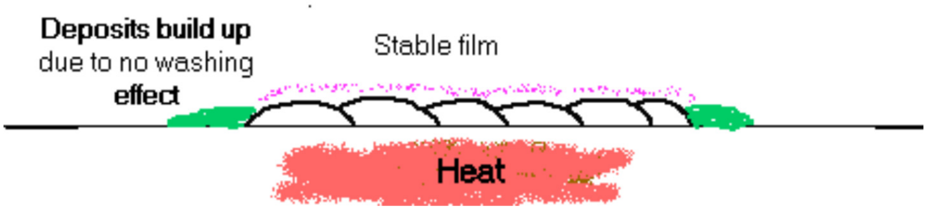
The roughness of the heated surface has a direct relationship to the deposit of scale. Each peak acts as a 'seed' for the scale to bind to.

Nucleate Boiling



Scale built up as a series of rings forming multi layers of different combinations. Much increased by corrosion products or prescience of oil, even in very small quantities.
Oil also increases scale insulatory properties.

Departure form nucleate boiling (DNB) Under normal conditions steam bubbles are formed in discrete parts. Boiler water solids develop near the surface . However on departure of the bubble rinsing water flows in and redissolves the soluble solids



However at increased rates the rate of bubble formation may exceed the flow of rinsing water , and at higher still rate, a stable film may occur with corrosion concentrations at the edge of this blanket.

Dissolved solids in fresh water

Hard water -Calcium and magnesium salts
- Alkaline
-Scale forming

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Soft water -Mainly sodium salts
- Acidic
- Causes corrosion rather than scale

Boiler water tests

Corrosion and tube failure caused by water chemistry

Recommended ranges(Co-ordinated phosphate treatment for w/t boiler)

pH	- 9.6 to 10.3
PO_4	- 4 to 20 ppm
N_2H_4	- 0.01 to 0.03 ppm
TDS	- < 150 ppm
Cond pH	- 8.6 to 9.0
Cl	- 20 ppm
O_2	- 10 ppb
Si	- 10 ppb

Chlorides

- Measure 100ml of sample water into a casserole
- Add 10 drops phenol pthalein (RE 106)
- Neutralize with sulphuric acid
- Add 10 drops of Potassium Chromate
- Titrate Silver Nitrate untill sample just turns brick red
- ppm as $CaCO_3$= (ml x 10) ppm

TDS

- Measure 100ml of sample water into a casserole
- Add 10 drops of phenolpthalein
- Neutralise with TDS reagent (acetic acid)
- Temperature compensate then read off scale in ppm.

Phosphates

- Fill one 10 ml tube with distilled water
- Fill one 10 ml tube with boiler water tests.
- Add 0.5 ml sulphuric acid (RE 131) to each
  Add 0.5 ml Ammonium Molybdnate (RE130) to each
  Add 0.5 ml Aminonapthol Sulfonic acid (RE 132) to each
  Stir well between each addition
- Wait 3 minutes for calorimetric compaison

Alternately Vanado-molybdnate test

- Place 5 ml boiler water in 10 ml tube
- Place 5 ml distilled water in other 10 ml tube
- Top both to 10 ml with Vanado-molybdnate reagent
- Place in colour comparator and compare after 5 mins

Hydrazine

- Add 9ml distilled water to one tube
- Add 9 ml boiler test water to anouther
- Add 1 ml hydrazine reagent to each
- Use colour comparator

Alkalinity Phenolpthalein

- 100 ml filtered water
- Add 1 ml phenolpthalein
- If pH >8.4 Solution turns pink
- Add H_2SO_4 untill pink disapears
- Ml 0.02N H_2SO_4 x 10 = ALk in $CaCO_3$ ppm
- Measures hydroxides and carbonates in sample, bi-carbonates do not show up so sample should not be allowed to be exposed to the air for too long

Alkalinity Methyl orange

Bi carbonates do not show up in the phenolpthalein sample as they have a pH < 8.4. Bi carbonates can not occur in boiler but if suspected in raw feed then the following test.

- Take phenolpthalein sample, add 1 ml methyl orange
- If yellow, bi carbonates are present
- Add H2SO4 untill red
- Total 0.02N H_2SO_4 x 10 = Total Alk in $CaCO_3$

pH

- 100 ml unfiltered sealed water poured into two 50 ml glass stoppered test tubes
- Add 0.2 ml pH indicator to one (pH indicator vary's according to required measuring range)
- Use colour comparator
- Due to difficulty of excluding air, electronic pH meter preferred

Sulphite reserve

- Exclude air at all stages

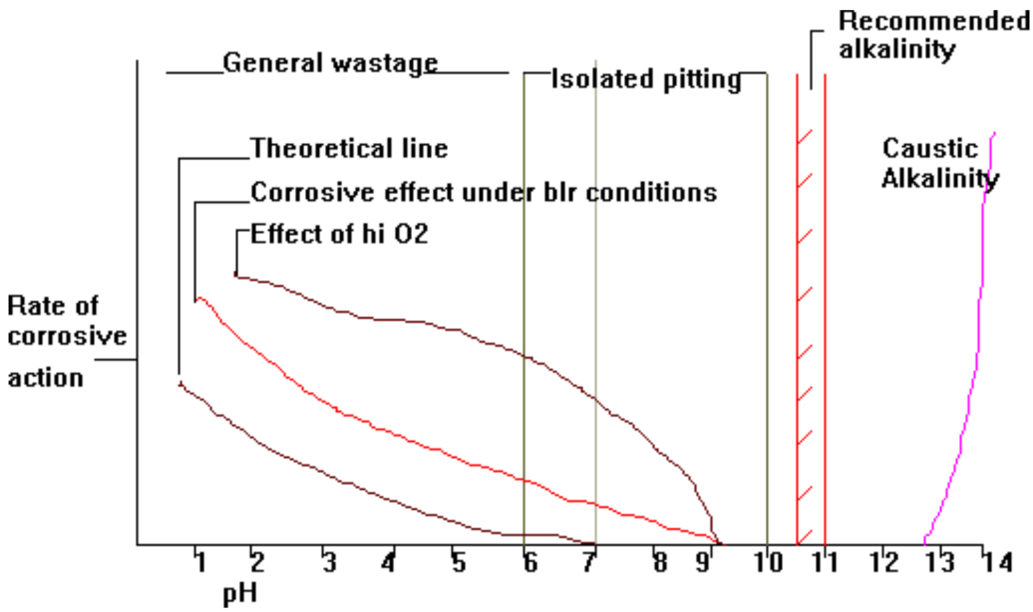
- 100 ml unfiltered water
- Add 4 ml H_2SO_4 + 1 ml starch
- Add potassium iodate-iodide untill blue colour
- ml Iodate-Iodide sol x 806 / ml of sample = SO_3 reserve in ppm

Ammonia in feed

- Only necessary where N_2H_4 used in blr
- Pour condensate sample into two 50 ml colour comparator tubes
- Add 2 ml Nessler reagent to one
- Wait 10 mins
- Use colour comparator

Boiler water treatment

Alkalinity



Treatment

For pressures below 20 bar dissolved O_2 in the feed does not cause any serious problems so long as the water is kept alkaline
However cold feed should be avoided as this introduces large amounts of dissolved O_2 are present, for pressures greater than 18.5 bar a dearator is recommended

Feed Treatment Chemicals

Sodium	**Hydroxide**
Calcium	Bicarbonate ($CaCO_3$ + Na_2CO_3)
Magnesium	Bicarbonate
Magnesium	Chloride.
.	.
Sodium	**Phosphate**
Calcium	Carbonate
Calcium	Sulphate
Magnesium	Sulphate
All in this column precipitated as hydroxide or phosphate based sludges	All in this column form sodium salts which remain in solution

- Sodium Hydroxide
  - Reacts with highly corrosive $MgCl_2$
  - Does not readily react with $CaSO_4$
  - Strongly alkaline

- Produces heat when mixed with water
- Absorbs CO_2 changing to Sodium Carbonate
- Unsuitable for standard mixes

- Sodium Carbonate Na_2CO_3 (soda ash)
  - Alkaline
  - At pressures above 14 bar some of the Sodium Carbonate decomposes to form NaOH and CO_2 . Increasing on pressure increase
  - Changes to Sodium Bi-Carbonate when exposed to air
  - Still usable but larger amounts make control difficult
  - Standard mix ingredient

- Sodium Hexa Meta Phosphate $NaPO_3$ (calgon)
  - Safe,soluble in water, slightly acidic
  - May be injected any where as will only react in the boiler
  - Suitable for LP blrs which require lower alkalinity

- DiSodium Phosphate Na_2HPO_4 (Cophos II)
  - Neutral used with alkaline additive
  - Combines with NaOH to give trisodium phosphate
  - Basic constituent

- TriSodium Phosphate $Na_3 PO_4$ (Cophos III)
  - Alkaline
  - When added to water decomposes to NaOH and $Na_2 HPO_4$
  - As water evaporated density increases and NaOH and $Na_2 HPO_4$ recombine
  - Phosphates can form Phosphides which can coat metal to form a protective barrier, with excessive phosphate levels, this coating can be excessive on highly rated boilers operating at higher steaming rates

Chemicals are normally added as a dilute solution fed by a proportioning pump or by injection from pressure pot.
Use of chemicals should be kept to a minimum.

Injection over a long period is preferable as this prevents foaming.

Excessive use of phosphates without blowdown can produce deposits of phosphides on a par with scale formations.

Therefore it is necessary to add sludge conditioners particularly in the forms of polyelectrolytes, particularly in LP blrs

Oxygen Scavengers

- Hydrazine $N_2 H_4$
  - Oxygen scavenger, continously injected to maintain a reserve within the boiler of 0.02 to 0.1 ppm and a feed water O_2 content of less than 10 ppb
  - At temperatures greater than 350^oC , will decompose to ammonia and nitrogen and will aid in maintaining balanced alkalinity in steam piping.Steam volatile, neutralises CO_2
  - Inherent alkalinity helps maintain feed water alkalinity within parameters of 8.6 to 9.0.
  - Used in boiler operating above 32 bar, will not readily react with O_2 below 50^oC hence

risk of copper corrosion occurs with the ammonia stripping off the continuously reforming copper oxides.
    - Supplied as a 35% solution

- Carbohydrazide $(N_2H_3)_2CO$
    - Is a combined form of Hydrazine
    - It is superior to hydrazine in performace and is designed to minimise the vapours during handling
    - Carbohydrazide and its reaction products create no dissolved solids
    - Is an oxygen scavenger and metal passivator at both high (230'C) and low (65'C) temperatures
    - Can be used with boilers up to 170 bar

- Diethylhydroxylamine DEHA
    - Like hydrazine, provides a passive oxide film (magnetite) on metal surfaces to minimise corrosion
    - Contributes to pH netralisation to an extent that seperate condensate control may not be necessary
    - Protects entire system-feedwater, boiler and condensate

- Sodium sulphite Na_2SO_3
    - Takes the form of a soft white powder
    - Slightly alkaline
    - Will react with oxygen to form Sodium Sulphate at about 8ppm Sodium Sulphite to 1ppm Oxygen
    - Use limited to low pressure boilers due to increasing TDS and reducing alkalinity by its action

- Tannins
    - Certain alkaline tannin solutions have a good oxygen absorbing ability with about 6ppm tannin able to remove 1ppm oxygen.
    - The reaction with oxygen is complex and unreliable, no official reserve levels exist for the maintenance of a system using tannin

- Erythorbic Acid (Sur-gard) R_1-C(OH)
    - An effective oxygen scavenger and metal passivator
    - It is the only non-volatile scavenger which can be used with spray attemperation
    - does not add measureable solids to the boiler water
    - May be used in boilers up to 122 bar
    - Officially recognised as a Safe Substance
    - As with hydrazine a small amount of ammonia is created in the boiler, it is not recommended for layup.

Polymer Treatment

Polymer is a giant molecular built up by stringing together simple molecules

E.G.
Polyelectrolytes-Formed from natural or synthetic ionic monomers
Polyacrylates - Polymers of acrylic acid
Polyamides - Polymers of amides

Polymer treatment prevents scale formation and minimises sludge formation. It can also loosen scale so established blrs introduced to this form of treatment may develop leaks where previously plugged with scale. Especially in way of expanded joints. Also can absorb trace oil

Use limited to LP blrs as no PO_4 present to prevent caustic alkalinity

For auxiliary blrs this is a superior form of treatment to the old alkaline and phosphate treatment. The correct level of alkalinity must be maintained as too low a level neutralises the electric charge of the polyelectrolyte. Too high causes caustic alkalinity.

Amine treatment

Compounds containing nitrogen and hydrogen.

Neutralising amines

Hydrazine N_2H_4

see above

Bramine (cyclohexalamine)

(Bull & Roberts amine treatment)

Neutralising amine as with hydrazine. Used with hydrazine to maintain feed water alkalinity within parameters. As a knock on effect will slightly increase boiler water alkalinity.

Stable at high temperatures so is used more than hydrazine to control the steam line alkalinity as there is less chance of copper corrosion which occurs with the prescience of ammonia

Proper boiler water treatment eliminates sludge and scale deposits within the boiler. However, over along period of time a film of copper and iron oxides build up on the tube surface. Most of these oxides are transported from oxides of corrosion within the feed system to the boiler with the condensate.

Bramine reduces this corrosion and eliminates the build up of these oxide deposits.

Mechanism of function

Condensate from the condenser is very pure and slightly acidic, often referred to as 'hungry water'. It can dissolve metals in trace amounts to satisfy this hunger.
Distilled make up water aggravates this situation containing much dissolved CO2 and hence being acidic carries its own corrosion products.
Trace amounts of bramine are introduced into the system to establish an alkalinity level greatly reducing the effects of the hungry water.

Some of the bramine is used almost immediately, most however, passes on to the boiler where it is then transported through boiler water, boiler stm drum, stm lines back to the condenser. It has no effect anywhere except the condensate system.

Bramine also has a cleaning effect and may assist in the cleaning the film off the tube over a period of time.
Bramine is safer to handle than Bramine and will protect all metals.

Hydrazine however readily breaks down to form ammonia which whilst protecting ferrous metals will attack those containing copper

Filming amines

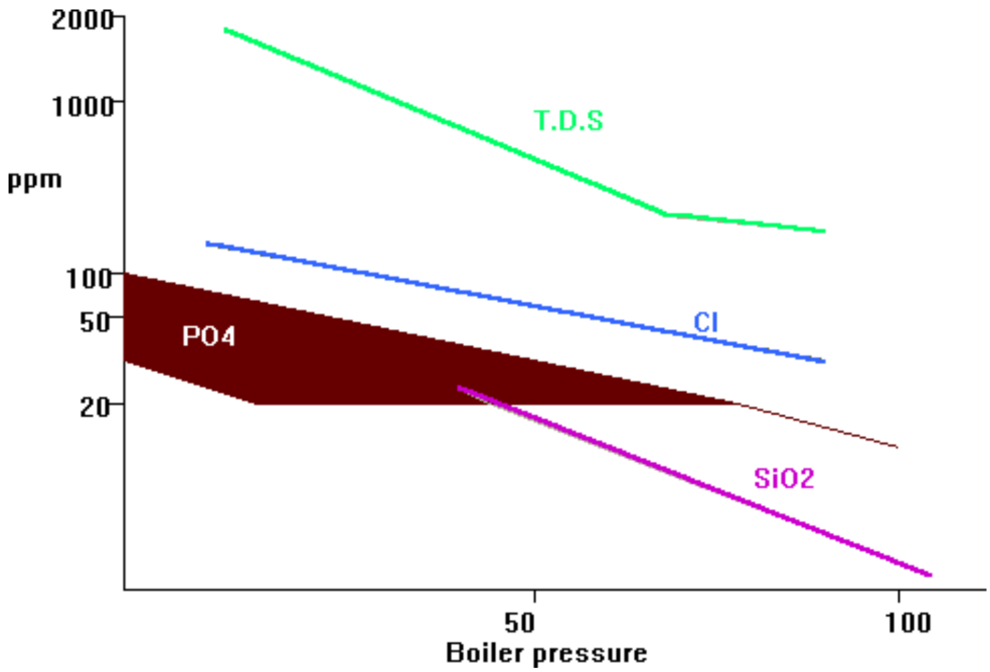
Shows neutralising tendencies, main function however is to coat piping with a molecular water repellent protective film

Injection of amines

May be injected between HP and LP turbines in the X-over pipe or after the dearator.
Adding in X-over pipe-reduces corrosion of copper alloys
Dearator only effective as a feed heater

Adding after dearator -Dearator correctly performing as a dearator and feed heater. If possible the best system is to have a changeover to allow norm inj into the X-over at sea and injection after the dearator when the turbine shut down

Limits of density/pressure



Sludge conditioning agents

Coagulants-

- **Mainly polyelectrolytes**
- **Prevents the precipitated sodium based particles forming soft scales**
- **Will keep oil in an emulsion**
- **the water must be kept alkaline**

Antifoams

- **reduce the stability of water film around steam bubble and cause it to collapse.**
- **Common type polyamide is an organic compound of high molecular weight.**
- **In the event of severe contamination separate injection of an antifoam is recommended**

Dispersing agents

- **Sludge conditioners such as starch or tannin.**
- **Prevent solid precipitates uniting to form sizeable crystals e.g. MgSO4**

Treatment in boilers (non congruent)

LP tank blrs (<14 bar)

Na_2CO_3- precipitates salts, provides alkalinity
$MgSO_4$- Sludge conditioners

Na_2CO_3 can break down to form NaOH in higher rated boilers hence initial dose with Na_2SO_4

Medium pressure tank blrs (<17.5 bar)

Na_2CO_3(3) + sodium phosphate(**4**) + sludge conditioners(**1**)

Medium to High pressure water tube <60 bar

Na_2CO_3 + Na_2HPO4 +sludge conditioners

Oxygen scavengers also used to allow magnetite (Fe_3O_4) layer to form in the boiler

Boiler operating above 42 bar require a dearator.

HP to UHP blrs (42 to 80 bar)

Due to level of decomposition of Na_2CO_3 . NaOH preferred for better controllability Na_2HPO_4

NaOH attacks the magnetite layer. Congruent treatment used.

Permissible limits

		Shell	WT	WT	WT	WT	WT
TEST>	PPM	<17.5b	<17,5b	<32b	<42b	<60b	<85b
Hardness	$CaCO_3$	<=5	<=5	<=5	<=1	<=1	<=1
P.alk	$CaCO_3$	150-300	150-300	150-300	100-150	50-100	50-80
T.D.S.	$CaCO_3$	<=7000	<=1000	<=1000	<=500	<=500	<=300
Cl	$CaCO_3$	<=1000	<=300	<=150	<=100	<=50	<=30
PO_4	PO_4	30-70	30-70	30-70	30-50	30-50	20-30
N_2H_4	N_2H_4	--	--	--	0.1 -1.0	0.1 - 1.0	0.1 - 1.0
SO_3	SO_3	50-100	50-100	50-100	20-50	--	--
SiO_2	SiO_2	--	--	--	--	--	<=6.0
Fe	Fe	--	--	--	--	--	<=0.05
Cu	Cu	--	--	--	--	--	<=0.02
pH	pH	10.5-11	10.5-11	10.5-11	10.5-11	10.5-11	10.3-11
Limits for feed water							
Cl	CL	<=10	<=5	<=1.0	<=1.0	<=1.0	<=1.0
O_2	O_2	----	----	<=0.006	<=0.003	<=0.015	<=0.01

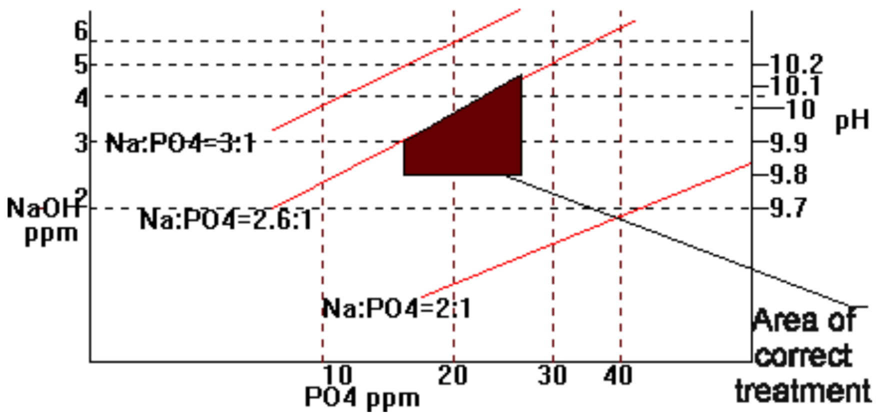
NH_3	NH_3	----	----	----	-----	-----	<=0.5
Fe	Fe	----	----	----	-----	<=0.01	<=0.01
Cu	Cu	----	----	----	-----	<=0.01	<=0.01
pH	pH	----	----	----	8.5-9.2	8.5-9.2	8.5-9.2

Co-ordinated and congruent Phosphate treatmentst

Alkalinity

NaOH under certain conditions dissolves boiler metal.

Co-ordinated treatment tries to avoid this by relying on the fact that NaOH and disodium phosphate combine to form trisodium phosphate. However, a small proportion of the NaOH always remains. Congruent treatment tries to avoid this by making a mix so that the Na^+ to PO^{-3}_4 ion ratio never exceeds 2.6 : 1 (Na_3PO_4 has a sodium to phosphate ratio of 3 : 1)



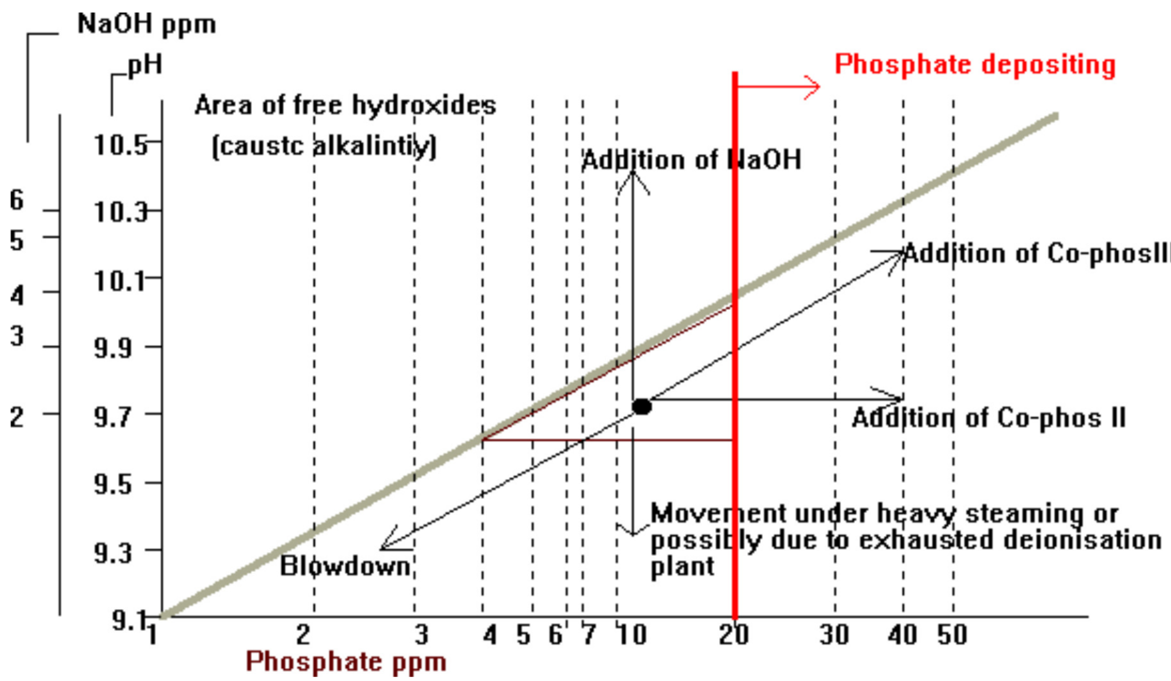
Co-ordinated phosphate treatment

Purpose

- **to maintain a phosphate reserve to react with incoming hardness**
- **To maintain sufficient alkalinity to minimise corrosion and aid in forcing the reaction with hardness salts.**

For boiler pressures above 40bar problems of caustic alkalinity caused by addition of caustic soda as part of a feed treatment occur.
With caustic alkalinity, free hydroxides concentration in a thin film at the tube surface destroying the protective magnetite layer and attacking the metal to form caustic gouging craters, and intercrystaline cracking as it attacks the iron carbide in the iron grain boundaries.
Avoiding the prescience of free hydrides is the only prevention from this form of attack

Co-ordinated phosphate-pH control



Maintaining within the control area is achieved by the addition of Co-phos III tri sodium phosphate based, and co-phos II, disodium phosphate based.

Co-Phos III is an alkaline product and in water decomposes to NaOH and Na2HPO4 increasing concentration recombine.

Co-Phos II is much less alkaline.

Falling into the area on the co-ordinated phosphate pH diagram below the lower dotted line means that normal treatment to bring back into the target area is impossible.

The only way of recovering the situation is by blowing large quantities of water out of the boiler

The ideal time for this is during trip testing when the boiler is isolated from the plant (and hence feed water flow to the boiler is much reduced). The flames are extinguished on the low low foxboro trip

It is also beneficial to blow down the headers at this time

Problems may arise when the mixed bed demineralisation plant is allowed to remain in need of regeneration for a long time. The make up water is so effected so as to lower the alkalinity of the boiler without a comparable drop in phosphate. This becomes particularly troublesome during periods of heavy make up, say during trip testing or heavy steaming.

Hide-out

It can be seen in high pressure boilers that as the steaming rate increases the levels of certain salts, particularly phosphate salts, does not raise in line with others. When the load is reduced the concentrations return to normal.

This is termed hide-out and is due to the reduced solubility of sodium phsophate at temperatures above 250'C

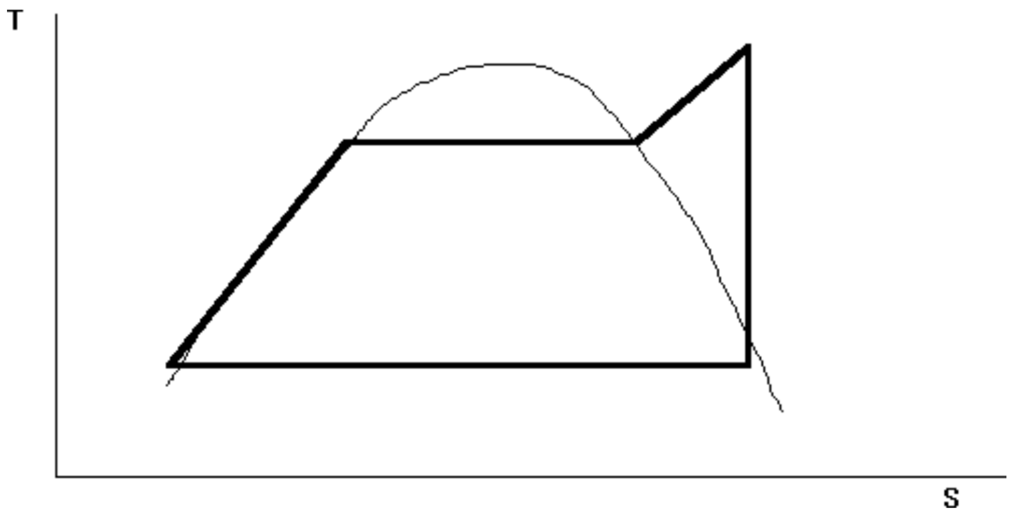
When phosphate hide-out occurs there is a risk of permenant scal deposition and/or evolution of free caustic which in turn could lead to severe corrosion due to caustic attack

Treatment using volatile solids free chemicals such as hydrazine, Eliminox and neutralising amines should be considered. This is termed All Volatile Treatment (AVT)

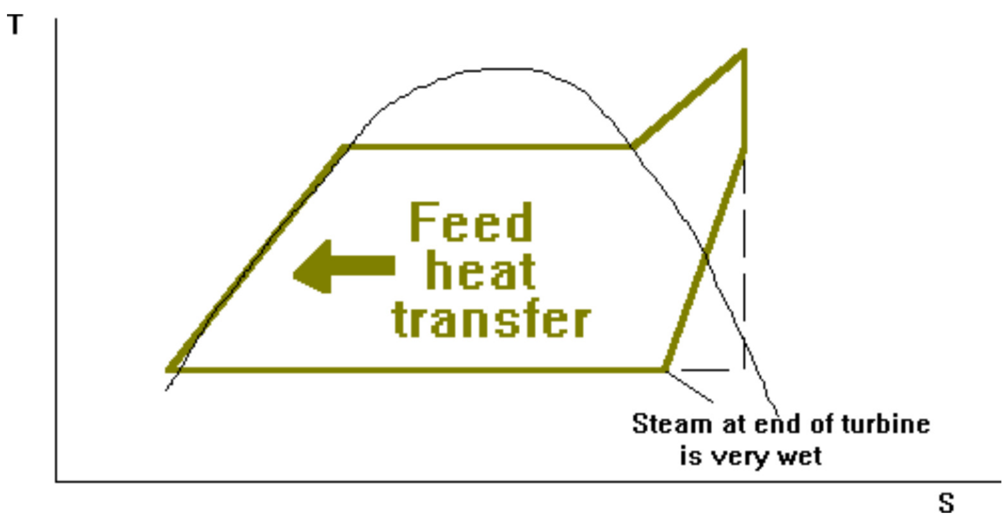
Theory of Feed Heating

The purpose of feed heating is to increase plant efficiency. With no feed heating steam gives up three times more heat to the cooling water as it does in doing useful work in the turbine. Hence, if a proportion of the steam is bled off to a feed heater it can give energy (its latent heat mostly) to the feed and so a higher proportion of the energy is reclaimed by the system as would have been gained by expanding it through the turbine to the condenser Feed heating can take two forms, one is contact heating which occurs in the Deaerator where the steam and feed water mix and and the water directly receives heat.

Theoretical cycle with all steam expanded through the turbine



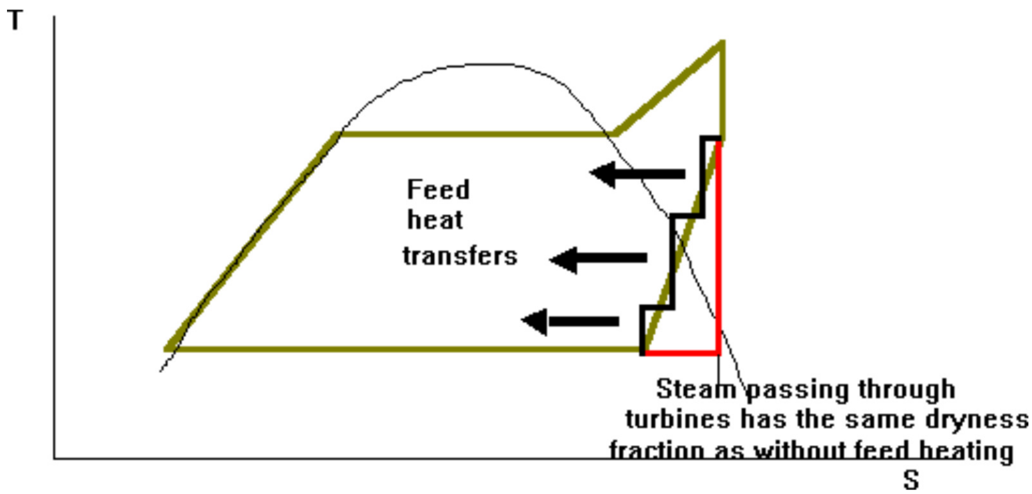
Theoretical cycle where all of the steam used in feed heating with 100% efficiency



This could only be possible where the turbines where fitted with a water jacket through which the feed water flows.

Theoretical practical cycle where a portion of the steam is bled

off in stages and used for feed heating

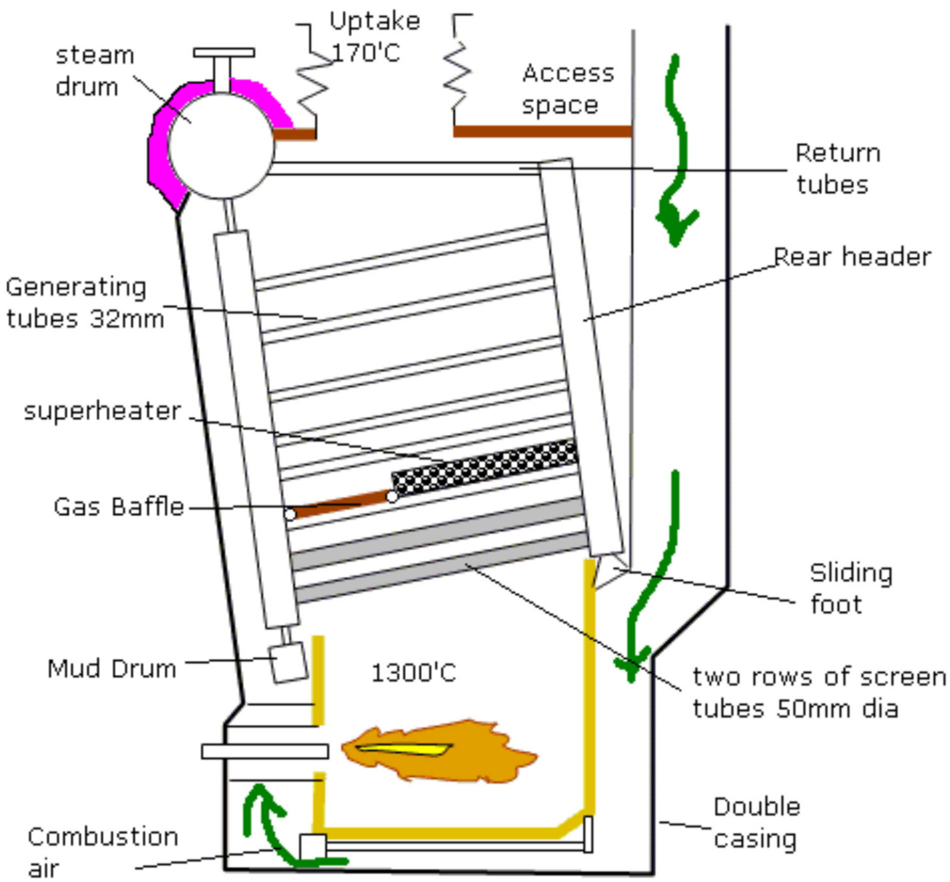


It should be noted that although thermal efficiency increases with the number of stages, it is governed by the law of diminishing returns and the improvement is reduces with successive stages. Hence the cost of the increased plant becomes a factor.

Bleeding off a portion of the steam gives the added advantage that the steam volume that has to be accommodated in the final stages of the turbine and condenser is reduced.

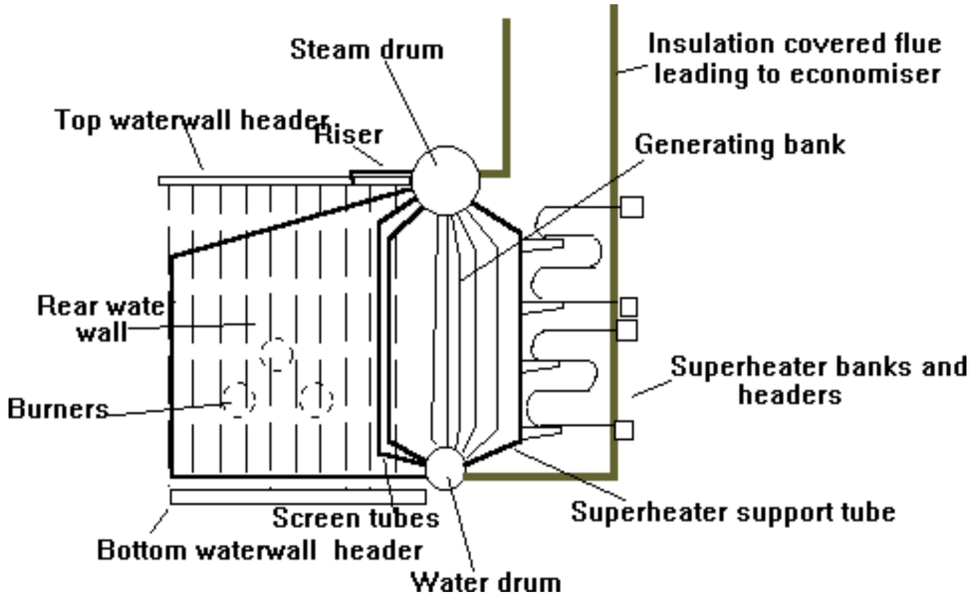
Basic Boiler Construction

Header

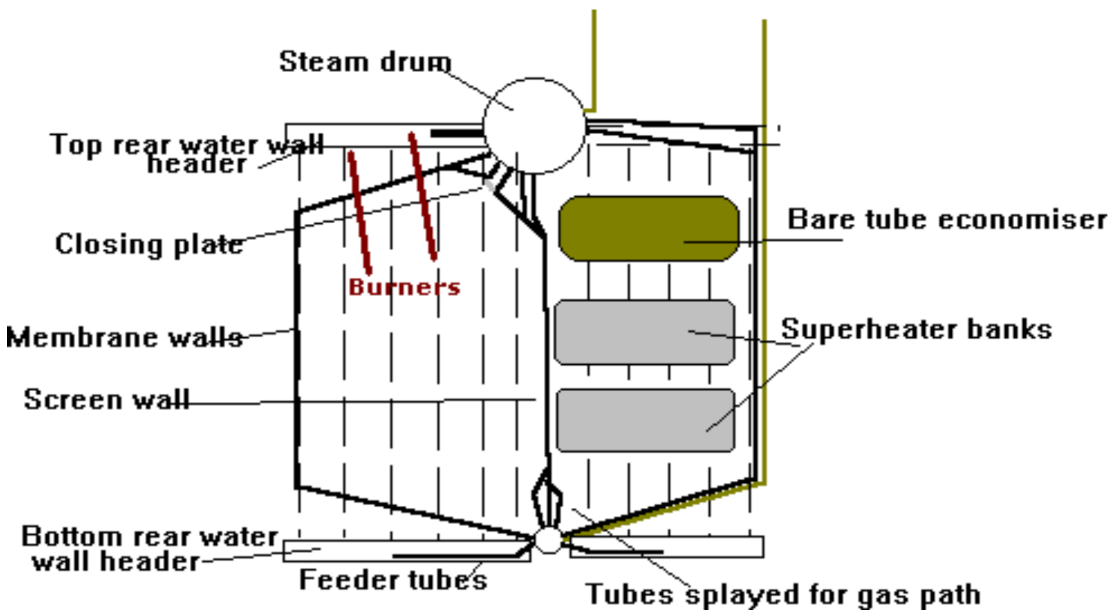


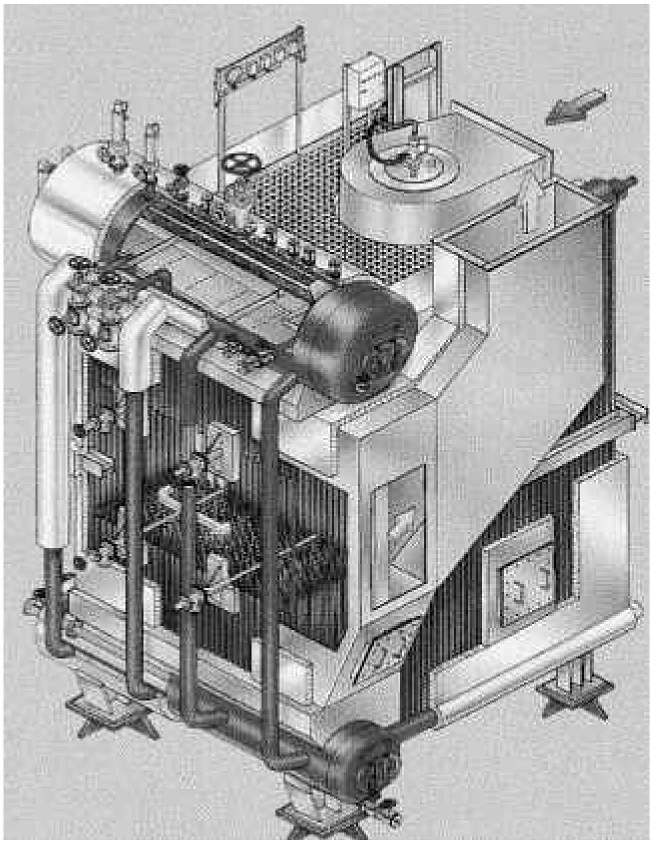
This design allows the use of lower quality feed. It is easy to clean and easy to maintian and replace tubes. Disadvantages are the large number of handhole doors and the extensive brickwork. The drum is all welded and the casing bolted

Front fired studded wall refractory covered boiler



Roof fired membrane wall modern Radiant heat boiler





Components

Steam drum

In the early designs the drums were riveted or solid forged from a single ingot, but for modern boilers the drum is generally fabricated from steel plate of differing thicknesses and welded. The materials used are governed by classification society rules. Test pieces must be provided.

The cylindrical drum is normally constructed from four plates. Two dished End plates, a thick wall tube plate (thicker to accommodate the holes drilled in it without increased stress) and completed with a thinner wrapper plate.

Construction takes the form of rigidly clamping the descaled, bent wrapper and tube plates together. In addition test pieces cut from the original material are attached to the construction in such away that the longitudinal weld extends either sided of the join. These pieces are later removed and shaped test shapes cut out from specified areas including across the weld.

The longitudinal weld is critical (taking twice the circumferential stress) and is normally carried out by specialised automatic machinery using submerged arc techniques.

The dished end pieces are accurately aligned and welded.

On completion the construction is cleaned and non-destructive testing- such as x-ray photography, carried out. Final machining is carried out and any stub pieces and doublers attached. The now complete drum is heat treated at 600 to 650'C.

The final process is hydraulic testing to classification requirements. Natural circulation within a boiler is due to the differing specific gravities of the water at the differing temperatures, the steam drum provides a reservoir of cool water to give the gravitational head necessary for natural circulation. Cool water entering the steam drum via the feed lines provides the motive effect for the circulation distributing it to the downcomers.

Also the space within the drum provides for the separation of the steam and water emulsions formed in the water walls and the generating tubes. Water droplets entrained with the separated steam are removed by separating components fitted in the drum as well as the perforated baffle plates fitted at the water line.

The space above the water line provides for a reserve steam space needed to maintain plant stability during manoeuvring conditions.

Also fitted are the chemical injection distributing pipe and the scuming plate.

The smaller the drum is made, the less thickness of material that is required. However, the limitation to how small is that sufficient space must be allowed for the separation of water from the steam before passing out to the superheater space otherwise dryers must be used. Also, due to the smaller reserve of water, larger fluctuations in water level occur during manoeuvring.

Water drum

Distributes feed water from the downcomers to the headers and generating tubes. Provides a space for accumulating precipitates and allows them to be blown down.

Water drum size is limited to that required to receive the generating tubes, for modern radiant heat boilers with only a single bank of screen tubes and no generating tubes between the drums, the water drum has been replaced by a header and the downcomers fed straight to the waterwall headers. With system blow down is done at the steam drum. Too small a water drum can cause problems of maintaining ideal water level and little steam reserve

Headers

These have a similar purpose to the water drum but are smaller in size. Due to their reduced size they may have a square cross section without resorting to exceptional thickness. .

Generating tubes

Consists of a large number of small diameter tubes in the gas flow, more commonly found in boilers of an older design

For roof fired boilers the generating bank may consist of one or two rows of close pitched tubes. For a modern radiant heat boiler the generating bank has been omitted to allow the replacement of the water drum by a distribution header, a bare tube economiser is fitted generating 5% of the steam capacity. The generation bank is normally heated by convection rather than radiant heat.

For a set water circulation the tube diameter is limited to a minimum as the ratio of steam to water can increase to a point where the possibility of overheating could occur due to the lower heat capacity of the steam.

The number of tubes is limited to prevent undercooling of the gas flow leading to dew point corrosion

Screen tubes

These are larger bore tubes receiving the radiant heat of the flame and the convective heat of the hot gasses. The large diameter keeps the steam/water ratio down hence preventing overheating. There main duty is to protect the superheater from the direct radiant heat. On a modern marine radiant heat boiler the screen wall is formed out of a membrane wall

Waterwall tubes

Contains the heat of the heat of the furnace so reducing the refractory and insulation requirements.

Comes in three designs

- water cooled with refractory covered studded tubes
- Close pitched exposed tubes
- Membrane Wall

Downcomers

These are large diameter unheated i.e. external to the furnace, their purpose is to feed water from the steam drum to the water drum and bottom headers.

Riser/Return tubes

These return steam from the top water wall headers to the steam drum.

Superheater tubes

These are small diameter tubes in the gas flow after the screen tubes. Due to the low specific heat capacity of the saturated steam they require protection from overheating in low steam flow conditions, say when flashing.

Superheater support tubes

These are large diameter tubes designed to support part of the weight of the superheater bank of tubes.

Material requirements

Tube temperatures for the water cooled sections is considered to be saturation temperature plus 15^{o}C. Solid drawn mild steel is generally used.

Tube temperatures for convection superheater sections is considered to be final superheat temperatures plus 30^{o}C. For Radiant heat a higher temperature is considered.

For Superheater tubes operating above 455^{o}C a Chrome Molybdenum alloyed steel is required.

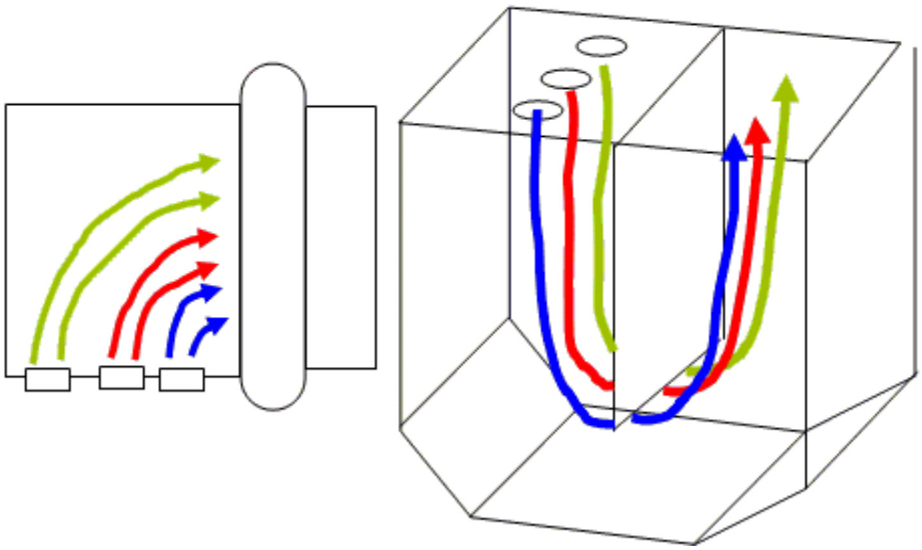
Advantages of membrane/monowalls

These were originally introduced in land power stations after experience had been gained in making the lower parts of the furnace sufficiently tight to hold liquid ash. This was achieved by welding steel strips between the floor tubes. Further development resulted in completely gas tight furnace wall panels being constructed by welding together either finned tubes or normal plane tubes with steel strips in between and welded. In both methods he longitudinal welds are done by automatic processes and panels of the required size are built up in the factory ready for installation into the boiler in one piece.

- Entire walls may be prefabricated
- Maintenance costs, particularly of insulation are lower
- Lower quality fuels may be used due to the much reduced amount of insulation reducing problems of slagging
- Simplified water washing procedures
- Due to gas tight seal there is no corrosion of outer casing.

A disadvantage would be that tube replacement following failure is more difficult. Also, the possibility of entire walls parting from the drum can occur during a furnace explosion.

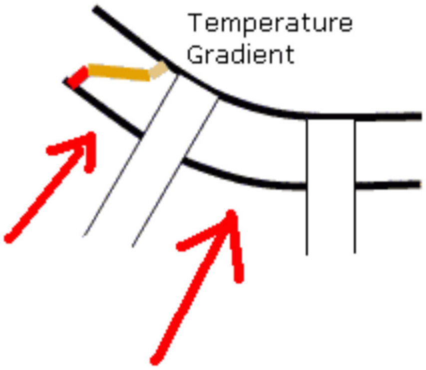
Advantages of roof firing over side firing



- Increased efficiency due to the longer length allowed for the flame giving more time for complete combustion. This also allows more heat to be released as radiant rather than convective cutting down the required number of screen wall generating tubes
- The longer period allowed for complete combustion means that less excess air is required, this has the knock on effect of lowering the Dew Point of the flue gasses.
- Equal length flames
- Better gas flow
- For roof fired the effect of each flame is the same, foir side firing it differs. To keep within the design limitations the boiler must be operated to the highest effect flame with the other two operating at reduced effect

Ligament Cracking Mechanics

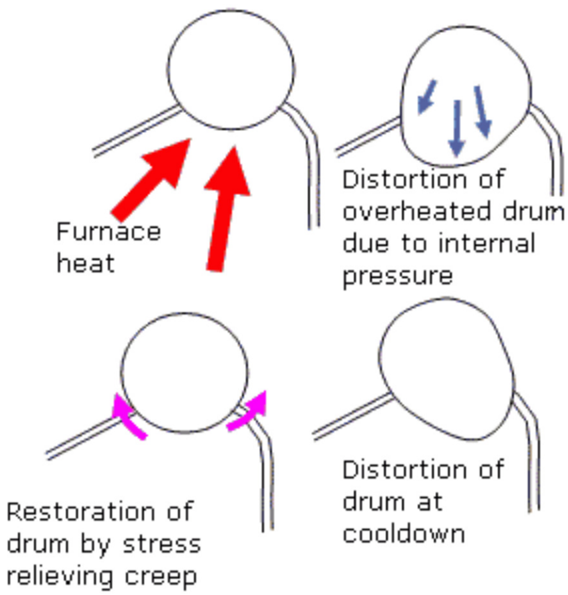
Generally associated with failure of refractory plug located beneath steam drum.

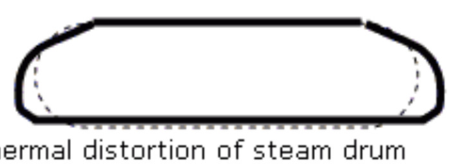


Hot gasses acting on the thick section tube plate set up a temperature gradient leading to creep, plastic flow to relief thermal stress and high tensile stress on the surface at cool down. In addition grain growth leads to the metal becoming brittle

A more severe form may lead to distortion of the entire drum in two possible directions. The thick section tube plate is exposed to the heat of the furnace and is subject to overheating. Thermal distortion takes place leading to stressing. This stressing is relieved by creep . When the drum cools a set distortion is in place

The distortion may occur in three ways, in a radial or axial direction as shown below

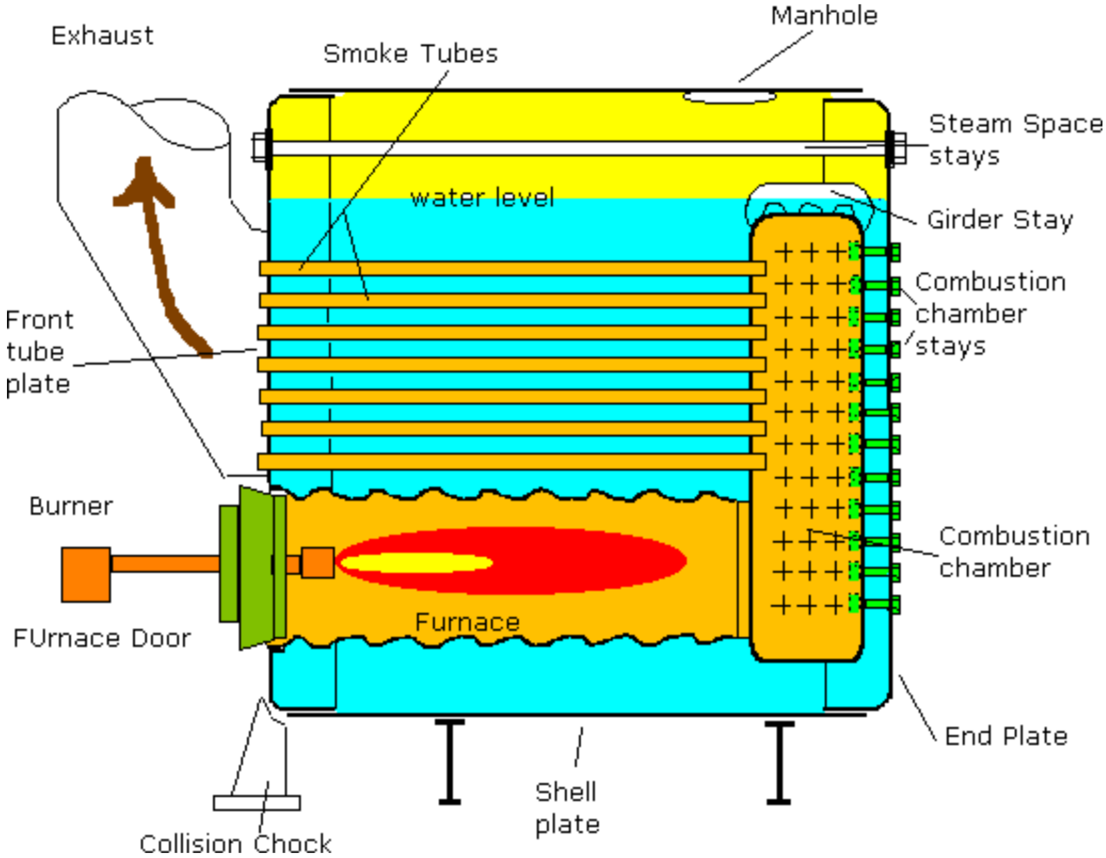




The Direction of the cracking indicates how it occurred

Smoke tube Boilers

Tank (scotch) Boiler



These were the most common form of boiler design before the introduction of water tube designs. See [Comparisons of water tube and Smoke tube boilers](#).

This style of boiler still see active service were low quantities of low quality steam are required, such as for cargo and fuel tank heating when in port.

This style of boiler is relatively cheap, supplied as a packaged unit and requires less stringent feed water conditioning and level control.

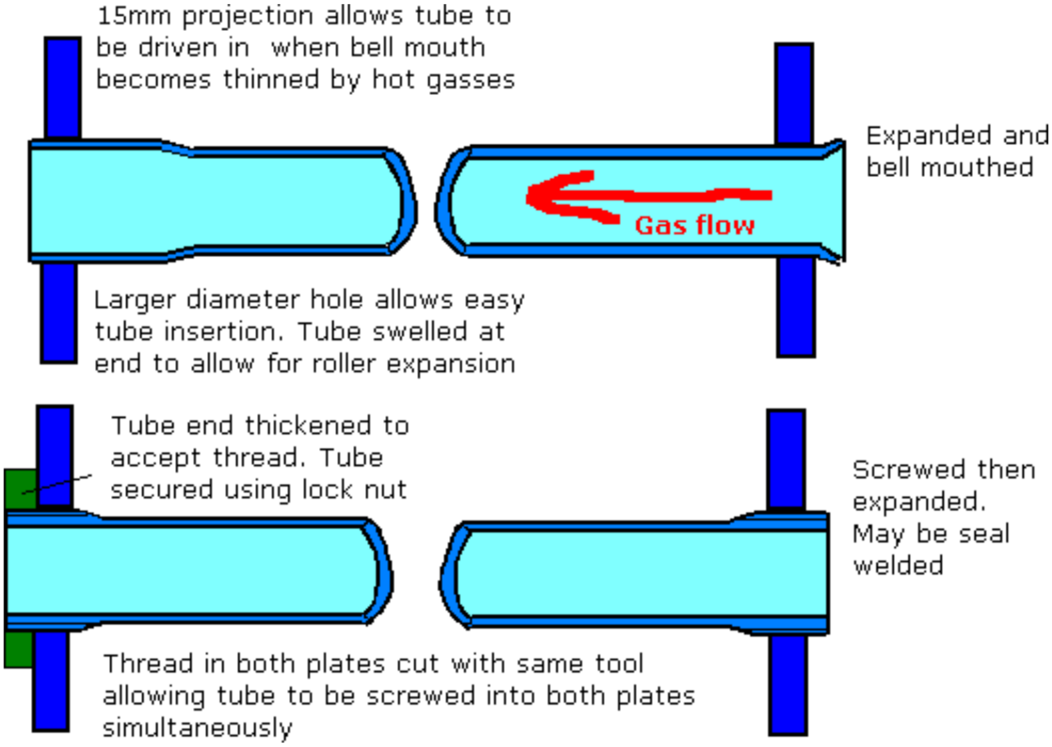
Design

Consists of a shell wrapper plate to which is welded (or for later designs riveted, end plates.. Pressure is naturally container in the shell plate due to is cylindrical design. The flat end plates, however, must be 'stayed' to prevent buckling and distortion.

The combustion chamber is of similar section and is also 'stayed'.

The boiler shown above is a single furnace, two pass design. Larger boilers may have multiple furnaces and have multiple passes by replacing the exhaust stack with a return chamber and fitting another bank of tubes.

The smoke tubes may be plain or threaded to act as stays. There are one stay tube for every three plain tubes approx.



To aid circulation the tubes are arranged in vertical rows to offer minimum resistance.

Fuel is combusted in the corrugated watercooled furnace. The corrugations increase the surface area and allow a degree of flexibility to allow for expansion and contraction.

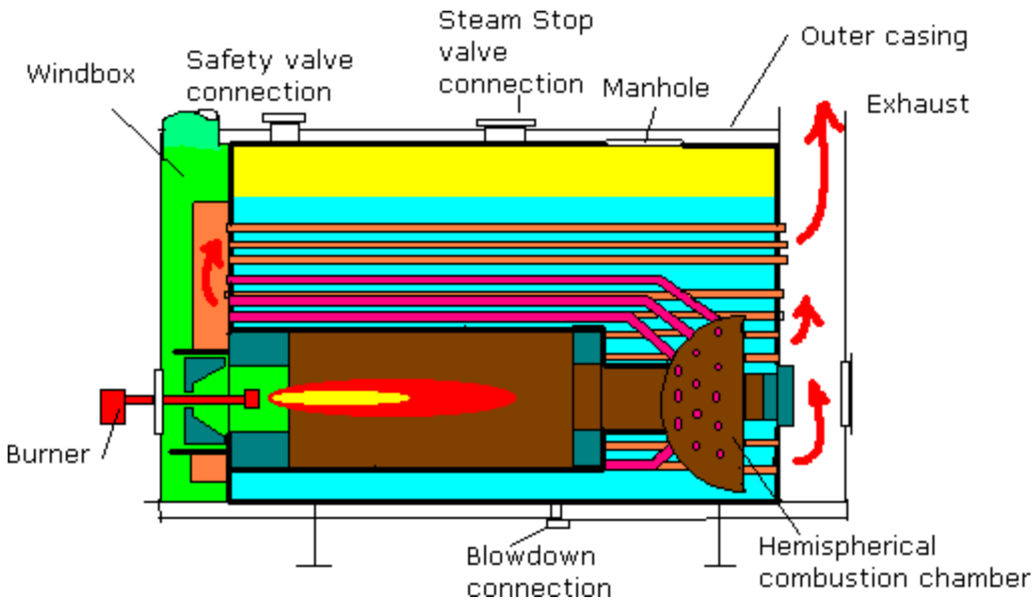
The hot gas passes to the water cooled combustion space though to the smoketubes. The upper portion of the combustion chamber lies close to the water level and is therefore liable to distortion due to in correct water level maintenance.

Access to the boiler is via a manhole door on the upper shell plate. In addition a smaller door may be fitted below the furnace to allow inspection and scale/sludge removal.

Modern (packaged) boiler

This style of boiler may be fitted to the vessel as a complete unit with its own fuel and water delivery systems, control and safety equipment mounted directly on the unit. Alarms and shut downs may be are given at the local control panel which may be interfaced with ships alarms system to allow UMS operation..

The design is simialr to the scothch boiler other than the combustion chamber wich requires no stays. This design is a three pass design



Operation

Although the maintenance of the water level is not so critical as with water tube designs, it should not be allowed to fall too much as overheating of furnace and combustion spaces leads to catastrophic failure due to component collapse. The content of the boiler is then expelled via the furnace door.

Similarly , although water treatment is not so critical scale must not be allowed to build up which can lead to overheating of material

Authors Note

Although package boilers of this design are fairly robust it should not be forgotten the potential for danger a poorly maintained unit can be.

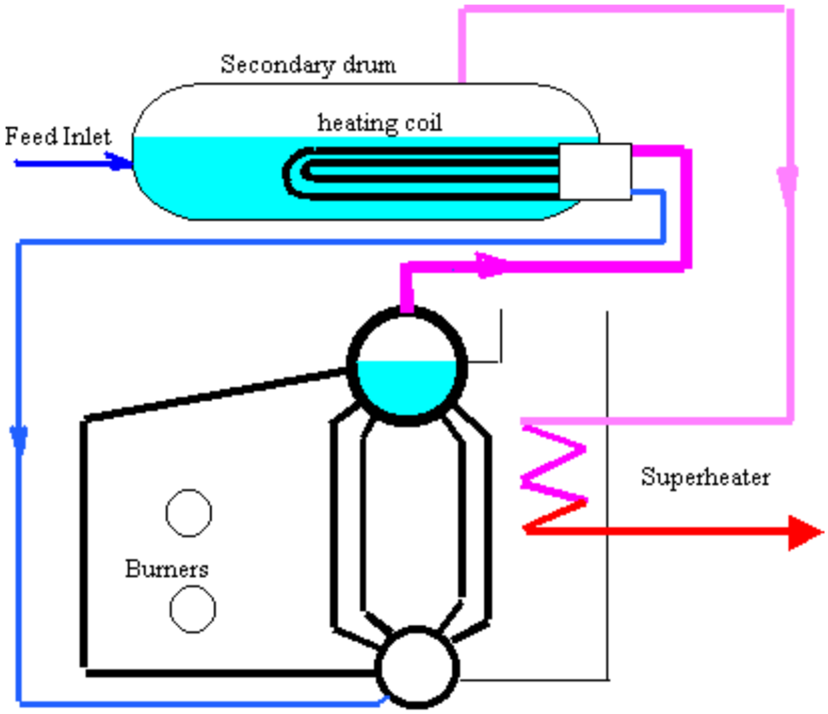
The author carried out a supposed routine inspection on one such unit. Opening the upper manhole revealed that the unit has been 'wet layed' with water left at normal working level rather than being pressed up . Severe pitting was present at and just below the water level.
The lower man hole door beneath the furnace was opened after draining the water. Heavy wastage could be seen later measured at 60 % of the shell plating with pitting on top of this. Evidently no oxygen scavenger, such as Sodium Sulphite, had been added before laying up.

In this condition, operation at full load would almost certainly have led to catastrophic failure.

Dual Pressure (double evaporation) Boilers

The main reason for the adoption of this design of boilers is to allow use of modern high efficiency watertube boilers witghout fear of damage through contamination by cargo or fuel oils.

The basic design consists of a D-Type boiler design upon which is mounted a Steam/Steam generator drum. The steam generated by the main boiler heats water in the Steam/Steam generator which produces steam requirements.



The primary drum is initially filled with high quality feed water and suitably dosed. Make up is limited to small amounts due to leakage therefore the feed pump may be of simple design. An example could be a steam or air driven reciprocating pump. The chemical treatment is simple with little requirement for addition or blowdown.

The above design shows the fitting of a superheater. These are normally only fitted where the generated steam will be required to power turbine operated machinery most typically an alternator.

Secondary drum.

The U-tube heating elements are passed through the manhole dorr and expanded into headers welded into the dished end of the drum. The tubes are well supported. A manhole may be fitted at the lower part of the shell allows access to the heating elements.

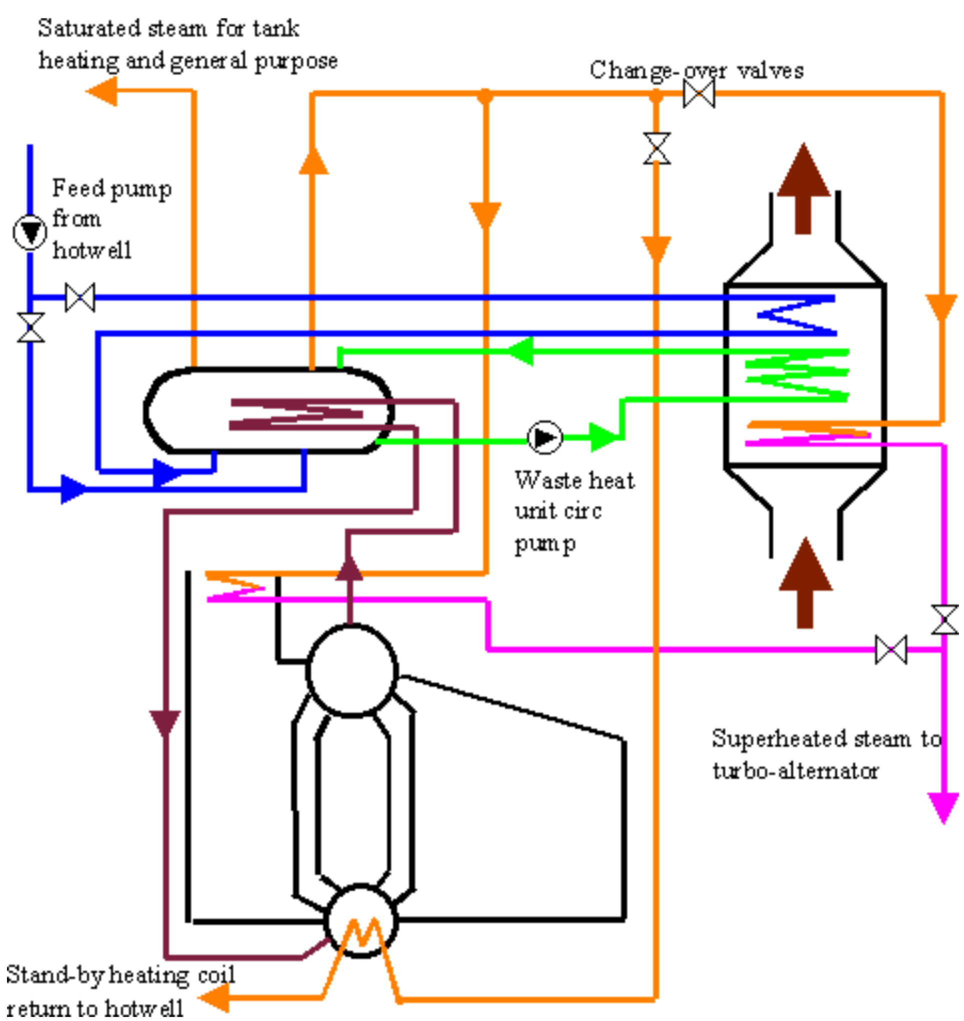
The drum is generally mounted integral, supports are attached to the structure of the primary boiler. The secondary drum also acts as a steam receiver for the exhaust gas boiler.Typical pressures are 63 bar for the primary circuit and 23.5 for the secondary.

The author has not sailed with pressures anywhere near this with this design. Primary pressures of 35bar and secondary pressures nearer 15 bar *have proven sufficient even to drive an alternator. Of note is that these designs are obviously more expensive than a normal single steam drum plant even taking into account the improved efficiency. They are therefore generally associated with larger motor powered plant with large waste heat units capable of supplying all requirements including an alternator. However the author has sailed on this plant on a 20,000 tonne product tanker.*

Where these boilers are installed in Motorships a "simmering coil" may be fitted. This is located in the primary drum and is supplied from the exhaust economiser to keep both circuits warm thereby preventing any possible damage due to lay-up.

Mountings are those typically found on any boiler with low level water alarms and low/low level shut off on both boilers. The accumulation of pressure test for the safety valves fitted to the secondary drum are calculated with the primary boiler firing at maximum rate generating maximum heating steam supply.

Typical circuit incorporating Dual Pressure Boiler



Under port conditions the main boiler is fired to providing heating steam for the secondary drum. From this steam is supplied for tank heating or to a turbo-alternator via a superheater.

When the vessel is underway the main boiler may stop firing. A waste heat circulating pump passes water from the secondary drum via the waste heat unit back to the drum. The steam produced is again available for tank heating and powering a turbo-alternator.

Cross over valves are fitted for Harbour and sea-duty conditions.

Advantages and disadvantages of watertube boilers

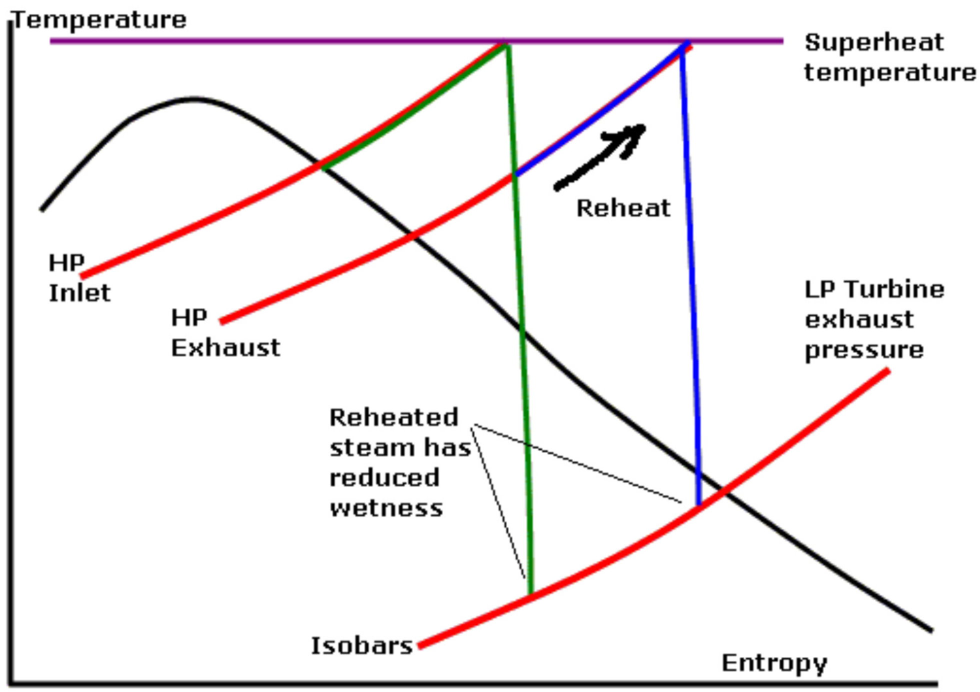
Advatages over tank

- Savings in weight of about 3:1 for a comparable heating surface area
- Possibility of using higher temperatures and pressures without unduly increaseing wall thicknesses increases plant efficiency.
- More efficient combustion space allowed
- Greater flexibility of the structure and rapid circulation prevents the problems of thermal stressing in the tank boilers which leads to grooving. In water tube boilers roof and floor tubes are sloped at 15' to ensure circulation
- thinner tube materials allow rapid steam raising and faster heat transfer rates
- Saving in space for sam steaming rate
- Wider safety margings- limited tube diameters and protected drum surfaces mean failure in tubes releases a flow of steam dependent on tube diameter
- Thin tubes are easier to bend, expand and bell mouth

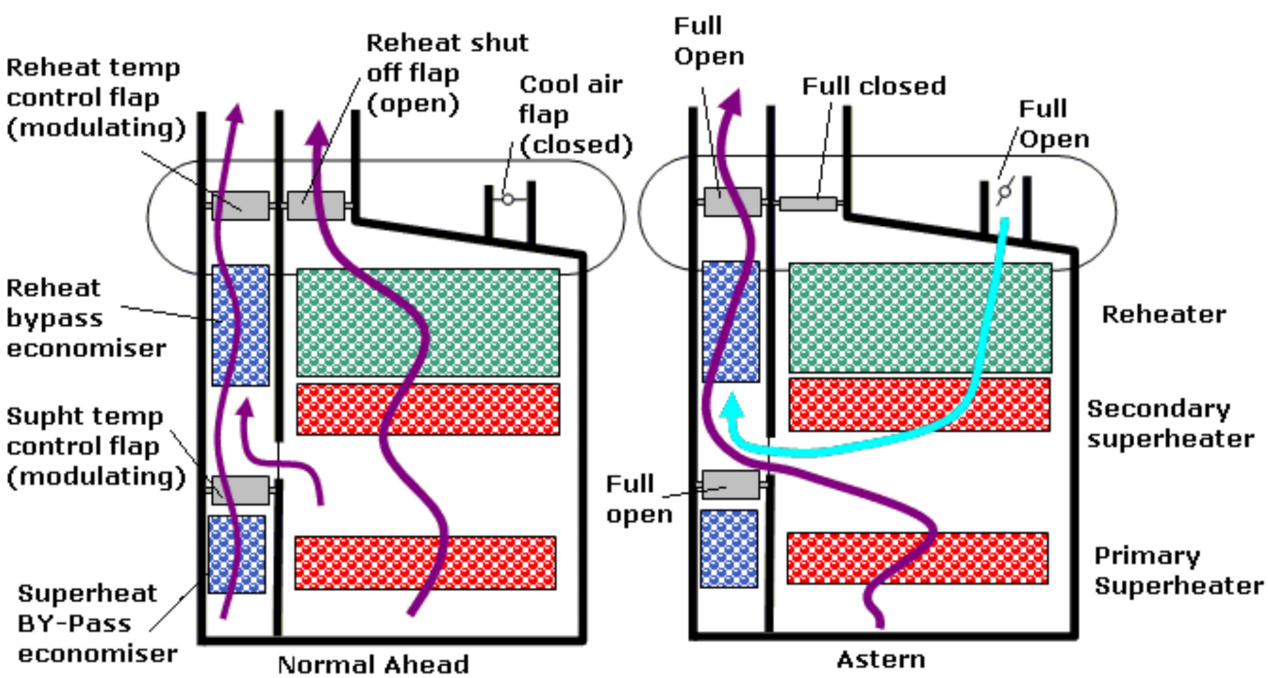
Disadvatages

- Lower reserve of water means a more efficient water level control is required
- High quality feed required
- little allowance to corrosion

Marine Radiant Reheat Boilers

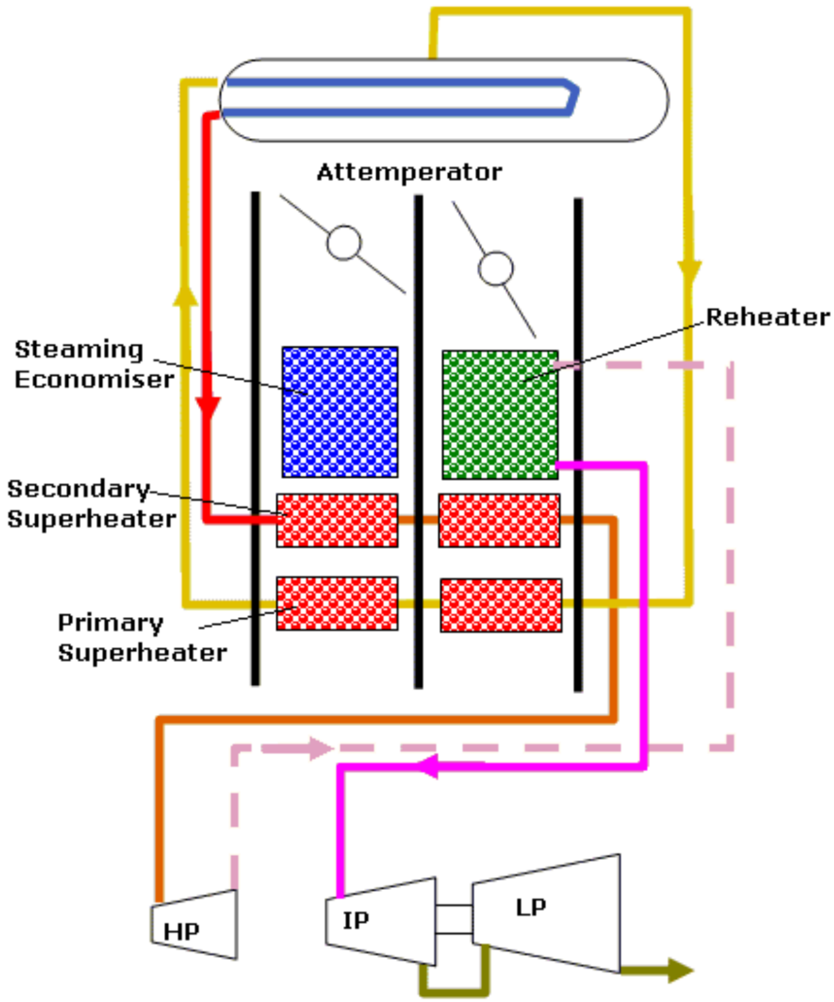


To increase plant efficiency reheat systems are used. In this the exhaust from the HP Turbine is led back to the furnace and reheated to superheat temperatures. This allows the steam to be expanded to lower pressures in the LP turbine with reduced need for blade taper twist and other efficiency degrading designs to cope with the steam wetness.



The boiler design is of a standard roof fired radiant furnace with a gas tight membrane water wall and single row of screen tubes. The convection space is devided into a superheater and reheater secion and a section containing superheat and reheat temperature control by-pass economisers. Gas dampers allow cooling air from the windbox to pass over the reheater section during astern manouevres to prevent overheating and thermal shocking when the plant is moved ahead.

An alternate design using water drum attemperation for superheat control rather than by-pass economisers splits the convective zone into two parts

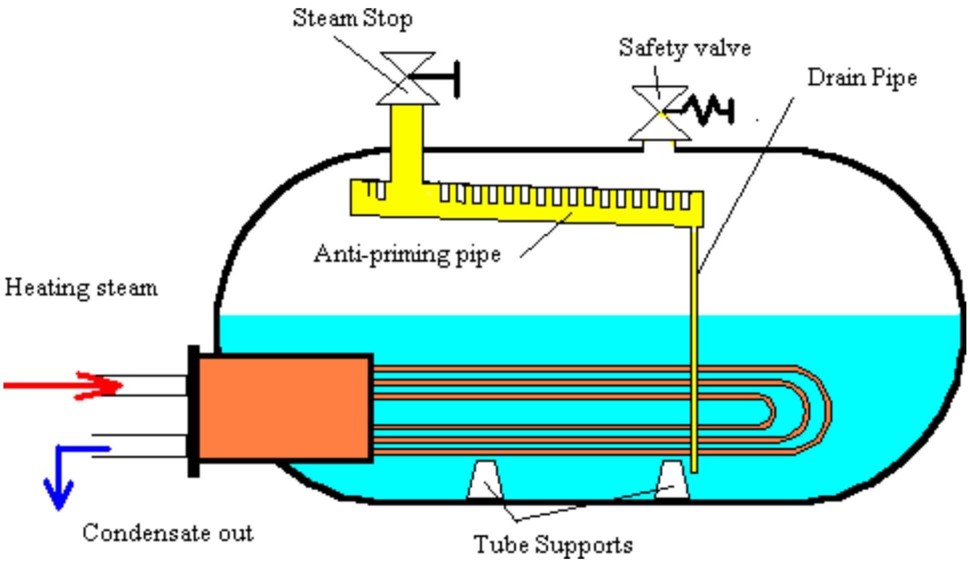


The superheaters in the reheat section ensure that gas is cooled sufficiently to prevent overheating in the reheat in the event of gas dampler leakage. Provision is made to allow windbox air into the reheat space in the event of damper failure.

Advatages of MRR boiler. These are common with any radiant boiler over the convective type design

- Increased plant efficiency
- Improved combustion
- Less excess air requirement. This has the additional advantage of reducing dew point corrosion in the uptake
- Refractory limited to burner quarls and exposed section of water drum and bottom header. This allows for poor quality fuels due to reduced slagging
- Furnace Gas tight

Steam-Steam Generators-



Found on steam propulsion plant and used for the production of low pressure steam for tank heating purposes. The heating steam circuit may be separated from the main system to reduce the risk of oil contamination in the main boilers

Generally the heating steam is supplied from the Intermediate Pressure system. Under sea conditions there is sufficient exhaust steam capacity to supply the IP system requirements. In separated duty , live HP steam may be separated and pressure reduced as make up..

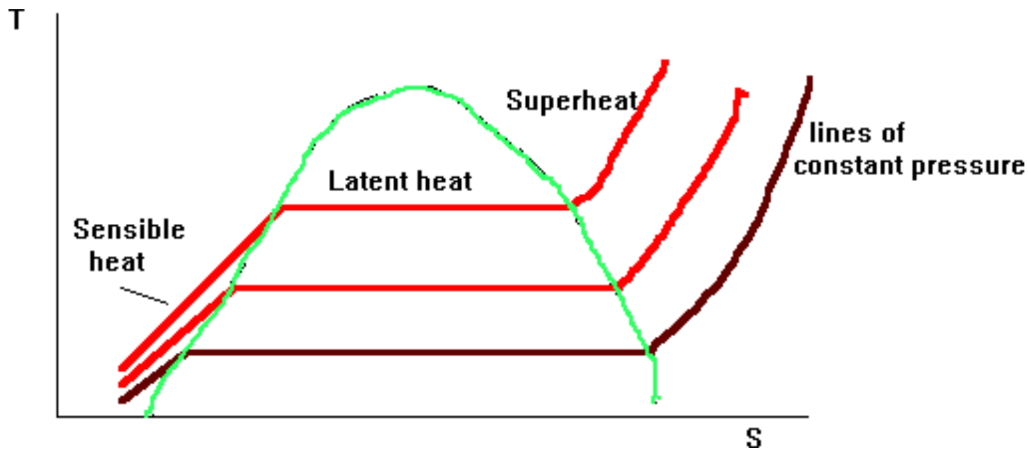
Superheaters

Reason for superheating steam

The maximum efficiency possible for a plant is given by the Carnot cycle and can be calculated using the formula

Efficiency = T1- T2/ T1

Where T1 is the maximum temperature in a cycle (kelvin), and T2 is the minimum temperature in a cycle.
For the steam plant these equate to blr outlet temperature and the exhaust temperature of the turbine.



Hence, to increase final temperatures at boiler outlet conditions either; the boiler pressure can be increased, or the degree of superheat can be increased. Boiler pressure increase is ultimately limited by the scantling requirements,more importantly however, the energy stored within the steam is little increased due to the reduction in the latent heat.

Increasing the degree of Superheat not only increases the temperature but also greatly increases the heat energy stored within contained another advantage would be that the onset of condensation through the turbine would be delayed. However this increases the specific volume which would require excessively large plant. Also there would be insufficient pressure drop for efficient expansion through the turbine. There would also be little allowance for feed heating.

There is therefore a combination of increased Pressure and Superheat to give the increased efficiency potential allied with practical design parameters.

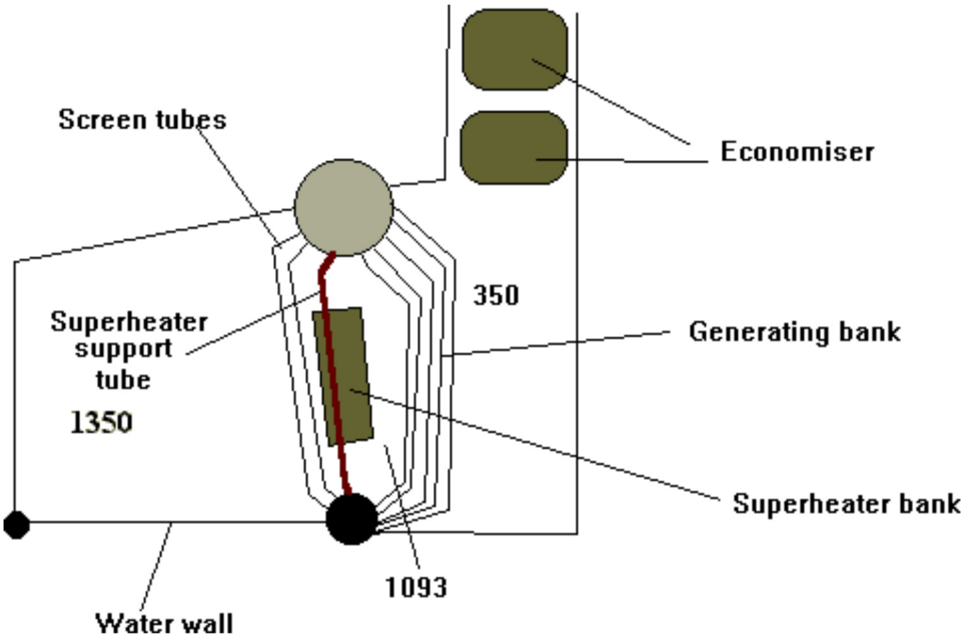
Limit of Superheat

Superheated steam, having a lower specific heat capacity then water does not conduct heat away as efficiently as in water cooled tubes, and hence the tube metal surface temperature is higher.

This has led to the external superheat design and parallel steam flows in an effort to keep metal temperatures within limits
For mild steel, upto 455^{o}C superheat is possible; for higher temperatures, up to 560^{o}C the use of chrome molybdenum steels is required. The use of special alloy steels introduces manufacturing and welding difficulties.
It can be seen that there is a requirement for some form of superheat temperature control

Positioning of the superheater

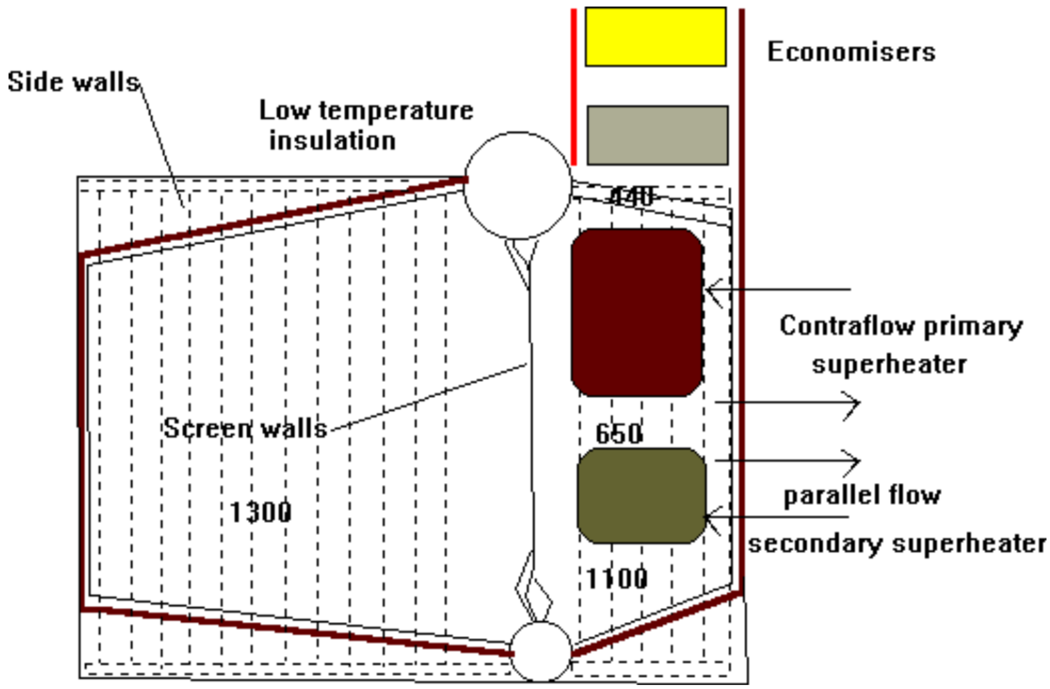
Integral (FW D-type)



This design suffered from heavy slagging of the tubes, particularly the superheater bank, caused by the vanadium bearing ash of the increasingly poorer quality fuel blends.

This ash caused a heavy bonding slag deposit which often bridged the gap between the tubes. This slagging attached to the hot surfaces of the superheater support tube led to wastage and failure.
Increasing slagging would eventually lead to blockage and hence reduced gas path with increased gas velocities over the smaller number of tubes, this led to overheating and failure.
Access for cleaning was limited, this and the problems outlined above led to the external superheater design

External (FW ESD III)



In this position the superheater was protected from the radiant heat of the flame and with roof firing complete combustion was ensured within the furnace space with no flame impingement, this allied to reduced gas temperatures meant that condiitons for the superheater bank was less arduous.
The positioning of the superheater banks allowed for easier inspection and cleaning. More effective sootblowing could also be employed.
With the positioning of the bank external meant that the surface area of the nest had to increased to give the same heating effect.
Mounting of the tubes in the athwartships direction allowed for a simpler mounting arrangement
The secondary superheater, mounted below that of the primary superheater was of the parallel flow type, this ensured that the lower temperature attemperated steam was in the tubes in the highest temperature zone. In modern Radiant Heat boilers it is common to mount the primary superheater below that of the secondary and use parallel flow throughout; this ensure adequate cooling throughout.

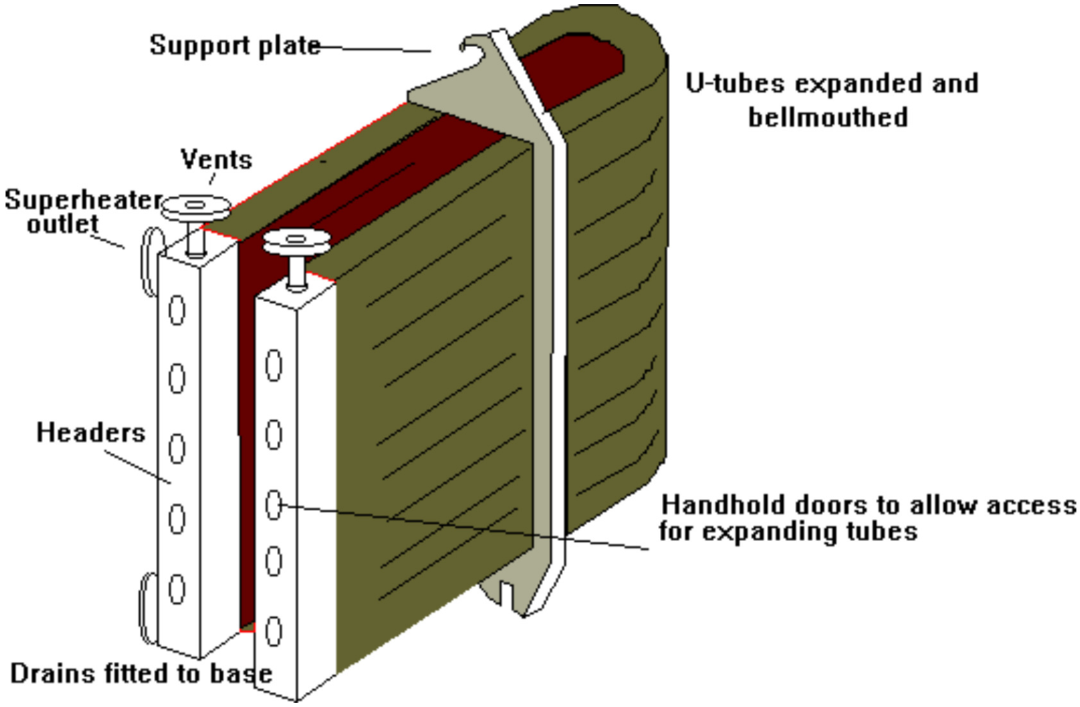
Designs of Superheater banks and mounting arrangements

U-Tubes

Use limited to the integral positioning fort he superheat bank, the modern method is to hang the tubes vertically, this prevents the sagging that can occur with the tubes in the horizontal.

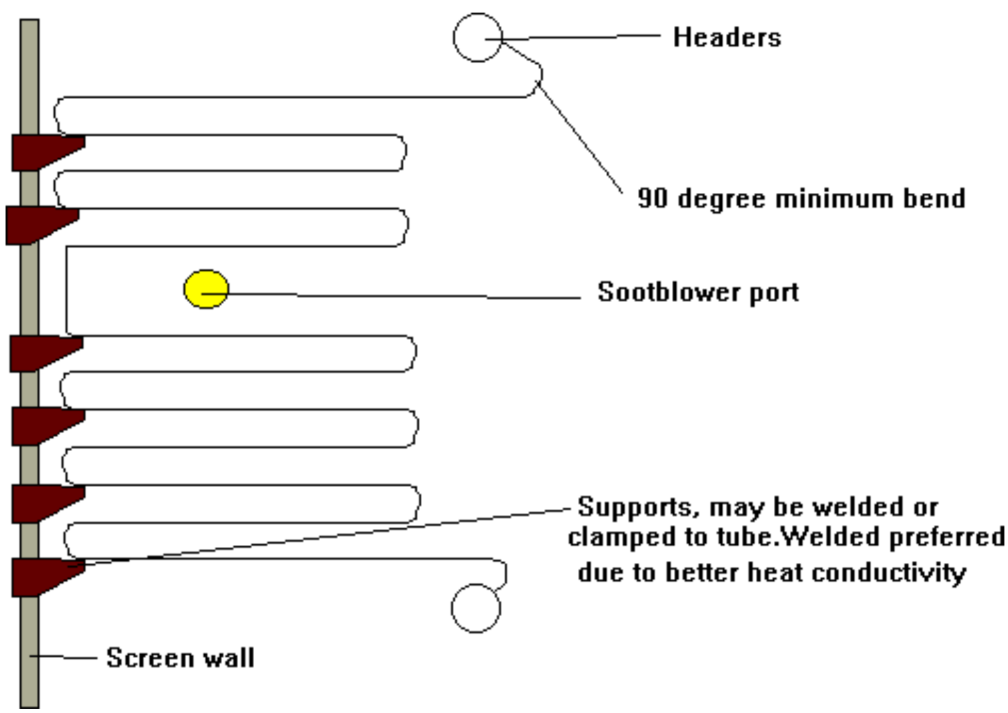
The tubes were supported by a support plate which hung off a special increased diameter water cooler tube called the support tube. As the supports were situate in a high temperature zone they were susceptible to failure.

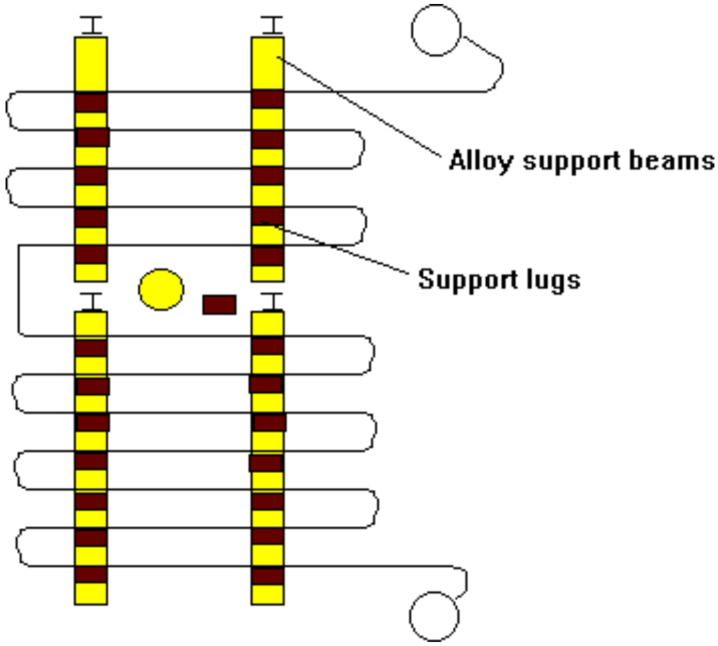
Division plates were welded into the headers, these allowed the steam to make many passes increasing the efficiency of the bank. Small hole were formed in these plates to allow for proper drainage, failure of these plates caused short circuiting, overheating and subsequent failures.
Failure of a single tube, although possible leading to a restriction in the flow meant that the heating surface was reduced by only a small amount.
The superheater inlet and outlet flange were mounted on the same side.



External (melesco type)

In this design there are no baffles fitted inside the header, instead the steam makes a multipass over the gas by way of the many limbs or bends of each tube. The disadvantage of this system is that if a tube should fail then a significant reduction in heating surface would occur.Simpler, more reliable support methods are possible allied to the easier access and sootblowing arrangement.This type of superheater has the advantage that the number of expanded or welded joints are reduced.





With this design the initial passes are made of Chrome Molybdenum steel. a transition piece attaches this to the mild steel passes.
The inlet header is made out of mild steel and the outlet an alloy steel.

Methods of attachment

Expanded

Only used in superheaters fort temperatures upto 450°C Tube ends must be cleaned and degreased and then drifted and roller expanded into the hole, the end of the tube must be projecting by at least 6mm. The bell mouth must have an increase of diameter of 1mm per 25mm plus an additional 1.5mm.
It is important that the tube enter perpendicular into the head, a seal will be assured if the contact length is greater than 10mm, if it is not possible to enter perpendicularly then the contact length should be increased to 13mm.
For larger diameter pipes then grooved seats are used.

Welded

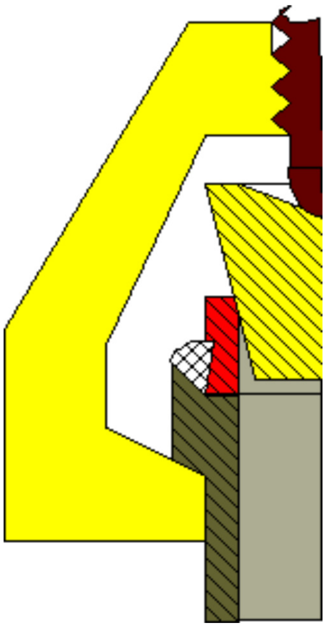
Welding gives advantages over expanding in that access to the internal side of the header is not so important and so the number of handhole doors can be much reduced eliminating a source of possible leakage. welding also generally provides a more reliable seal.

The disadvantage is that heat treatment following welding is required.

The purpose of the backing ring fitted to the conventional attachment method is to prevent the weld metal breaking through into the tube

The Melric joint offers the following advantages over the conventional method;

- Dispenses with butt joints and internal backing rings
- Allows for maximum access for welding
- The joints can be annealed locally by electric heat muff or torch according to manufacturers recommendtions
- The stub bosses can be readily blanked off externally in the event of tube failure and so do not require the access to the header internal side



Air Heaters

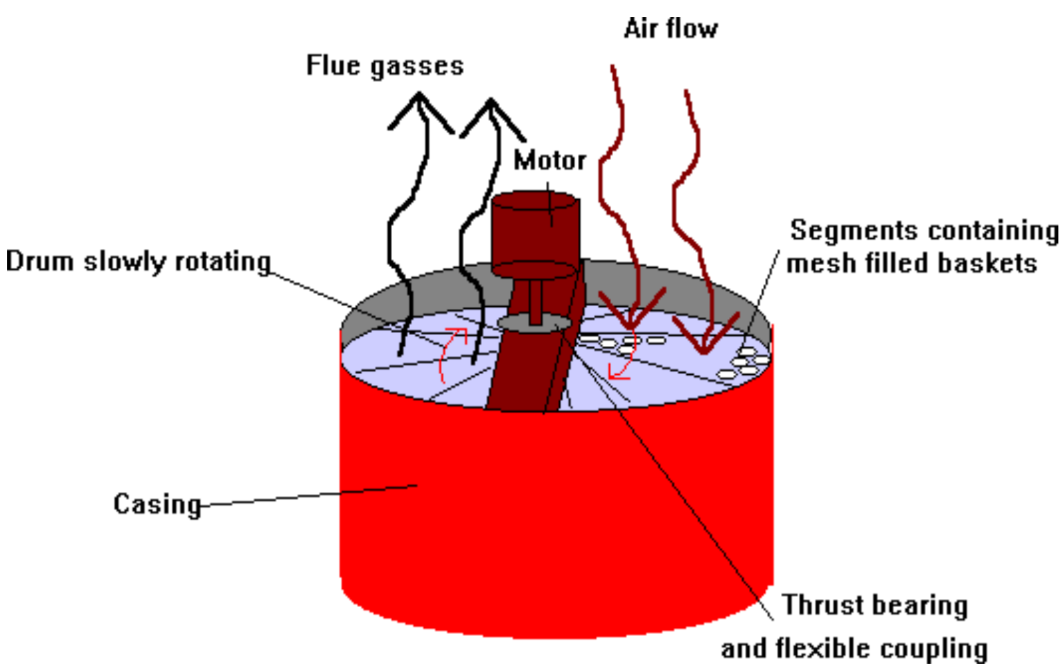
Reasons for their use

- These are fitted for three main reasons
  - To increase efficiency by recovery of heat from flue gases (except where bled steam heaters are in use, these increase overall plant efficiency but by a different method)
  - Accelerate rate of combustion
  - Avoid effect of cold air impinging on boiler surface
  - As a by product air heaters also form a convenient way to warm up a standby boiler before initial firing.
  - However, the effects of dew point corrosion and fouling in smoke tube air heaters should be taken into account when designing the heat absorption limit.I.E. the amount of heat to be removed from the flue gas should have a limit.
  - For water tube boilers gas air heaters are only considered where the temperature at inlet to economiser is greater than 200^{o}C. Due to greater heat transfer efficiency between gas/water economisers are preferred to gas/air exchangers.

At low loads all gas/air heaters should be bypassed to keep uptake temperatures as high as possible.

Types of air heaters

Lungstrom gas/air heater (regenerative)



The drum contained within the cylindrical casing is formed into segments into which are placed removable (for cleaning) baskets, consisting of vertical plates (to give minimum resistance to flow) The drum slowly rotates, about 4rev/min, driven via a flexible coupling,gear train, clutch and thrust bearing by one of two electric motors; one mounted on top the other below.

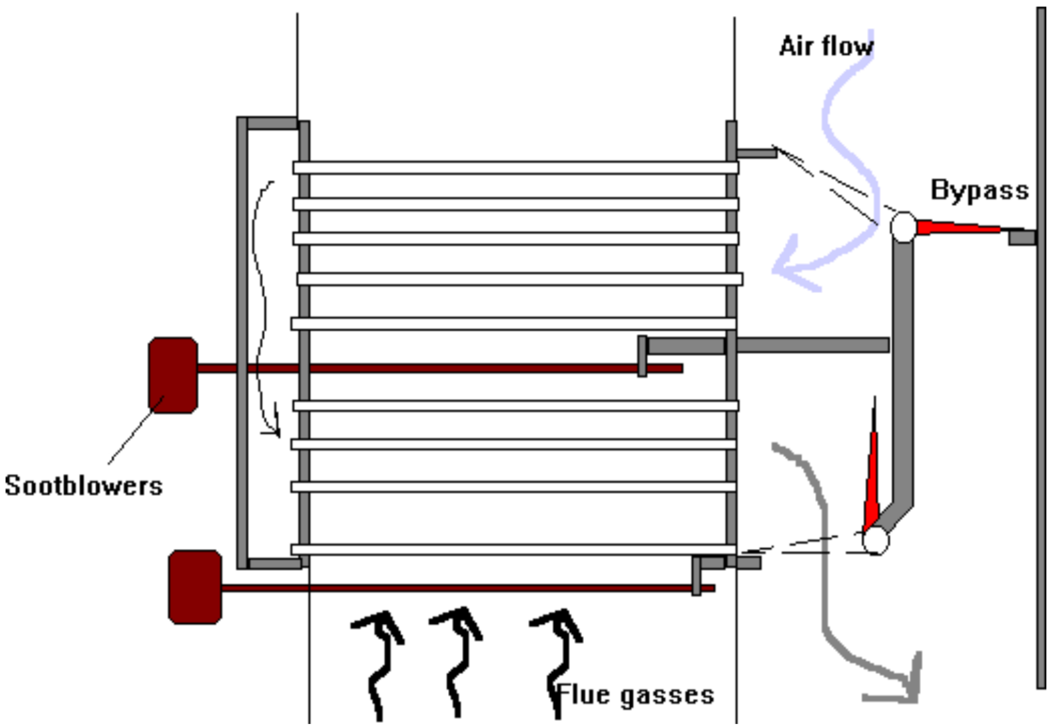
As the drum rotates a segment will enter the gas side, here it removes heat from the gas, it continues to rotate until entering the air side where it will give up its heat to the air. The heat transfer is very efficient, however, soot and corrosive deposits quickly build up in the mesh and hence an effective soot blowing method is essential. This normally takes the form of an arm , pivoted at the circumference of the drum with a single nozzle at the other end. This sweeps acros the drum rather like a record arm. One of these arms are fitted top and bottom.

Gas leakage to the air side is prevented by the air being at a higher pressure and by fine radial clearance vanes fitted in the drum segments.

By passes for both air and gas sides are fitted to prevent fouling with the reduced gas flow and temperature, also during manoeuvring when the possibility of different gas/air flow rates occurring leading to high metal temperatures and possible fires.

Failure by uptake fires is not uncommon with this as in most gas/air heater designs.

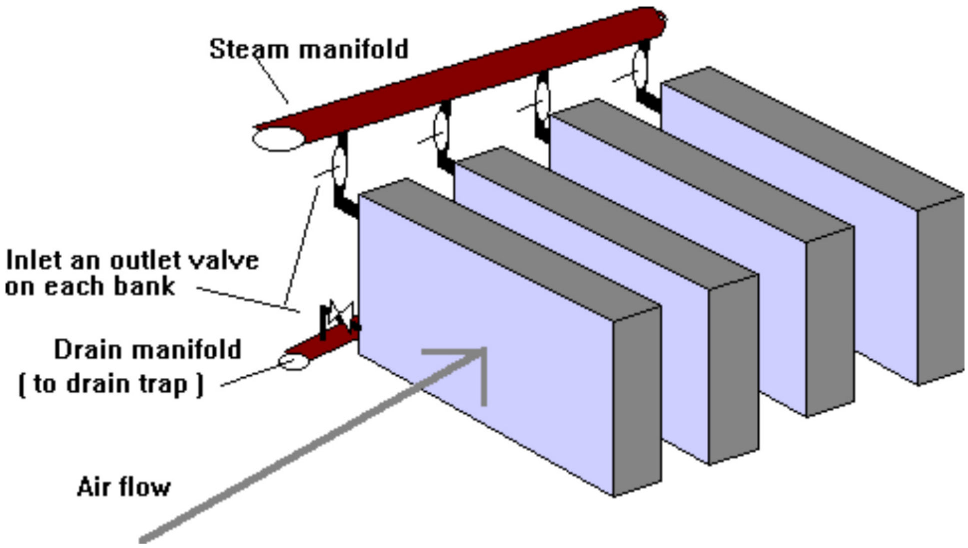
Tubular gas/air heater

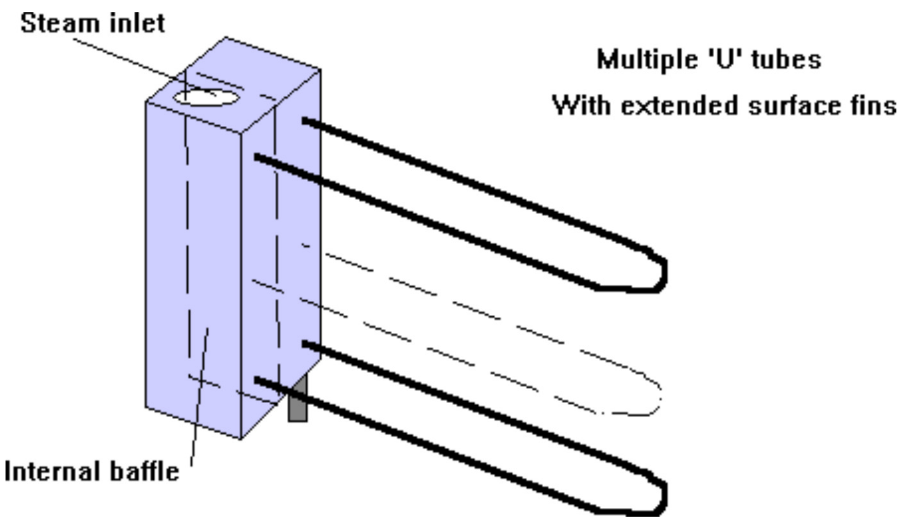


Shown above is the horizontal tube type air heater which was less susceptible to choking with soot than the vertical types sometimes found with older scotch boilers.

To aid cleaning water washing was sometimes carried out to aid the sootblowers

Bled steam air heater





The use of individual banks and 'U' tubes allow for ease of isolation when these become perforated without large loss of heating surface. The tubes were expanded into the headers and made of cupronickel with copper fins.

Burners

Combustion of fuel in furnace and burner design

Process

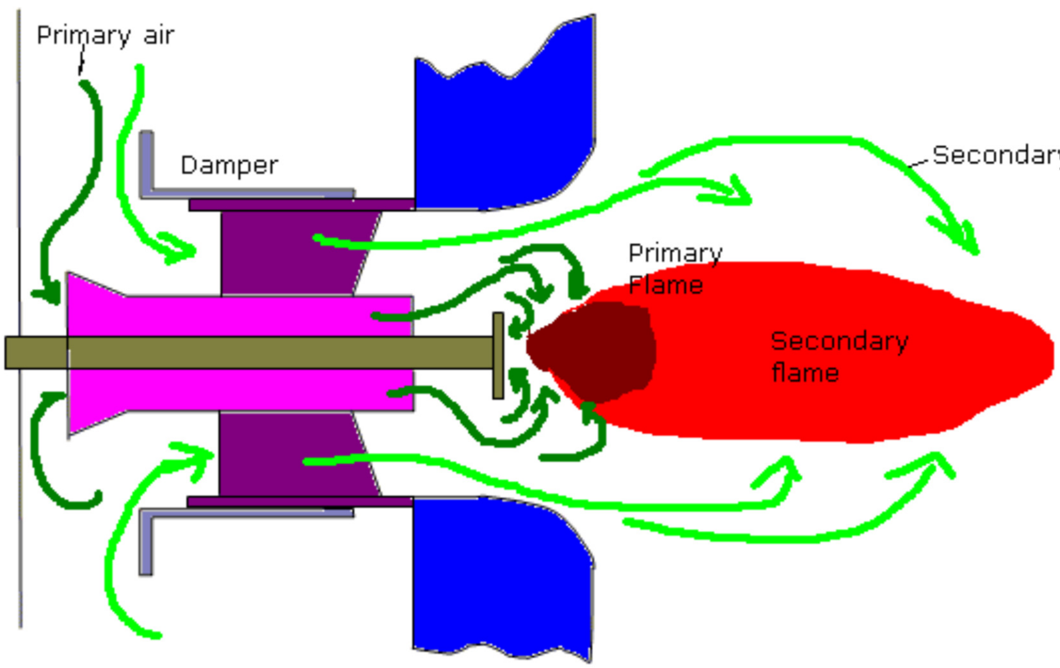
The heat producing constituents of the fuel are hydrogen, carbon and sulphur.

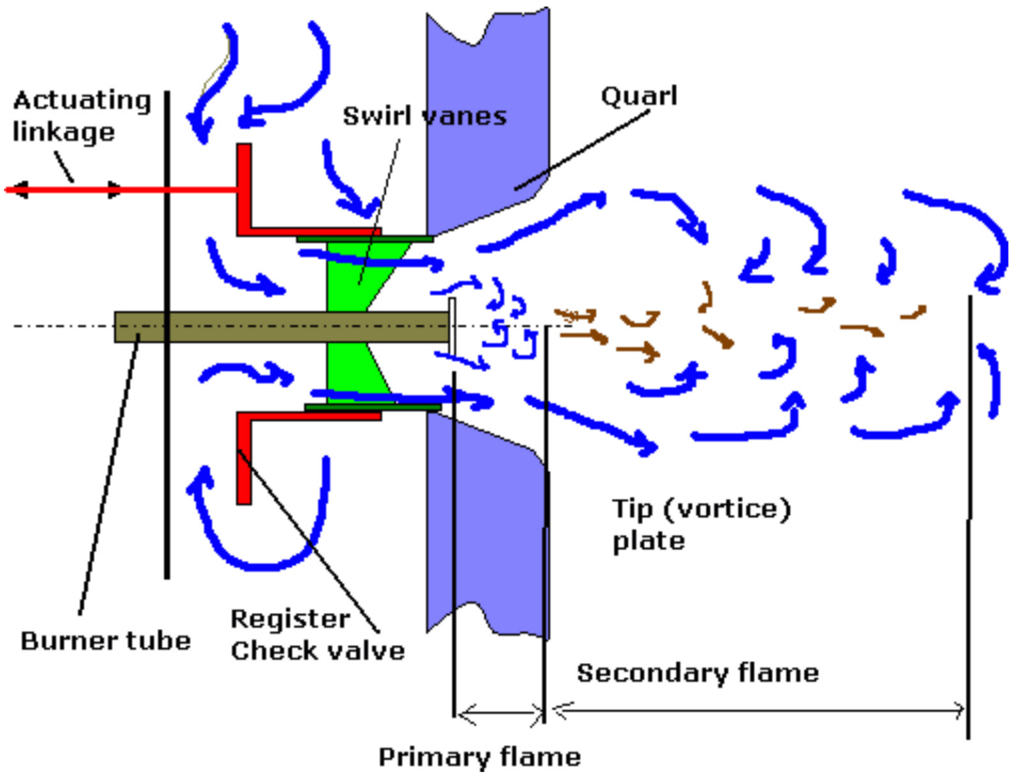
The calorific value of the combustion processes measured in mega joules for each Kg of fuel burnt

- Carbon to carbon dioxide - 34
- Hydrogen to water - 120.5 (assuming the water vapor is not allowed to condense)
- Sulphur to sulphur dioxide - 9.3

The main cause of heat loss with the process is that taken away by nitrogen. Therefore, to achieve maximum efficiency the excess air should be kept to a minimum. However there is a limit to the reduction in the excess air in that the combustion process must be fully completed within the furnace and within a finite time.

The main type of combustion process is called the suspended flame. The flame front remains in the same position relative to the burner and quarl.. The fuel particles pass through the flame completeing their combustion process and exiting at the same rate as the fuel entering.





Primary Flame-To burn oil the temperature must be raised to vaporisation temperature, this can not be done in heaters due to gassing but is done by radiant heat in the flame. The lighter hydrocarbons in the atomised spray are rapidly heated and burnt in the primary flame. The heavier fractions pass through this achieving their vaporisation temperature. The primary flame is essential to good combustion. By design the primary flame exists where it receives maximum reflected heat from the shape of the quarl. The size of the primary flame (shown smaller than actual in drawing) just fills the quarl space. Too large and impingement leads to carbon deposits building up. Too small unheated secondary air reduces combustion efficiency. The tip plate creates vortices reducing the mixing time for the air/fuel and reduces the forward speed of the flame

Secondary Flame-Here the heavier fractions are burnt. The velocity of the air and fuel must be matched to the required flame propogation rate.

Combustion in furnace space

For proper combustion of fuel in the furnace and adequate supply of air must be supplied and intimately mixed with a supply of combustible material which has been presented in the correct condition.

Air- it is the purpose of the register, swirler vanes and (vortice) plates, and quarl to supply the correct quantity of air for efficient combustion suitably agitated to allow proper mixing.

The air is generally heated on larger plant to;

- prevent thermal shocking
- improve the combustion process
- improve plant efficiency (bled steam and regenerative)

Fuel It is the purpose of the burner to present the fuel in suitable condition for proper combustion. Generally this means atomising the fuel and giving it some axial (for penetration) and angular (for mixing) velocity. For effective atomisation the viscosity of the fuel is critical, for fuels heavier than gas or diesel oils some degree of heating is required. It should be noted that the temperature of the

fuel should not be allowed to raise too high as this can not only cause problem with fuel booster pumps but also can cause flame instability due to premature excessive gassification (is that a real word-answers to the normal address)
The smaller the droplet size the greater the surface areas/volume ratio is, this increases evaporation, heating and combustion rate.

Combustion zones

Register- supplies the correct quantity of excess air. Too little allows incomplete combustion, smoking, soot deposits and flame instability. Too much excess air reduces combustion efficiency by removing heat from the furnace space, may cause 'white' smoking and promote sulphurous deposits. In addition too much excess air increases the proportion of sulphur trioxide to dioxide promoting increase acid corrosion attack in the upper regions.
The register and to some extent the quarl determine the shape of the flame, short and fat for side fired boilers, long and thin for roof fired.

Flame burning off the tip- may occur after initial ignition or after a period of high excess air. The effect of this is to move the primary flame away from the quarl thereby effecting the combustion process leading to black smoke and flame instability. Two methods of bringing the flame back are to reduce excess air and introduce a hand ignitor to ignite the fuel correctly, or to rapidly close then open the register damper

Types

There are six main types of burner in common use;

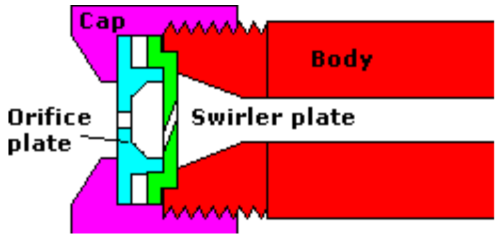
- Pressure jet
- Spill type pressure jet
- Variable orifice pressure jet
- Spinning cup
- Steam assisted
- Ultrasonic

Turndown ratio ratio of minimum to maximum flow (roughly the square root of the ratio of maximum to minimum pressure)

Pressure jet

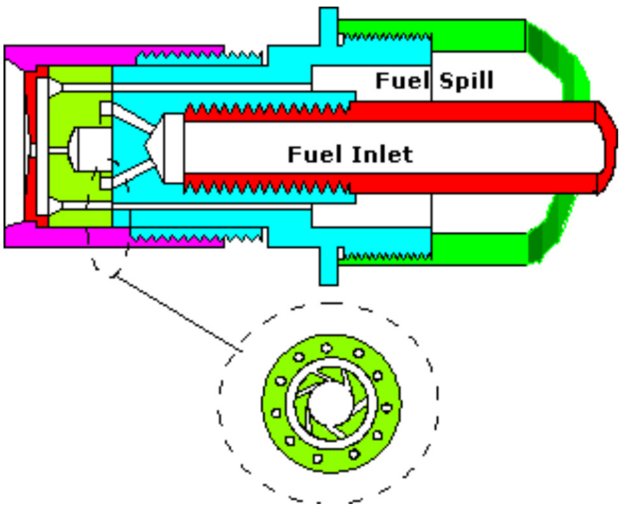
This is the simplest and oldest design of burner. Atomisation of the fuel is achieved by forcing the fuel under pressure through an orifice at the end of the burner, the pressure energy in the fuel is converted to velocity. Spin is given to the fuel prior to the orifice imparting centrigual force on the spray of fuel causing it to atomise.

The disadvantage of this burner is its low 'Turn-Down' ratio (in the region of 3.5). The advantage is that it does not require any assistance other than supplying the fuel at the correct pressure. Due to this it is still seen even on larger plant were it is used as a first start or emergency burner.
Anouther disadvantage over assisted atomisation burners is the lack of cooling from stam or air means the burner must be removed when not in use from lit boilers to prevent carbonising in the tube



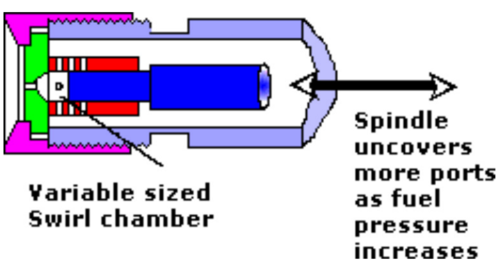
Spill type pressure jet

The method of atomisation is the same as for simple pressure jet type. The burner differs in that a proportion of the supplied fuel may be spilled off. This allows for increased turn down ratio

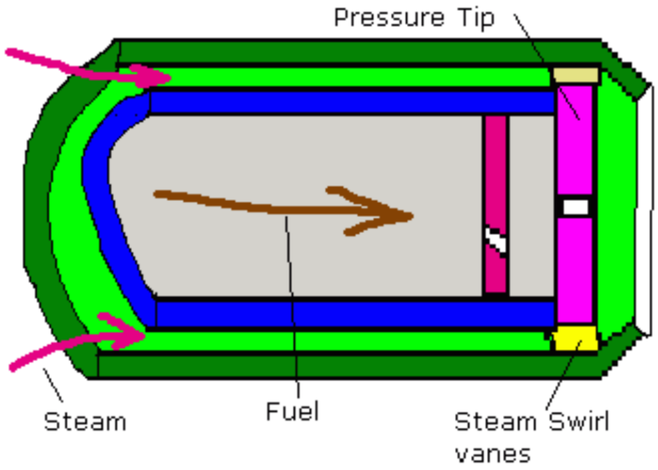


Variable orifice pressure jet

Fuel Pressure entering the burner acts against a spring loaded piston arrangement. Increasing pressure causes the piston to pull a spindle away from the tip, this has the effect of enlarging a closed swirl chamber and uncovering ports. In this way atomisation efficiency is maintained over a greater fuel supply pressure range



Steam assisted



Steam assisted atomisers. This can refer to both external and Internal steam/fuel mixing although conventionally they refer to external mix. In these no mixing of the steam and fuel occurs within the burner itself.

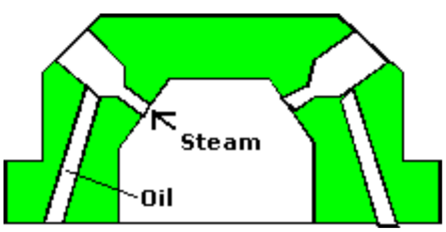
Fuel is suplied to a standard pressure tip atomiser. Steam passes around the fuel passage and exists through an open annulus having being given an angle of swirl to match the fuel spray. At low fuel pressure the steam, supplied at constant pressure throughout turndown, provides for good atomisation. At higher fure pressure the pressure tip provides for the atomisation.

For first start arrangements compressed air may be used.

Steam atomisation

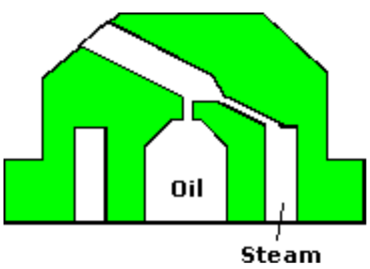
The two main types of internal mixing (the most common) ar the 'Y' jet and the Skew jet .

Y- Jet



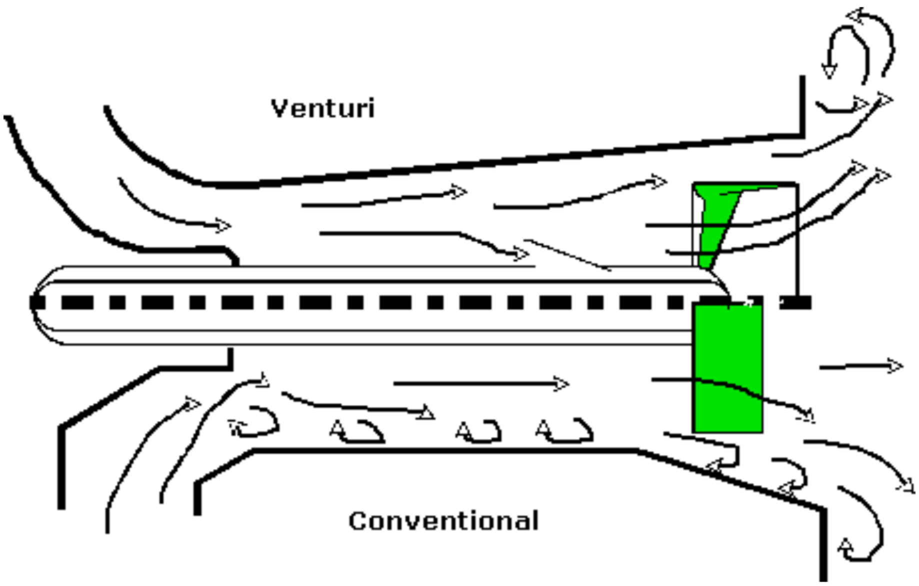
Here the steam anf fuel are mixed into an emulsion and expanded in the holes before emision creating good atomisation. This design is tolerant of viscosity changes and is frugal on steam consumption and require reduced fuel pump pressures .

Skew Jet



The main advantage of this design over the 'Y' jet is the reduced 'bluff' zone due the reduced pitch diameter of the exit holes.

Matched to a venturi register, a very stable efficient flame is formed. The Fuel/Steam mix exits the nozzle in a series of conic tangents, fuel reversals inside the fuel cone allow efficient mixing with air over a wide 'Turn-Down ratio (20:1). In addition this type of nozzle is associated with reduced atomising steam consumption (0.02Kg per Kg fuel burnt) **Venturi and conventional register throat design**

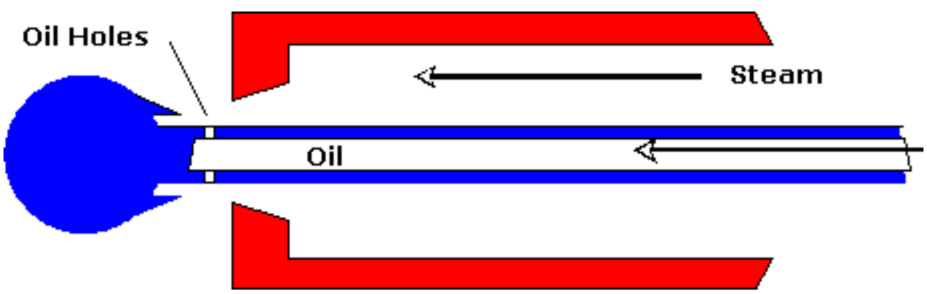


Ultrasonic

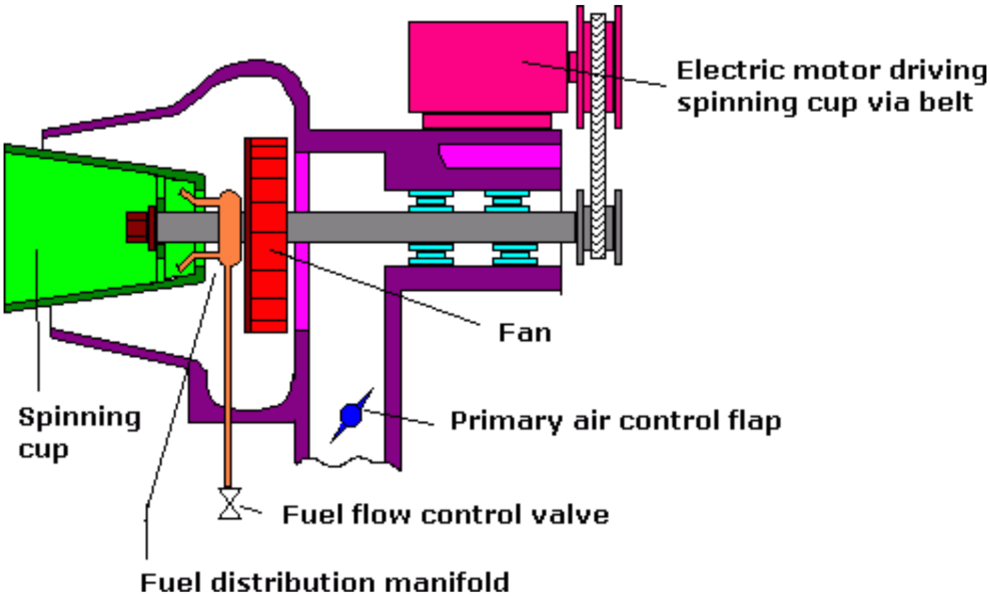
Manufactured by Kawasaki is said to offer the following advantages;

- Wider turn down ratio with lower excess air (15 :1)
- Low O_2 levels
- Simplified operation
- Reduced acid corrosion problems

Atomisation is achieved primarily by the energy of ultrasonic waves imparted onto the fuel by the resonator tip which vibrates at a frequency of 5 MHz to 20 MHz under the influence of high speed steam or air impinging on it. Extremely small droplet sizes result which allow for a very stable flame.



Spinning Cup

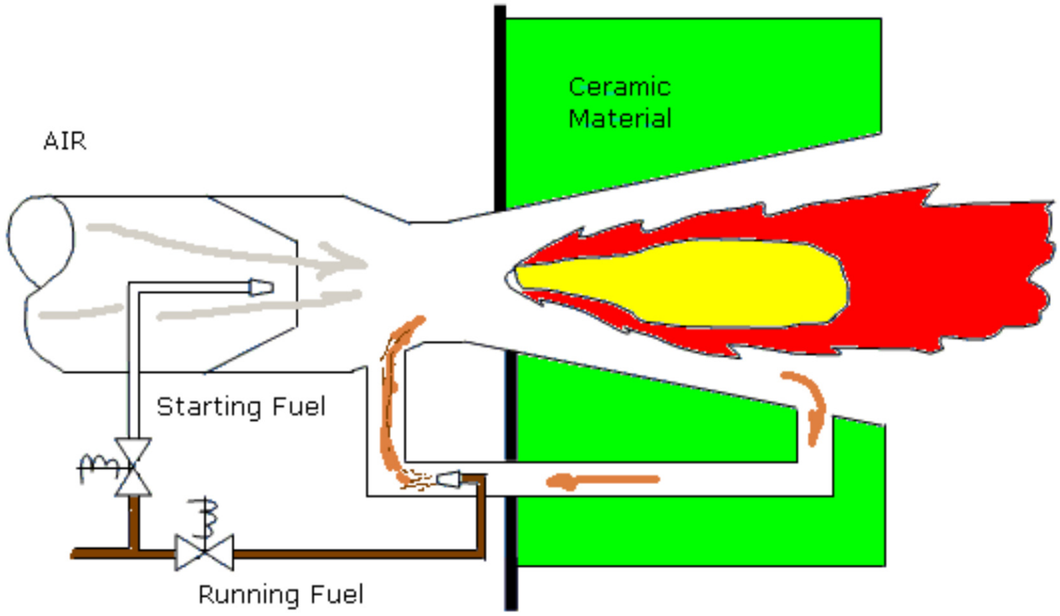


Fuel is introduced onto the inner running surface of a highly polished fast spinning cup (3 to 7000 rpm). Under centrifugal force this fuel forms a thin film.
Due to the conical shape of the cup the fuel flows to the outer edge spilling into the primary atomising air stream. The fuel is broken into small droplets and mixed with the primary air supplied by the shaft mounted fan. Secondary air is supplied by an external fan for larger units.
Packaged units of this design have the air flow valve controlled by the fuel supply pressure to the distribution manifold.

The spinning cup offers the following advantages;

- Wider turn down ratio with lower excess air
- Low O_2 levels
- No requirement for atomising air or steam
- Low fuel pressure requirements to an extent that gravity flow is sufficient
- stable flames achievable with very low fuel flows although maximum flow limited by size of cup. This, allied to being limited to side firing making the design more suitable for smaller installations.

Blue Flame



This highly efficient and claen burning method is very close to stoichiometric combustion. Under normal conditions a portion of the hot gasses from the combustion process is recirculated. Fuel is introduced into the gas were it is vaporised. The resultant flame is blue with little or no smoke

Refractories

A material in solid form which is capable of maintaining its shape at high tempo (furnace tempo as high as 1650^{o}C) have been recorded.

Purpose

i. *To protect blr casing from overheating and distortion and the possible resulting leakage of gasses into the machinery space.*
ii. *To reduce heat loss and ensure acceptable cold faced temperature for operating personnel*
iii. *To protect exposed parts of drum and headers which would otherwise become overheated. Some tubes are similarly protected.*
iv. *Act as a heat reservoir.*
v. *To be used to form baffles for protective purposes or for directing gas flow.*

Properties

i. *Must have good insulating properties.*
ii. *Must be able to withstand high tempo's*
iii. *Must have the mechanical strength to resist the forces set up by the adjacent refractory.*
iv. *Must be able to withstand vibration.*
v. *Must be able to withstand the cutting and abrasive action of the flame and dust*
vi. *Must be able to expand and contract without cracking Note: no one refractory can be used economically throughout the boiler*

Types

i. *Acid materials- clay, silica, quartz , sandstone etc*
ii. *Neutral materials-chromite, graphite, plumbago, alumina*
iii. *Alkaline or base materials- lime, magnesia, zirconia*

Note that acid and alkaline refractories must be sepperated

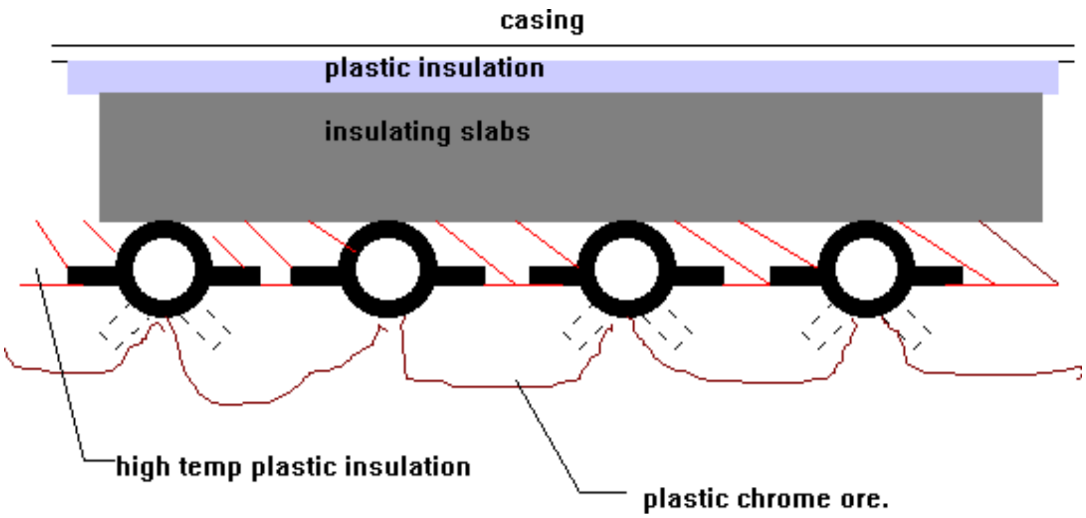
Forms

i. *Firebricks- these are made from natural clay containing alumina , silica and quartz. They are shaped into bricks and fired in a kiln*
ii. *Monolithic refractories- These are supplied in the unfired state, installed in the boiler and fired in situ when the boiler is commissioned.*
iii. *Mouldable refractory- This is used where direct exposure to radiant heat takes place. It must be pounded into place during installation . It is made from natural clay with added calcided fire clay which has been chrushed and graded.*
iv. *Plastic chrome ore- This is bonded with clay and used for studded walls. It has little strength and hence stud provides the support and it is pounded inot place.It is able to resist high temperatures*
v. *Castable refractory-This is placed over water walls and other parts of the boiler were it is protected from radiant heat . It is installed in a manner similar to concreting in building*
vi. *Insulating materials- Blocks, bricks , sheets and powder are usually second line refractories. I.E. Behind the furnace refractory which is exposed to the flame. Material; asbestos millboard, magnesia , calcined magnesia block, diatomite blocks, vermiculite etc. all having very low heat conductivity.*

Furnace linings

Studded tubes

- these are lined with plastic chrome ore

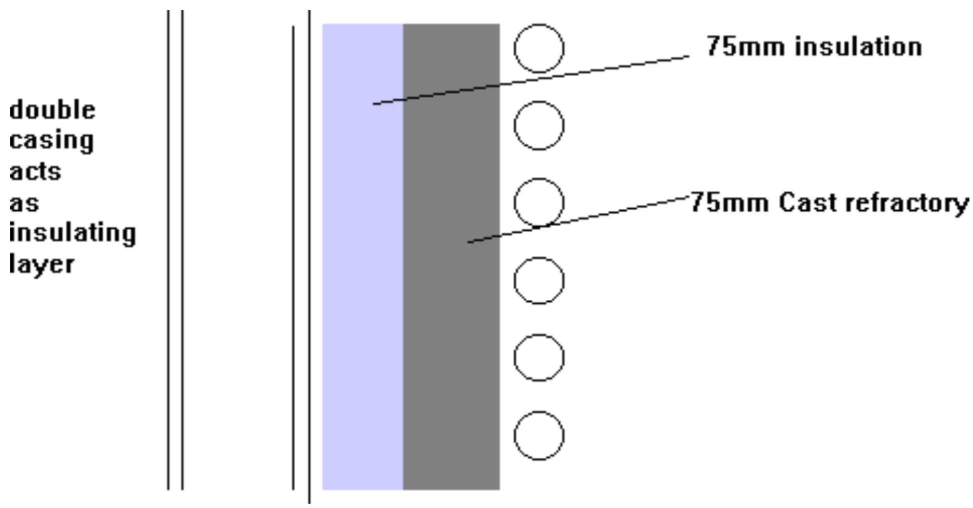


The amount of studding and the extent of tube surface covered with chrome ore is varied to suit the heat absorption rate required in the various zones of the boiler furnace.

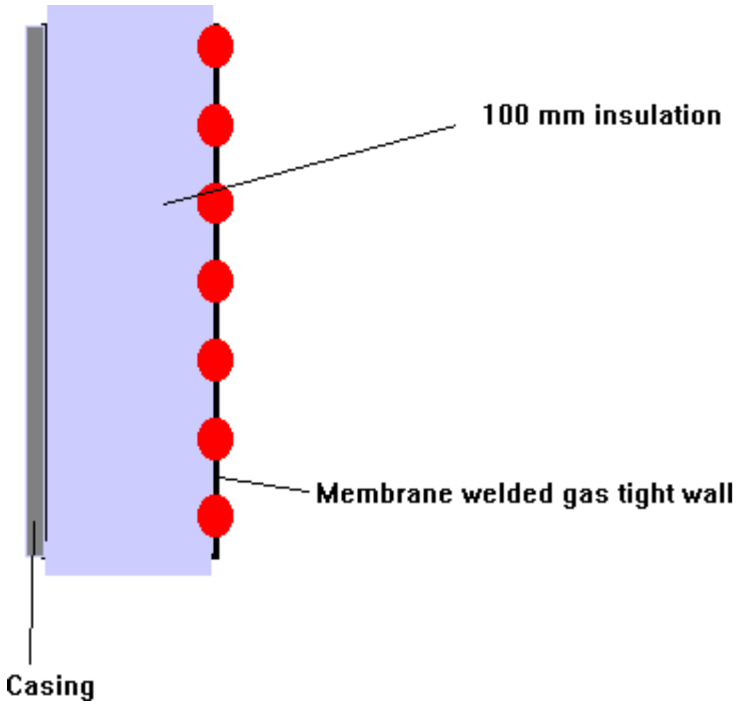
Floor tubes may be situated beneath a 3" layer of brickwork, the tubes are embedded in chrushed insulating material below which is a layer of solid insulation and then layers of asbestos millboard and magnessia.

PRESENT DAY TYPES

TANGENT WALL.



Membrane wall



Furnace floors

- Two layers of 50 mm firebrick above the tubes and 100 mm slab insulation below. Tubes in castable insulation are covered with crushed firebrick. **Note**; Before castable insulation applied ,tubes coated with bitumen to allow expansion clearance when tubes are at working tempo

Front walls

- In front fired boilers these need additional insulation (200 mm) made up of 125 mm mouldable refractory backed by 50 mm castable or slab and 25 mm of asbestos millboard.

Burner openings

- These have specially shaped bricks called quarls or have plastic refractory

Brick bolts

There are two basic types;

i. *using a hole right through the brick*
ii. *Using a recess in the back of the brick.*

A source of weakness is where bricks crack, bolts will be exposed to the direct heat which leads to failure.
Adequate expansion arrangements must be provided. For floor tubes a coating of bitumastic is first applied before the castable refractory is applied. When the boiler is fired the bitumastic is burnt away then a space is left for expansion

Refractory failure

This is one of the major items of maintenance costs in older types of boiler

SPALLING

This is the breaking away of layers of the brick surface. It can be caused by fluctuating temperature under flame impingement or firing a boiler too soon after waterwashing or brick work repair.

May also be caused by failure to close off air from register outlet causing cool air to impinge on hot refractory.

SLAGGING

This is the softening of the bricks to a liquid state due to the prescience of vanadium or sodium (ex sea water) in the fuel. This acts as fluxes and lowers the melting point of the bricks which run to form a liquid pool in the furnace Eyebrows may form above quarls and attachment arrangements may become exposed Material falling to floor may critically reduce burner clearance and reduce efficiency

Flame impingement may lead to carbon penetrating refractory.

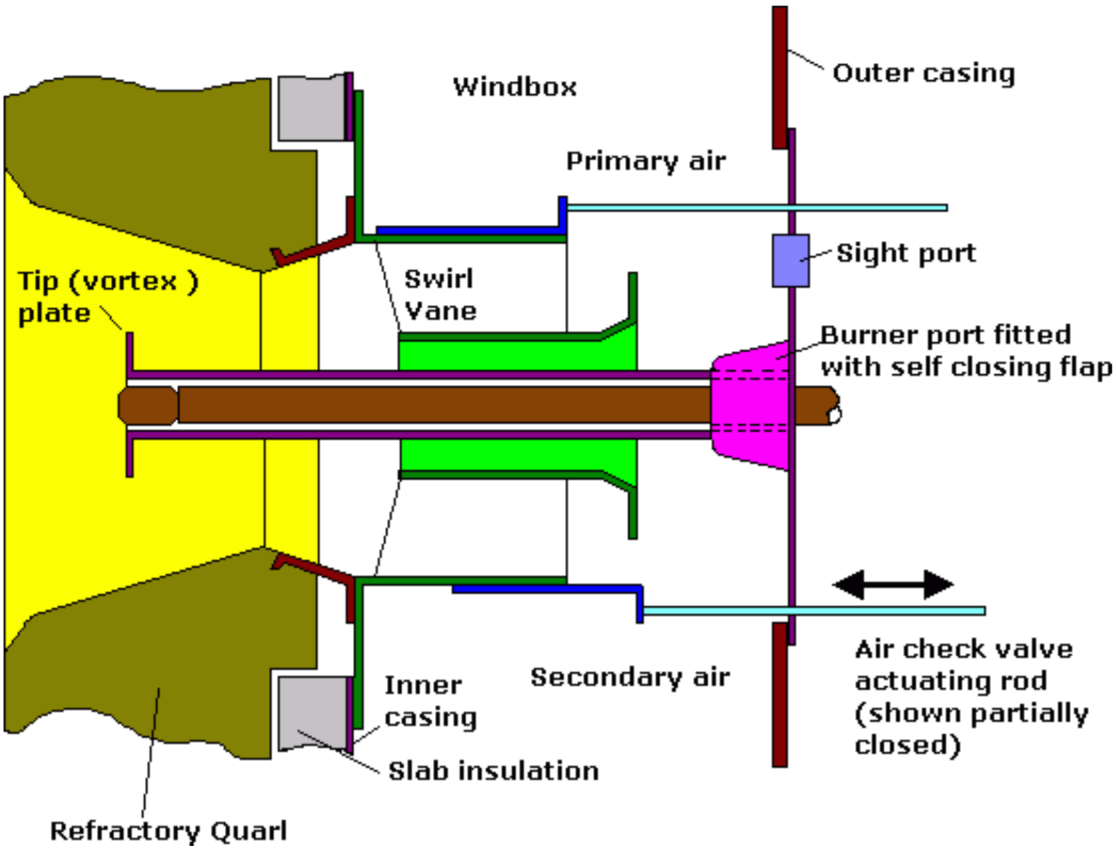
SHRINKAGE CRACKING

Refractories are weaker in tension than in compression or shear thus, if compression takes place due to the expansion of the brick at high temperature , if suddenly cooled cracking may occur.

Failure of brick securing devices

Registers

AIR REGISTER



This is the name given to an assembly of vane air swirler plates etc fitted within the boiler casing in association with each burner ,its functions is to divide air into primary and secondary streams and to direct them such as to give the correct air flow pattern.

The air must pass through the air check to enter the register . In some cases the check can be formed by the swirl vanes themselves by rotating them about their axis, in other cases a sliding sleeve is used.

The inner primary air flows until it reaches the tip plate (stabiliser) then spills over to form a series of vortices which reduces the forward velocity of the air. This retains the primary flame within the quarl . The outer , secondary air passes over the swirler vanes which causes the air to rotate thus assisting the mixing of air and fuel.
The secondary air shapes the flame, short and fat for side fired, longer and thinner for roof fired.
A small amount of cooling air is allowed to flow to the tip plate and atomiser tip.

It is important that the air check forms a tight seal otherwise thermal shock can damage the quarls when the burner is not in use The front plate is usually insulated , the complexity of the air control is related to the TDR .The steam jet types have the steam providing additional energy for the mixture of air and fuel.

- see 'burners' for description of profiled registers

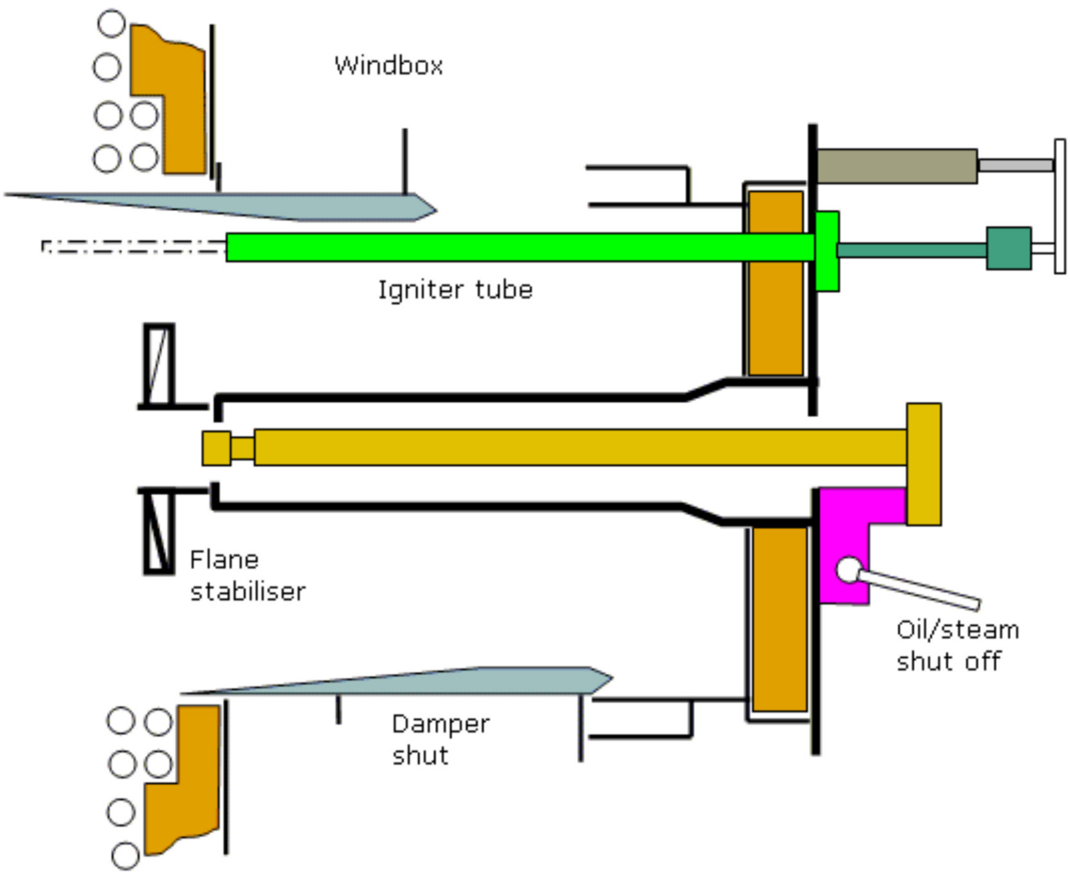
PREPURGING OF FURNACES

Furnace explosions caused by oil vapour and air present in furnace in explosive proportions. To a lesser extent a blowback is a furnace explosion. Prevention is by purging with air.

Usually adequate purging is provided within the combustion control however makers timings should be strictly followed .

N.B. This is particularly important with membrane wall boilers where the pressure wave is contained within a strong cell which if ruptured, has disastrous consequences.

Modern design



Superheater Temperature Control

Reason for superheating steam

Basically the control of temperature is to protect the superheater by preventing the metal temperatures reaching a dangerously high level reducing mechanical strength and leading to failure.

Water flowing through a tube conducts heat away much more effectively than steam due to its higher specific heat capacity. This means that tubes carrying water have a metal temperature much closer to the fluid passing through it.

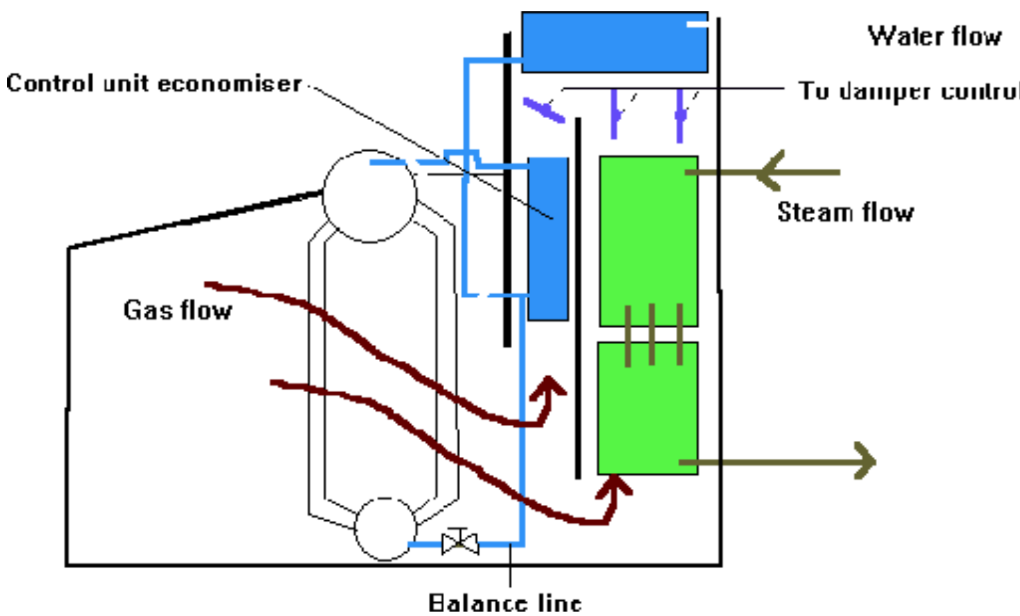
Where superheat temperatures upto 455^{o}C are in use then the use of mild steel is not a problem, for superheat temperatures above this then alloys of chrome molybdenum steels are used (upto 560^{o}C), difficulties in welding means that there use is restricted to only within the highest temperature zone and a transition piece fitted to connect to remaining mild steel tubing.

Superheat temperature control is therefor fitted to ensure superheat temperature does not exceed design limits.

Methods of regulating superheat temperature

a, By regulating the gas flow over the superheater by means of dampers

FW ESD II

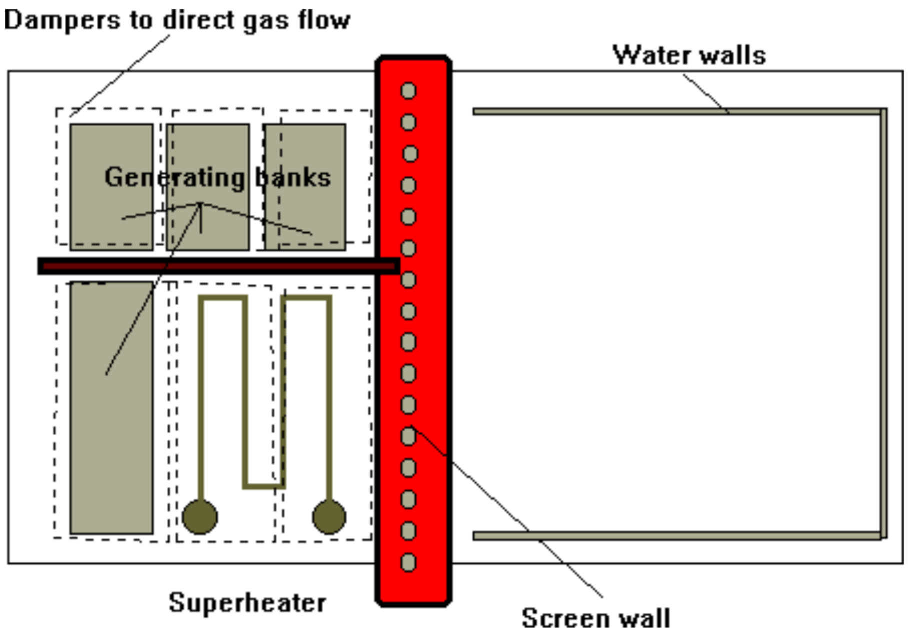


The balance line prevents any tendency for the control unit to steam under conditions of low feed flow say due to sudden load change or especially when flashing (several of these have been burnt out due to incorrect flashing procedure)

The control unit operates the linkages via a control arm, if the superheat is too high then gasses are diverted to flow over the control unit and less gas now flows over the superheat bank.

The control arms and the dampers were very susceptible to damage caused by operating in the hot gas path. Also this control was very sensitive to excess air which can raise the superheat temperature by increasing the heat energy removed from the furnace.

Babcock and wilcock selectable superheat



This design gave a wide range of temperature control, it operated in a similar manner to the Foster Wheeler ESD II. The gas path is separated by a baffle which has flaps located above the tubes operation of which can determine the superheat temperature, as the superheater only extends across one path it is made out of 'W' rather than 'U' tubes.

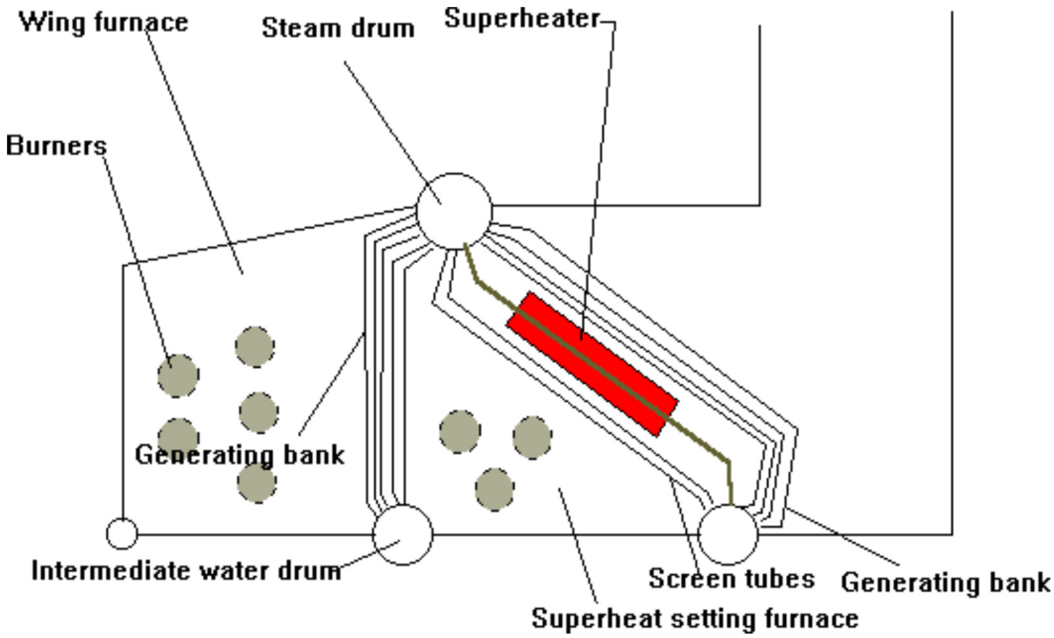
This design suffered from similar problems to the ESD II with regard to flaps and flap linkages susceptibility to corrosion.

b, By use of multi furnace boilers

Babcock and wilcock Controlled superheat)

The superheat temperature was regulated by changing the position of lit burners within the boiler, shutting off burners in the main furnace and replacing them with flames in the wing furnace had the effect of reducing the superheat temperature as the gasses are cooler when the reach the superheater bank. In this way the superheat temperature could be varied by 60^{o}C.

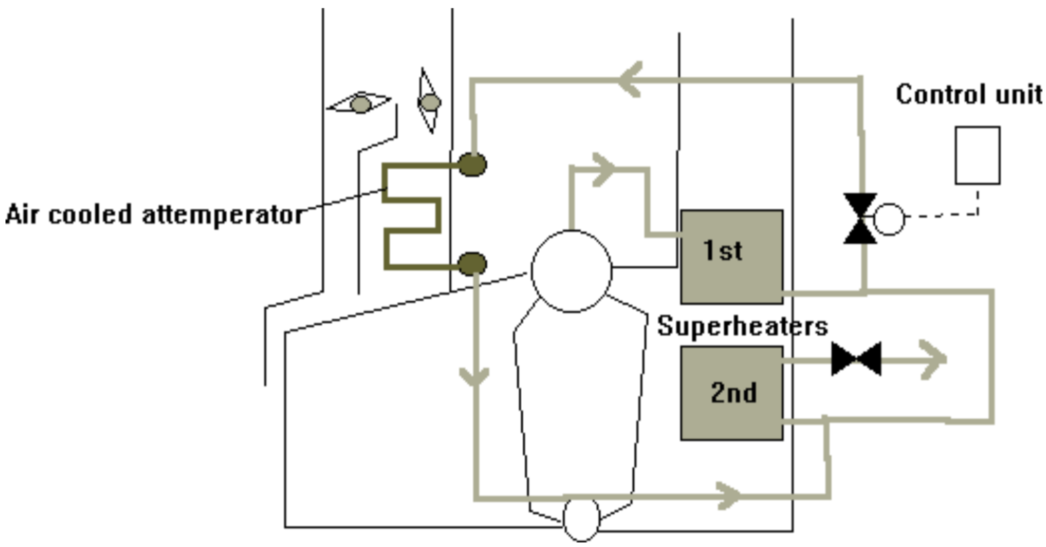
The advantage of this system was the superheat temperature could be maintained over a wide variation of load. To prevent reversal of flow in the intermediate generating bank a baffle plate is fitted in the water drum which allows the first two rows of the bank to be isolate from the rest and to be supplied by their own two downcomers.
Difficulty was encountered in maintaining the correct air/fuel ratio during differential firing of the two furnaces.
During flashing only the wing furnace is used to give better protection for the superheater



c,Use of air cooled attemperators

Air cooling effect of the double casing is lost in this arrangement so additional insulation must be fitted to ensure that the casing temperature does not exceed safe handling limits.

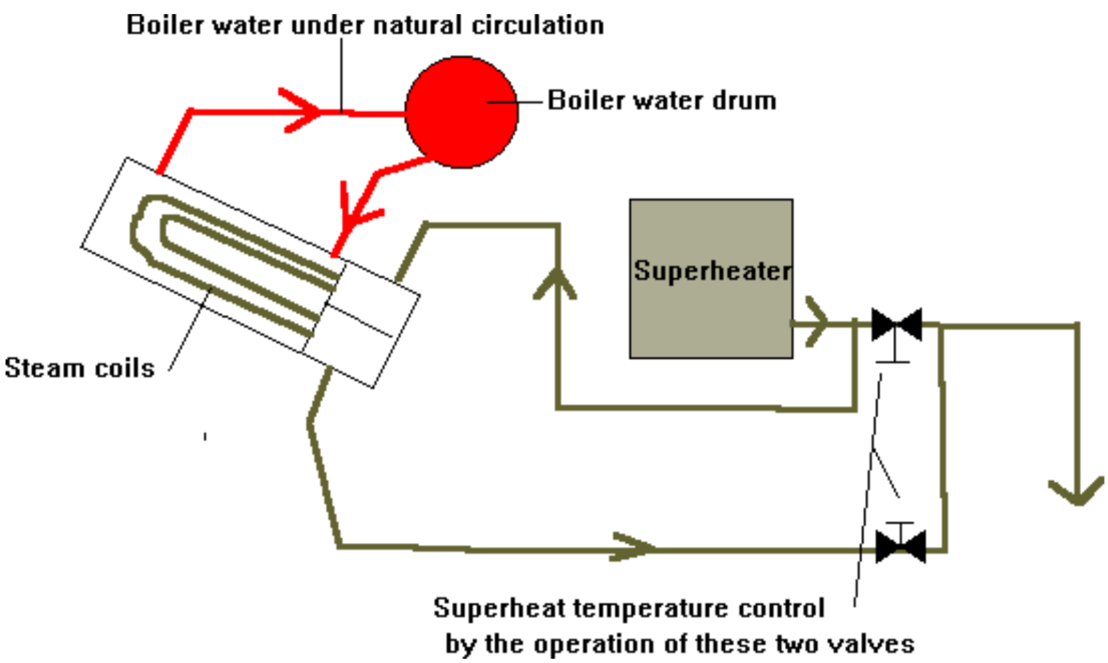
As air is a relatively poor cooling medium large attemperators are required allied to increased FD fan output required to overcome frictional resistance losses. There is an overall increase in weight, size and initial cost which led to the system being superseded by the regulated gas flow method and then by water or spray cooled attemperation



d, Use of separately fired superheater

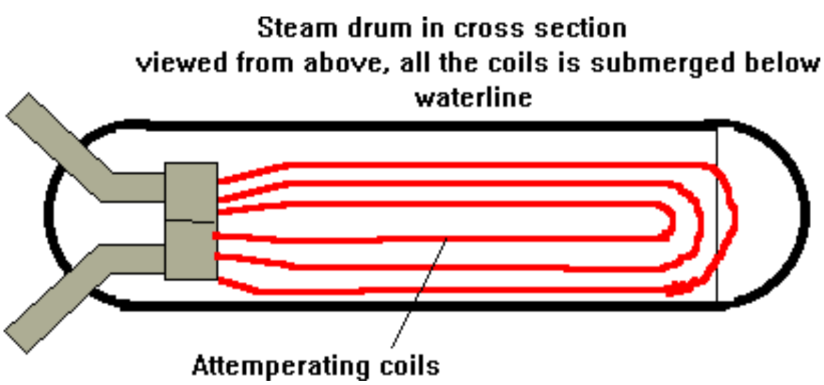
In very rare use, normally limited to tank boilers

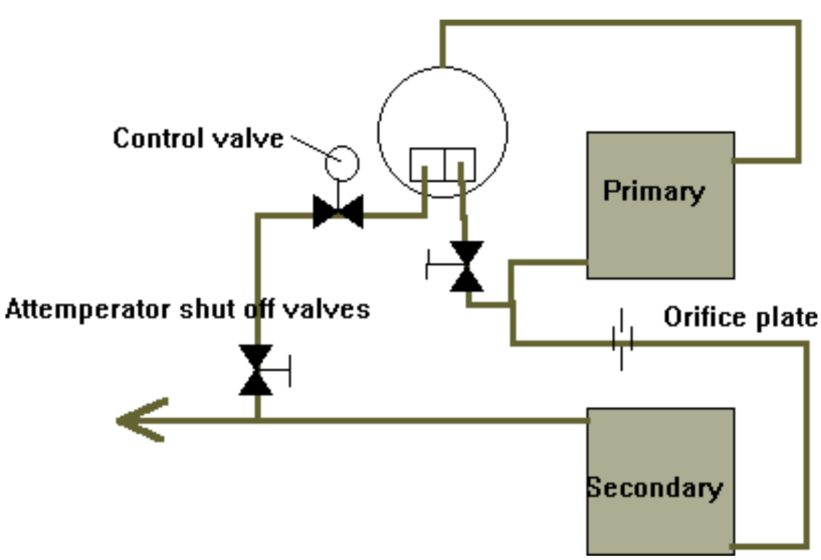
e, Use of boiler water attemperator (external mounting)



Superheat control is achieved by diverting a proportion of the steam through the simple tubular heat exchanger attemperator

e, Water cooled attemperator (internal)



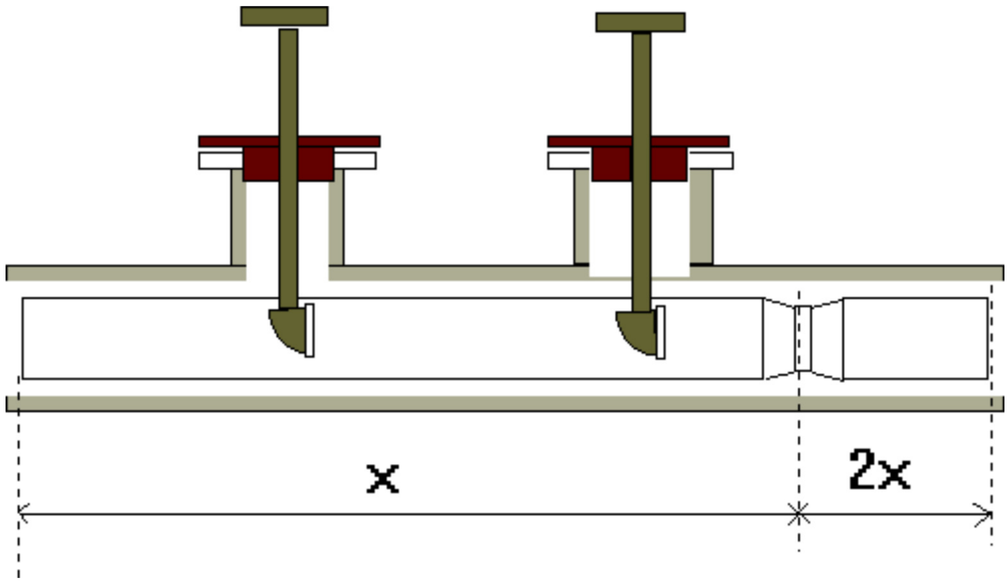


Shut off valves have to be fitted to the attemperator as in the event of tube leakage the boiler will empty in to the attemperator as it is at a slightly higher pressure due to frictional losses in the superheater.

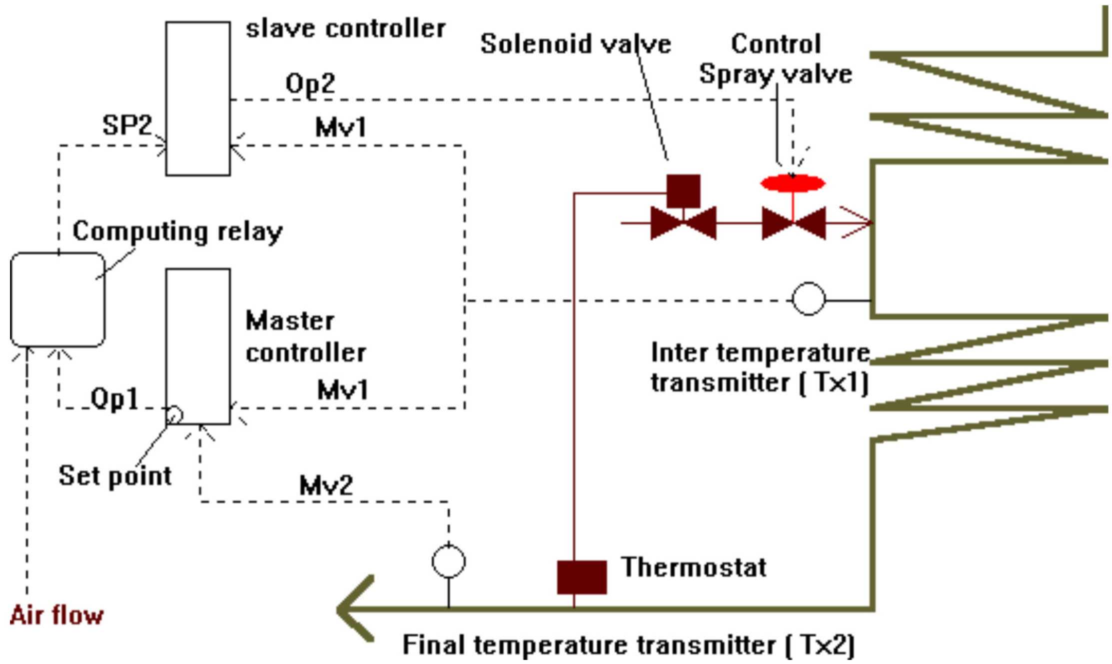
g, Water spray attemperation

This the most common form of attemperation in use, it consists of two spray nozzles which spray feed water into the steam as it passes from the primary to secondary superheaters. The water receives heat from the steam and thereby reduces the superheat of the steam. To prevent thermal shocking of the transfer pipe, a thin flexible inner tube is fitted.

The spray valves work in series with one reaching its maximum capacity before the second comes into use, the control system takes as its measured value both the outlet temperature and either steam or air flow (load). The spray valves are often designed to be of the air to open variety so in the event of air failure they will fail safe open.



Modern Superheat temperature control system



The main system components are a P+I+D Mater controller (reverse acting, hence output increases for measured values above setpoint) in which the desired final superheat temperature is set, working in cascade is a P+I slave controller whose output controls the spray attemperator control valve.

There is a temperature transmitter on the inlet to the secondary superheater (Tx1, fitted after the spray) and a secondary superheater outlet temperature transmitter (Tx2).

Tx1 output Mv1 is fed to both the master and slave controllers, in the slave controller this forms the measured value

Tx2 output Mv2 is fed to the master controller and forms the measured value, here it is compared to the required set point entered. The output Op1 is sent to the computing relay.

Master controller Op1 = -(Desired set point - Mv2)
(reverse acting)

In the computing relay the signal is added to the rate of change of air flow signal, as the air flow is taken from the combustion control circuit it forms a load signal. In this way the circuit has the ability to react quickly to load changes before they actually begin to effect the temperatures.

The output of the computing relay is fed to the slave controller as its set point Sp2 the set point for the slave controller now has the error of the final superheat and an amount by which the volume rate of air flow (and hence boiler load) would tend to change the superheat contained within.

The set point Sp2 is compared in the slave controller to the output from the secondary inlet transmitter Tx1 signal Mv1.

Slave controller Output Op2 = Setpoint Sp2 - Mv1

The use of the controllers in cascade speeds up response to system changes.

Computing relay Output SP1 = OP1 + d/dt (air flow)

It is necessary to add the air flow signal as this has a direct effect on the superheat temperature. If there was a load demand increase the combustion control would increase fuel and air to the boiler, this would cause an increase in the superheat steam temperature as there would be some lag until the steam flow increased due to the increased fuel . Once the steam flow has stabilised then the increased steam flow will match the increased gas temperature and so the temperature will reduce. It can be seen then that only during the transition period when the fuel/air has increased but the steam has not that the increased spray is required, this is why the rate of change of air flow rather than volume is used in the control system.

If the measured superheater outlet temperature drops then Mv2 drops, OP1 decreases (the master controller is reverse acting), this is fed through the computing relay and so the set point Sp2 for the slave controller decreases. The setpoint of the slave controller has now fallen below the measured value and hence its output will decrease. This signal OP2 is fed to the spray valve which will shut in increasing the superheat temperature .

If the load on the boiler increases the output of the computing relay increases and hence the set point Sp2 increases, the output of the slave controller Op2 increases and hence the spray valve starts to open even though the increased air flow and hence gas temperature passing over the superheater is yet to be detected in the superheated steam either Tx1 or Tx2, in this way problems of process and control lags can be negated.

The output of Tx1, Mv1 is fed not only to the slave controller but also to the master controller; Its function here is to prevent the master controller from saturating and hence speeding its response under certain conditions. It does this by feeding the integral bellows via the integral restrictor in the controller rather than the more normal feedback arrangement of the output feeding the Integral bellows via the restrictor. In this way the master controller always takes account of the inter temperature.

With the normal layout in low load conditions, should Mv2 fall below the setpoint the Integral action will force the controller into saturation if the temperature fails to recover. This can happen as even with the spray valves shut there may not be enough energy in the flue gasses to heat the steam upto the required temperature in low loads.

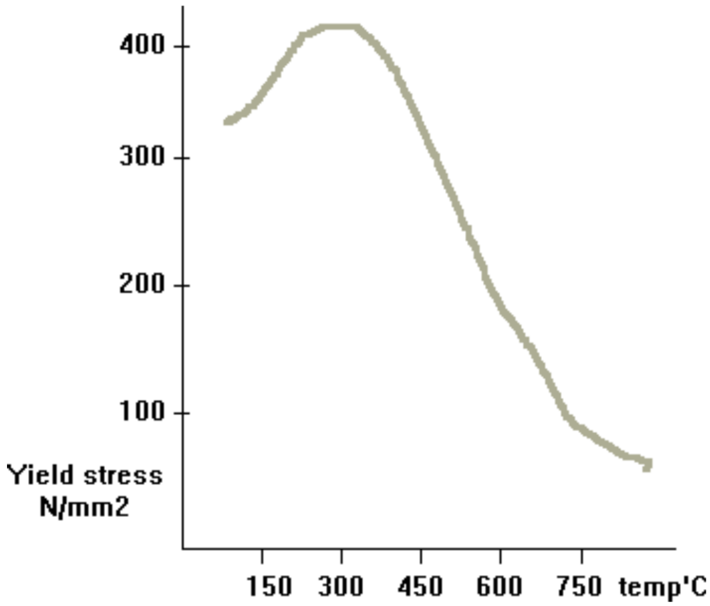
By using the output from Tx1, Mv1 then the controller will fail to go into saturation as the integral bellows will receive a signal Mv1 rather than its falling output Op1.

Other additional fittings

Shown on the diagram is a fitting sometime used to protect the system in the event of failure of the spray control valve, this takes the form of a thermostat set so that should the temperature fall below a certain value it will operate a solenoid valve fitted before the spray control valve to shut off the feed. It can be seen that in the event of loss of superheat control , and hence with the spray valve failed open, some form, albeit very coarse , of superheat control can be maintained by use of the thermostat and solenoid valve.

There is alarms fitted to both the inlet and outlet from the secondary superheater as well as a main engine trip due to high superheat temperature. A boiler trip may be fitted for low superheater outlet temperature.

External tube failure

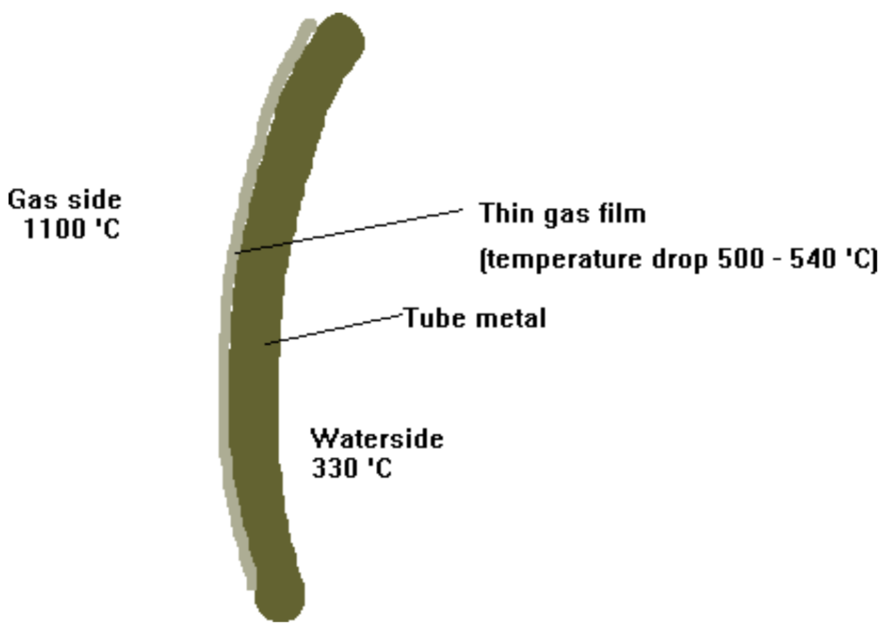


From the graph above for carbon steel, it can be seen that there is a rapid drop in strength above 430^{o}C.

Long term overheating is a condition where the metal temperature exceeds the design limit for a long period. The mechanical strength is reduced as a function of the increase in temperature.

Deposits on the external surface and thin gas film layer aid in reducing the metal temperature. Deposits on the inside increase tube metal temperatures.

Temperature drop across the thin film gas layer



Bulging of many different forms tend to precede bursting.

Thermal oxidation

If the metal temperature exceeds a certain value dependant on the material rapid excessive oxidation can occur

This oxide layer can often form with faults, and can be exfoliated due to thermal stressing or vibration. The result is a thinning of the tube due to this cyclic thermal oxidation and spalling

A failed tube suffering from this will have the appearance of tree bark.

Creep rupture

Plastic deformation due to metal overheating may occur. Microvoids form eventually leading to failure. Can be distinguished by a thick ragged edged fish mouth with small ruptures and fissures leading off.

Chain graphitization

Uncommon. Damage begins when iron carbide particles (present in plain carbon or low alloy steels) decomposes into graphite nodules after prolonged overheating (metal temperatures > 427^{o}C).

If the nodules are evenly distributed then this not cause a problem. However, some tomes the nodules can chain together and failure occurs along the length of the chain (as in ripping a postage stamp along the perforations)

Normally found adjacent to welds and determination as cause of failure requires examination under a microscope to observe nodules.

Short term overheating

Metal temperatures of at least 454^{o}C and often exceed 730^{o}C; failure may be very rapid. Not normally associated with a water chemistry problem rather than maloperation or poor design.

In very rapid overheating little bulging occurs and the tube diameters are unchanged in way of the fish mouthed failure (normally thick walled edge)

Under less arduous conditions some bulging occurs and the failure may have a finely chiselled edge

Multiple ruptures are uncommon.

care must be taken not to confuse a thick walled short term overheating failure with the many other possibilities such as creep failure, hydrogen embrittlement and tube defects.

Erosion

One of the most common causes of erosion within a boiler is sootblowing erosion . Especially those tubes adjacent to a misdirected blower.

Should the blower stream contain water then the erosion is much more severe. Ash picked up by the steam also acts as an abrasive. This is why proper warming through and drainage is essential

Other causes may be failure of an adjacent tube or to a much lesser extent by particles entrained in the combustion products

Internal water chemical causes

For a listing of the failures caused by water chemistry see relevant document 'Corrosion and failures in boiler tubes due to water chemistry'

Oil Ash Corrosion

High temperature liquid phase corrosion phenomenon where metal temperatures are in the range 593'C to 816'C. hence normally restricted to superheater and reheater sections.
It can effect both the tubes and their supports.
May arise after a change of fule with the formation of aggressive slags.

Oil Ash corrosion occurs when molten slag containing vanadium compoundsform on the tube wall according to the following sequence

- Vanadium and sodium compounds present in the fuel are oxidised to Vn_2O_5 and Na_2O.
- Na_2O acts as a binding agent for ash particles
- Vn_2O_5 and Na_2O react to form a liquid (eutectic)
- Liquid fluxes the magnetite exposing metal to rapid oxidation

Catalytic oxidation of the metal surface by Vn_2O_5 occurs. The tube outer surfaces are thinned, stress increases in the inner layers and failure by creep rupture occurs

Corrosion of superheater by slag with a fusion temperature of 593 to 704'C requires all utility boilers to have a steam temperature not exceeding 538 to 551'C

Scale formation in the tubes leading to high metal temperatures can lead to this type of corrosion.

Elimiation may require the chemical analysis of both the fuel and the slag to determine the corrosive constituents. The fusion temperature of the ash can be determined. Fuel additives may be used. Magnessium compounds have been used successfully to mitigate problems by forming a complex with Vn_2O_5 and Na_2O with a very high fusion temperature.

Low excess air retard the oxide formation

Chemical cleaning

Water wall fire side corrosion.

may occur where incomplete combustion occurs. Volatile sulphur compounds are released which can form sodium and potassium pyrosulfates
Thesechemically active compounds can flux the magnetite layer. This is more commonly found in coal fired boilers

Uptake Fires

On break out of an uptake fire the priority is to boundary cool to contain the fire and give cooling effect.

Modern ship

An uptake fire generally starts when the load on the boiler is reduced. This is due to the quantity of excess air being very low at high loads.

Should a fire break out then the possibility of speeding up and reducing the excess air should be considered.

The amount of feed heating should be reduced to lower the inlet feed temperature and aid with cooling parts.

Where the possibility exists of damage to the superheater, then after first relieving pressure, it should be flooded.

Older ship

Where the excess air on older boilers is high even at high loads a different plan of attack must be used.

The flames should be extinguished and the air shut off. The amount of feed heating should be reduced.

The safeties should be lifted to keep a high steam flow and hence high feed flow requirements. (the boiler is now being fired by the uptake fire)

Lifting the safeties give the added advantage of reducing the boiler pressure and hence corresponding saturation temperature of the water aiding the cooling effect

Tackling the fire

If a direct attack should be made on hot non-pressurised parts then the nozzle should be set to solid jet and aimed at the seat of the fire.

This should not be carried out on hot pressurised parts due to the risk of a steam explosion.

Dry powder is a suitable extinguishing medium.

Disassociation

Under certain conditions an extremely destructive fire, commonly known as a hydrogen or 'rusting' fire, may occur Under high temperatures water will tend to disassociate to hydrogen and oxygen. The percentage amount increases with increased temperature These will recombust again liberating heat In a fire there is a danger that the use of superheated steam as an extinguishing agent (say sootblowers on an air heater fire) could in fact feed the fire and accelerate the growth. For example the displacement which occurs about 707^{o}C

Heat + Hot $3Fe + 12H_2O$ Ћ $3FeO_3 + 12\ H_2$

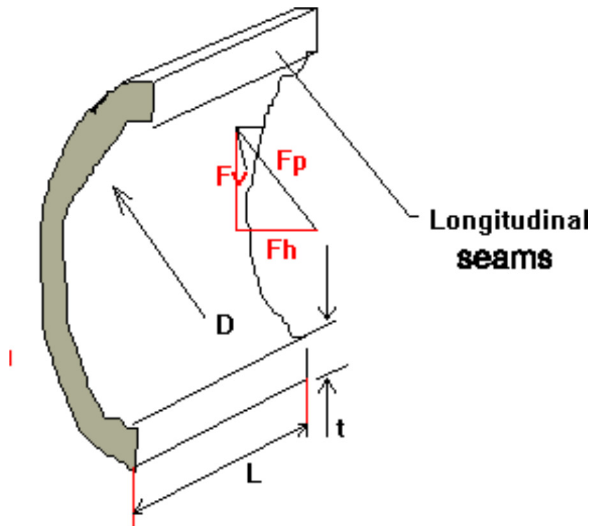
see Theory section for a more complete explanation

Tackling this type of fire is very hazardous and consists mainly of boundary cooling and shutting off water and air supplies as effectively as possible.Under no circumstances should steam smothering be considered.

A typical scenario for this fire is a badly cleaned uptake igniting leading to tube failure

Stress in boiler drums

Circumferential



L=Length of cylinder
t= Material thickness
D= Diameter
F_p= Force acting on cylinder due to pressure
F_h= Resolved horizontal component of force

Equal forces act on all surfaces. If a vertical section is cut then the forces may be considered to be resisted by the longitudinal seam for the horizontal direction.

i.e. **horizontal forces to left=Horizontal forces to right**

= resisting force in seam

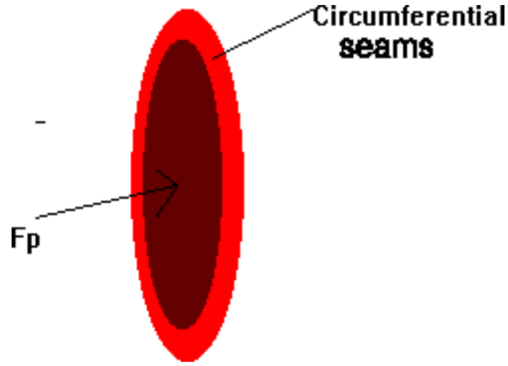
Pressure x projected area = stress x C.S.A of joint

By using projected area the horizontal component of the pressure force is automatically resolved

p x dia x L = stress x 2 x t x L

(p x dia x L)/ 2 x t= Stress (longitudinal joint)

Longitudinal



Similarly

Horizontal forces to left = Horizontal forces to right

Pressure x end plate area = Resisting force in circumferential joint

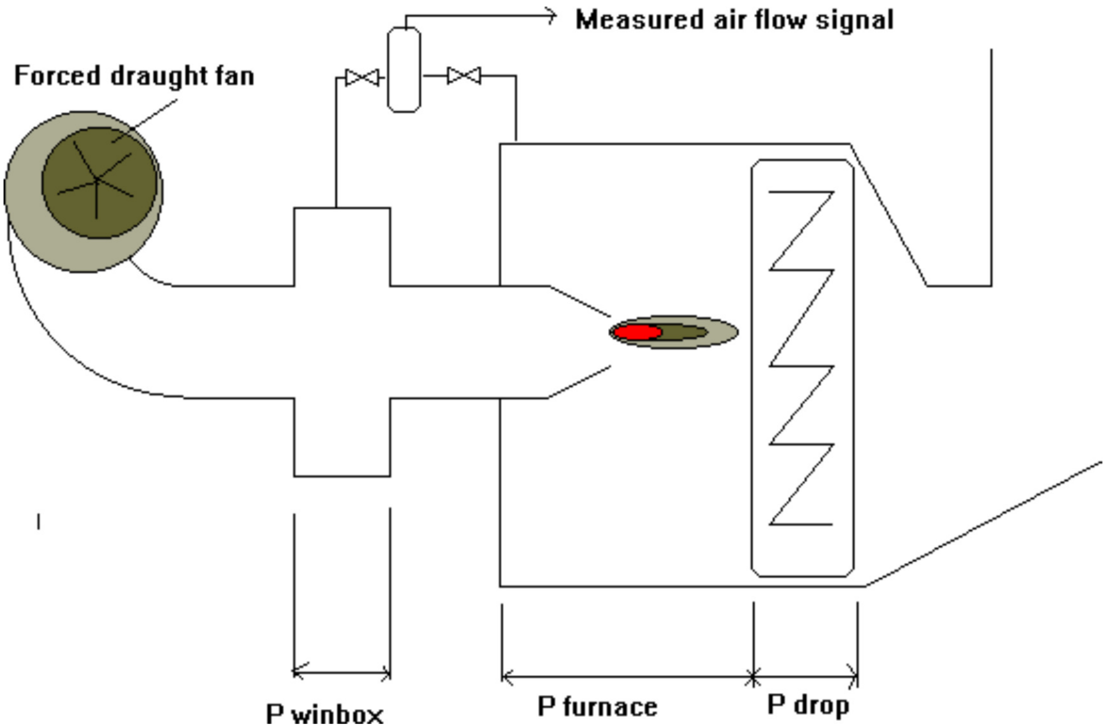
P x (pi x d^2)/4 = stress x csa (circumferential joint)

= stress x pi x d x t

(p x d)/ 4 x t = stress (longitudinal)

Hence, circumferential stress is twice that of the longitudinal stress and hence seams in the longitudinal axis must be twice as strong.

Boiler panting



If a boiler was open ended to atmosphere then boiler panting would not occur. However it is not, instead combustion products must flow over a whole range of items all of which contribute to a pressure drop indicated as P drop. For example, screen tubes, generating tubes, superheater tubes, economisers etc. All of these items cause a pressure drop which varies according to the combustion variations.

Mechanism of panting

The system shown above is considered to be in steady state. The windbox pressure is at a slightly higher pressure than the furnace pressure which is at a higher pressure than atmospheric.

If there was a sudden disturbance to the plant, for example, poor combustion caused by say low atomising steam pressure then combustion of the fuel would be less efficient. The pressure in the furnace will drop, the P drop increases and the mass/volume of the furnace gases increases. The actual volume of the gas has however reduced.

The furnace pressure drop will then cause increased air flow from the windbox (after some period allowing for inertia). The density of the air remains high and Pdrop remains high.

This in rush of air into the furnace aids the combustion process of the flame and also burns up any fuel products not completely combusted. This has the effect has the effect of reducing the density of the furnace atmosphere, increasing its volume, reducing Pdrop and increasing furnace pressure.

The flow of air from the windbox reduces as the pressure differential reduces. The poor combustion of previous is re-established and the whole process is repeated.

The cycle time will depend on the aggravating process i.e. in this case the poor combustion caused by the low atomising steam pressure., the volumes of the respective chambers as well as the size of the inlet for windbox air flow and also the amount of restriction caused by the elements forming the P drop.

This example only describes one possible scenario, in reality there may be many different sources all acting together or independently to cause the panting.

Probably the most common cause of panting is an uptake fire, others may be such as slagging of the tube stacks or even build up of the furnace floor on front fired boilers.

Effects

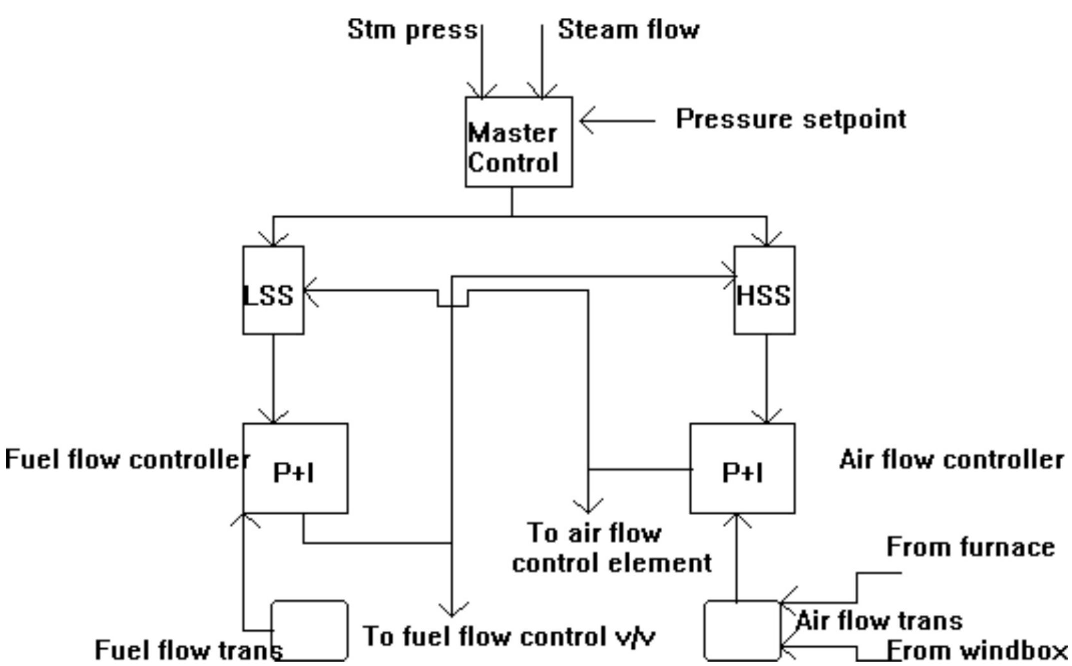
The effects of panting are too cause a low frequency (governed by volume/ P drop criteria) oscillation of furnace spaces repeated to a lesser extent in the windbox and flue gas spaces.

For membrane boilers which are by design air tight the effect can be to cause heavy mechanical loading on all points especially on the drum connections, placing unwanted tensile stressing on welds. Other no less important effects are poor combustion leading to inefficient operation and choking of the tube stacks.

Remedies and remedial action

Modern combustion control equipment by their design inherently act to prevent panting. When the drop in furnace pressure is detected by the air flow transmitter it is sent to the P+I controller as a reduced air flow measured value.The P+I controller acts to increase the air flow hence going some way to negate the cycling problem caused by the inertia of the air.

Should a boiler start panting during its life, the condition of the internal surfaces should be inspected and deposits removed.



Boiler Mountings

Definition - various valves and fittings are required for the safe and proper working of a boiler . Those attached directly to the pressure parts of the boiler are referred to as the boiler mountings.

Minimum requirements for boiler mountings

- **two safety v/v's**
- **one stm stop**
- **two independent feed check**
- **two water gauge or equivalent**
- **one pressure gauge**
- **one salinometer v/v or cock**
- **one blowdown/scum v/v**
- **one low level fuel shut off device and alarm**

Functions

SAFETY V/V-protect the boiler from over pressurisation. DTI require at least two safety v/v's but normally three are fitted ,two to the drum and one to the superheater. The superheater must be set to lift first to ensure a flow of steam through the superheater.
These must be set to a maximum of 3% above approved boiler working pressure.

MAIN STM STOP-mounted on supherheater outlet header to enable boiler to be isolated from the steam line if more than one boiler is connected. V/v must be screw down non return type to prevent back flow of steam from other boiler into one of the boilers which has sustained damage (burst tube etc) v/v may be fitted with an emergency closing device.

AUXILLIARY STOP V/V- similar to main stops but connected to the auxiliary steam line

FEED CHECK V/V'S- a SDNR v/v so that if feed p/p stops the boiler water will be prevented from blowing out the boiler. The main check is often fitted to the inlet flange of the economiser if no economiser fitted then directly connected to the boiler. The Auxiliary feed check is generally fitted directly to an inlet flange to the drum with crossovers to the main feed line. Usually fitted with extended spindles to allow remote operation which must have an indicator fitted.

WATER GUAGES- usual practice is to fit two direct reading and at least one remote for convenient reading.

PRESSURE GUAGES-fitted as required to steam drum and superheater header

SALINOMETER COCKS OR V/V'S-fitted to the water drum to allow samples to be taken.Cooling coil fitted for high pressure boilers.

BLOWDOWN COCK- used to purge the boiler of contaminants.Usually two v/v's fitted to ensure tightness . These v/v's lead to an overboard v/v.

SCUM V/V-These are fitted where possibility of oil contamination exists. They are designed to remove water and/or contaminants at or close to normal working level.

SAFETY VALVES

At least two safety valves have to be fitted to the boiler. They may be both mounted on a common manifold with a single connection to the boiler. The safety valve size must not be less than 38mm in diameter and the area of the valve can be calculated from the following formula

C x A x P = 9.81 x H x E

where

H= Total heating surface in m^3
E = Evaporative rate in Kg steam per m^2 of heating surface per hour
P = Working pressure of safety valves in MN/m^2 absolute
A = Aggregate area through the seating of the valves in mm^2
C = the discharge coefficient whose value depends upon the type of valve.

C=4.8 for ordinary spring loaded valves
C=7.2 for high lift spring loaded valves
C= 9.6 for improved high lift spring loaded valves
C= 19.2 for full lift safety valves
C= 30 for full bore relay operated safety valves

LIFT PRESSURE

The safety v/v must be set at a pressure not exceeding 3% of the approved boiler working pressure. It is normal to set the suphtr safety below that of the drum to ensure an adequate flow of stm for cooling purposes under fault conditions. Similarly the superheater should be set to close last.

10% ACCUMULATION OF PRESSURE RULE.

With all the flames in full firing the stm stop is closed, the boiler pressure must not increase by more than 10% in 7 minutes for water tube of 15 mins for tank boilers with the safety lifted. this is normally waivered for superheater boilers. Instead calculations and previous experience used.

BLOWDOWN

The pressure drop below the lifting pressure for a safety v/v is set at 5% by regulation although it is more normal to set v/v's at 3% to prevent excessive loss of stm. For boilers with a superheater it is important that the superheater v/v not only lifts first but closes last.

Adjustement of the blowdown may be necessary following adjustment of the popping setpoint (Increaseing set point lengthens blowdown). Adjustment is achieved by altering the height of the 'adjusting guide ring' on the full lift safety valve design shown below. Over raise adjustment of this ring can lead to mal-operation with the valve not fully opening

SETTING

Must be set with the surveyor present except when on the waste heat unit. A chief engineer with three years experience may then set the safety valve but must submit information to surveyor for issue of certificate.
Superheated steam safety valves should be set as close to operating temperature as possible as expansion can alter the relationships between valve trim and guide/nozzle rings which can effect the

correct operation of the valve.

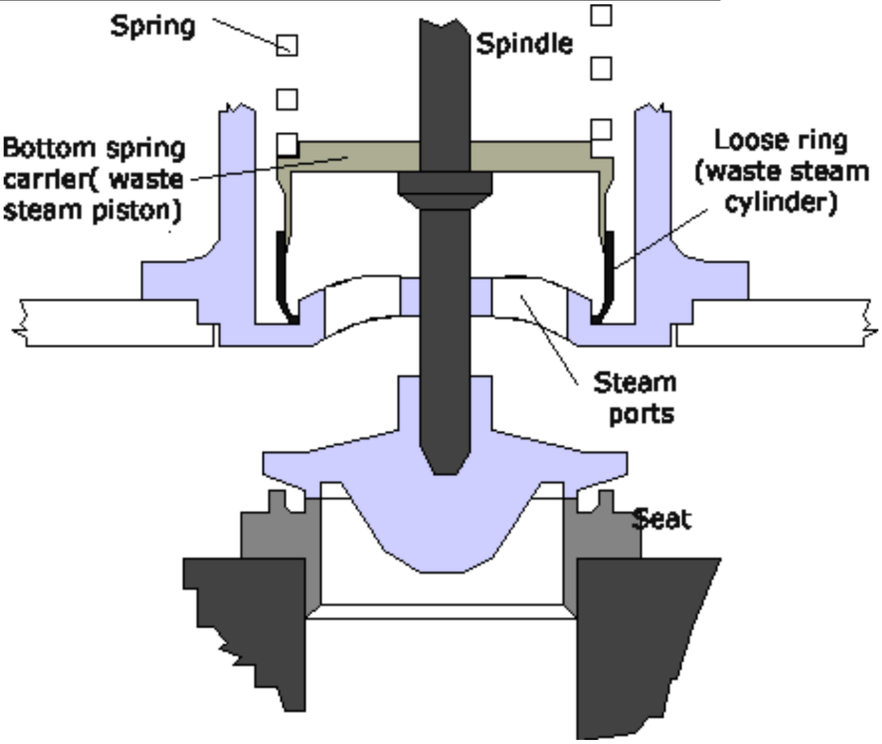
a. Two safety valves- each set independently
b. Each safety valve must release entire steam flow in pressure accumulation test
c. Surveyor uses specially checked gauge
d. One valve gagged
e. valve initially set to approximately the correct position then steam pressure increased to set pressure
f. adjust valve to lift
g. raise and lower pressure to check
h. fit locks to both valves on completion

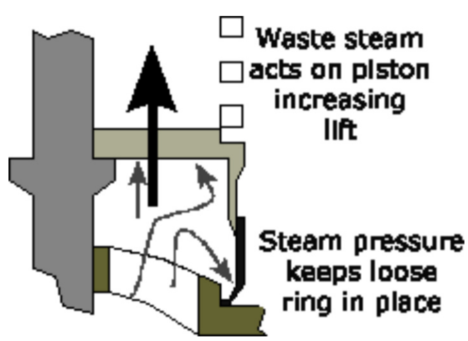
Easing gear to be checked free before setting valves. Steam should not be released as this can damage seat.

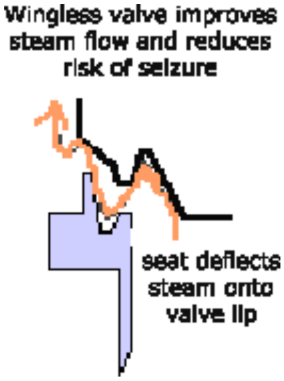
Improved high lift safety valve

Differences in the ordinary and high lift designs

Ordinary	High Lift	Improved high lift
Winged valve	Winged valve	Wingless valve
No waste piston	Waste piston	Waste piston
	No floating ring	Floating ring







For superheated steam the aggregate area through the seating of the valves is increased, the formula is

$$As = A(1 + Ts/555)$$

where

As = Aggregate area through the seating of the valves in mm^2 for superheated steam

A = Aggregate area through the seating of the valves in mm^2 for sat steam

Ts = degrees of superheat in ^oC

As is greater than A due to the higher specific volume of superheated steam requiring more escape area.

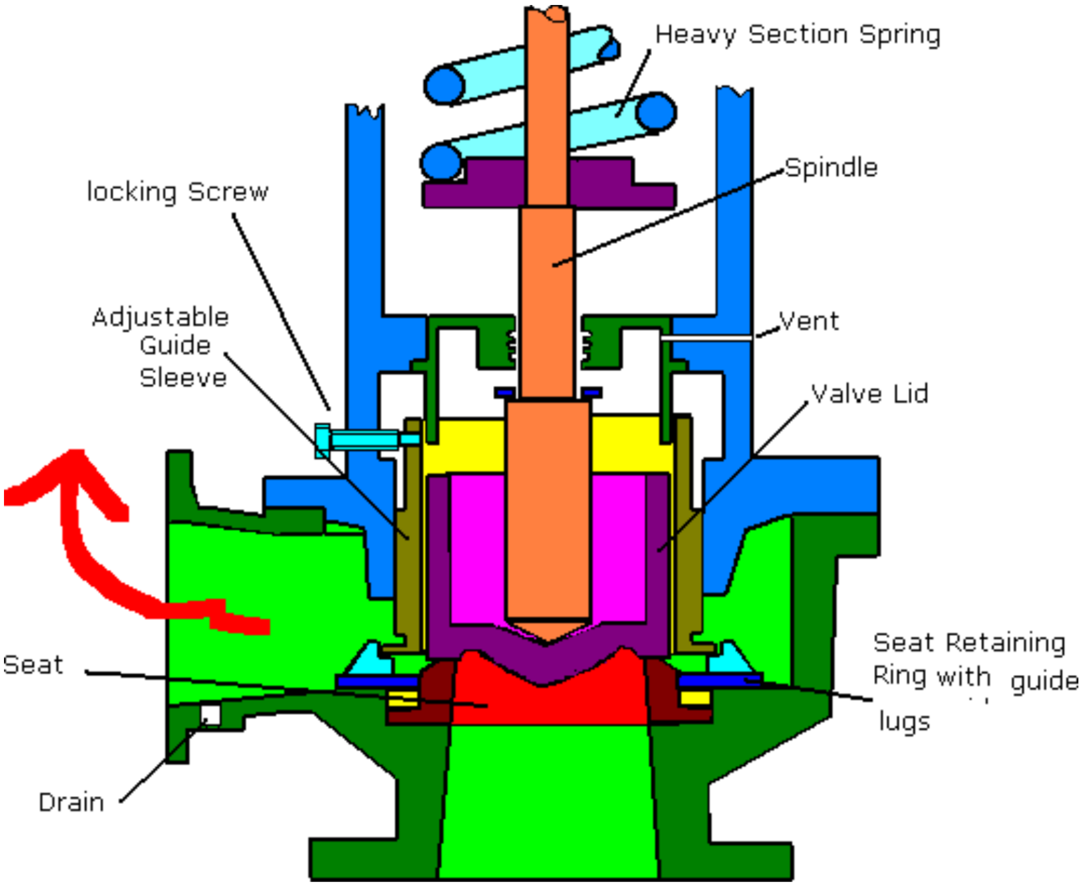
The manifold pipe must have an area equal to at least H of A, the exhaust must have a diameter dependent on the type of valve but up to 3 x A for a full bore relay operated valve.

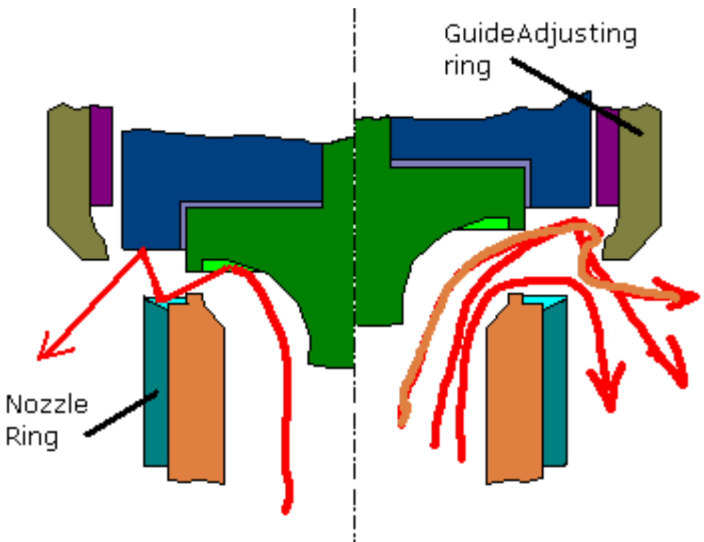
A drain pipe must be fitted to the lowest part of the valve, it should have no valve or cock and should be checked clear on regular occasions.

Materials

Materials for all parts must be non corrodible. Common materials are Bronze, Stainless steel or Monel metal, depending on the conditions of service. The valve chest is normally made of cast steel.

Full lift safety valve





This is a modern version of the high lift safety valve incorporating the piston and reaction force effects to improve valve lift. In addition the inlet pipe is tapered to give a nozzle effect increasing the reaction on the lid.

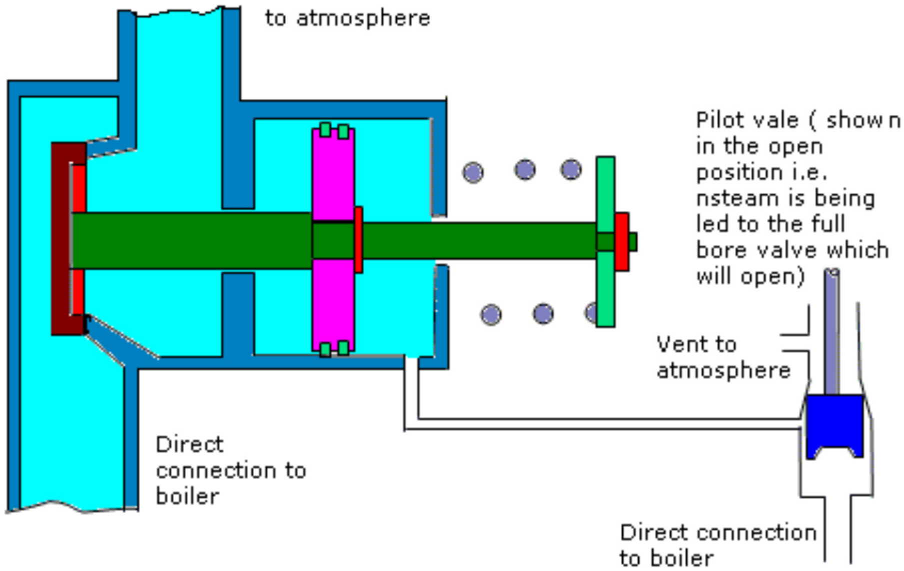
The initial lift is produced when the steam pressure under the disc exceeds the spring pressure. As the valve begins to open a thin jet of steam escapes and is deflected by a small angle on the nozzle ring. As the lift increase the steam begins to react against upper guide ring increasing to 'full bore'lift. **Full Bore** lift is defined as that point where the area of the nozzle, rather than the lift, limits the discharge capacity of the valve. The form of the valve offers an increased area to the steam jet stream and the design allows for a piston effect of the valve trim assembly as it enters in the guide ring cylinder, both these effects increase lift and improve action of the valve

The guide sleeve is adjustable allowing alteration of the blowdown.

With boiler pressure dropping the valve begins to close. When the lid just exits the guide sleeve

there is a loss of the reaction and piston effect and the valve tends to snap shut cleanly.
Blowdown adjustment is achieved by altering the height of the adjusting Guide Ring. On some designs a second adjustable ring is mounted on the nozzle, this allows adjustment of the 'warn' or 'simmering'period and increases the popping power. Adjustment of this ring is critical to operation, after factory setting it is generally unnecessary and no attempt should be made to remove slight 'warn'

Full lift safety valve



Seen fitted to large high pressure boilers.

This design offers sveral advantages over simple high lift valves

- Complicated design to achieve high lift is obviated
- Pilot valve may be mounted on the drum and the main valve maounted on the superheater thus making the system more sensitive to load changes (over pressurisation will first be seen in the steam drum before the superheater. In addition the pilot valve and main valve piston arrangements are subject to lower steam temperatures
- Boiler pressure will assist to close the main valve rapidly leading to very small blowdown

Easing gear

This is fitted to safety valves to allow manual operation of the valve in an emergency.

Gauge glasses

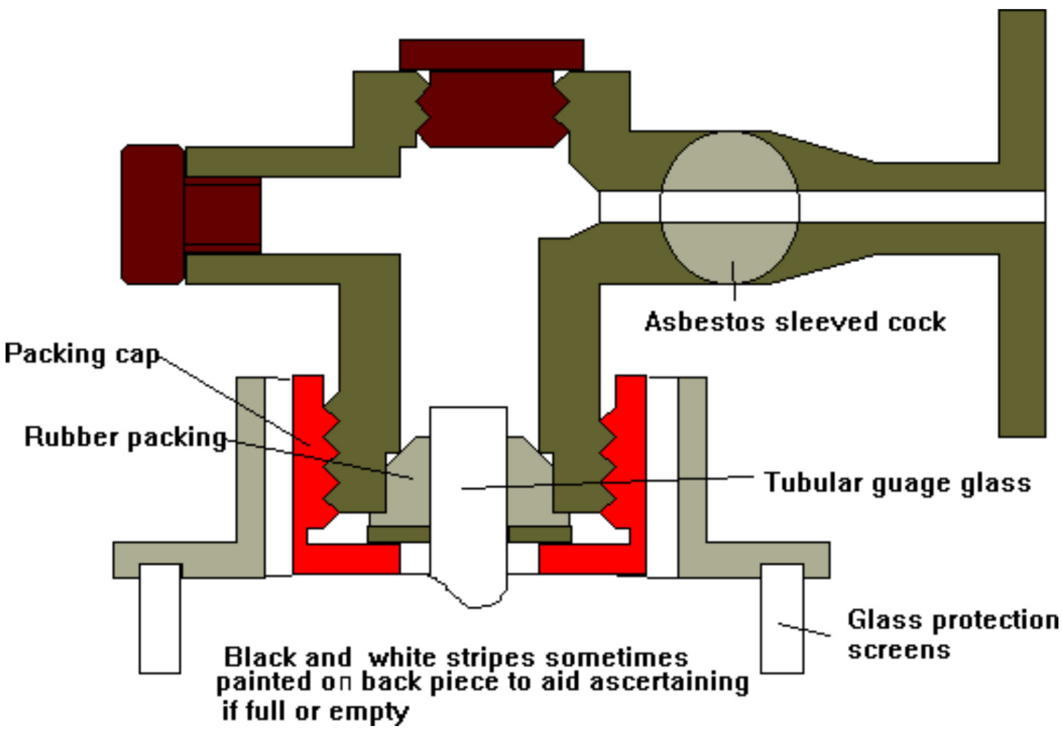
General

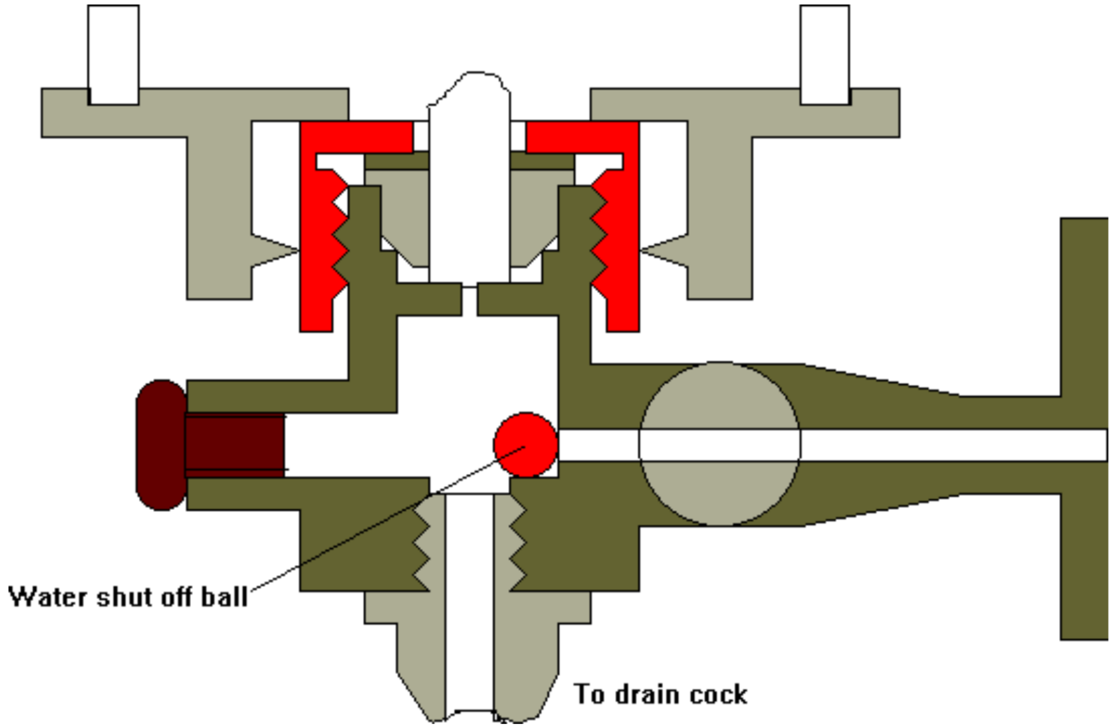
The requirements are that there must be two independent means of reading the boiler water level. Normal practice for propulsion plant boilers are the fitting of two direct reading level gauges and a remote display readout.

Low pressure boilers(up to 17.5 bar)

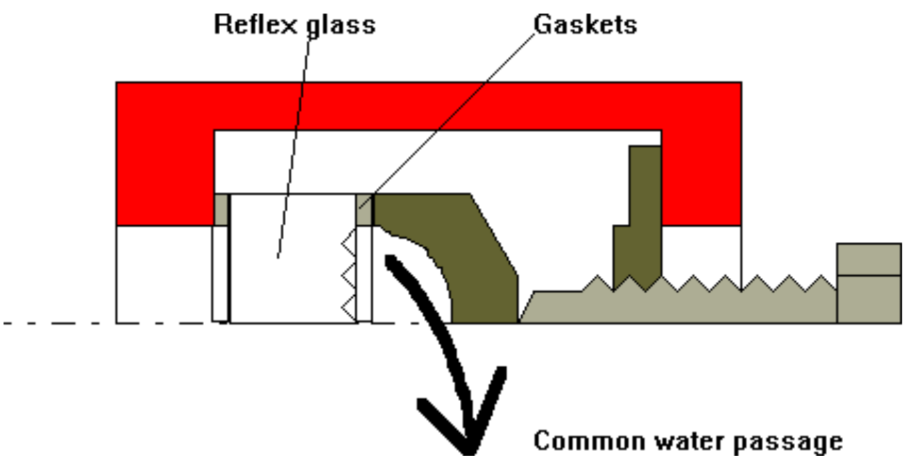
Small vertical boilers may be fitted wit a series of test cocks to ascertain the level, this is deemed unsuitable for boilers above 8.2 bar and/or 1.8m in diameter.

Tubular gauge glass



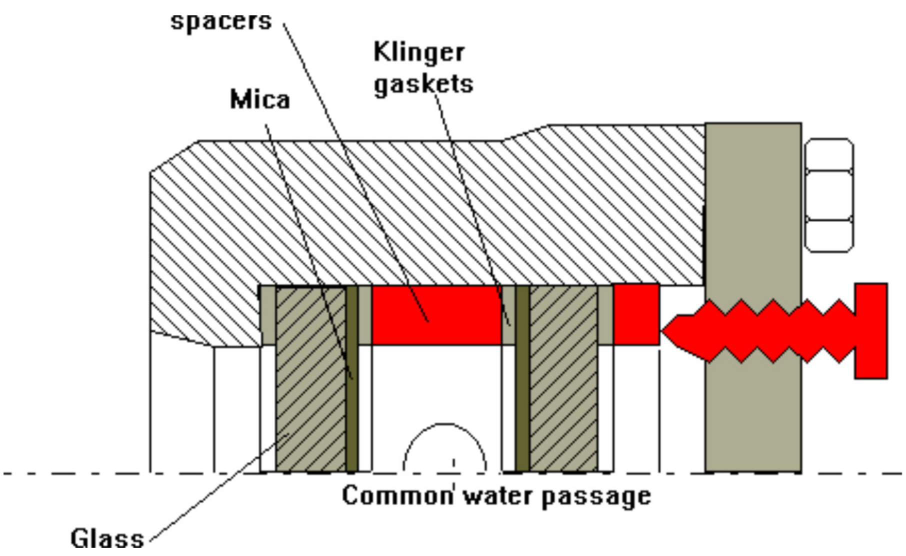


Medium pressure boilers



Reflex glass is used due to the fact that light falling on the glass is reflected by the steam but not by water, and so the glass appears bright where there is steam and dark where there is water.

High pressure boilers

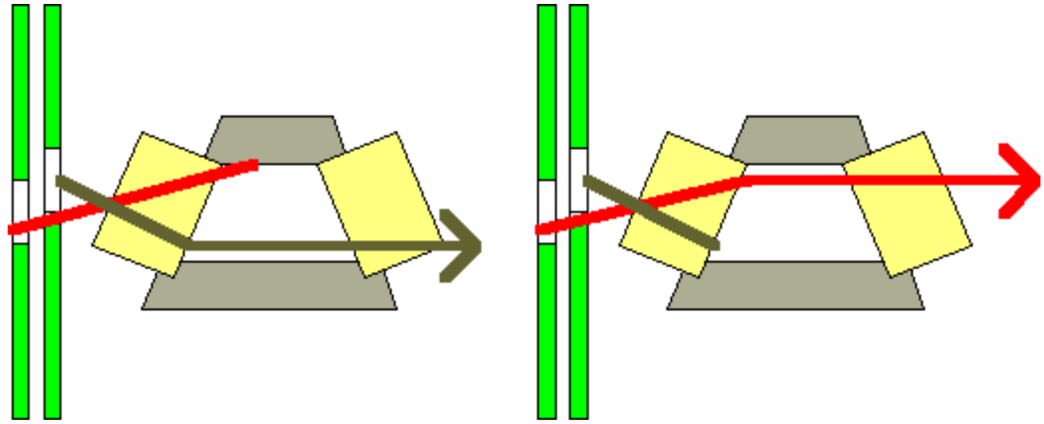


A ball is located in the water side to prevent large quantities of water entering the engineroom in the event of the glass failing and the subsequent large expansion of the water as it flashes off to steam. An orifice restrictor is fitted to the steam valve.
Mica is placed on the water side of the glass to protect against erosion and chemical attack of the high temperature water.

General gauge glass faults

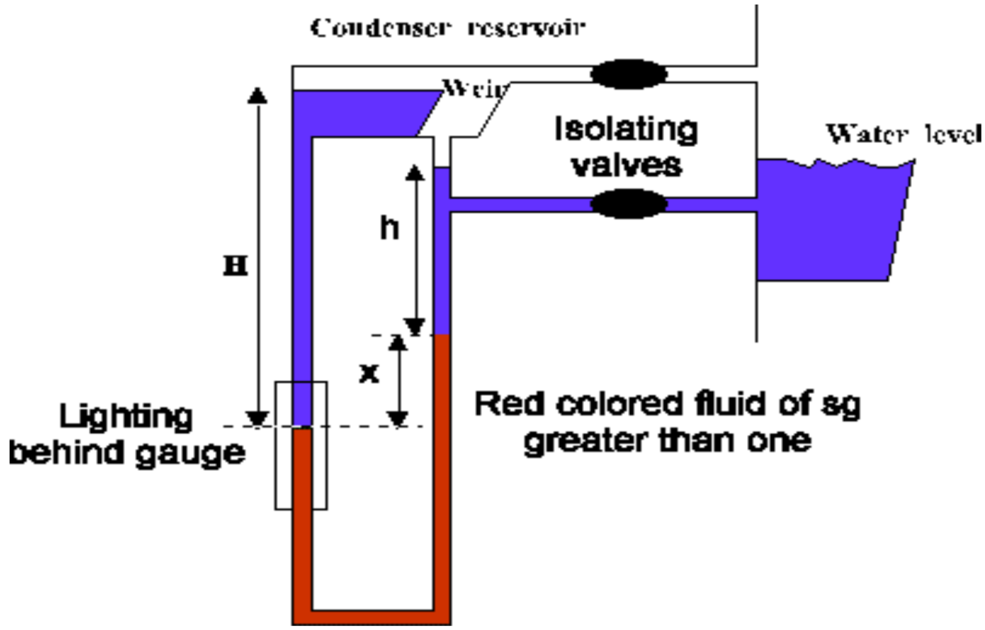
Due to the evaporation of water leaking through the cock joints a build up of deposits can occur. This leads to restriction and eventual blockage of the passage. If this occurs on the steam side then the level tends to read high as the steam condenses.
Another reason for blockage is the cock twisting, hence the cocks are all arranged so that in their normal working positions, i.e. steam/water open , drain shut, the handles are all pointing downwards. Possibility of the sleeving rotating on the cock has led to the use of ribbed asbestos sleeves which must be carefully aligned when fitting.
For tubular gauge glasses the length of the tube is critical and should be checked before fitting

Bi-color gauges



Igema remote reading indicator

Fitted in addition to gauges required by statute and not in place of them. The red indicator fluid does not mix with the water



Equilibrium condition is when H= h + rx where r is the specific density of the indicator fluid.

If the water level rises h increases and x reduces. Therefore H will be reduced and water will flow over the weir of the condenser to maintain the level constant. If the water level were to fall h would be reduced, x increase and H would be increased. Water therefore must be made from condensing steam in order to keep the condenser level constant.

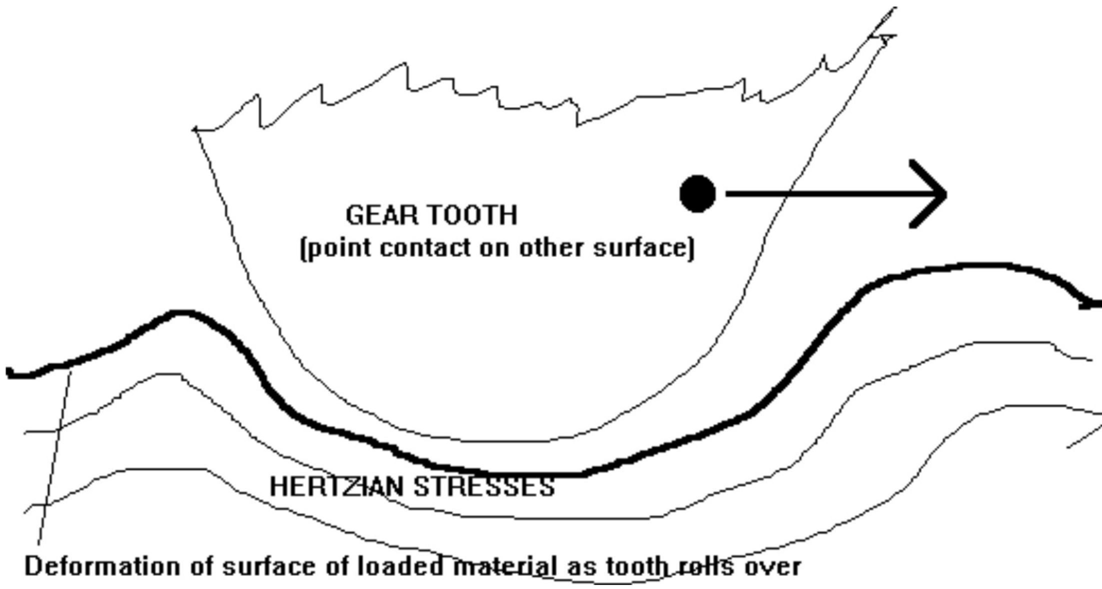
Faults associated with Spur and helical gearing

SLOGGER

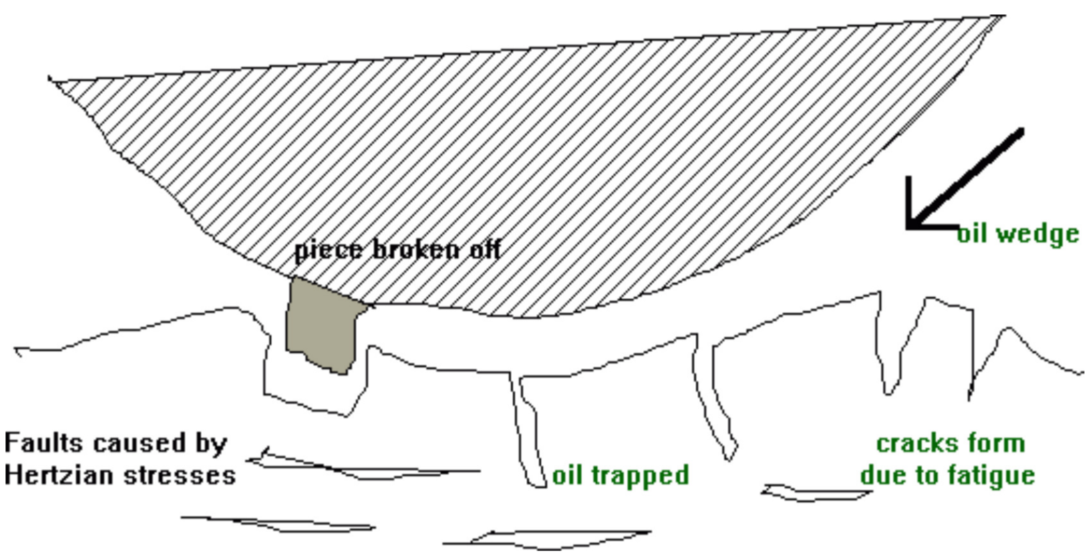
Hammer like action between teeth caused by variations in pitch or torsional vibration , may be negated by nodal drives

PITTING

The mechanism for pitting is poorly understood . One theory is that it starts below the surface and parallel to it . When extended to surface oil under hydrodynamic pressure is forced in.



Shown above is the deformation of the surface due to the rolling action of one tooth over the other. Subsurface hertzian stresses are formed which run parallel to the surface.

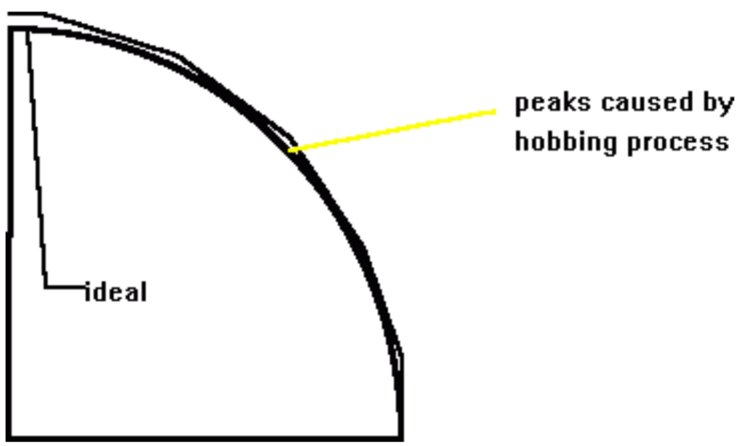


Most severe on the pitch line or just below it , but may also be found on the **dedendum** of both driving and driven teeth and is dependant largely on finish

There is experimental evidence which suggests that pitting occurs only where there is a low ratio of slide to roll. With worm and most **hypoid** gears, excessive side slide tends to wear away high spots before true pitting would occur.

With spur and bevel gears , as each tooth passes through the centre of the mesh , the entire load is momentarily concentrated on the pitch line. If the area along the pitch line has already started to pit , this concentration of load on the roughened surfaces of spur gears is quite likely to increase the pitting progressively until the tooth surfaces are destroyed or severely damaged.

On the other hand , with helical , herringbone and spiral gears , there is less likely hood of destructive pitting . This is because each tooth during the mesh makes contact along a slanting line which extends from root to tip. This line cuts across the pitch line , and therefore, though pitting may have roughened the area along the pitch line, the line of contact always extends beyond this roughened surface, and thus the load is carried on undamaged root and tip areas. Under these such circumstances , pitting may cease as soon as the few, isolated high spots along the pitch line have been removed.



INITIAL

New gears suffer initial pitting , these can disappear on the teeth as they work harden. Normal wear polishes out pits . Further problems can be avoided by proper running in

Back to back loading of the gearbox on opposite hand sets can allow the gearbox to be run in using high torque , low speeds.

Initial pitting is attributed to local overstressing caused by asperities and profile irregularities (see diagram above). The teeth of new gears may have variations in smoothness. Although these variations may be too small to break through the oil film , yet they may be large enough to affect gear operation. In addition , there may be variations in the hardness of the surface metal. When smoothness or hardness is non- uniform across the tooth , the distribution of load is also non- uniform. Thus as the teeth pass through the mesh, the load is concentrated on local high spots or hard spots.

The running in process reduces asperity's , and profile irregularities , surface stress becomes more uniform and pitting is arrested .

Profile inaccuracy can lead to root pitting and more rarely pitting on the addendum.

INCIPIENT/(corrective)

Most commonly found on wide-faced gear teeth, because of the difficulties in obtaining true and uniform contact across the entire width of the teeth.

On routine inspection pitting may be found . This is incipient pitting and requires close monitoring, unlike initial pitting which is only found on the maiden voyages, and can occur at any time during the life of the gearbox.

Careful monitoring will determine whether this is an isolated case or whether it will lead to progressive pitting with potentially destructive results.

Classic causes are overloading and misalignment (similar to progressive, and different to initial which is caused by high spots.) .If found then the gear case should be regularly inspected and the cause ascertained and removed.

The pitting , once the cause has been eliminated should polish out.

PROGRESSIVE

May occur were initial or incipient pitting has not been arrested . However progressive pitting may be mistaken for initial but the pitting is not caused by **asperities**.

Progressive pitting may halt or may continue to destroy the face.

Alternately it may halt , lie dormant then restart.

Most progressive pitting is wider in scope than initial pitting with branching fatigue cracks extending deep into the metal. Progressive pitting is followed by DESTRUCTIVE pitting which rapidly leads to failure

MICROPITTING

Fine attrition of the dedendum surface with a distinct wear step at the pitch line . Mating teeth may wear to a conformable shape and operate as so without problem.

May be regarded as a form of wear . However , secondary pits may occur increasing roughness to an unacceptable point.

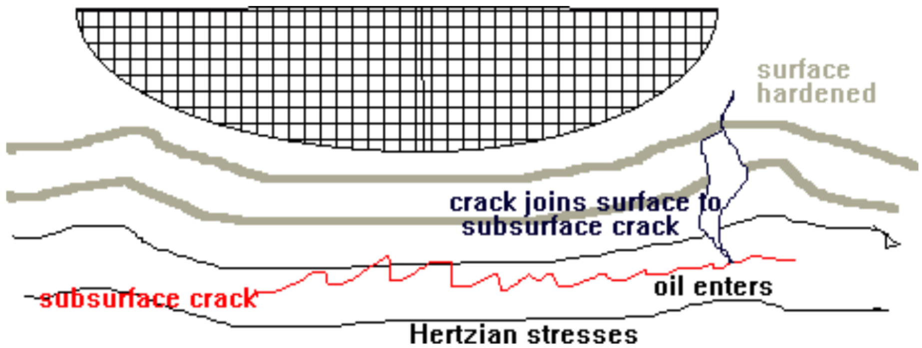
Development of wear steps, is not fully understood but may be associated with superimposed vibration - say from propeller or main engine.

If the tooth surface is poor or if overloading occurs pitting proceeds reducing load bearing surface eventually destroying the tooth.

SPALLING

Deep scallop shaped pieces of metal are removed , possible causes are overloading but is more generally seen as a surface hardening process failure.

It is caused by the same mechanism as pitting and flaking. Subsurface cracks form below the surface following the lines of hertzian stress. These may be joined to the surface by cracks formed due to the deformation of the surface under load. Oil forced in to these cracks under hydrostatic pressure enters the subsurface cracks were its non compressibility causes the crack to expand, were it joins other surface cracks and the piece detaches .



Very careful honing with a carborundum stone can be helpful but care should be taken not to alter the tooth profile

Cracking , flaking and spalling often indicate incorrect heat treatment ; or in the case of ground gears, faulty grinding.

Most often found in case hardened or surface hardened gears but may also appear on work hardening gears such as phosphor bronze.

It can be seen that pitting, flaking and spalling are all related , the mechanics of failure is the same in each case and only the size of metal loss is different .

FLAKING

Caused by heavy overloading or over stressing the subsurface of the metal and is a surface hardened phenomena.

The heavy compressive or shearing action on the subsurface can exceed the yield point stress of the metal and large flakes may break away.

Can be caused by insufficient depth of surface hardening

Rippling of the subsurface may also occur caused by plastic flow.

Similar formation to pitting but has a much increased length/breadth to depth ratio .

On hardened gears , flaking or spalling may be accelerated by abnormal heat hardening strains which decrease resistance to sub surface shearing forces . Heavy loads on worm gears may subject fairly large areas of tooth surface to greater stresses than the metal is able to permanently carry. Sub surface fatigue takes place which results in damage to the bronze gear-tooth surface . This condition is often referred to as worm wheel pitting.

SCUFFING/ (WEAR)

This type of failure - caused by the local breakdown of oil film as the surfaces slide over each other during mating and disengaging - led to the development of EP additives. It was also found that increasing oil viscosity was beneficial.

With oil film breakdown, very high tempo are generated and welding of local high spots occurs Similar to that occurring with **microseizure**). These are then torn apart.

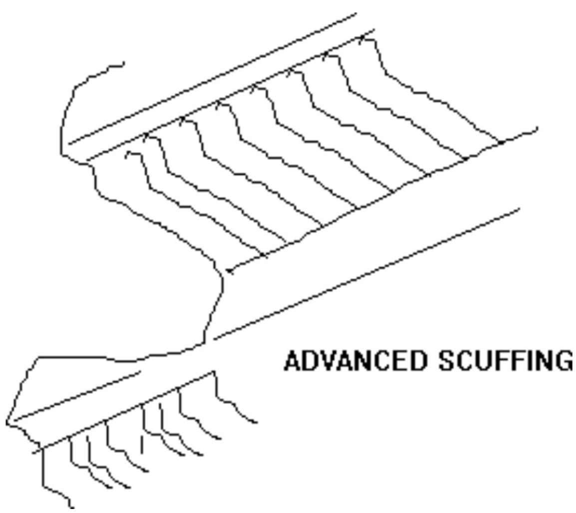
It is most prevalent at the tips and the root were relative sliding is at its greatest .

Were the oil film thickness is greater than 3x the CLA values of the surface finish scuffing is unlikely to occur.

Evidence shows that onset occurs when a tempo related to the lubricant an surface material exceeds a flash point.

Scuffing is definitely due to failure of the oil film to carry the load, either because the operating conditions are abnormally severe, or because of incorrect oil selection. In either event , the thick wedge type film gives way to the microscopically thin , boundary type lubrication which in turn lacks sufficient film strength. to protect the gear teeth from excessively friction and the plastic flow of the 'skin surface' of the metal.

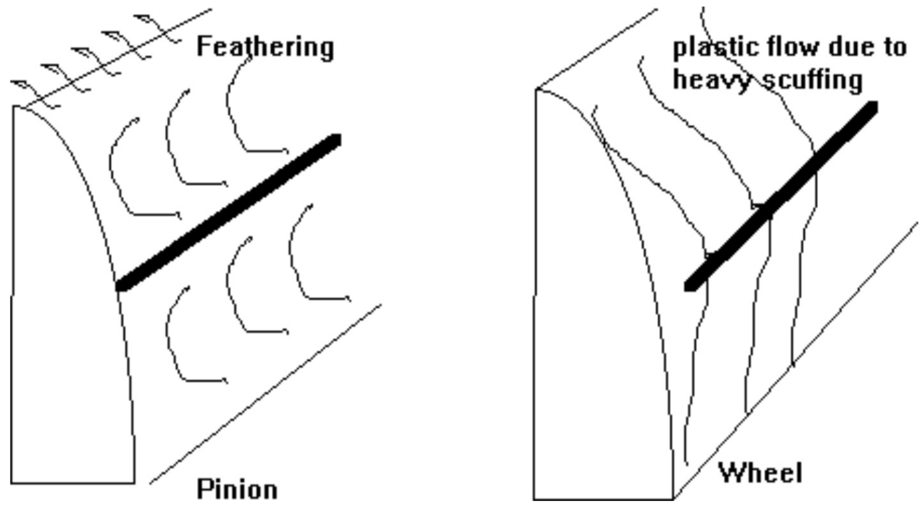
Under conditions of wedge film lubrication, failure of the film would occur where the combined film- forming effect of both rolling and sliding is least, namely the pitch line. Therefore , with fluid film lubrication , seizure would first occur near the pitch line and plastic flow would then tend to wipe the metal over onto the tooth areas that are in contact during the second half of mesh (interval of recession) . Scuffing in the areas above the pitch line on driving gears and below the pitch line on driven results.



Where operating conditions are more severe and boundary lubrication is resultant , the entire surface of the tooth will be scuffed .Pressure welding and plastic flow then takes place during the intervals of approach as well as recession , and surface destruction will extend from root to tips of the teeth of both gears . Even though scuffing is the initial cause of failure , severe damage may eventually bring about abrasion and scratching.

It should be noted that EP additives are very soluble in water ,hence, care should be taken when putting this oil through a purifier.

During the interval of approach , the direction of sliding on the contact surfaces is toward the pitch line on the driven gear and away from pitch line on this pinion. At the pitch line the direction of slide reverses , so that during the interval of recession it is still toward the pitch line on the driven gear and still away from the pitch line on the pinion.. Thus , when surfaces scuff, weld and flow under pressure , the direction of slide always tend to wipe the metal on the metal on the driven teeth towards the pitch line and away from the pitch line on the pinion teeth.



May spread to whole tooth , a feather being formed over the tooth tip . If occurs at one end of the tooth this can indicated a misalignment.

Poor surface finish and overloading are the prime causes normally found in softer materials of the wheel.

Use of scuff resistant materials , better surface finish , chemical cleaning and thermo chemical treatments can help, as can surface coatings

Light honing plus more attention to oil viscosity and tempo may help.

Experimental evidence show that scuffing or scoring resistance is raised by increasing the pressure angle, increasing tooth depth or when possible increasing the helix angle and providing tip relief. Scuff resistant metal combinations may be used, better surface finish, chemical and thermo-chemical treatments, surface coatings can all help to increase scoring resistance

Incipient scuffing

If the surface finish is poor , contact between the asperities can be made through the almost rigid (i.e. very high viscosity caused by the very high pressures) oil film, generating heat causing the tempo of the gears to rise, reducing inlet oil viscosity and reducing oil film thickness . Some materials when supplied with the correct lubricant quickly polish out incipient scuffing . With harder gears this process takes longer . The risk is high due during the running in period but minimised by chemically active EP oils or with a surface treatment such as phosphating

SCORING

Should a ferrous particle enter the mesh it can be embedded in a tooth .On mating the particle is heated up by welding, fails in the heat effected zone , and quenches in the copious supply of oil. Some of the oil is carburised , absorbed into the particle , which is now very hard and becomes embedded in a tooth forming a spike. This then gouges a score in the teeth as they mesh until it becomes polished out . If the mark is on the pitch line then a point will form rather than a gouge

ABRASION/ (SCRATCHING)

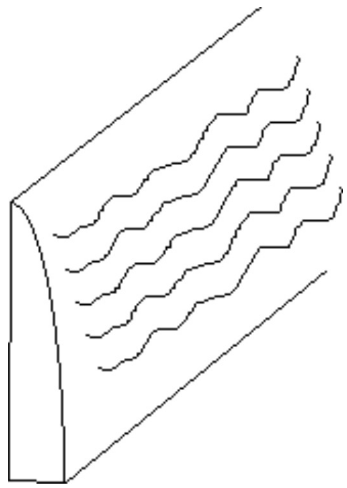
Caused by foreign abrasive materials entering the mesh

May appear as a score from root to tip caused by hard projection on one or more teeth penetrating oil film- this can be referred to as scoring or ridging or may appear as random scratches caused by dirt in the oil.

Another form leads to a highly polished surface and is caused by very fine particles or dust in the oil.

The only remedy is careful filtration and honing of bad grooves. Cleanliness is most important. Very heavy abrasion can lead to change in tooth profile.

PLASTIC FLOW



Due to plastic , cold working of the metal which flows ahead of the pressure area building up a wave of metal until by work hardening the ripple resists the flow.

Immediately after this a further wave forms. in extremes, a line of pits form on the crest caused by the subsurface shearing rather than the compressive stress.

Main factors are unsuitable material , overloading and misalignement .

Hypoid and spiral gears are particularly susceptible to this . This type of failure occurs particularly following partial lube oil failure. Plastic flow rather than scuffing occurs.

When slight , the rippling effect maybe advantageous acting as oil reservoirs.

Fish scaling

As the flow increases in severity, then the tooth profile alters to a similar condition to that seen due to scuffing.

GALLING.

Very heavy teeth damage due to various reasons, requires new teeth.

BREAKAGE

Has four main causes;

i. *overload*
ii. *defective material*
iii. *faulty workmanship.*
iv. *fatigue*

Also may be caused by foreign material falling in to the mesh. Checks for cracks should be carried out at regular intervals especially following overload.

Checks can be carried out using dye penetrant on magnetic indicators.

CORROSION

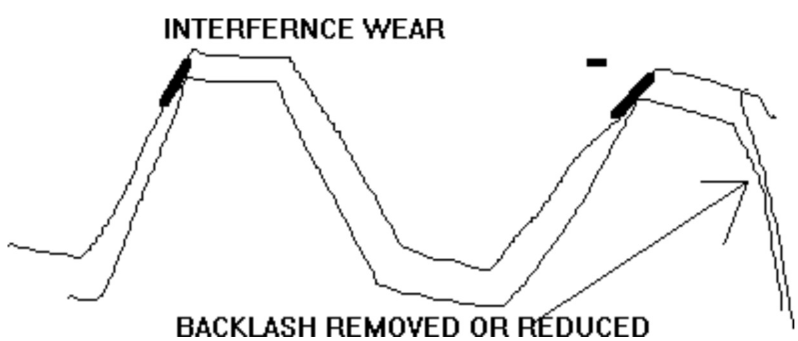
The supply of dehumidified air to the crankcase is carried out to prevent corrosion.

Corrosion products can lead to the rapid deterioration of the lube oil and lead to sludge formation .

Regular checks should be carried out to ascertain the efficiency of the dehumidifier.

INTERFERENCE WEAR.

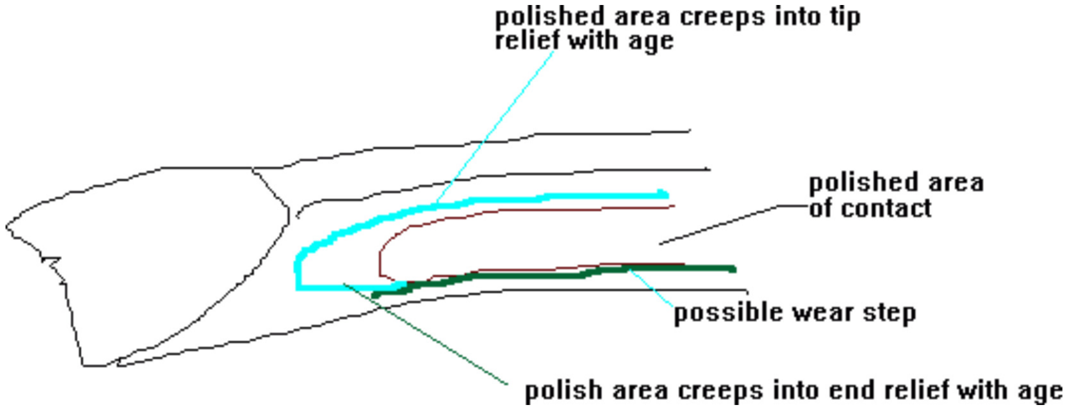
This occurs where teeth become too closely engaged .This can occur when fitting new bearings which are incorrectly bored.



PROBLEMS FOUND DURING NORMAL USE.

In normal use, a contact area becomes polished .A wear ridge may form which may move as the bearings become worn, if new bearings are fitted then the position of the ridge will move. Problems may the occur of the teeth slipping off the ridges leading to noise and possibly removing thin shards of metal.

Plants running at reduced load, hence reduced tooth bending moment wear in a certain area . Should the plant then be run at full load it may be found that due to the wear the tip relief is now insufficient.



MISALIGNEMENT- Causes problems of overloading at the ends of teeth.

EXCESSIVE BRG CLEARANCE-Pinion moves out of mesh to far, hence load taken on ends of teeth giving excessive bending forces.

INCORRECT TOOTH PROFILE- Pitting and noise

PARTIAL SEIZURE OF ROTOR FLEXIBLE COUPLING- Gearing loads transferred to turbine possibly causing to turbine.
If the axial clearance is completely taken up then the main thrust (as the pinion is locked by the double helical arrangement) WORM GEAR FAILURES Pitch line pitting as described for spur tooth gearing does not occur in worm gearing. Due to the greater slide in this type of gear than in spur or helical gears, the tendency is for the tooth surface in equalities to be worn away before metal fatigue occurs . Tooth surface failure by abrasion or scoring can occur exactly as in other type gears, but the most commonly encountered worm gear failures are the flaking or scuffing types. Heavy loads on worm gears may subject relatively large areas of tooth profile to stresses sufficient in severity to cause sub surface fatigue and eventual flaking of relatively large pieces of bronze. Flaking on worm wheel gears is frequently heaviest on the ends of the tooth leaving the mesh. Spot tempo in this areas are higher than elsewhere and it is probable that the fatigue resistance of the bronze is lowered as a result . In some cases localized flaking may be due to misalignment. Lubrication failures do occur on worm gears either due to unsuitable oils , incorrect or excessive loading. Scuffing is the usual type of failure and this is influenced by the grain structure of the bronze .

HYPOID GEAR FAILURES

Where hypoid gears are involved , surface failures on teeth may take several different forms . These steel to steel gears are generally so heavily loaded , especially in automotive equipment, that although they are flood lubricated , boundary lubrication is the usual condition. Metal to metal contact is therefore , unavoidable. With the correct lubricating oil in use , the degree of metallic contact and the generation of frictional heat between the rubbing surfaces is minimized . Irrespective of speed, such conditions result in smooth , dull polished or brightly burnished tooth surfaces with negligible wear. When hypoid gears show evidence of unsatisfactory lubrication , the surfaces may have the appearance of being either rippled , ridged , flaked , pitted or scored.

The particular surface appearance that developed depends on the type and severity of operating conditions i.e. on the speed of rubbing and the magnitude of loading carried by the working surfaces. Furthermore it depends on the lubricity, film strength and anti weld characteristics of the lubricant.

The working surfaces of hypoid gear teeth sometimes develop fine ripples (fish scale appearance) . When this happens , the ripples have the appearance of being formed by the metallic flow which builds up a wave of metal ahead of the pressure area, The appearance of the surface indicates that each wave quickly becomes sufficiently work-hardened to resist further flow , whereupon contact then moves over the hard surface to repeat the process immediately beyond. This results in the formation of small wave-like ripples of work-hardened metal at right angles to the diagonal lines of slide , it seems to occur only at comparatively slow speeds.

As rippling progresses, the continued cold-working of the metal causes sub-surface fatigue cracks to develop, with the result that thin flakes of metal ultimately break loose from the surfaces and drop off. This flaking (spalling) action is more pronounced on the tooth surfaces of the pinion due to the smaller number of teeth among which the load is distributed.

A tooth sometimes appears to have a smooth and very highly polished or burnished surface. Under a microscope , however , the smooth surface may take on a very finely ridged appearance with innumerable short, parallel ridges extending diagonally across the working surface of the tooth i.e. in the direction of the slide. Each ridge appears to be made up of many short ridges added approximately end to end. They do not have the appearance of typical scratches or score marks. The hills and valleys have a smoothly rounded outline.

Either a rippled surface or a burnished surface may develop a ridged appearance with ridges of such size that they can be seen and felt .There is no evidence of gouging or tearing but due to the size of the ridges considerable cold working has occurred. Continuation of this cold working leads to the fatigue point being passed . When this this happens , small cracks develop and minute particles of overstressed metal break loose and drop off., leaving fine pits along the crests of the ridges . This pitting may occur over the entire working surface of a hypoid gear tooth . It , therefore , should not be confused with pitting of spur or helical gear teeth which is due to entirely different causes and occurs only near the pitch line. Continued and extensive pitting eventually results in the removal of considerable areas of metal from the tooth surfaces and extensive flaking.

On hypoid gear teeth , scoring results when particles of metal are displaced or transferred from teeth of one gear to the teeth of the mating gear. It may also be referred to as scuffing or galling, particularly in the advanced stages. Scoring is the final result of a combination of factors i.e. High rubbing . speeds and loads , low film strength and insufficient anti-weld character of the oil. When film strength is lacking, considerable metal-to-metal contact will occur, and if the rubbing speed is high enough , frictional heat at microscopic points of contact will create local welding tempo .If the oil lacks anti-weld (E.P.) character scoring results.

Normal wear

When gears are of the proper design , construction and hardness, do not operate at excessive loads and are correctly lubricated, a condition of normal wear result. Normal wear over a long period and under conditions of flood lubrication gradually smoothes rubbing surfaces of the teeth and work-hardens them to a polish. As the surfaces become smoother and more work hardened , friction and wear decreases until a condition may be reached where further wear practically ceases. There may be signs of long use , but the metal is peened , rolled and polished to a smooth hard surface. Correct boundary lubrication on hypoid gears results in a smooth , dull matted gear-tooth surface and relatively little wear.

CALCULATION OF MAX TOOTH LOADING.

Severity of tooth contact ; is generally expressed in terms of:

Tangential load/face width

Alternately a 'K' factor based on the Hertzian stresses is used

K= W/Fod x mg + 1/mg

W= tangential load on gear teeth (lb)
(pinion torque/pitch radius of pinion)

Fo = face width of teeth (inches)
d = pitch diameter of pinion (inches)
mg = gear ratio; pinion speed / wheel speed

In the 1950's 'K' factors for turbine reduction gears were about 35 to 80 for unhardened alloy pinions on carbon steel wheels. With improved materials, heat treatment and manufacture; hobbed, shaved gears can have 'K' factors of:

150 max. for primary reduction (through hardened)
130 max. for secondary reduction

For hard/soft combinations 240-210 respectively

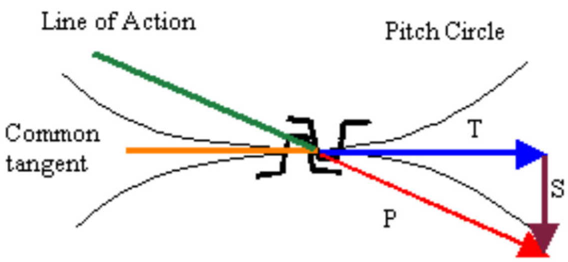
Certain high performance naval vessels have a 'K' factors of 300

The most common failure is when a tooth or part of a tooth breaks off due to fatigue

Impact failure is rare and generally due to negligence.

Tooth design

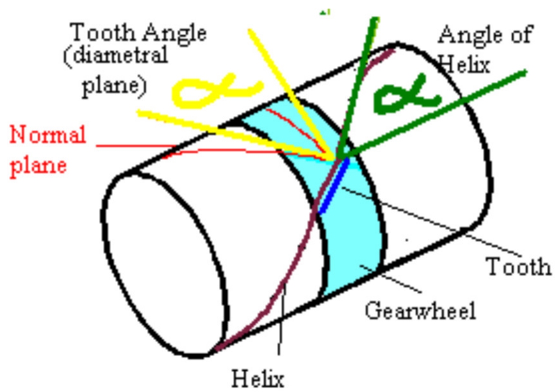
Forces acting on Spur Gears



T= Force transmitted due to torque (torque/pitch radius)
P= Actual Force
S=Force tending to cause seperation of wheel and pinion

Forces all act in the same plain as the pitch circle surface diametral plane. The force that must be transmitted by the gearing is that related to the power developed in the turbine P=2πnT hence for the same power the torque is inversely related to the speed of transmission.
This resultantforce P = Tcosθ is found on both driving and driven teeth.
Straight (spur) gear teeth meshing is accompanied by impact as the load is transmitted from tooth to tooth. No more than 1.2 to 1.4 teeth are in mesh at any one time.

Forces acting on Helical Gears



For helical gears the force triangle is inclined to the diametral plane. An additional component acts along the shaft.
It is normal, for large gear sets, to have a second attached wheel with teeth angled opposite to the first to cancewl out this component.
As the pitch circle is now in the form of an ellipse it is now necessary to resolve the angles in the normal and diametral plane to find a new pressure angle so the forces can be resolved in the diametral plane.
This can be shown to give the formula

$\theta' = \tan^{-1}(\tan\theta / \cos \alpha)$

θ' = Pressure angle in diametral plane
θ = Pressure angle in normal plane
α = angle of helix

As cosα is less than 1 then θ' is always greater than θ hence the actual loading on a tooth is increased slightly for the transmission of the smae force.

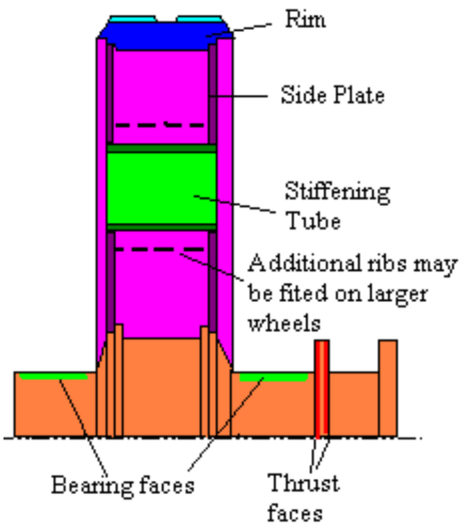
The angle of helix given to helical gears (about 30^{o}) is to ensure that one end of a tooth engages before its preceding teeth has disengaged. In this way several teeth may be in mesh and smooth transfer of load is allowed. The axial loading caused by this type of mesh is countered by having back to back opposite hand teeth.

Due to unbalanced axial loads caused by irregularities in the manufacturing process and wear, the gear teeth tend to shuttle and flexible coupling arrangements must be able to cope.

Gear Bearing Load

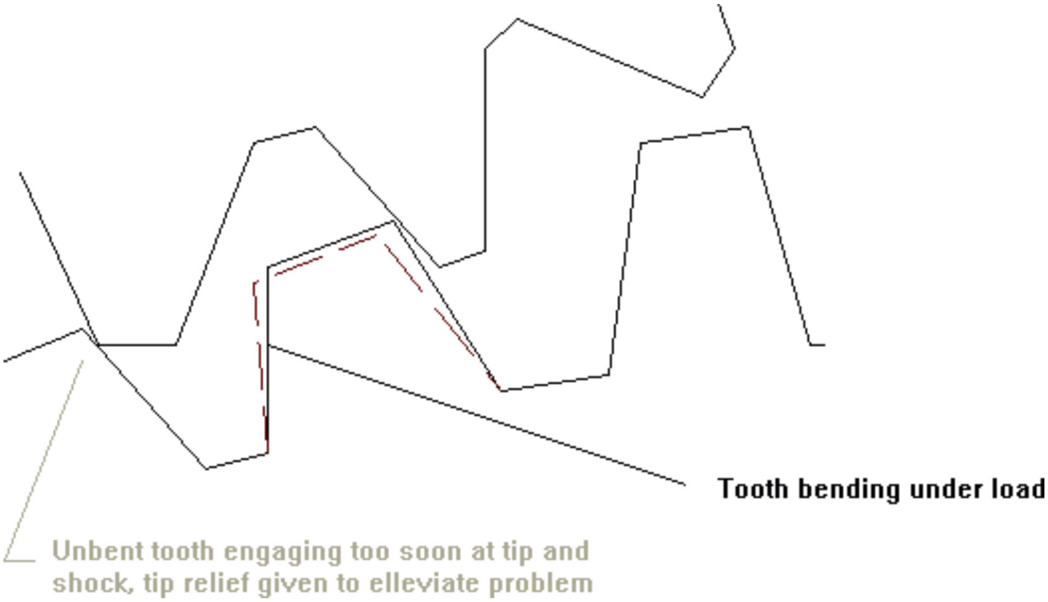
The forc P must be carried by the bearings. Additionally the weight of the gear wheel must be carried. By resolving the force triangle the resultant magnitude and direction of force may be calculated. The bearing split on some gearbox designs are angled to be at right angles to the resultant force direction under full load. Oil supply holes are provided well away from the direction of load. Relief and oil channels are provided to carry the oil to the load point. The length to diameter ratio is approx. 2/3
Fo the main gear wheel which may have more than one pinion a polygon of forces must be resolved at the wheel centre to determine resultant ahead and astern load on the bearings

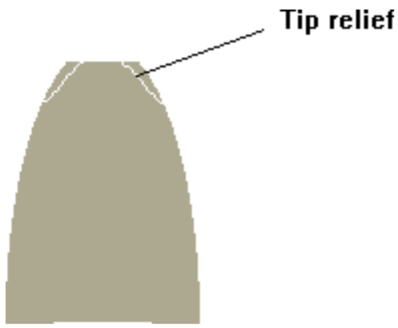
Construction of Primary Wheel



The wheel cenrte is forged integral with the shaft. Wheel is stiifened by a number of axial steel tubes welded to the side plate. This type of construction is resistant to vibration.
No key is fitted

Tip relief





Some early methods of gear cutting led to a lack of uniformity between the start and end of the helix. Teeth relief is given to prevent shock loading caused by this. Some teeth relief is also given to reduce loading and prevent subsequent breakdown of the oil film. Too much tip relief reduces the effective depth to a point where the number of teeth in contact is reduced. Also due to the distortion of the Torque twist and bending due to the tooth load and bearing reactions the load tends to be thrown towards the outer edge of the tooth. Hence, the ends of the teeth are chamfered to 30^{o} both from tip to root but also the tooth width is reduced by chamfer to about half root width .

Tooth cutting process

The gear teeth are cut in a separate room which is kept at constant temperature. They are hobbled, then they are shaved (a scrapper takes off very fine slivers and is free to follow the tooth form)

The ends and tip of the teeth are relieved.

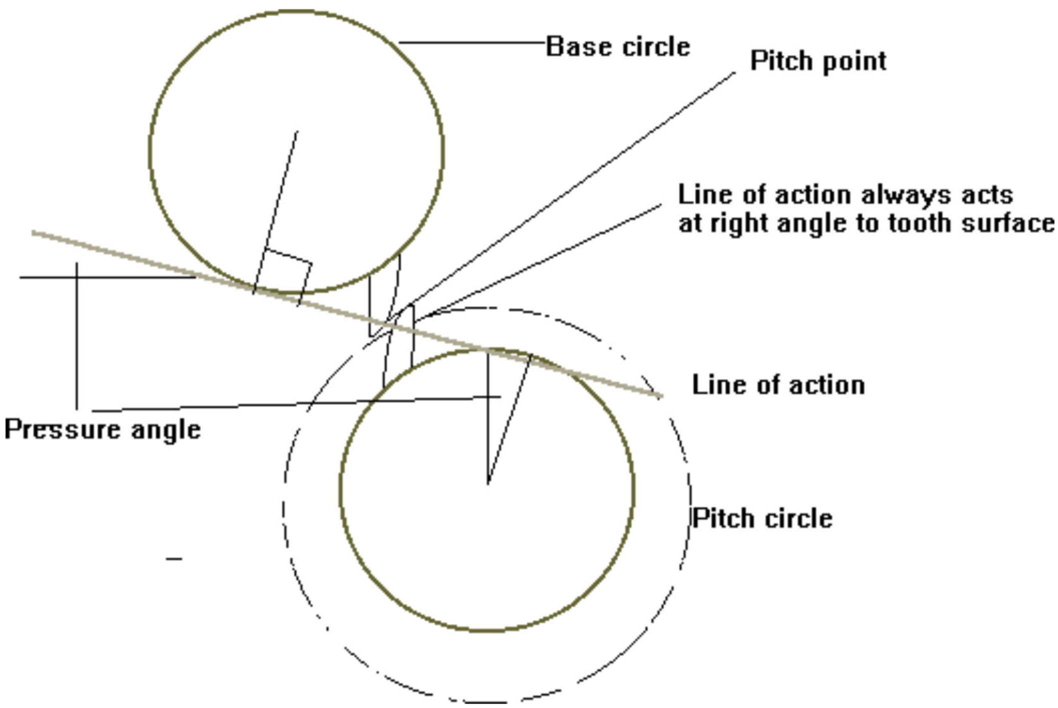
Pinion and wheel are arranged so as not to be as multiples of each other e.g. if ratio 10:250 was required the designer would use 10:251 so that there where many revolutions before two teeth repeated a mesh

Involute shape

Often described as the form a the end of a taut string on a drum follows when it is unwound.

This form gives a strong root section, improving the resistance to bending whilst being able to tolerate a degree of misalignment.

Nomenclature

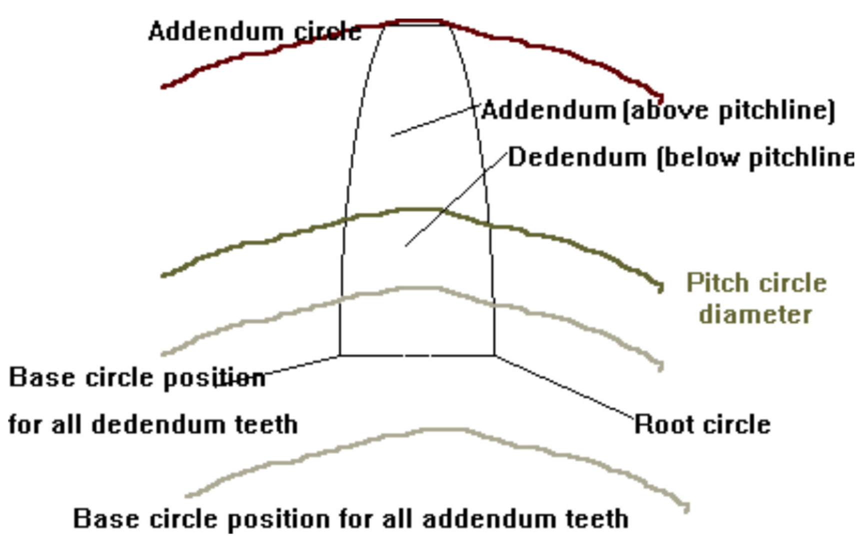


It can be seen that increasing the distance between the centres of the gears will not change the gearing ratio but will change the pressure angle.

The pitch circle can be related to the diameter of a drum with no gear teeth when related to gear speeds and hence gear ratio's.

n1/n2 = d1/d2 = N1/N2

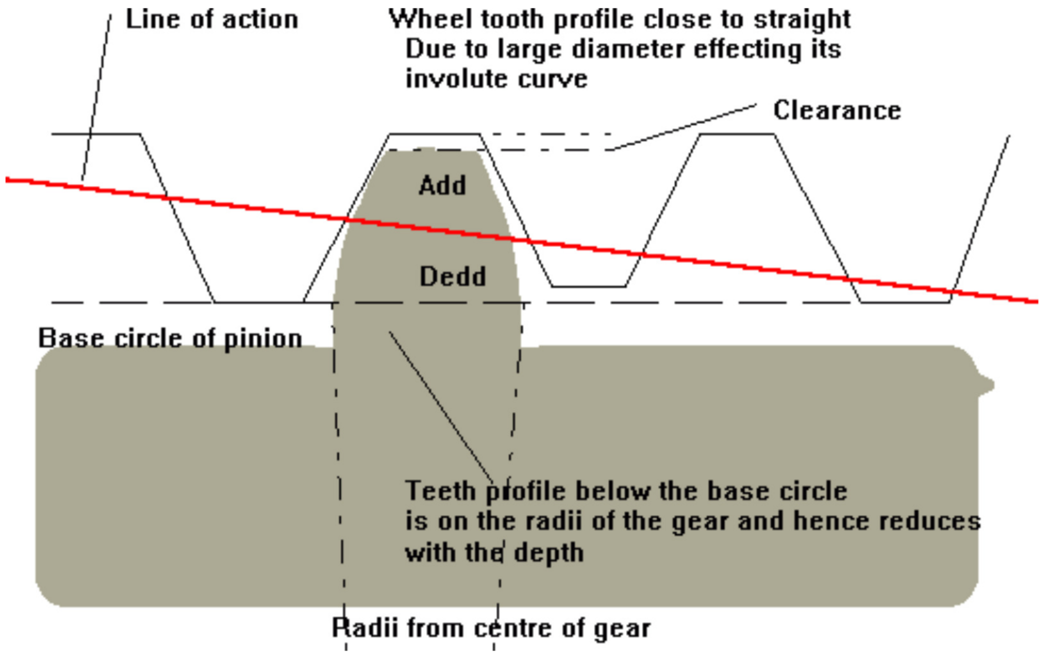
n = speed of rotation
d = diameter of pitch circle
N = Number of teeth



Geartooth nomenclature

The pressure angles are normally kept between 14.5 - 20^o . Too high and it tends to produce sharp pointed teeth of increased pitch. Too fine and it tends to produce undercutting.

The root circle must be at a radius greater than the base circle for the tooth shape to fall on the involute curve. By definition, any undercutting below the base line cannot be of the involute shape i.e. the involute curve is generated from the base circles of both gears. For pinion of the all addendum form the root circle is pushed out to the base circle so all of the tooth is of the involute shape. The mating teeth are then all addendum. the teeth engage with pure rolling action at the pitch circle and are only in contact during the arc of recess with the relative sliding in one definite direction over the whole tooth



The addendum and deddendum for the pinion and wheel are made different to give the clearance. This allow oil to become entrapped flow around and out giving a cooling effect. Also it allows debris to be washed out. The provision of the clearance also allows fillets to be introduced into the base of the teeth without causing interference.

Modified teeth (not normal nowadays)

The pinion, being subjected to the highest stress fluctuations is more likely to fail. Hence the pinion may be given a positive **Addendum Modification** to increase the thickness of the root thereby reducing bending stresses. This is especially seen on pinions with a small number of teeth to avoid undercutting If the pinion was made with all addendum, the arc of contact would be reduced and the wheel would require all deddendum teeth profile. This gives a very thick root form for the pinion , this is particularly seen on nested gears.

BACKLASH

The backlash in a tooth is limited to oil film thickness and also to allow movement to alleviate problems caused by;

i. *Angular movement*
ii. *Expansion*
iii. *Flexibility within gear set*

MATERIALS IN USE

Up until 20 yrs ago 'through hardened' materials were widely used and still are but less frequently. These are carbon steel wheel rims and nickel steel pinions.

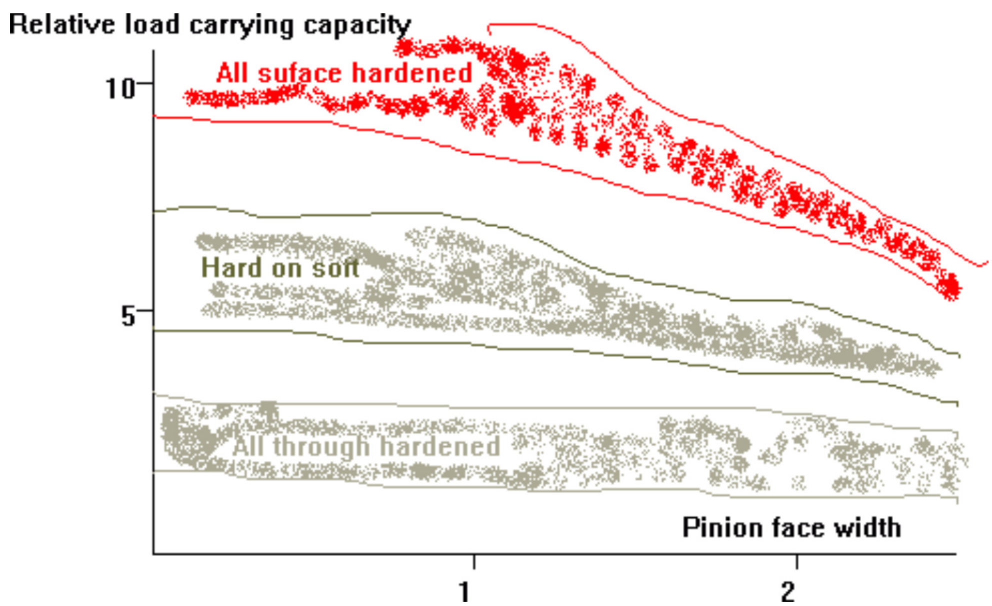
The factors which govern the suitability of a material are;

1. *Surface strength,i.e. resistance to pitting and flaking. This has found to increase with tensile strength but only to a point with fatigue strength.*
2. *Tooth bending fatigue strength i.e. the ability to resist fracture at or about the root due to the cyclical application of loads*
3. *The ability to resist scuffing and scoring during short term lubrication failure, and a resistance to wear.*

The ideal was to have both wheel and pinion carburised then machined to remove imperfections caused by the carburising process. Here materials are held at 900'C in carbon rich atmosphere. However this is expensive and difficult to carry out on large wheel rims.

Heat treatment is carried out after the hardening process.

Balance is to use the hard on soft principle, after hobbing and shaving only the pinions are hardened by nitriding (the shaft is heated in an atmosphere containing free hydrogen, created by heating ammonia to 500'C)
Nitriding created little distortion hence making grinding unnecessary.



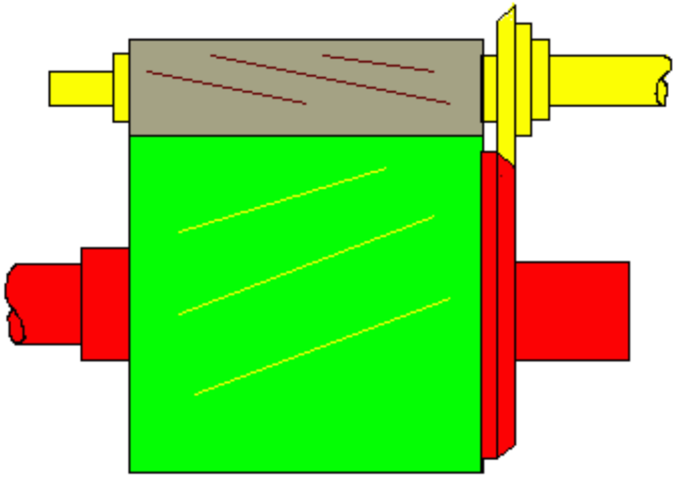
Providing proper design and manufacture and adequate lubrication the surface should tend to work harden and provide a polished surface. As the surface improves so does friction and wear. Pinion may be 3% nickel, chromium, molybdenum steel. Wheel may be 0.4-0.5 % carbon steel

Advantages of Helical and Double Helical gearing

SINGLE HELICAL	DOUBLE HELICAL
Comparative simplicity in grinding No gap, low helix angles - 15 '	*Longer grinding times , normal gap normal helix angle - 30 '*
Complete absence of pinion shuttling obviates the use of sliding couplings Apex wander due to different composite pitch errors cause shuttling.Gear tooth couplings do not respond because of the high frictional loads. Best compromise is to use axially flexible couplings. With highly accurate gear manufacture this effect is small	
Axial thrust on primary high speed pinion unless taken by turbine thrust bearing can lead to high losses if flooded thrust pads are used. The use of brown boveri thrust cones can be used to overcome this problem.(see Below)	*No axial thrust and no high speed thrust bearings required. Final reduction wheel located by propeller thrust bearing*
Ball and roller bearings may be used to take end thrust	
Quill shafts can be solidly coupled to primary wheels and secondary pinion. The helix angle on each being arranged to balance the axial thrusts.	
Simple side bearings serve to locate the shafts . The axial thrust of the final reduction wheel being carried by the propeller thrust bearing.	
Axial tilting moment on wheels generally negligible.	*No tilting moment*
Small helix errors can be perfectly corrected . Allows tooth helix angle adjustment to negate bending , torsional and heating effects and hence balance loading across the teeth. Helix errors can be adjusted in a similar way, but not so perfectly as for single helical	
Summary The main advantage is that the double helical gear does not have end thrust However they do take more time to manufacture and are slightly heavier	

Brown Boveri Thrust Cone

This is a method of absorbing end thrust in single helical gears without resorting to large thrust bearings. This design is seen insmall steam turbine generator sets.

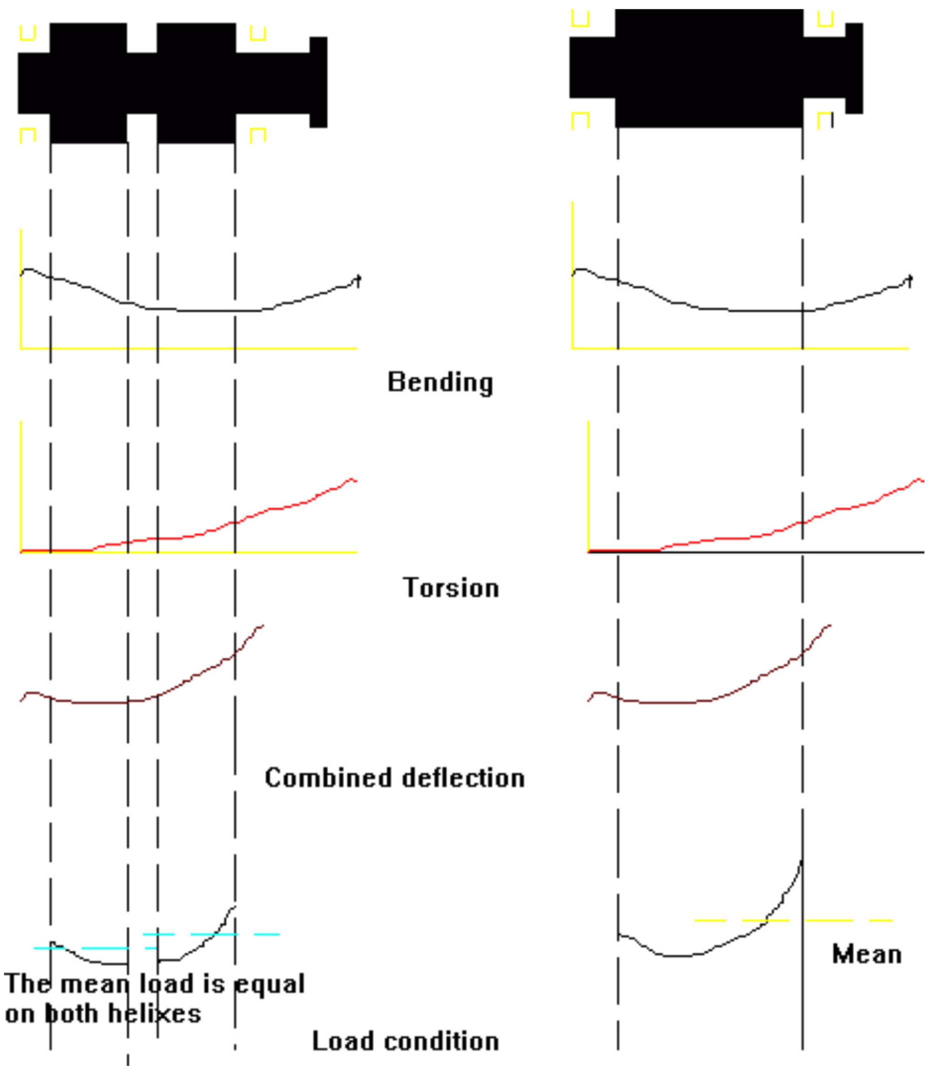


With the cone system there is a line of contact and a very large relative radius of curvature with a large oil entraining velocity of 220 ft/s .There is thus considerable axial resilience with the large radius of curvature, a small radial width of cone is sufficient to take the thrust

Teeth angle correction

When a pinion having a uniform meshing at no load, is torqued at one end, it bends and twists according to a known algebraic combined deflection ,the load distribution is proportional to the tooth deflection.

New load distributions can be calculated which can take into account alignment , bearing flexibility and thermal effects.



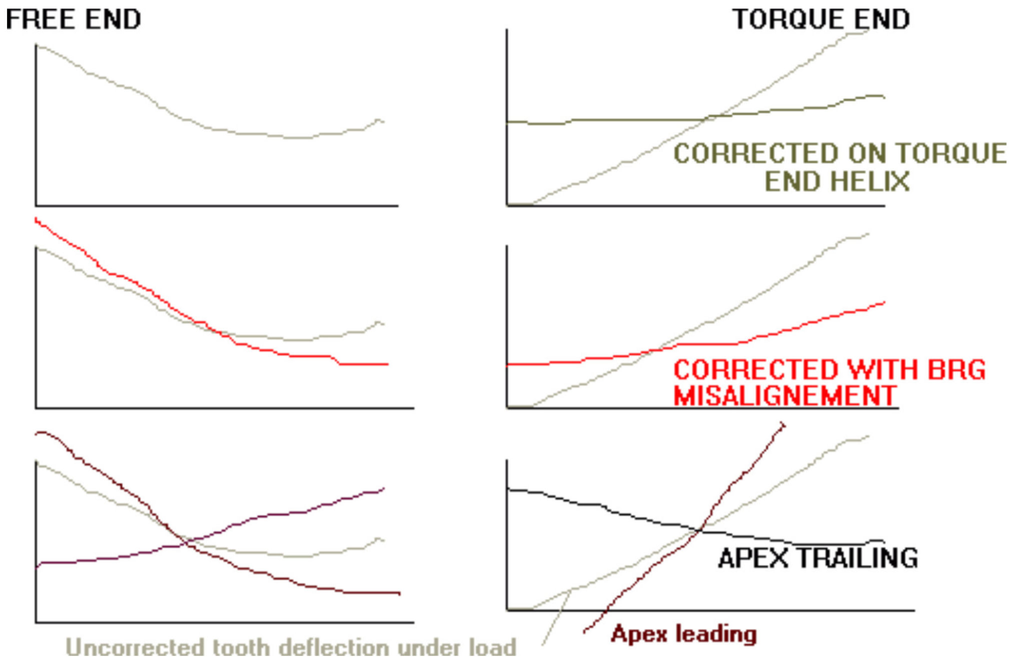
It can be shown that the tooth separation for double helix gears is less than that for single helix gears.

Temperature effects

Usually the pinion operates at a higher temperature than the wheel. The pinion will expand and hence the pitch will change. The change in axial pitch is most important as this wears the teeth at one end of the helix

With apex trailing , the teeth bear hard on the inner ends and with apex leading the teeth bear hard on the outer ends.

Apex trailing is advantageous as apex leading teeth tend to compound the effect of heat distortion into the torque distortion



Types of Gearing

Spur gears

These are the most common form of drive. They are cylindrical and have the teeth cut straight and parallel to the axis of rotation. The tooth form can be one of several, but there is no axial thrust component on the bearings as the teeth are straight. The efficiency of the spur gear can be as high as 98% and capable of practical speed ratios of 10:1 although 6-7:1 is more common.

The main disadvantage of spur gears lies in the fact that they tend to be noisy at over 1000ft/min. If made to exceptionally fine limits of accuracy, plain spur gears can be used at far higher speeds in turbine drives.

Single Helical gears

Helical gears are produced by cutting the teeth at an angle to the gear axis and the teeth follow a spiral path thus making for gradual tooth engagement and load distribution. Efficiency is as great as for spur gears.

Ratios of 10:1 are possible with increased load over spur gears. A degree of axial thrust is produced which must be catered for in the bearing design. Angular contact or tapered roller bearings are employed. On larger designs where plain bearings are fitted a thrust block arrangement must be fitted.

Single helical gears can be used at speeds up to 4000 ft/min

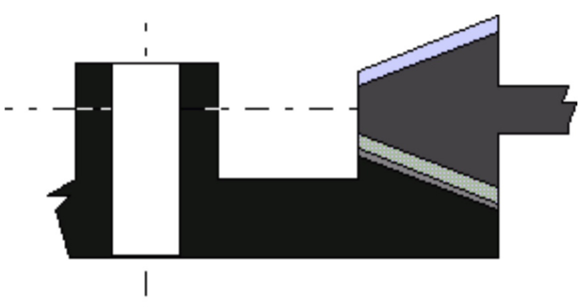
Double Helical gears

Commonly specified where the axial thrust from a single helical design would be too large or where there plain bearings are used. To balance the side thrust the teeth are formed on each gear in helices of identical angle but opposite hand. For cast commercial gears the teeth are sometimes of the uninterrupted type, cut by the planing process. For hobbed gears a 3 in wide gap is left for the hob clearance.

Single reductions of 10:1 with double reductions of 75:1 and triple reductions of 350:1 are used

Pitch line velocities from 4000 to 20000ft/min are possible depending on the accuracy of manufacture.

Bevel gears



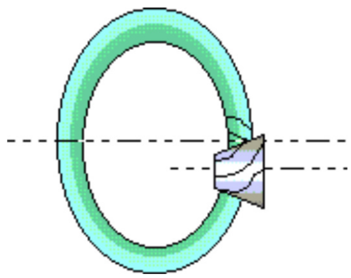
Bevel gears are used in situations where it is desired to transmit motion between two shafts whose axis intersect. The most common type is that in which the teeth are radial to the point of intersection of the shaft axes or apex and these are known as straight bevel gears.

The tooth action is similar to that of spur gears, being in line contact parallel to the pitch line. There is no longitudinal sliding between the teeth, but there is an end thrust developed under tooth load which acts away from the apex, thus tending to separate the gears. Thrust bearings must therefore be provided. The maximum gears ratio is 4:1. The maximum speed at pitchline is 1000ft/min.

Spiral bevel gears

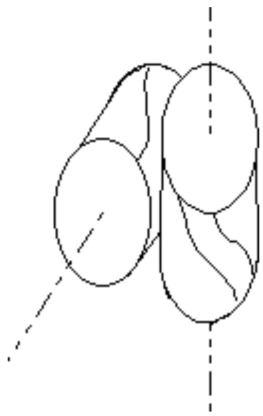
The spirally cut gears like the helical gear in its relationship to the spur gear, can withstand higher speeds than the straight cut bevel and is quieter in action. Unlike the straight cut bevel gears which can be shaped or precision forged the spiral bevel gears must be made on a special machine (made by Gleason Co). Pitchline velocities of 4000ft/min maximum can be handled.

Hypoid gears



Similar in appearance to the spiral bevel gear it is distinguished by having the pinion axis offset to the wheel axis. They are mainly used in the automotive back axle drives where they provide smooth tooth engagement at the high speeds combined with high load carrying capacity.

Spiral or crossed axis gears



These gears are identical in every way to helical gears, the only difference is that they are used to transmit power between shafts that are not parallel. Mating gears must have the same base pitch but their helix angled may vary. The contact made by the pitch cylinders of spiral gears is point contact only and there fore spiral gears are suitable for light duties only.

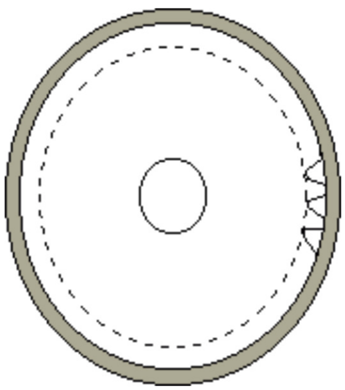
Zero Bevel gears

These gears have teeth that are curved in the same general direction as straight teeth. They are spiral gears of zero spiral angle.

Skew Bevel gears

In this form the pinion shaft is offset in relation to the wheel. The pinion may have straight teeth or it may have skew teeth similar to a helically cut bevel gear. The object is to obtain more gradual tooth engagement than with a straight tooth bevel. An additional advantage is that it sometimes makes possible the provision of bearings at both ends of the pinion shaft. Skew bevels are seldom used as they are difficult to set up.

Internal gears

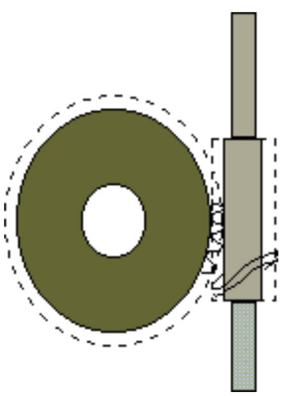


The meshing condition of this sort of gear are said to be better than those of the external gears for the reason that the contact area is between a concave and a convex surface, while also making better conditions for lubrication.

Other advantages include shaft direction is the same for input and output, Greater load capacity is possible, increased safety as the teeth are guarded.

Disadvantages include difficulty in supporting the shaft, range of gear cutting processes is reduced and tooth interference is a common problem.

Worm reducer gears



conditions for worm gears include the following;

a. shafts at right angles
b. large speed reductions in smallest compass
c. smallest number of gears

A worm drive comprises a cylindrical worm having helical teeth or threads, similar to a helical gear, meshing with wheel with a concave face. The tooth contact is a line one and heavy loads can be handled. Efficiencies claimed for worm gears are 97% and above. Ratios of 1000's to one is possible with double worm drives and it is the most popular form of industrial drive.

Spiroid gears

In addition to the above bevel gears there is a special type which has right angle non intersecting gears having tapered pinions with threads of constant axial lead meshing with face type gears. This is used mainly in the automotive industry.

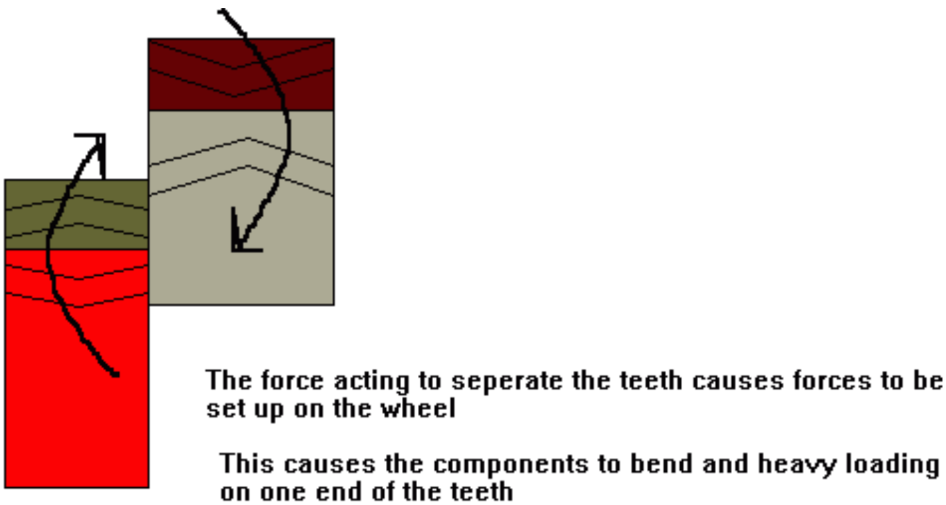
Gearbox casing and layout

These are subjected to a complex array of forces from all the components. It is preferable that all these are dealt with within the gearcase and little or no residual forces act on the supports. Also it is preferable that there is no transfer of load from an external source, say the propeller.

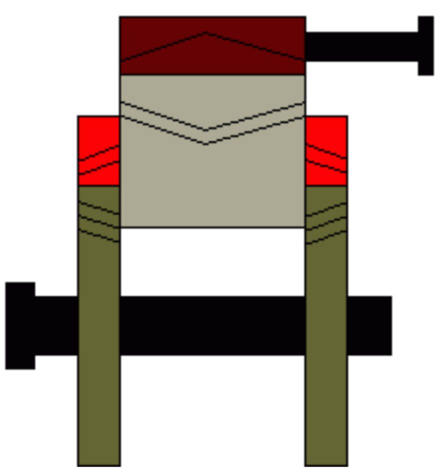
The gear casing is generally constructed of fabricated steel plates, the casing must have a certain degree of flexibility internally in the planes in which the bearing loads act to allow for incorrect tooth contact.

The residual weight and turning moment is supported by as small an area as possible to negate forces transferred by the movement of the ships hull

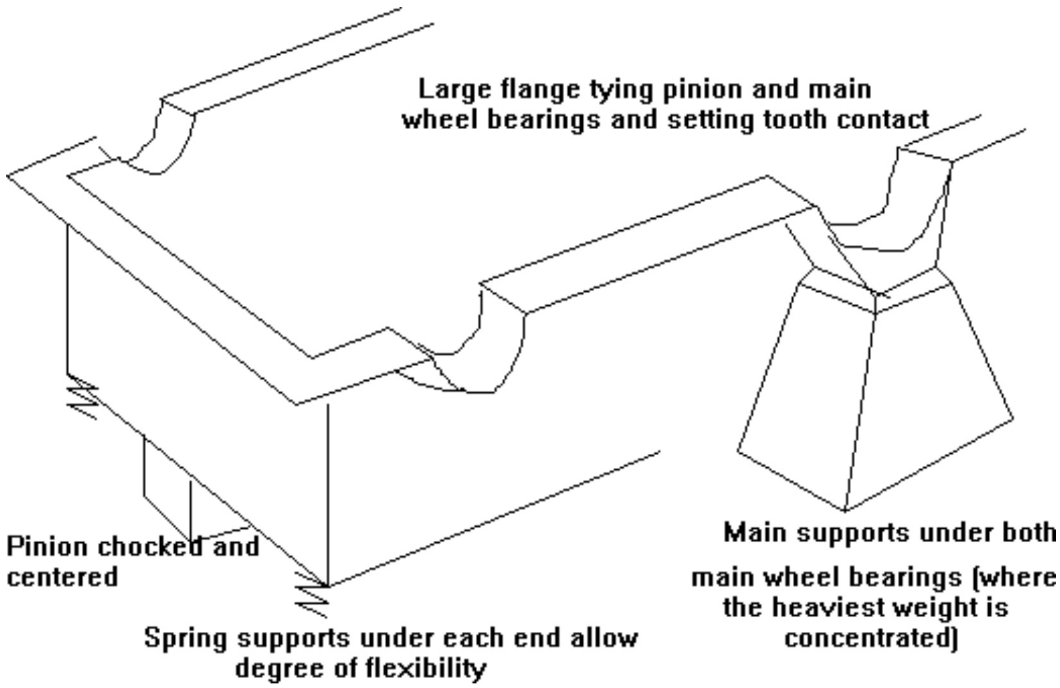
Turning moment (generally found on systems using Tandem style gearing)



This led to the introduction of nested interleaved gear sets

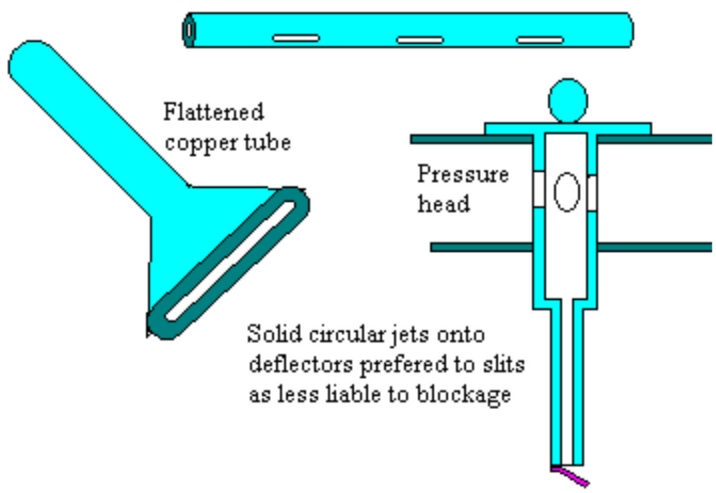


However, to prevent undue movement in the oil clearance of the mid component, the pitch of the primary pinion and secondary wheel had to be the same. The pitch on the secondary wheel was limited to commercial viability. This makes for a coarse pitch on the primary ,all addendum teeth where encompassed on the primary pinion for strength



Gear oil sprays

The position of the oil sprays within a gear casing are of paramount importance. Power losses and overheating in high speed gears may be reduced by applying some of the oil to the teeth as they disengage. This being the side where the cooling effect is greatest. This helps to prevent scuffing and shows the importance of reducing the bulk temperature of the oil.



Lubricating oil is supplied to flexible couplings, bearings and the line of contact between pinion and wheel.
For the gearing oil is sprayed under pressure diectly into the line of contact from a distance of 25 - 50mm. there may be three or four sprays per mesh. For bothahead and astern directions. Oil must be supplied under sufficient pressure to ensure total wetting before being flung off by centrifugal force.
Vents as fitted to the crankcase as the oil at the point of contact becomes hout leading to increased vaporisation. Sight glasses or indicators may be provided to ensure positive flow of oil

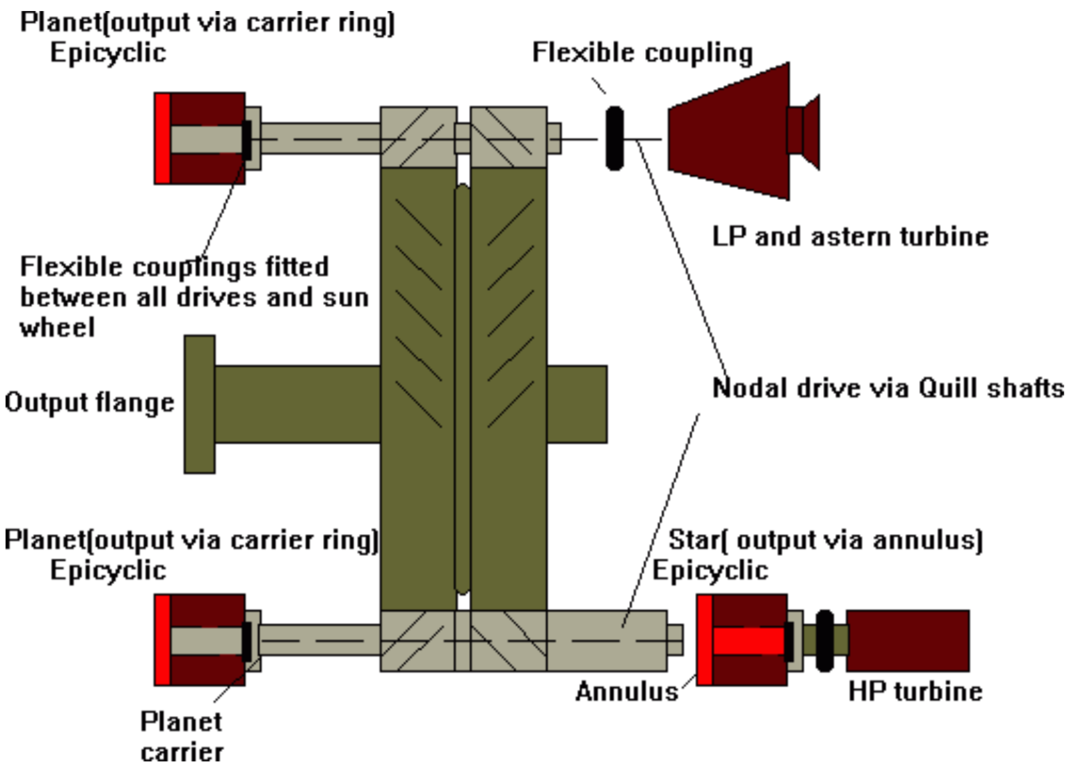
QUILL SHAFTS

The turbine is connected to the pinion by a torque tube. Here two flexible couplings are used ; this may be dynamically balanced before fitting

Quill shafts are fitted to increase the length of the shafting without increasing the overall length. This has the advantage that gear teeth may be brought to mesh at the node point and hence point of minimum vibration.

Teeth hence have a steady load instead of a fluctuating cyclically with vibration. Hence, the drive is sometimes called a **nodal** drive.

Plant layout



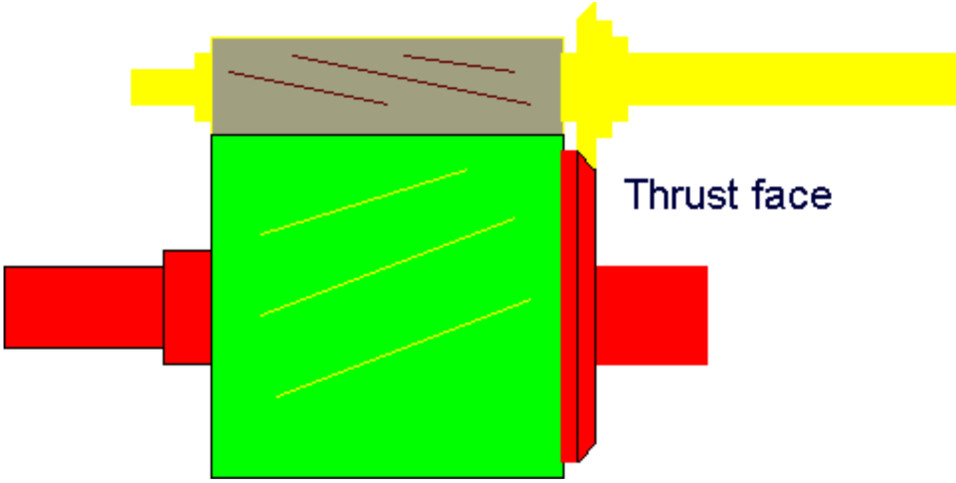
The gearing fitted to the SS Leonia and other large turbine propulsion plants is of the **Articulated type**, this is indicated by the fitting of the flexible couplings to the Epicyclics allowing a certain degree of misalignement to exist and allow for any machining errors in the fully floating sunwheel.

The first stage reduction is that of Start type Epicyclic, Star rather than Planetary is used due to the problems of distortion of the Planet carrier ring under centrifugal stress can lead to uneven tooth contact and loading.

The Pinion is allowed free axial movement by the planets on their oil film, this allows for the shuttling of the main wheel to be accomodated (the shuttling caused by machining errors in the rim)

The Brown Boveri Thrust cone

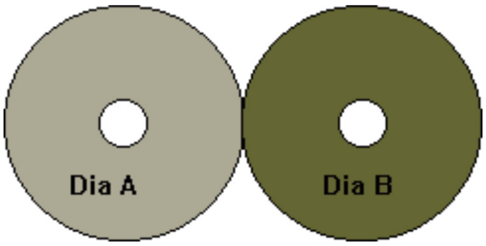
The disadvatage of using a single helical gear is that there is a resultant axial thrust. Traditionally this would be counteracted by using an oversize thrust block. A simpler method is shown below where resultant axial forces are reacted out by thrust cones mounted on the pinion and wheel



With the cone system there is a line of contact and a very large relative radius of curvature with a large oil entraining velocity of 220 ft/s .There is thus considerable axial resilience with the large radius of curvature, a small radial width of cone is sufficient to take the thrust

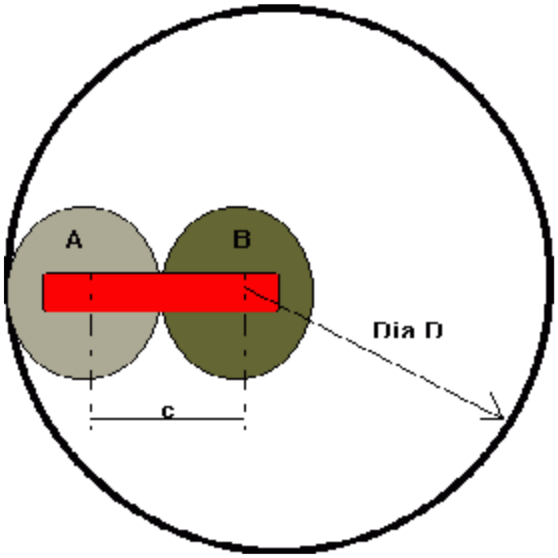
Epicyclic gearing

Principles of operation



If dia 'A' = dia 'B' then for one rotation of 'A' a point on the surface of 'A' would move through a distance equal to 2 x Pi x Ra; the distance that would be traveled by a point on 'B' would be 2 x Pi x Rb and as Ra=Rb. the ratio is 1:1.

One rotation of 'A' causes one rotation of 'B'



If the gear 'A' is fixed and 'B' allowed to rotate freely around it constrained within an annulus; then for one rotation of 'A' and corresponding rotation of 'B' the point of contact on the annulus would have moved through a distance equal to 2x P x Ra.
The circumference of the annulus would be equal to 2 x P x (Ra + Rb), hence for

one revolution of 'A' then 'B' would have only traveled half way round the annulus.

By varying the size of the sun and planets the gear ratio can be altered. The outlet drive could be taken either off the bar 'c' or if 'c' was fixed off the rotating annulus.

Comparison of Epicyclic gearing to Tandem gearing

Advantages

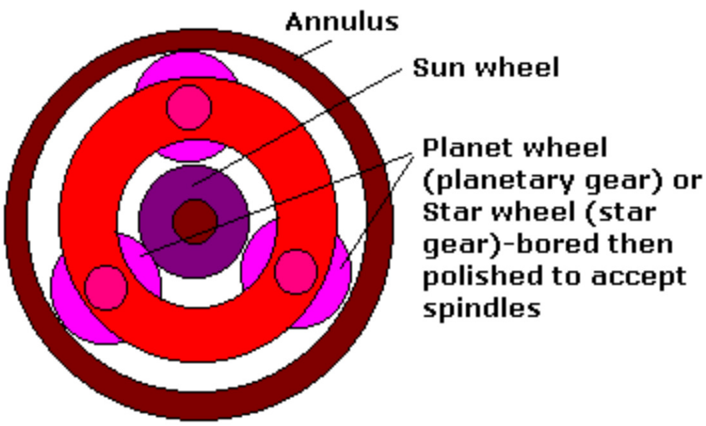
- The output may be reversed to requirement
- Small size and weight for given ratio (approx. 75% of wheel/pinion)
- Output same direction as input for planetary (ratios of 3-12:1)
- Output opposite direction to input for star (2-11:1)
- Co-axial input/output

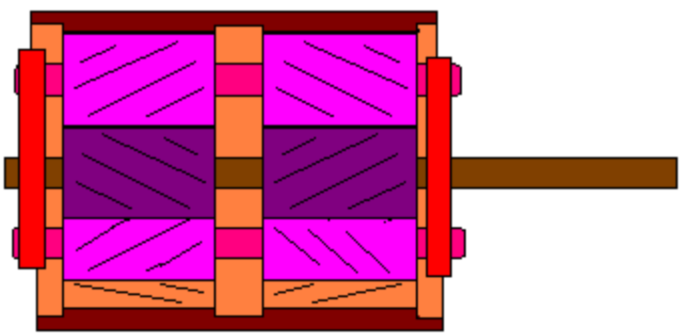
- Initial cost may be slightly lower
- Slightly improved efficiency
- Operating cost lower
- Lower plant height

Disadvantages

- Requires very accurate alignment
- relatively high tooth load
- increased number of rotating parts
- Inspection and maintenance more difficult
- Increased meshing frequency means higher grade materials required

Types





The Star annulus has teeth on the inner rim. A resilient mount is provided when the star annulus is fixed. This allows a certain degree of distortion to occur reducing tooth loading. The planet wheels are located by a planet carrier ring, on fitted at each end

The system may be constructed in three different ways

- Planetary- The star annulus is fixed. Input is via the sun wheel and out put through the plant wheel carrier ring
- Star-The planet wheel carrier is fixed. Input is via the sun wheel and output through the star annulus- This system is often seen as the first stage of turbine reduction gearing due to the possibility of high centrifugal stresses distorting the plant carrier ring and causing tooth overloading
- Solar- The sun wheel is fixed. This system is seldom used except in back to back epicyclics

The fixed member is called the torque reaction member. The number of wheels is determined by tooth loading

Epicyclic gearing alignement

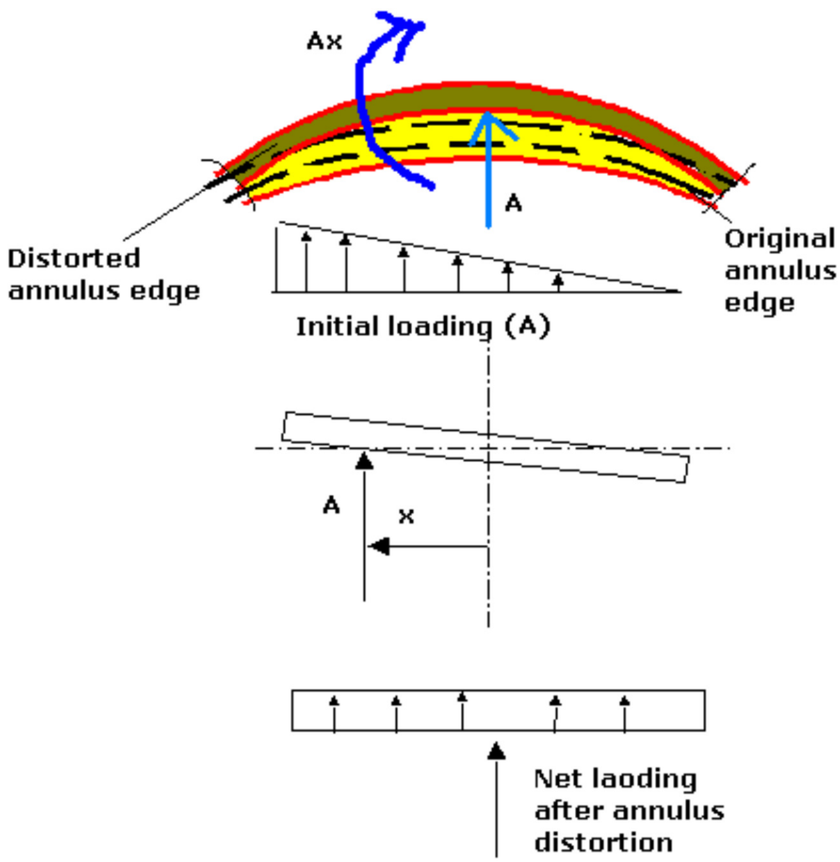
In normal operation epicyclic gear designs the planet pins are straddle mounted on a rigid carrier and are precisely aligned to each other.

If they are not the load distribution across the face is affected, but not the load sharing.

The sun pinion and flexible annulus are centered by the planet wheels when under load

With the ideally supported annulus, load sharing between the planets is ensured by the radial flexibility and uniform loading across the teeth by the self correcting toroidal twisting of the annulus and by the high accuracy of the gearing.

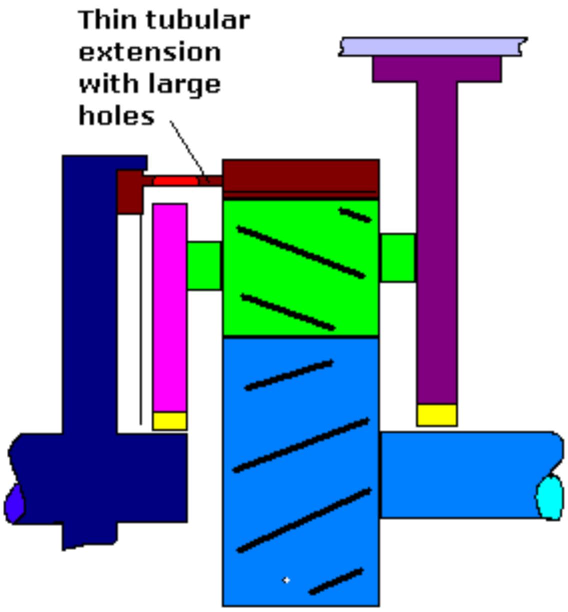
Toroidal twisting of annulus



The effect on tooth loading depends of on the supporting method of the annulus.

Introduction of Annulus flexibility

MAAG star gear



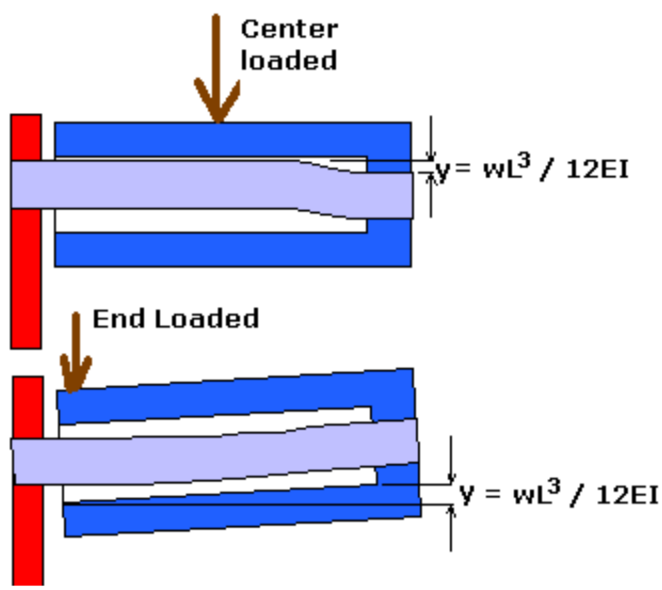
Toroidal twisting effect on the annulus is reduced to a minim by having the tubular extension thin, and nearly in line with the axial thrust from the teeth.

Other designs include the Allen-Stoeckicht where the split annulus of a double epicyclic gear are given a degree of movement within the carrier fo the two rings, this carrier itself is given a degree of axial movement by being fixed to the outer casing by a straight cut tooth coupling.

Also the Renk design has the annulus supported by a series of leaf sleeve spring packs. The annulus is split into two separate annuli. This design permits both torsional and radial movement and to a lesser degree angular movement in the diametrical plane. All movement is dampened by the oil and friction within the spring packs

Introduction of flexible pin

Plane wheel spindle (vickers)



For this design the annulus is made radially stiff.

Tooth Design

Standard involute double helical tooth arrangements are used.

The planet/annulus centres and pressure angles are standard

Changing the diameter of the base circle within the tooth height does not effect the gear ratio. However, matching the root circle to the base circle makes the tooth all addendum and hence all the tooth is on the involute curve and no undercutting exists. This is especially used for the highly loaded teeth of the sun wheel.

The sun/planet ring used slightly increased diameters so as much as the tooth depth is used as possible.

Carrier ring

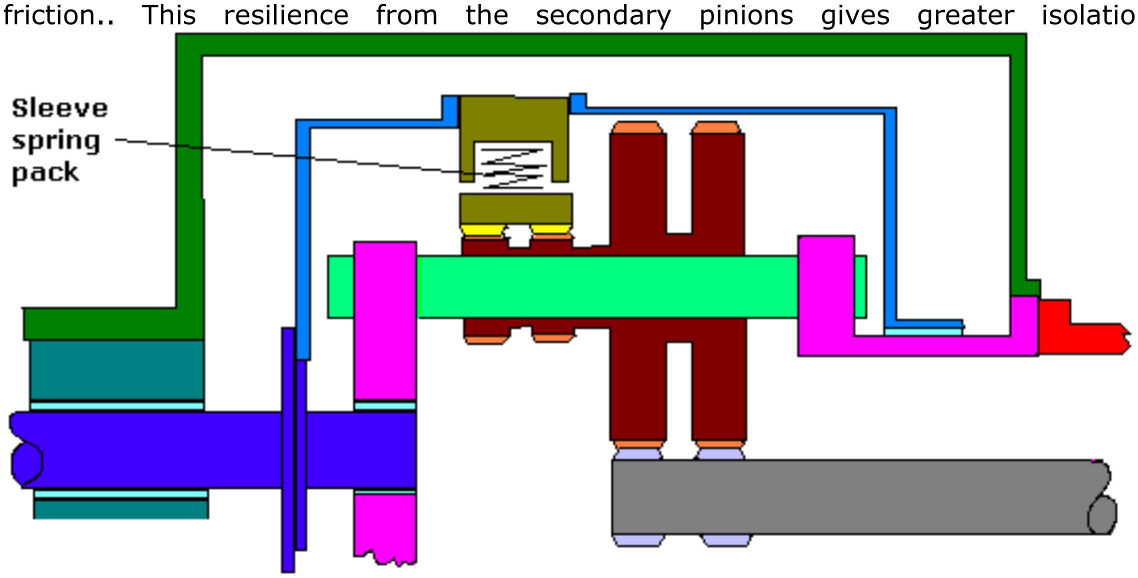
Nearly always in the form of a short hollow cylinder .

having the following advantages

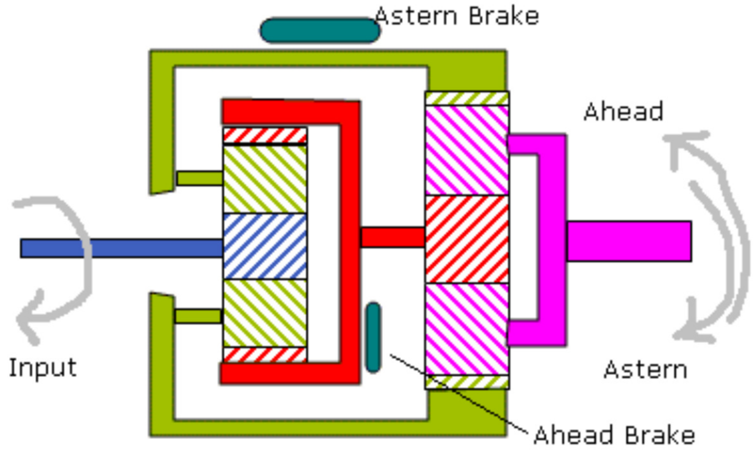
- ease and economy of manufacture
- strength and stiffness
- concentricity and potentially good balance

Renk Compound Gear

Offers 17-1 reduction capacity. The sleeve pack is adjustable to give the required torsional characteristics. The springs also give some bending flexibility and dampening through oil and friction.. This resilience from the secondary pinions gives greater isolation to the gear



Reversing

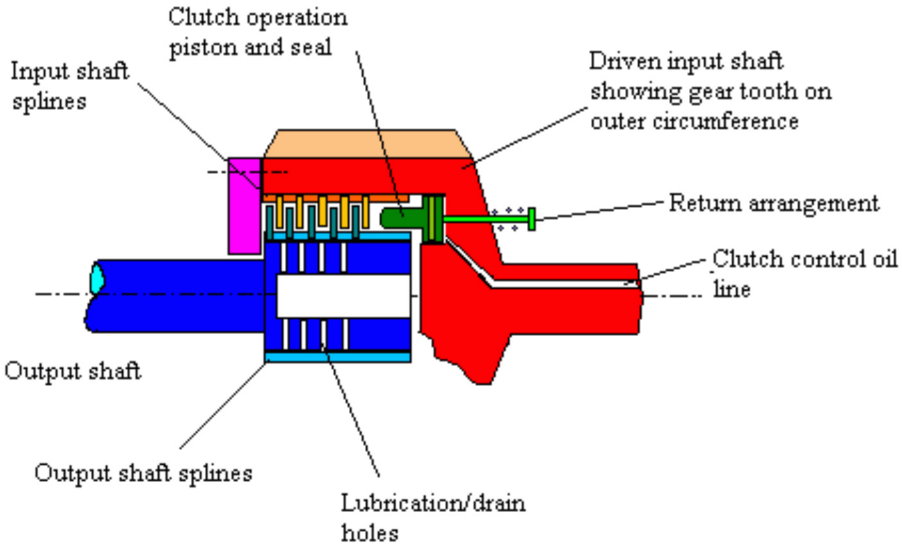


By application of either the ahead or astern brake the direction of the output shaft can be controlled. This system act as abn alternative to a reversing engine or CP propeller

Clutches

Clutches are generally designed to engage at minimum load and engine speed. Operation above this can lead to excessive gearbox and clutch loading and can shorten life or lead to catastrophic failure

Friction Plate



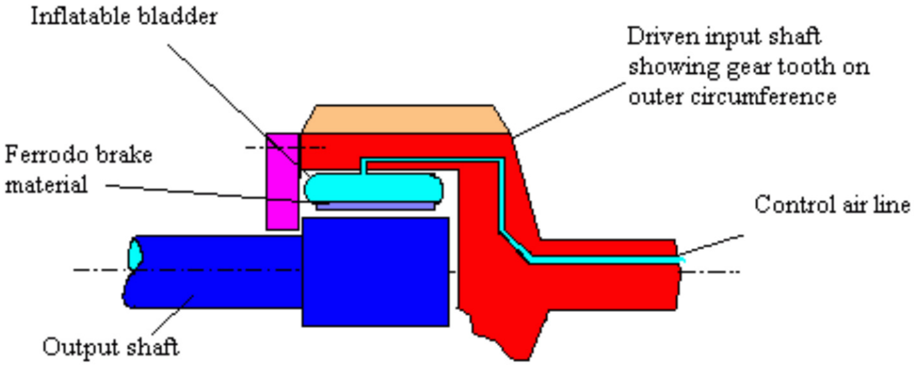
Oil forces the friction plates, generally made from a suitable steel alloy material or leaded bronze, together. These loose plates are alternately splined to drive or driven shaft.

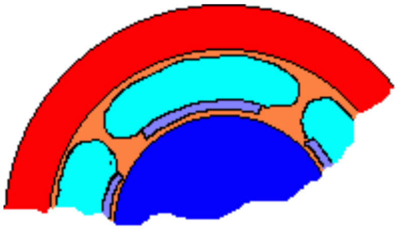
The oil is supplied under a controlled flow via an accumulator so allowing a gradual engagement over a short period. The oil is generally supplied via a solenoid valve from the gearbox lube oil system

Emergency drive is allowed by fittings screws which jack the plates firmly together

Pneumatic clutches

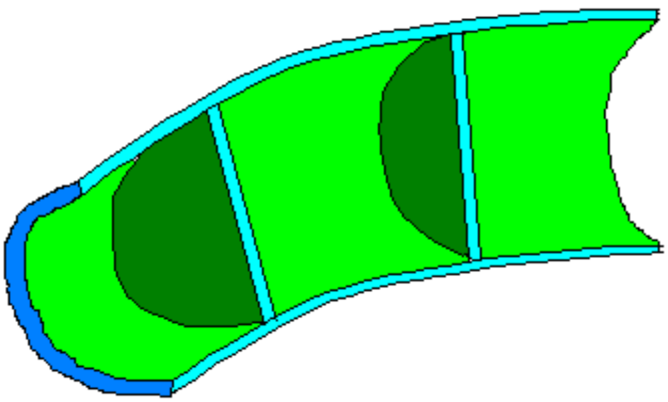
Takes the form of an inflatable tyre on which is mounted ferrodo clutch lining. Air is supplied via a slipper arrangement to the tyre segments which inflate forcing the clutch material into contact with the driven inner circumference.

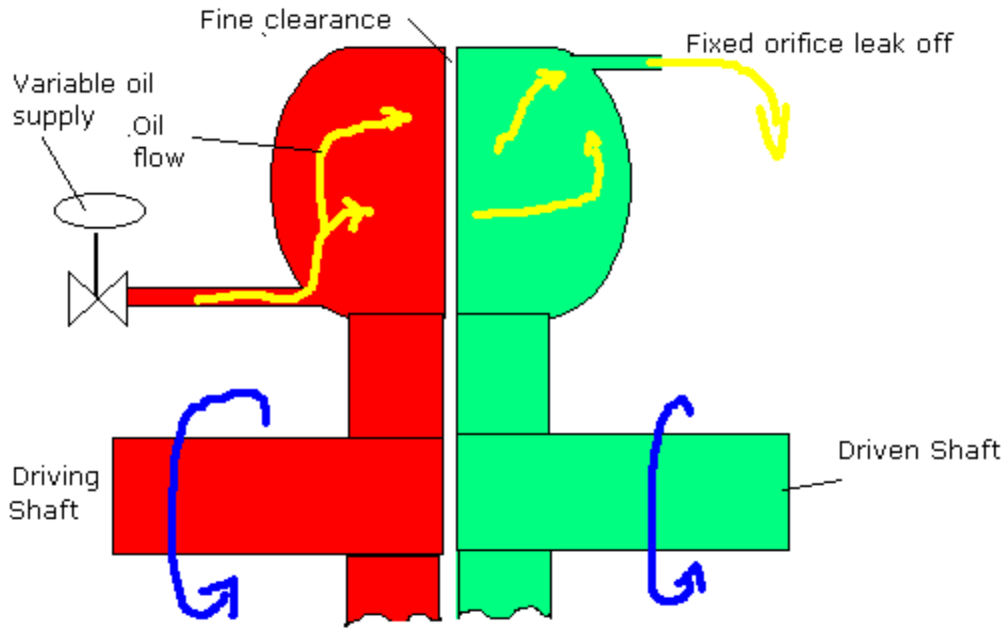




Emergency drive is via though bolts which pass radially though drive and driven wheel circumferences

Fluid friction clutches





Operate using the shear resistance of the clutch fluid. For marine use this is generally a fine grade mineral oil although synthetics may be used.

A pumped control flow is delivered to the drive assembly and allowed to flow to the driven assembly. As the flow increases so more of the assemblies become available for driving and slippage reduces eventually reaching a maximum.

Commisioning and Inspections

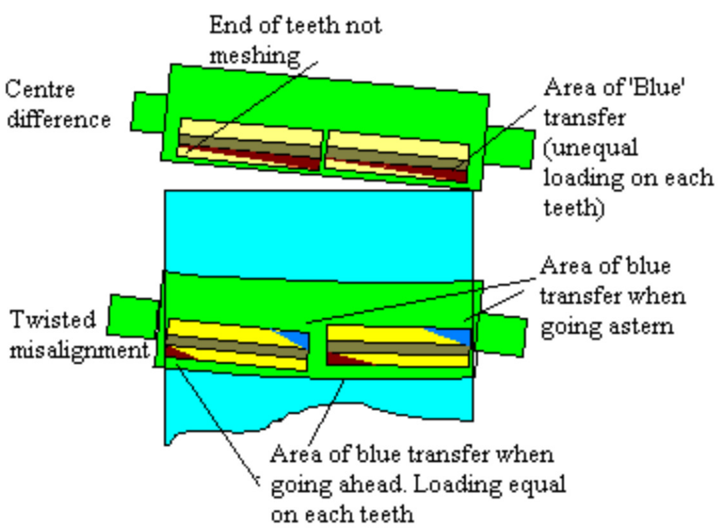
Gear Inspections

- Ensure that the steam is off the turbines and the turning gear is engaged.
- Wipe around inspection doors to prevent immediate dirt ingress
- Allow sufficient time for the gear case to cool before opening
- If inspection is non-routine, that is say due to an abnormality ensure extra time for cooling and open doors initially away from the area of concern
- Guard against items being dropped accidentally into gearcase
- Use only flame proof lighting
- Rotate main wheel at least one full turn
- Inspect all teeth for damage, record defects as appropriate. This normally takes the form of a sheet onto which a sketch showing the size and extent of damage (such as pitting) and a section fo added notes. These sheets are kept as a historic record of the gear allowing judgement on deterioration rate.
- Observe oil sprays and other internal fittings
- Look for rusting indicating faulty dehumidifier

Should a fault be found it may be necessary to check alignment, the condition of the flexible couplings, bearings and mounting arrangements.

Checking for mis-alignment

This can be done by blueing one of the teeth then viewing the complimentary mating teeth. Where the blue has transferred this is where the teeth have meshed and this can be compared to the polished area of the on load contact areas.



There will be some difference to the on load polished area as the displacement component tending to push the two centres apart, pushes the pinion up in its bearing. For very accurate aligement this force can be represented by pulling the pinion away from the wheel

If damage to the Bull wheel is suspected , say due to rapid decelleration of the propeller, and the Bull wheel may have slipped its shrink fit then alignment should be checked in a number of positions.

Operation and Maintenance

A gear set will operate satisfactory provided;

- It is operating within limits
- It has sufficient high quality oil supply
- Close attention is paid to alignement during refits
- Flexible couplings are maintained

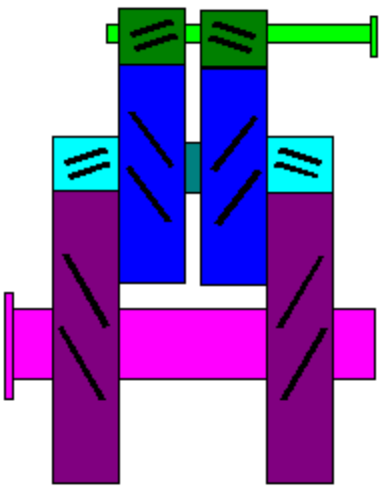
Oils should have anti-rust additives, water content should be kept below 0.2%

Excessive rust and sludge can lead to failure due to corrosion fatigue particularly in gears suffering from pittings
Blued tapes taken on inspection may be kept to record wear
IME recommends inspection periods no more frequent than 6 months to prevent undue contamination.

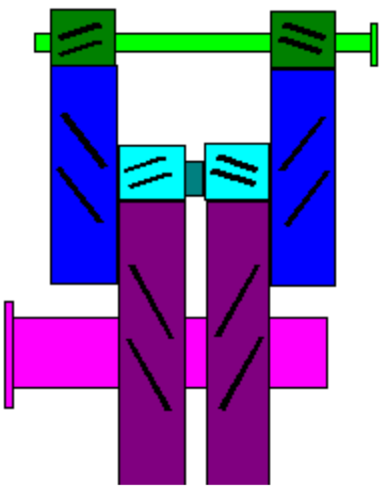
Gear layouts

SHown below are various layouts for a two stage reduction gearbox

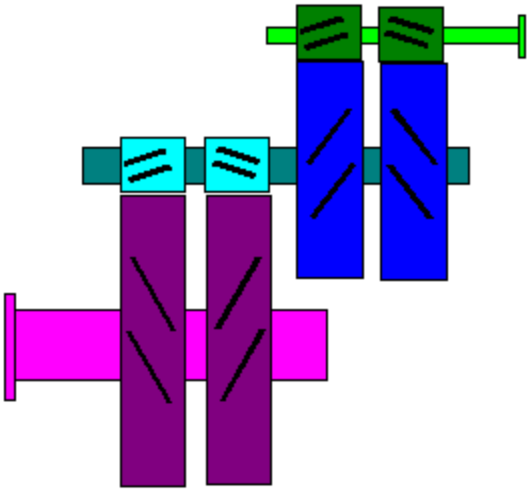
Interleaved (split secondary)



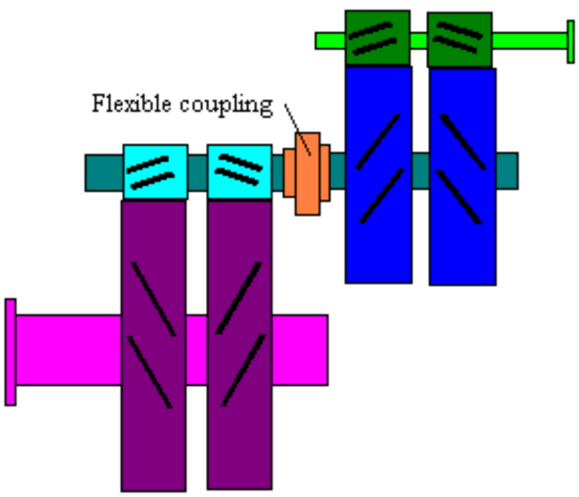
Interleaved (split secondary)



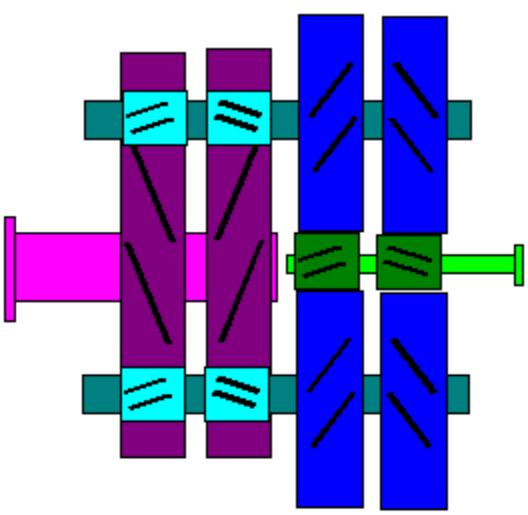
Tandem



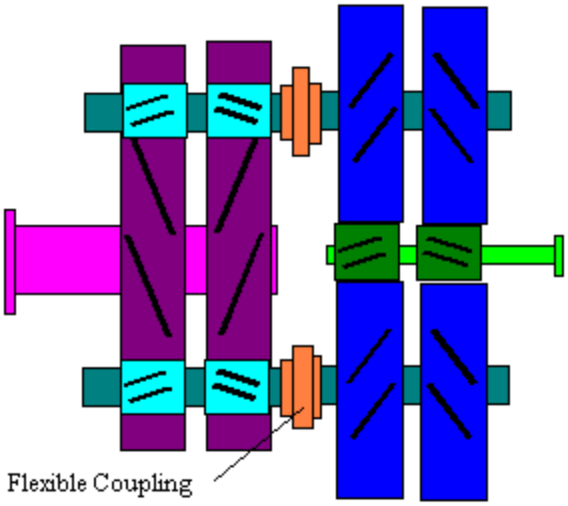
Tandem (articulated)



Locked Dual Tandem



Locked Dual Tandem (articulated)



The connection between the rotor and pinion shaft is always via a flexible coupling

The dual tandem arrangement has the advantage that there are two pinion contacts on the secondary wheel. This halves the tooth load and allows a much smaller wheel.

To achieve this, however, requires very accurate setting uo so that one pinion does not sit in its backlash whilst the other is loaded.

This may be achieved by setting one pinion so that it gives the correct contact then slightly rotating the other pinion until it is fully contacted and then 'Locking' the whole arrangement. One method of doing this is by taper fit flexible couplings which can be moved relative to the shaft by application of hydraulic pressure between the mating surfaces.

Extensive use of quill shaft and flexible couplings is made to negate effects from pitch errors creating high dynamic tooth loading. Great care must be taken with the alignement of the primary pinion and primary wheels as this is very highly stressed.

Single Tandem

Advantage
- Simple
- Length of shafting provides damping to vibration
- carry very high loads
- capable of accepting minor manufacturing errors
- primary and secondary gear may be dismantled independently
- large turbine axis / output shaft distance allows use of underslung condensers

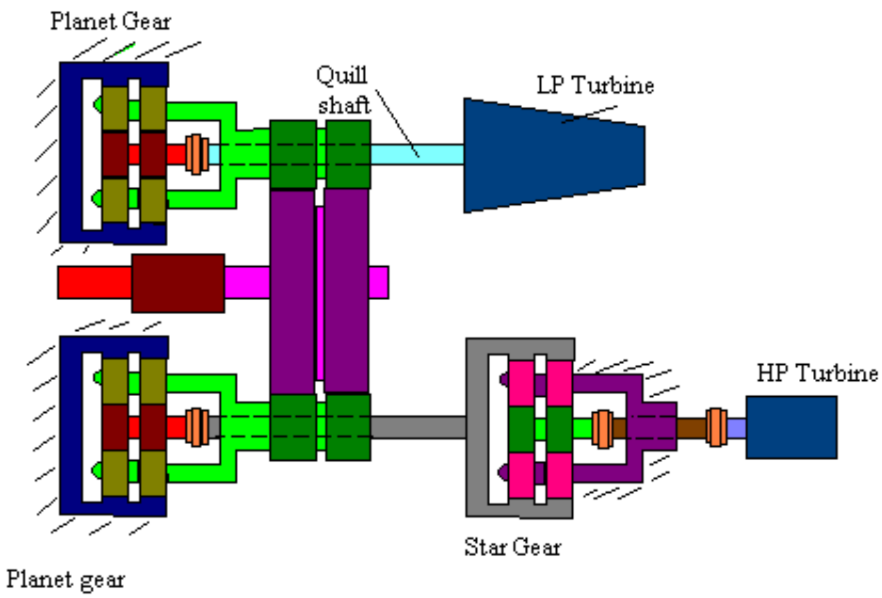
Disadvantage
- Heavy
- Large

Dual Tandem

Advantage
- Much smaller secondary wheel
- Lighter
- Small turbine axis / output shaft distance allows reduced height

Disadvantage
- Small turbine axis / output shaft distance requires axial flow condenser or angled prop
- Complicated alignement proceedure and fault intolerant
- Multitude of parts

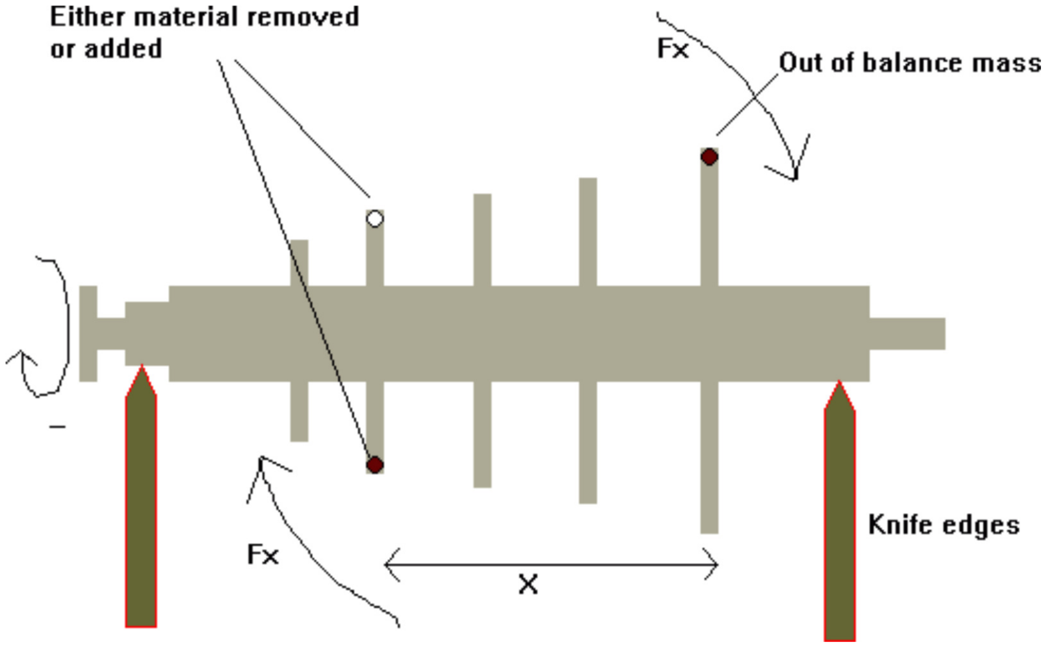
Triple/Double reduction steam plant gearbox



The main wheel pinions are fre to move axially because of the axial freedom of the planets on their bearing oil film
The first stage of the HP turbine is a start gear. This due to the high speed of the HP turbine causing centrifugal stress to distort a free planet carrier causing meshing problems. With a star gear the plane carrier is fixed.
Sun wheels are connected via flexible couplings to allow for manufacturing and alignement errors

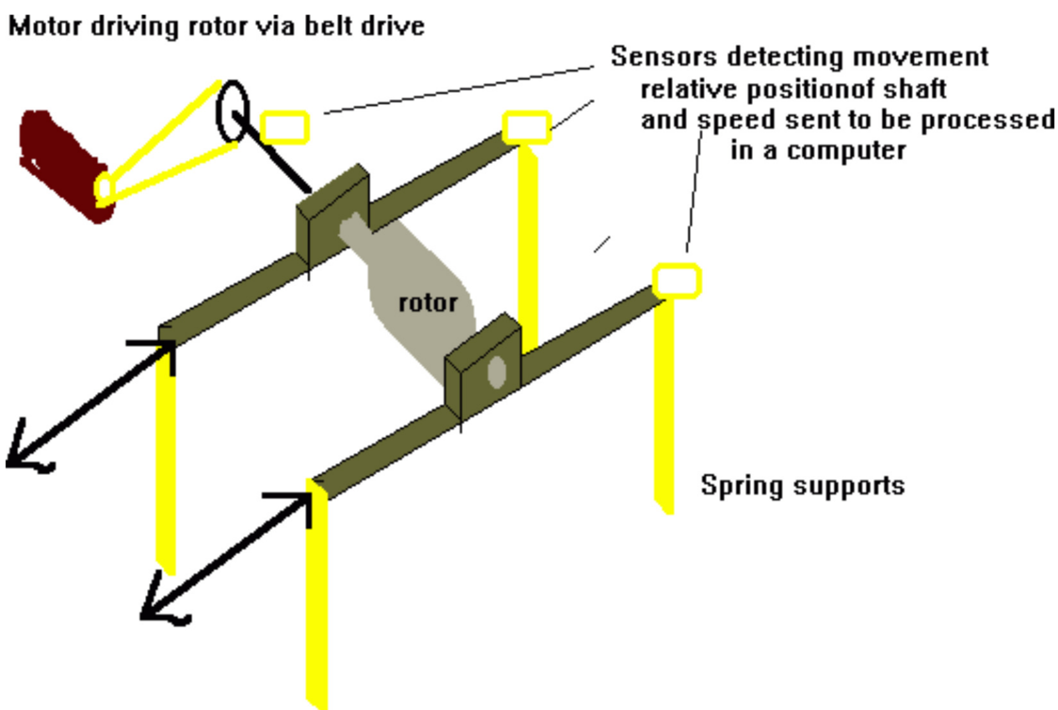
Turbine Balancing

STATIC BALANCING



For static balancing the rotor may be simply rotated on knife edges, the position it stops in indicating the position of the excess mass, material may then be either removed or added. However, unless the material is added or removed from exactly opposite the are of excess, then an axial turning moment indicated on the diagram as Fx exists when the imbalance is acted upon by centrifugal force when rotating, a wobble will occur.

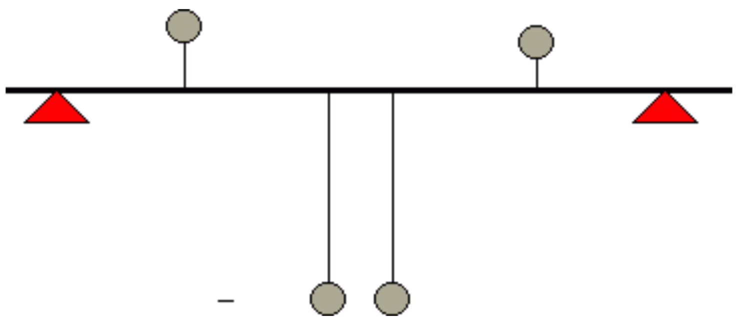
LOW SPEED DYNAMIC BALANCING



This machine balances the rotor whilst it is still out of its casing. For best balancing the rotor is placed in its casing and run at high speed

HIGH SPEED DYNAMIC BALANCING

Another example is shown below, the rotor would pass a static balance test and a low speed dynamic balance test; but the tendency for the rotor to sag would mean that at speeds near to or at critical a very heavy vibration would occur.



Hence, a high speed dynamic balance is required, and as the bearing rigidity has quite a large effect on the critical speed (if the bearings are flexible the point of location will change increasing the distance between supports), then the test is done by placing the rotor in its bearings in its casing.

Any out of balance will cause vibration at the critical speed

Balance is achieved by placing a weight under the shroud at one end and half weights under the shroud at the two opposite ends, directly on the opposite side of the rotor thereby maintaining dynamic balance.

By trial and error the correct weights are found, material is removed on the opposite sides to the weights,and the weights removed

Critical speeds of rotors.

Even perfectly machined rotors once placed between bearings will tend to sag and hence do not run concentric. For turbines the centre of mass is by necessity very close to the centre of rotation (It is this deflection which leads to out of balance and subsequently this deflection is used in Critical speed calculations) and hence the natural frequency of transverse vibration ties in very close to the Critical speed.

For its calculation the rotor is considered to be a simple beam supporting several point loads (these can be calculated by splitting the rotor into sections and summing the mass within), these are typically due to wheel, blading. shrouding etc.

A formulae may be used;

$$\mathbf{N_c = 16.8/d_c^{-1}}$$

Where d_c is the static vibration.

For turbines whose normal max speed is higher than critical, balancing is carried out at full speed.

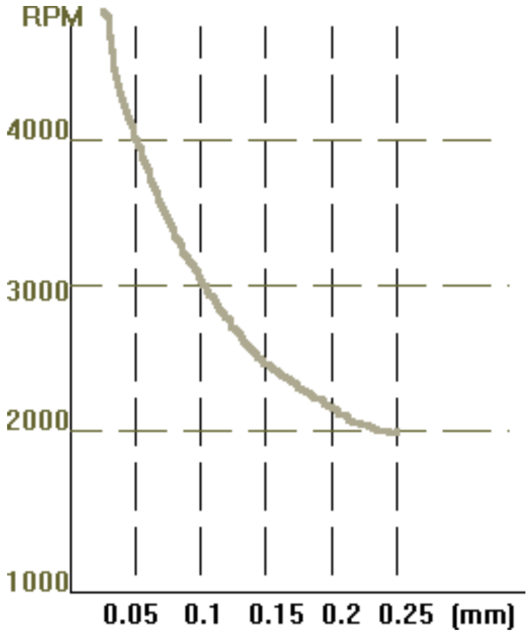
Turbines maybe built stiffly so that the critical speed occurs above norm max, speed. This means that to make the rotor stiff the diameter must be increased which increases the gland area and bearing loads.If the rotor is made less stiff so that critical now occurs within the normal operating revs, then care must be taken to pass quickly through the critical.

Problems caused by incorrect warming through

The main object of warming through is to ensure straightness of the rotor.To do this a negligible temperature gradient must exist throughout the rotor.

There is a tendency for the rotor to hog where the steam is introduced(that is to say the rotor bends due to temperature gradient rather than sagging under gravitational forces) with the rotor steam is introduced. Hence the rotor must be rotated.

The graph below indicates the importance of this.



The line is the out of balance force due to centrifugal force equal to the mass of the rotor.

Hence, the offset at 3000rpm to cause an out of balance equivalent to the mass of the rotor is 0.102 mm

testing of the engines after shut down ahead and astern should be taken as part of the warming through process. Close watch of the relevant nozzle box temperatures is a good indication of the condition of the turbine.

Second object of warming through is to prevent distortion of the casing. Rotation of the rotor churns up the steam and provides adequate mixing. With underslung condensers the temperature gradient is virtually unavoidable, hence separate condensers are better.

The third objective is to prevent thermal stresses caused by the temperature gradient in thick materials such as at the bolt flanges. Vertical slots are often provided to help alleviate this problem, this distortion can also lead to non concentricity of the casing

This is particularly prevalent in open cylinder designs such as axial plane or double casings.

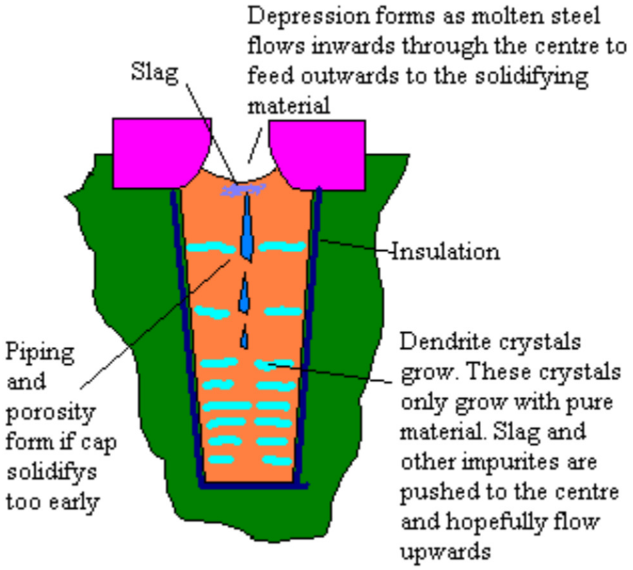
Heat transfer rate is at its greatest where the steam is condensing on the surface of the casing. This in turn is governed by the inlet pressure of the warming through steam. Hence, warming through in steps providing adequate period to stabilise the temperature at each step.
Complete warming through cannot occur until nearly at full power , hence, warming through much above atmospheric saturation temperature is pointless.

Also as part of the LP turbine runs at lower temperature, warming above 100^{o}C is unnecessary. Protracted warming through periods are unnecessary. A temperature of 82^{o}C at the LP inlet belt in 30 mins is acceptable

Vibration caused by an out of balance of the rotor may be alleviated by running for a short period at reduced engine speed followed by a slow increase in speed.

Turbine Construction

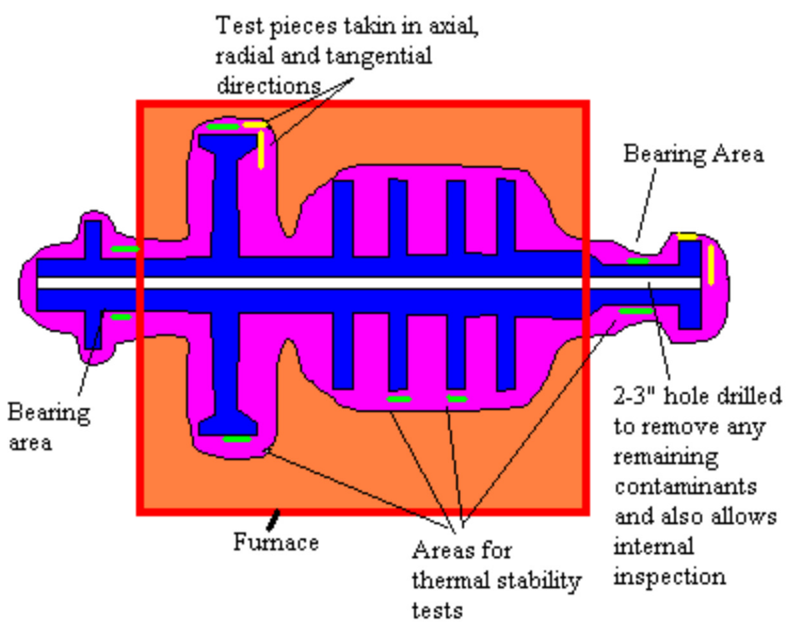
Vertical Casting



Only the bottom part of the ingot is used.

Rough Forging

It is a requirements that forgings are heavily worked. Any small holes or defects canbecome hammer welded together. No forging is carried out below the plastic flow temperature as this can lead to work hardening. Forging will allow continuous grain flow



ultimate tensile stress and elongation checked. This must be near enough equal in all 3 directions.

After rough machining it is put in for a thermal stability test. For this final machining is given to the areas indicated. The end flange is marked at 90' intervals. Then the rotor is encased in a furnace. Pokers are placed onto the machined areas and accurate micrometer readings taken. The rotor is rotated though 4 positions marked on the flange.

The rotor is then heated to 28'C above normal operating temperature and slowly rotated.

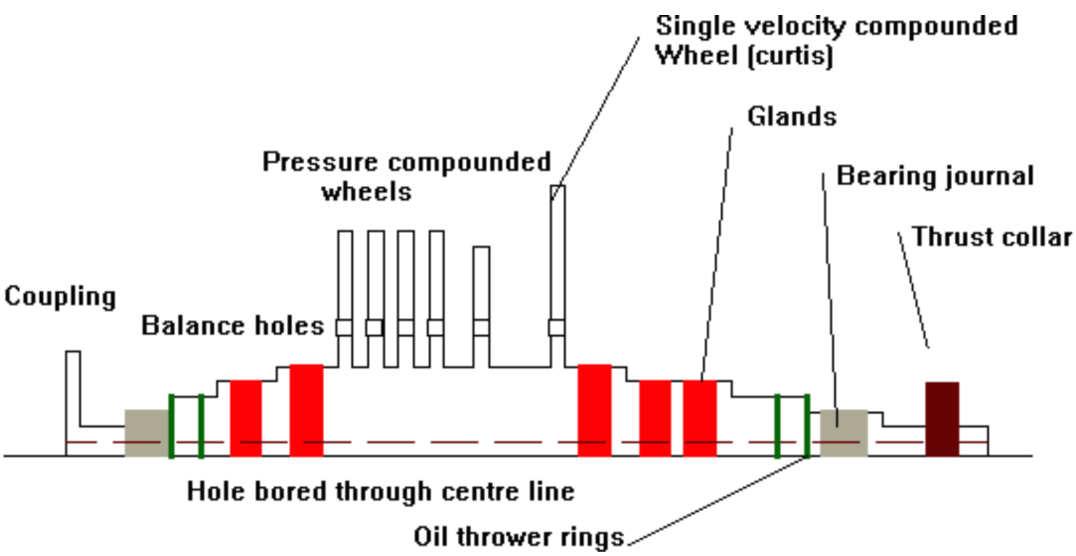
Measurement is then taken at hourly intervals until 3 consistant readings are taken (hence the rotor has stopped warping). The rotor is then allowed to cool and a set disparity allowed.

For turbine sets operated at greater than 28'C above their designed superheat then run the risk of heavy warping as well as high temperature corrosion and creep.

Final machining is now given. The rotor is statically balanced and then dynamically balanced and check to ensure homogenity.The rotor is bladed then again dynamically balanced.

HP rotor

Most modern HP rotors are made of a single gashed forging of high quality steel.A hole of 50mm is bored axially through the rotor to allow for internal ispection and to remove impurities and internal flaws which can cause premature failure. In addition to the blade wheels also found on the rotor are; Thrust collar, Journal bearing surfaces, Oil thrower, Gland, Conical seat, thread or flange to attach flexible coupling



Most modern HP turbine rotors are of the **Rateau** or pressure compounded design.

Reduced number of stages (8 to 10) give a shorter rotor and provides savings in weight and length. Also provides for better critical vibration characteristics.

Rotors are solid forged providing

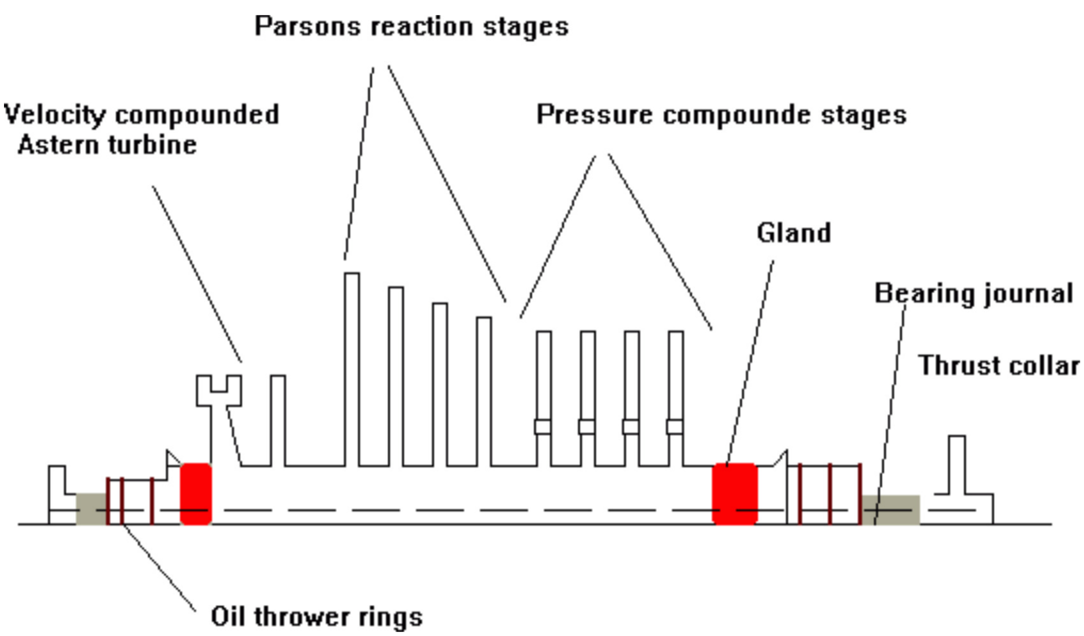
1. **Homogenous rotor with even grain flow**
2. **Even expansion**
3. **Good thermal stability with less likelihood of distortion under high temperatures**

After forging the rotor is machined, wheels may be parallel or slightly thickened at the base . The methods is also used for the LP turbine which has 7 to 9 stages plus 2 to 3 astern.
After rough machining rotor is given a thermal stability test, after further machining and fitting of blades the rotor is given a static and dynamic balance.
This design is known as the **Gashed disc rotor** and gives a minimum shaft thickness and hence a minimum area for gland sealing to prevent steam leakage.

Material (up to 566^{o}C)

0.27 - 0.37% Carbon
1.0% Manganese
0.04% Sulphur
0.2% Silicon
1.0% Chromium
0.5% Nickel
1.5% Molybdenum
0.3% Vanadium

LP Rotor



The loss of efficiency due to the two stage velocity compounding of the astern turbine is more than made up by the reduction in windage whilst running ahead (the design must still be able to supply 70% of the ahead revs which approximates to 40% of the ahead power) The impulse blading may have up to 20% reaction effect at the mean blade height.

The astern stage consists of one single wheel two stage velocity compounded followed by a single stage wheel.

Material

0.45% Carbon
0.15% Silicon
Trace amounts of phosphorus and sulphur

Blade material

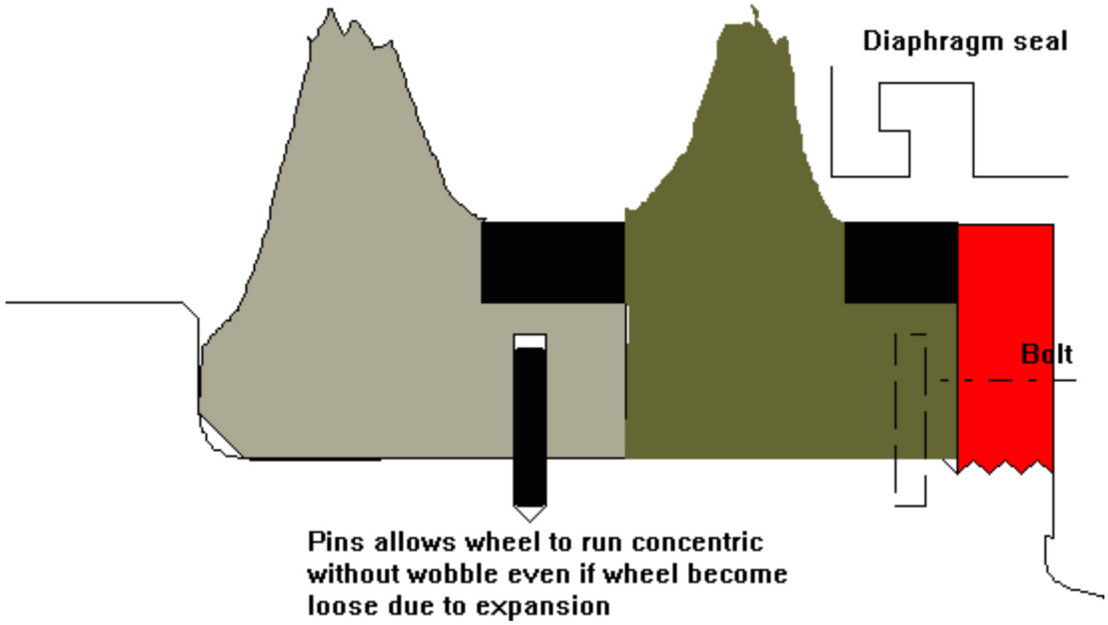
11.5 - 13.5% Chromium
1% Nickel,manganese and silicon
0.12% Carbon
Trace amounts of sulphur and Phosphorus

Built Up design

The Stal-Laval LP turbine is designed not to be flexible.This is possible as the problems of gland leakage is not so great as on the HP turbine, the HP turbine has reduced diameter rotor so reducing the gland sealing area but allowing flexibility.

Having a stiff rotor allows the Astern turbine to be built up and hence allows the bulk of the LP rotor to be forged from a low grade steel whilst only the Astern parts are made from the material necessary to withstand the superheated steam.

If the rotor was flexible and a built up astern turbine wheels fitted then a possibility of fretting exists.



The use of separately machined astern wheels allows the original forging to be more simplistic.
The forging of the higher grade steels required for use in superheat conditions require an increased amount of energy, and hence expense, in the original forging and subsequent machining process.

Another big advantage is that the astern wheels being of smaller mass and free to expand means that they can take more rough treatment then if they formed part of a single mass. The discs are forged from solid ingots and then machined so as to produce a force.shrink fit when heated and hydraulically pressed onto shaft.

The fit is all importnat and must take into account;

- Stretch under centrifugal force (particularly under overspeed)
- Discs reach working temperature before shaft when warming through

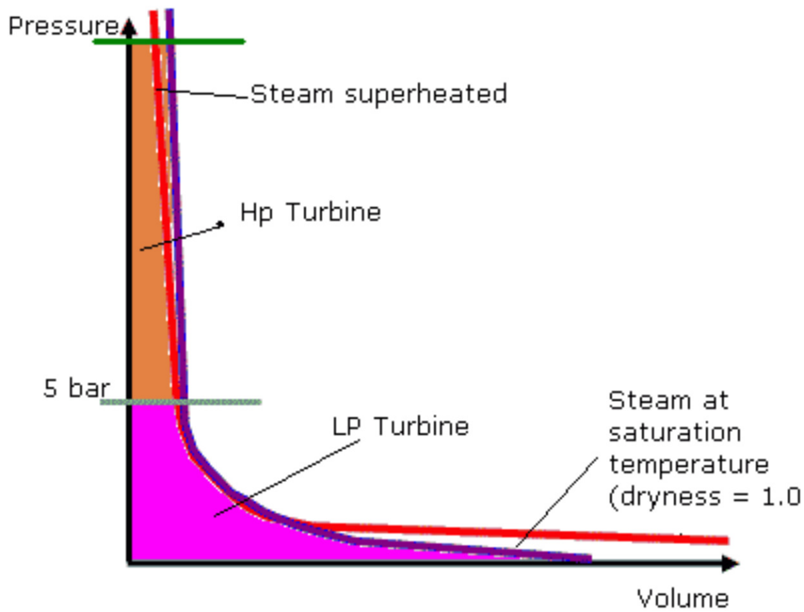
The disadvantage of force fit is that under high temperature condition, the metal being subject to stresses is susceptible to creep.
The result of thisis that due to the radial and tangential stress the wheel tends to grow in size. The wheel tends to loosen and fretting corrosion can take place

For HP rotors, generally, one wheel per step is allowed with a small clearance between each wheel. The whole is secured by a locknut and each wheel keyed to ensure positive transmission of torque. These keys are displaced by 180' for each step.

For LP turbines 3 wheels per step can be accommodated.

As the combined rotor shaft/wheel hub diameter is about twice that of the gashed rotor the sealing surface is greatly increased

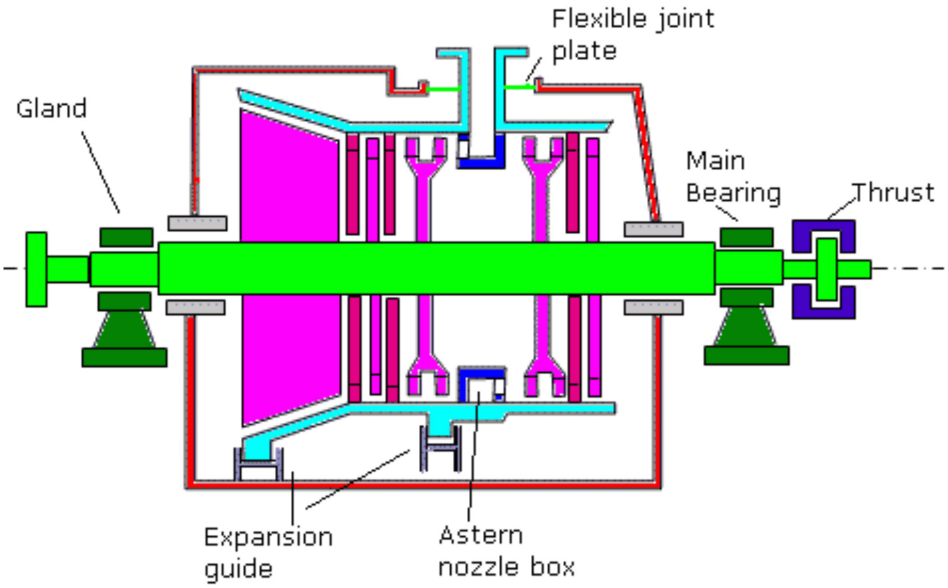
Relative volumes of steam in HP and LP turbines



It can be seen that whereas the increasing volume of the steam in the HP turbine is moderate, The increase in the LP turbine is significant requiring blade height to be increased in successive stages. In the final stages both the height and the angle of the blades have to be altered. See notes on taper/twisting of blades) e

Single Cylinder plants

These are usually found on short run ships such as passenger ferries although there present day use is very restricted For this design criteria the **Single Cylincer Double Casing turbine** was developed



Advantages of using A single cylinder

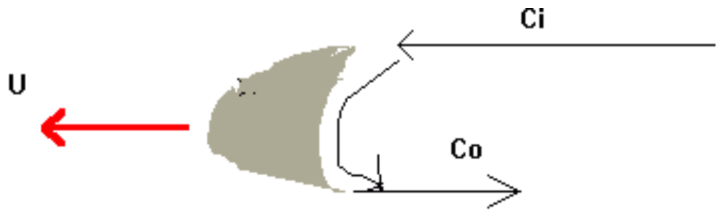
- Lower first cost
- Easy to inspect and maintain
- No cross over pipes to give heavy side thrust
- Short warming through time, rapid shut down time
- Rapid manouevring
- Single setting gland control (glands are operating subatmospheric all times)

Advantages of using A double casing

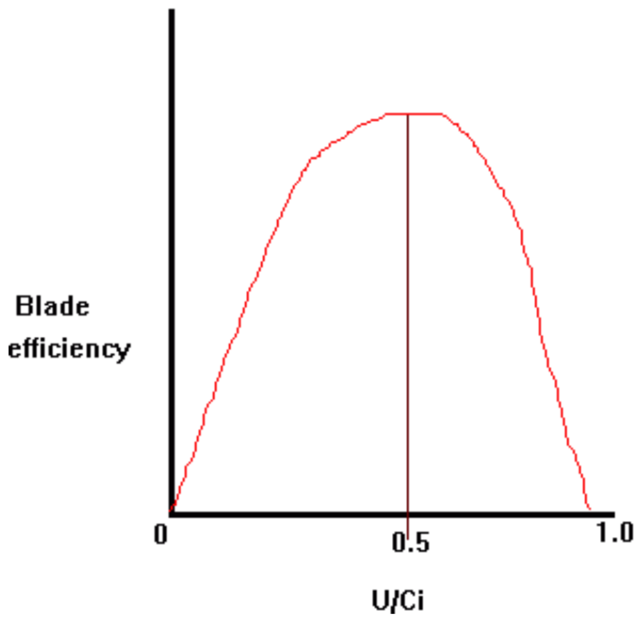
- As the glands operate on the low pressure side of the turbine they may be of simplified and shortened design
- The outer casing temperature is only slightly above engine room temperature simplifying lagging requirements.
- The outer casing may be fabricated from mild steel
- Radiation losses reduced at full power
- Smaller temperature gradients reduce the possibility of distortion
- All expansion/contraction and side thrust is absorbed by the inner/other casing interface reducing the possibility of misalignement to the gearing

Turbine blades

Impulse blading system design

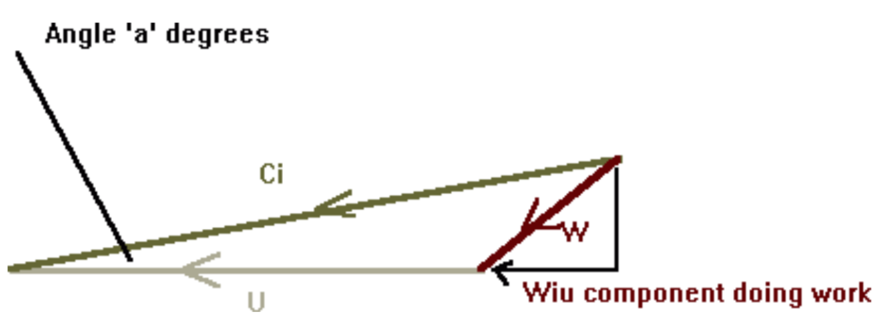


Stm entrance angle =0 degrees



Hence, maximum blade efficiency is when entrance angle is at 0^o and when the blade is rotating at 1/2 the speed of the jet stream

As the steam must enter at an angle a^o



Optimum value for U / Ci = 1/2 cos a (0.45 to 0.48)
Maximum blade efficiency = Cos^2 a (14^o to 20^o)
Impulse blading may have up to 20% reaction effect at mean blade height.
Astern turbines generally consist of a single wheel on which are mounted a tow stage velocity compound followed by a single stage wheel

Properties required of the blade material

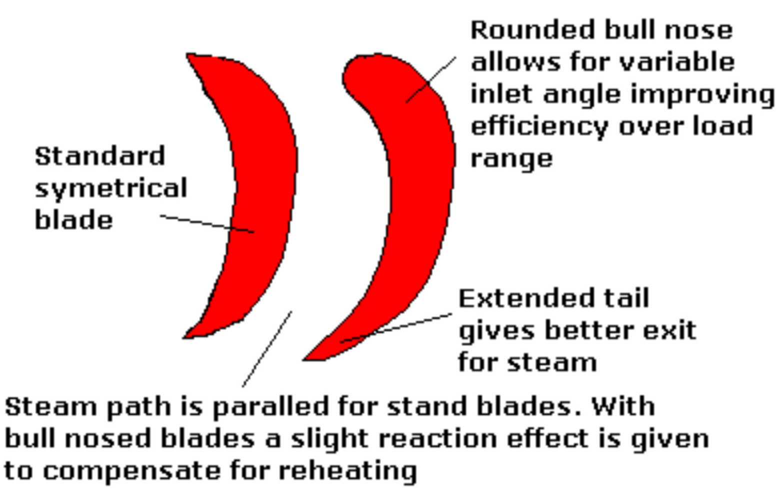
- Good tensile and fatigue strength
- Toughness and ductility at working temperature
- Resistance to corrosion and erosion
- Rate of expansion similar to both rotor and casing
- Machinability
- Low density
- Good vibration dampening properties
- Good crep resistance
- Weldability

Typical blade material is

- 11.5 to 13.5% Chromium
- 1% Nickel
- 1% Manganese
- 1% Silicon
- 0.12% Carbon
- Trace Sulphur & phosphorus

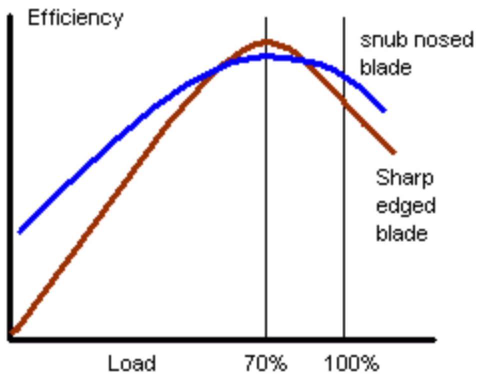
Low tensile stainless steel preferred to high tensile stainless iron due to better fatigue resistance. Where lacing wires are to be brazed in special care must be made as to the intergrannular penetration effects of the braze

Bull nosed blades

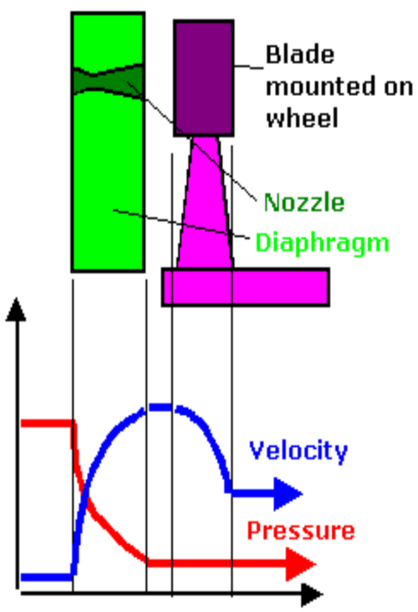


Standard blades have the same inlet and outlet angles.
Bull nosed blades are capable of accepting a wide range of steam angles without serious increase in blade losses.

The cross sectional area is increases and hence the blade is stronger and better resistant to vibration. The increase thickness also allows a circular tang to be fitted for attaching a shroud. Non circular such as square tangs require the shroud to be punched rather than drilled which introduces residual stress, micro-cracking etc.



De Laval Impulse Turbine-Single Stage

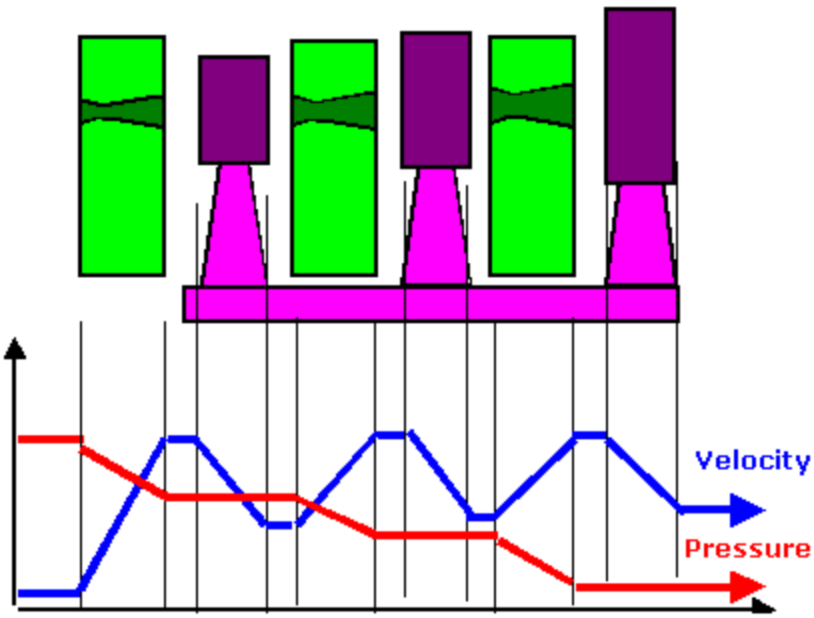


Optimum efficiency occurs when the blade is moving at half the speed of the jet stream. To achieve this very high rotational speeds would be required (in the order of 15000 rpm). High centrifugal stress, high journal speed and excessive gearing requirements prohibits the use of such system for propulsion by itself.

This system is often found as the first stage of a HP turbine were a large pressure drop is required to allow for a smaller turbine. Only the nozzle box has to cope with full boiler pressure and temperatures simplifying design especially of gland boxes. Special material requirements are again restricted to nozzle box. Reduced pressure within the following stages reduces tip leakage

The steam leaving the blades has a high kinetic energy indicating high leaving loss.

Pressure Compounding (Rateau)



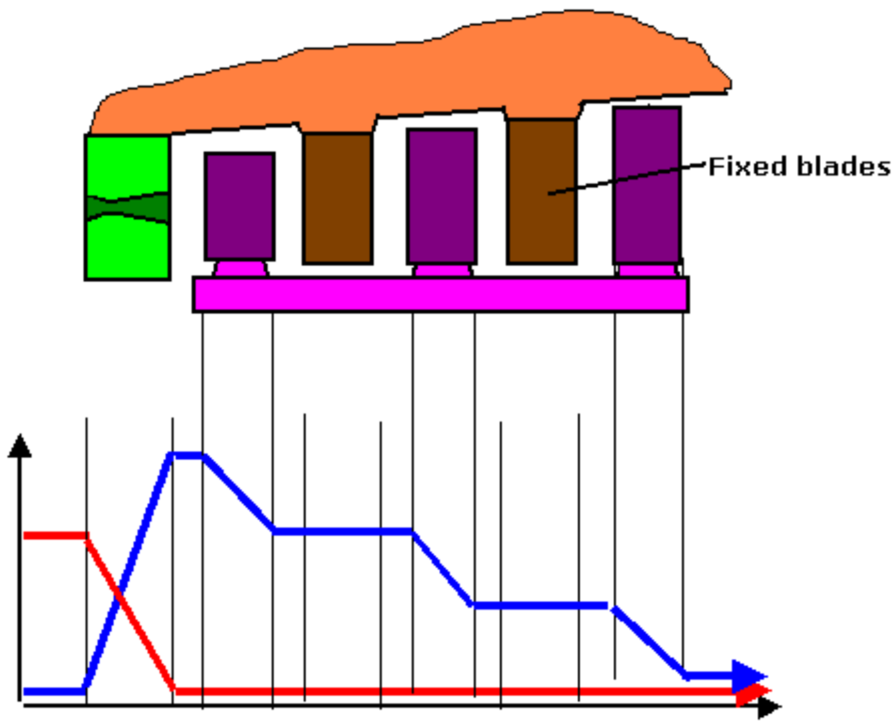
The overall heat and pressure drop is divided between the stages. The U/Ci ratio is 0.5 for each stage. By careful design the rotor mean diameter may be kept to a minimum.

Excessive number of stages produces an overly long rotor, these leads to problems of critical vibration, increased rotor diameter, increased stage losses due friction and windage and increased gland leakage both at the main glands and the diaphragm plate glands. This due to the increased number of glands and the increased rotor diameter.

Stage mean diameter and nozzle height are increased at the LP end as the steam expands to the limits of centrifugal stress. Nozzle and/or blade angles may be altered to accommodate the increase in volume reducing the requirement to increase blade height excessively.This is referred to as taper-twisting

The blade height increase towards the LP end means that the rotational velocity also increases. Hence for the same value of U/Ci they can deal with higher inlet steam velocities and hence higher enthalpy drops p>The design produces a short lightweight turbine used where size, weight and strength are more important than efficiency. E.G. feed pumps , astern turbines and the inlet portion of HP turbines where it provides a large initial drop in temperature and pressure lightening the rotor and reducing the need for high grade alloys for remaining stages

Velocity Compounded (Curtis)



For a two stage system U/Ci = 1/4, for a three stage system U/Ci = 1/6

There is no pressure drop except in the nozzle (although in practice some drop occurs due to losses as the steam passes over the blade). Dividing the velocity drop across the stages leads to a loss of efficiency but gives a more acceptable blade speed reducing centrifugal stress and simplifying gearing arrangement.

For a three row system, the steam speed at inlet to the first row is 6 times the blade speed, reducing the velocity makes the conditions at the final stages close to ideal.

To maintain the same mass flow for the reducing velocity, blade height is increased to the limit of centrifugal forces. Taper-twisting and flattening of the blade angle is then given to the final stage blades.

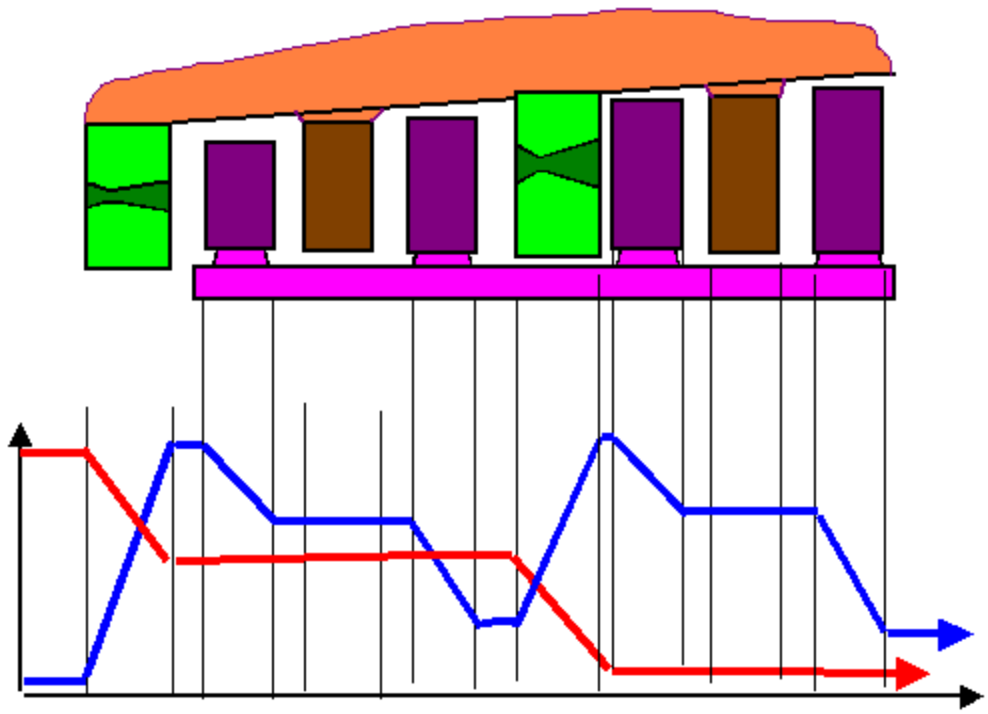
Some reheating occurs due to friction of the fixed blades associated with a loss of velocity of about 12%

Theoretically efficiency is independent of the row number. However in practice efficiency and work done in final stages reduces and therefore overall efficiency drops with increase rows.

Typical values for efficiency are

- two wheel curtis 68%
- three wheel curtis 50%
- Single wheel rateau 85%

Pressure-Velocity Compound



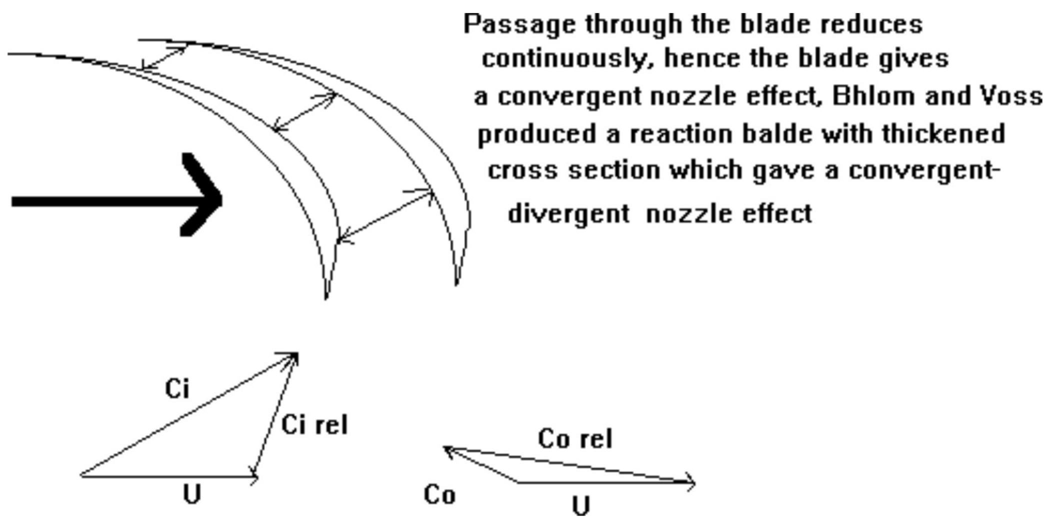
This system gives the advantage of producing a shortened rotor compared to pure velocity compounding. In addition it also removes the problem of very high inlet steam velocities and the reduction in efficiency and work done in the final stages.

In this design steam velocity at exit to the nozzles is kept reasonable and thus the blade speed (hence rotor rpm) reduced.

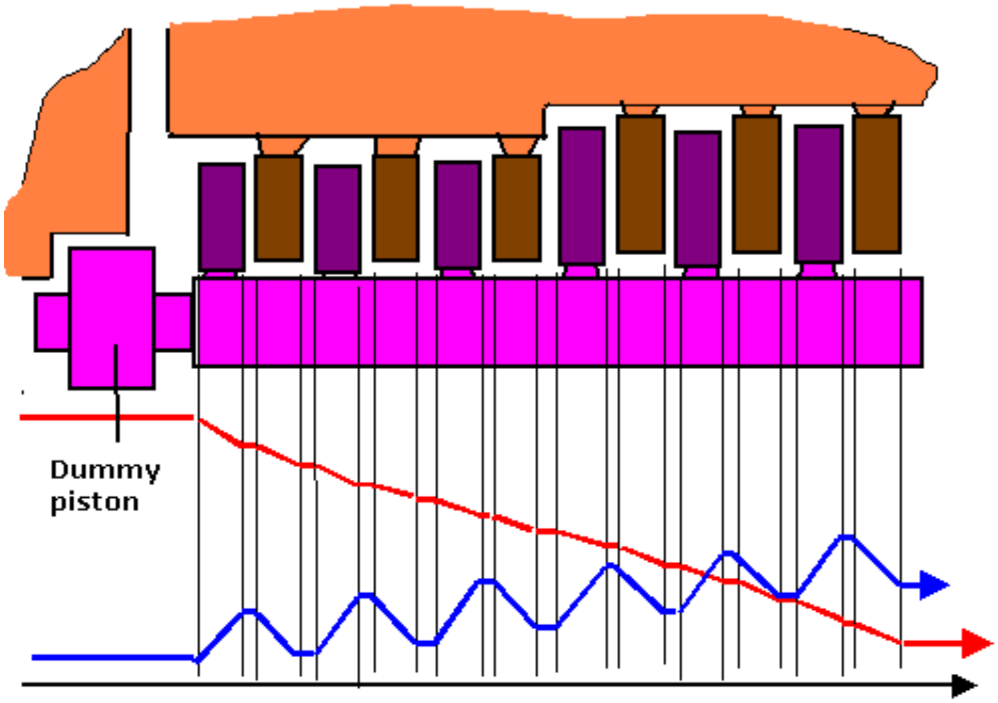
Typical applications are large astern turbines

Reaction

U=Blade speed
Ci= velocity of steam at inlet to blade, i.e. leaving nozzle(giving nozzle angle)
Ci rel= velocity of steam relative to the blade(giving blade inlet angle)
Co= Velocity of steam at outlet of blade



Parsons Impulse-Reaction



The original blade design was thin section with a convergent path. Blohm & voss designed blades similar to bull nose impulse blades which allowed for a convergent-divergent path. However due to the greater number of stages the system did not find favor over impulse systems

U/Ci = 0.9

If the heat drop across the fixed and moving blades are equal the design is known as half degree reaction.

Steam velocity was kept small on early designs, this allowed the turbine to be directly coupled to the prop shaft.

Increased boiler pressure and temperature meant that the expansion had to take place over multiple rotors and gearset.

As there is full admission over the initial stage, blade height is kept low. This feature alone causes a decrease in blade and nozzle efficiency at part loading. In addition, although clearances at the blade tips are kept as small as practical, steam leakage causes a proportionally higher loss of work extracted per unit steam

Blade tip clearances may be kept very tight so long as the rotor is kept at steady state.

Manoeuvring, however, introduces variable pressures and temperatures and hence an allowance must be made.

End tightening for blades is normally used. This refers to an axial extension of the blade shroud forming a labyrinth. When the rotor is warmed through a constant check is made on the axial position of the rotor. Only when the rotor has reached its normal working length may load be introduced. Alternatively tip tightening may be used referring to the use of the tips of the blade to form a labyrinth against the casing/rotor. This system is requires a greater allowance for loading and is not now generally used.

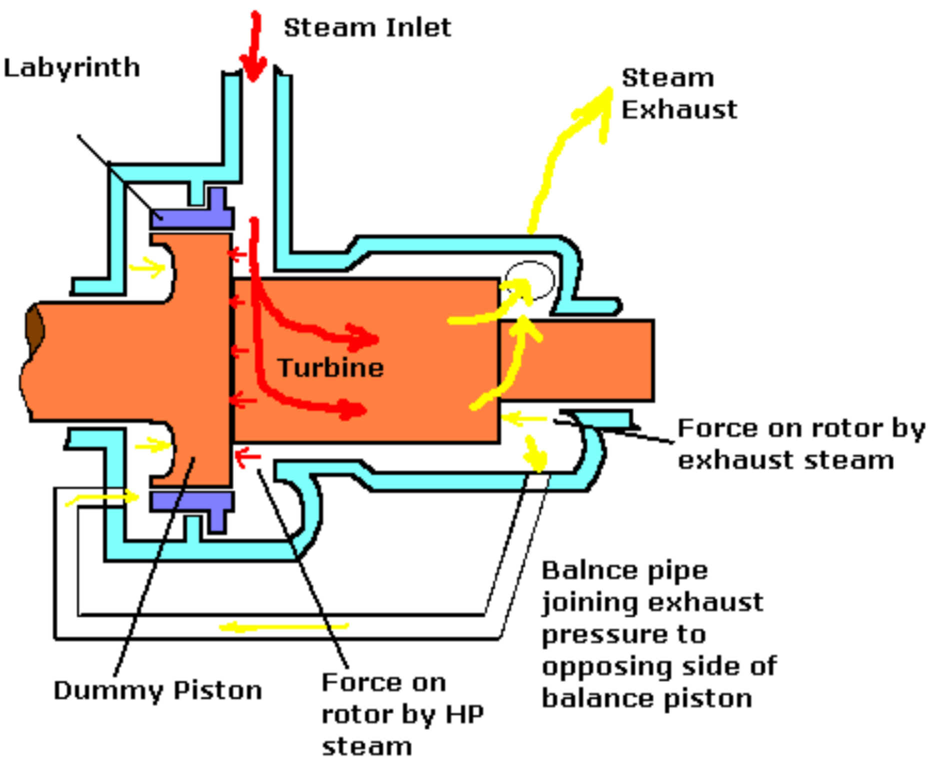
To keep annular leakage as small as possible these rotors tend to have a smaller diameter than impulse turbines.

To keep the mass flow the same with the increasing specific volume related to the drop in pressure requires an increase in axial velocity, blade height or both -see above. Altering the blade angle will also give the desired effect but if adopted would cause increased manufacturing cost as each stage would have to be individual. Generally the rotor and blading is stepped in batches with each batch identical.

The gland at the HP end is subjected to full boiler conditions and is susceptible to rub. The casing must be suitably designed and manufactured from relevant materials.

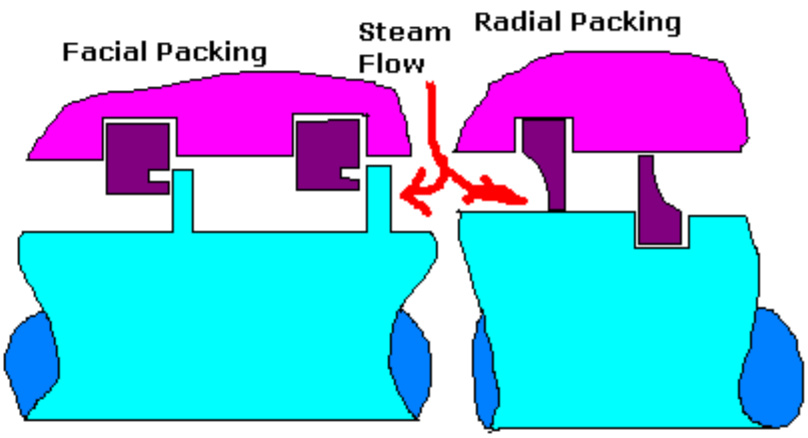
A velocity compounded wheel is often used as the first stage(s) giving a large drop in conditions allowing simpler construction of casing and rotor and reducing length. Special steels are limited to the nozzle box.

Dummy piston arrangement on Parsons Turbines



In parsons reaction turbines there is always an end thrust due to the steam at inlet being higher than the exhaust. This leads to high thrust bearing loading. The dummy piston arrangement is a wheel or drum integral to the rotor. Forces are balanced by the drum offering a greater surface area to the low pressure balancing steam than to the HP steam.Note the drawing above is not to scale.

A labyrinth arrangement is fitted to seal the drum.



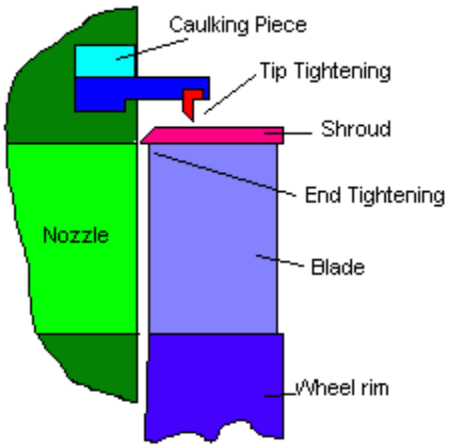
Double Flow Turbines

These are found mainly on large LP turbines. Here steam enters mid rotor and passes axially towards both ends. The advantages are;

- End thrust is balanced removing need for dummy pistons or cylinders on reaction turbines . Reduces the size of the thrust on impulse-reaction turbines
- As steam flow is split the final stages blade height and angle is reduced allowing for increased efficiency and reduced centrifugal stress. Greater power per unit size may be absorbed.

The main disadvantage of this system is increase rotor length leading to increased risk of sagging

Blade Sealing



May be end or tip tightening

End Tightening
This is seen particularly on reaction turbines. It requires accurate positioning of the turbine rotor and is normally associated with lengthy warm up perios during which the position of the rotor is carefully monitored. Operational limitations on rapid power changes may be in place. The author has seen this system in use on very large but compact turbo alternators which required a warm up period consisting of increaseing the rotor speed in stages over one hour

Tip Tightening
Clearance is governed by maximum blade centrifugal stretch

Turbine blade fixing

Blade stresses

The predominant stress in turbine blades is centrifugal and concentrated at the root

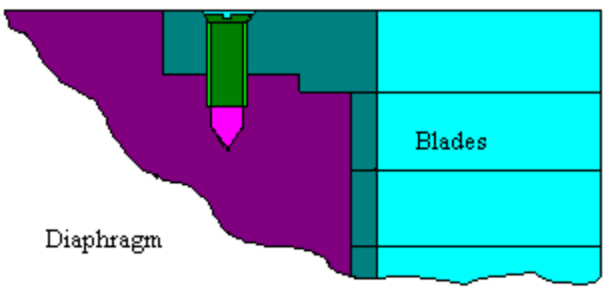
Vibration is set up in blades due to fluctuations in steam flow.Particularly in impulse turbines where partial admission is used

Further stress is caused by expansion and contraction as well as bending stresses due to the action of the steam

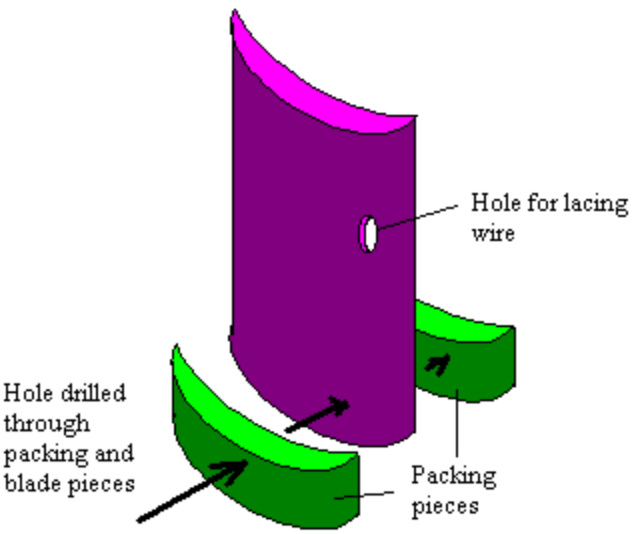
In addition to these stresses occur during manoeuvring due to speed changes.

Fixed Blades

Although not subjected to centrifugal force, the fixed blades of curtis velocity compounded turbines are subjected to vibration in a similar way to the rotating blades. The root fixture must, by necessity, be secure to prevent fretting



Reaction Blades



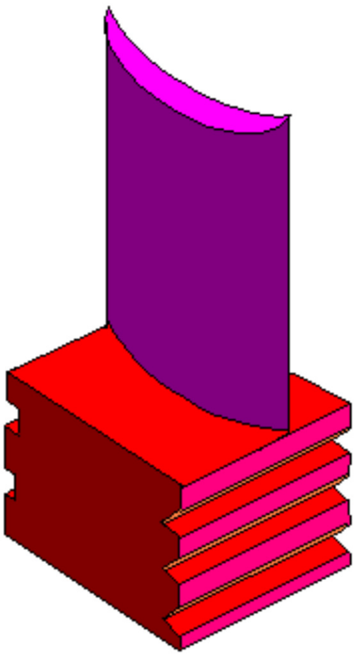
Blades are rolled to correct shape then cut to length.

Up to 50 blades are then assembled in a jig of correct radiurwith a distance piece to give the correct spacing.

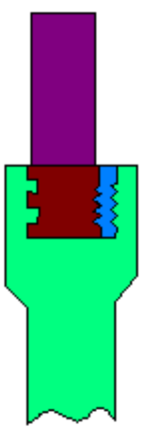
The root is drilled and the upper part machined so as to accept shrouding fro end-tightening, or thinned for tip tightening.

After assembly on the jig a hole is drilled though the base and a wire passed through. The whole assembly may then be removed and brazed or spot welded to form a solid curved section.

The arc is then machined to the desired root form. Shown below is a single blade section of the arc showing typical root form.



The segment is dropped into position pushed axialy and a caulking piece fixed



A gate is formed in the final blade which receives a further thin section piece made of copper which is caulked in.

The fixed blades in reaction turbines are made in a similar fashion except that the end blades as held in by a screw and locking strip as the horizontal joint. ALso the root may be of a simpler design due to the lack of centrifugal stress.

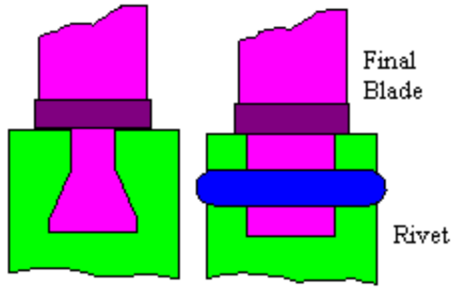
For higher speed, higher rated turbines the built up method may not be acceptable due to the stresses.

These blades may then be made of soild individual sections. The blades enter through a gate with the final blade being caulked into position.

The gates for each groove are staggered to assist balancing. The lacing wire/shrouding is then fitted.

Impulse Blades

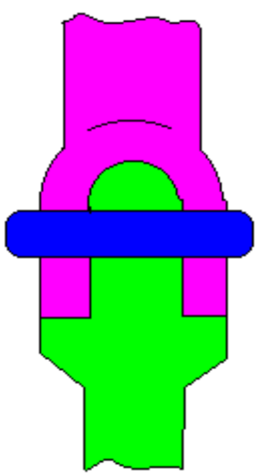
The most common form is the dove tail.



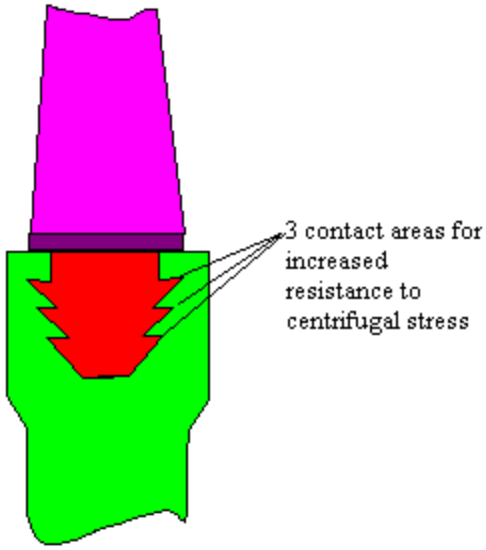
The groove is cut away to form a gate to allow the fitting of the blades. The final blade is riveted in position.

Blades subjected to higher centrifugal stresses, for example the longer tapered blades found in the final stages of the LP turbine, may have the fir tree root method which allows increased contact area without weakening root or wheel rim.

To reduce centrifugal stress on the wheel straddle root form of blade fixing may be used thinning the wheel rim. The straddle may be a simple fork design or of fir tree root. Rivets are added for strength.



Inverted fir tree root

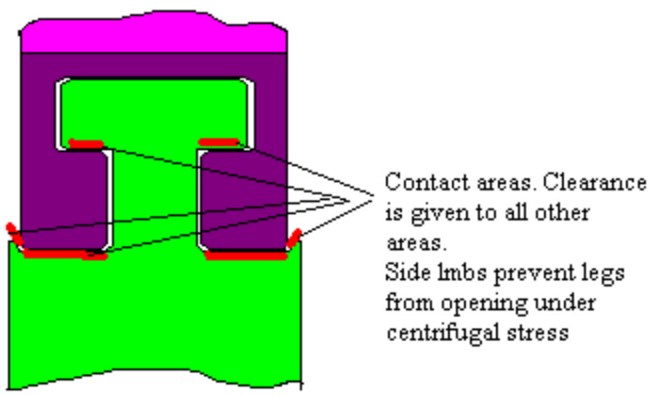


Fir tree root attachment is very strong but requires accurate machining and manual blade fixing is not possible. The gate is filled with a machined block with no blade and then riveted to secure.

Multiple forks

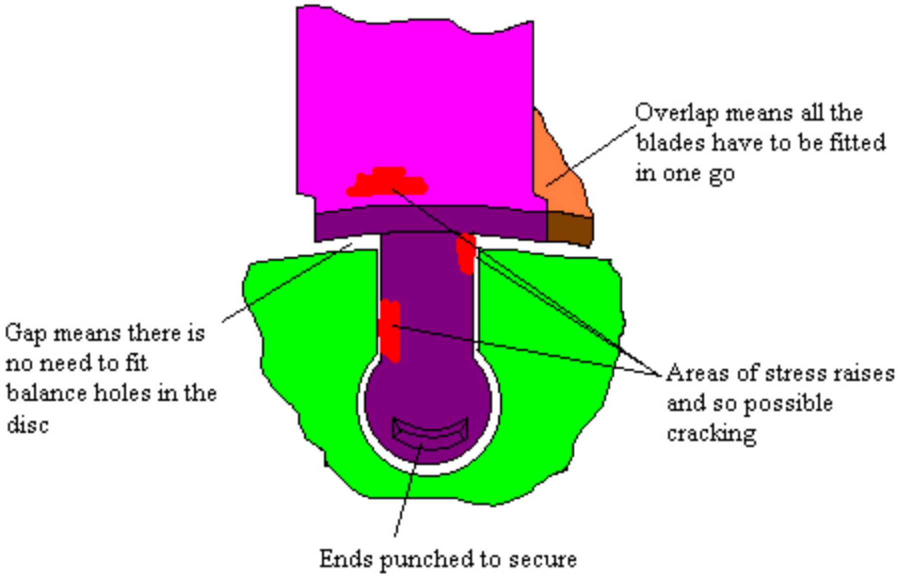
For very large blades, say at the end if the LP turbine, the root, and thus wheel rim, would be required to be very large. Multiple forks may be used which are comparitively easier to machine.

Straddle 'T'



Straddle 'T' used rather than inverted 'T' so that the holding faces on the rim can be easily inspected for defects.

Stal Laval bulb root



The main advantage of this system is that the blades are introduced into the rim axially. Therefore the individual fitting of the blades required with circumferential root arrangements is unnecessary

Where the distances between the bulb becomes so small as to risk failure of the rim, staggered bulb root depths are used with alternating short and long shank lengths.

For these types of blades the shrouds are part of the blade. On this shroud are two tabs. A shrouding wire is passed around the circumference over the shroud and the tanbs are bent over. This has the advantage that in the event of root failure some support is given to the blade. Multiple shroud wires are filled rather than a singe one for ease of manufacture allowing smaller tabs, and also to reduce mechanical stress. On more modern designs the groove is moved to the end of the shroud and a welded shroud wire fitted.

Sizing the rim

When the rim is first cut and the entrance gate formed, a test blade with slightly too large root (or feet) is carefully filed and then tapped around the rim. This blade is then discarded. The real blades are then carefully filed and fitted taking into account the wear on the rim. The nating face of the blades are filed to ensure even blade pitch. A tight fit is essential with a steam turbine, if not then severe fretting and failure will occur.

Turbine blade vibration

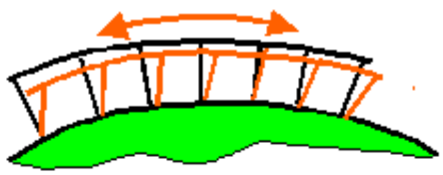
Damping wires, Lacing wires and shrouding are fitted to

- reduce stress due to vibrations in the blade excited by such as steam flow fluctuations as the blades pass the nozzles. This is referred to as the 'passing frequency'. This particularly occurs with partial admission
- To prevent spreading of the long thin blades found in the final stages of the LP turbine. Shrouding is not fitted to these blades to allow adequate drainage. Due to the high specific volume losses due to spillage is relatively small
- Steam changing direction as it passes over the blade tends to build up in the concave face. There is a tendency to flow to the tip where if unchecked it can spill over leading to considerable loss of efficiency. This is particularly important in parsons turbines expecially as the initial stages of the HP turbine where the steam has a low specific volume.

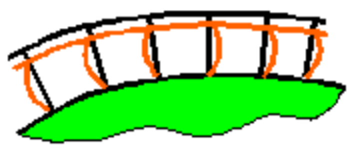
The vibration associated with turbine blades is referred to as the 'clamp-pin' type and is determined by vieing the blades in their packets i.e. blade groups attached by their shroud.

Frequency types

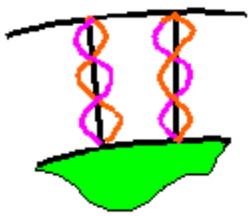
The lowest frquency is of the whole packet vibrating.



Higher frequency is where as equal number of blades bow in oposite directions



Higher still frequencies occur where each blade vibrates



Lacing, Damping and Binding wires

There are four sources of vibration damping under normal operating conditions

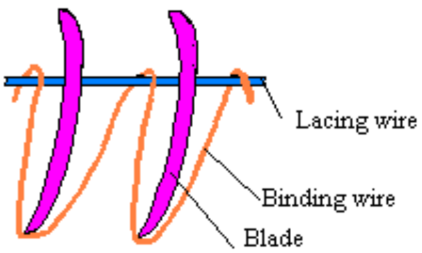
- Internal damping of the blade material
- Inherent dry friction damping of the blade assembly at the root and tip
- Fluid damping or viscous damping due to the steam environment
- Mechanical damping through fitting of damping aids such as damping or lacing wires etc

Lacing wires fitted at an anitnode provide a very effective form of dampening. However, the antinode may exist at different positions for the different types of vibration so a compromise on the position has to be reached.

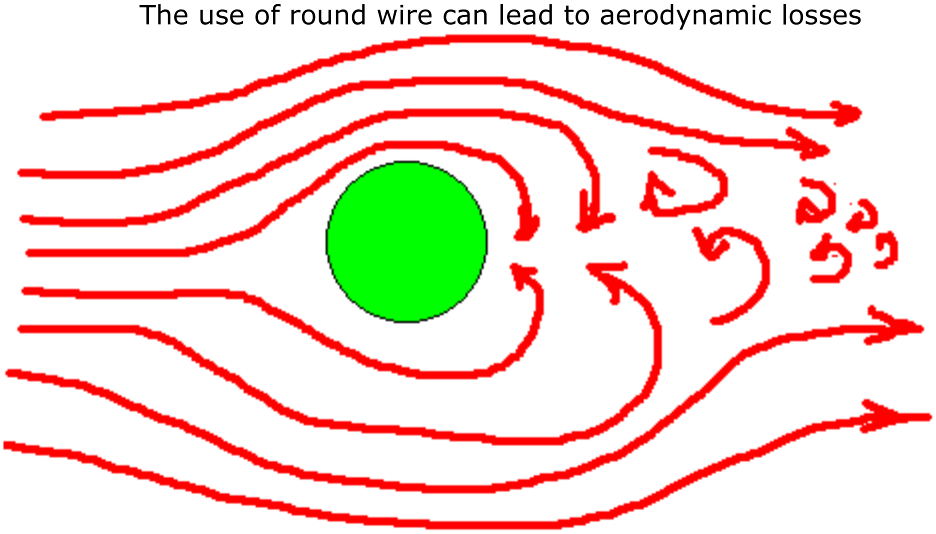
A **Damping wire** which is 'free fitting' is free to move within the holes. Centrifugal force throws the wire to the outside of the hile where frictional effects help dampen the vibration. The disadvantage of damping wires is that heavy fretting can eventually cause the holes to widen to an extent that the rotor has to be rebladed.

Lacing wires are brazed in and are therefore strengthening and hence are not necessarily placed at an antinode but rather where the blade is thickest.

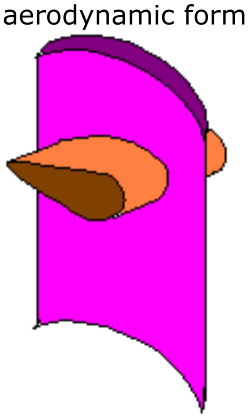
Binding wire is used to strengthen the trailing edge of the blade. This is a very old fashioned technique and is little used.



The use of round wire can lead to aerodynamic losses



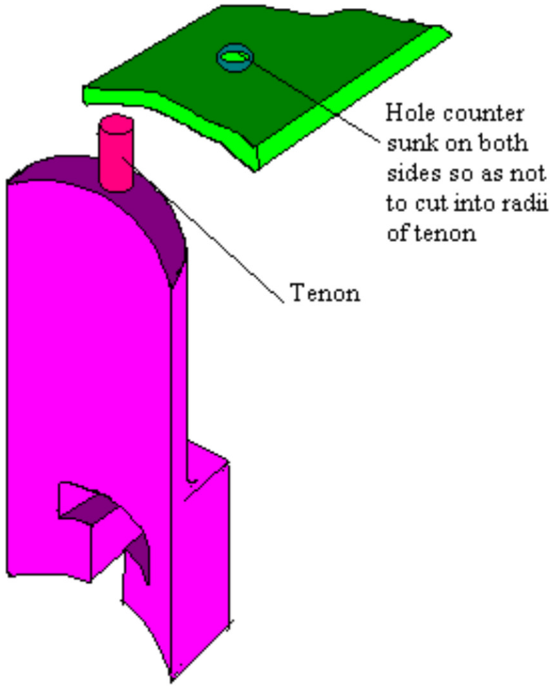
Snubber or bumbing blocks may be cast or forged into the blade. These have a highly aerodynamic form.



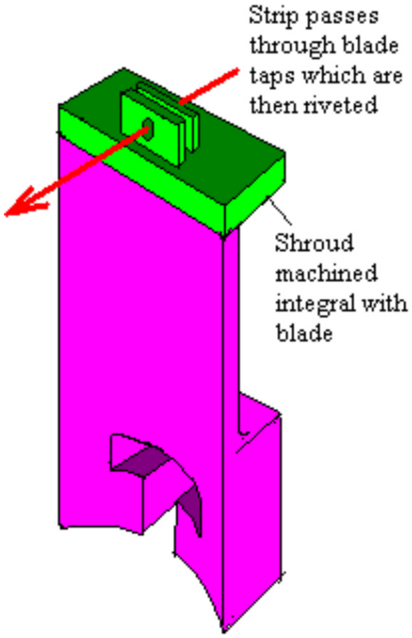
The damping is then achieved by both the bumbing of the blades and the following resistance to breaking as a vacuum formed at the joined faces tries to hold them together. A certain amount of fluid damping also occurs.

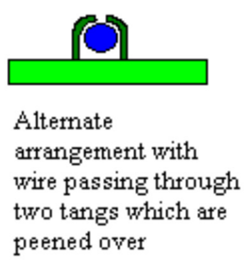
Shrouding

May be fitted by brazing, welding or riveting.



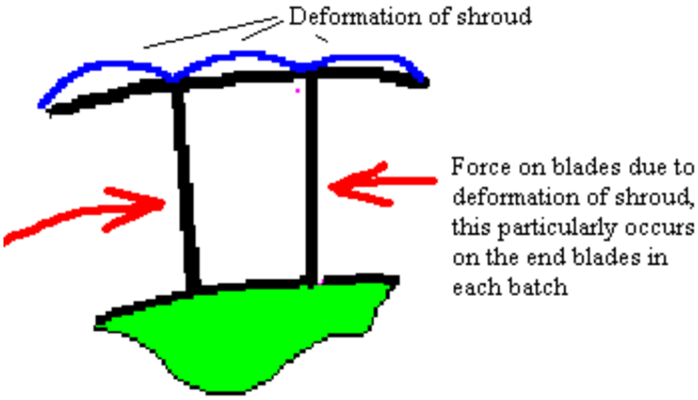
The shrouding is fitted over the blade, the tenon is then either riveted with 4 or 5 blows or welded. Care must be taken either method of fixing as it can lead to crack formation. Once the shrouding is fitted the surveyor may request a **pull off** test. The pull is determined by calculation and governed by the expected centrifugal stress on the shroud during normal operations.

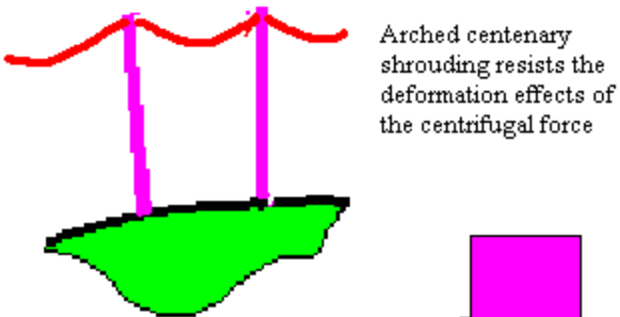


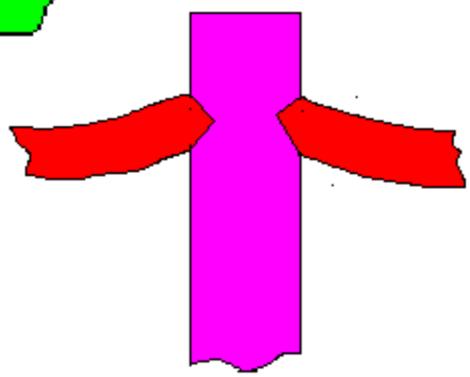


Centenary Shrouding

For blade batches where the centrifugal stress on the shroud of very large LP blades is significant, then centenary shrouding is employed.


Deformation of shroud
Force on blades due to deformation of shroud, this particularly occurs on the end blades in each batch


Arched centenary shrouding resists the deformation effects of the centrifugal force



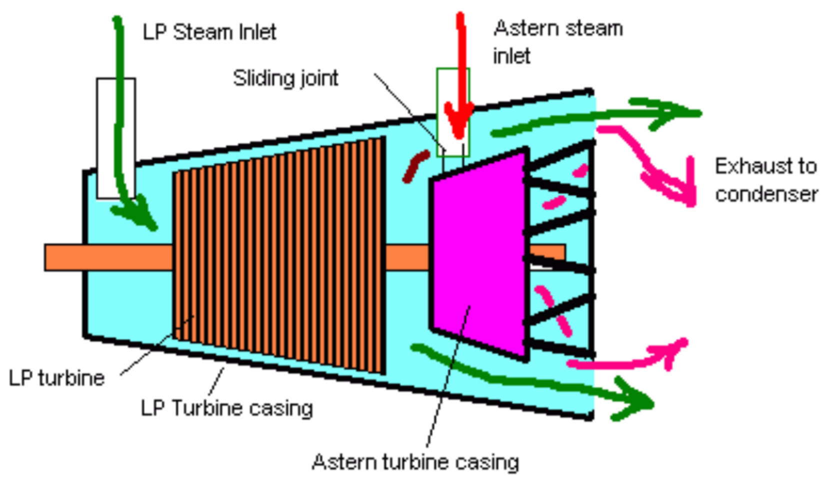
Turbine Casing

The casing is made of four main parts

- **Bottom Half**-If all the nozzles are contained in the top half, then the bottom half is subject to steam at wheel case pressure and temperature only and can therefore be made of cast iron.
  The bottom half in this case extends from end to end and contains the following listed from ford to aft
  i. *Thrust bearing housing*
  ii. *Ford Journal bearing*
  iii. *Ahead casing proper*
  iv. *Ahead exhasut belt*
  v. *(Astern casing and belt if fitted)*
  vi. *Aft gland housing*
  vii. *Aft Journal bearing*
  viii. *Flexible coupling housing*

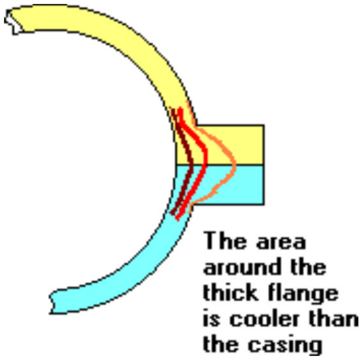
  Ahead Nozzle box-Contains ahead nozzle, subjected to boiler pressure and temperature hence made from cast steel
- **Turbine casing cover**- Subjected to reduced pressure and temperature and can therefore be made of cast iron
- **Astern Nozzle box**- Seperate top covers may be supplied to allow ease of maintenance for thrust and journal bearing

LP Turbine Casing

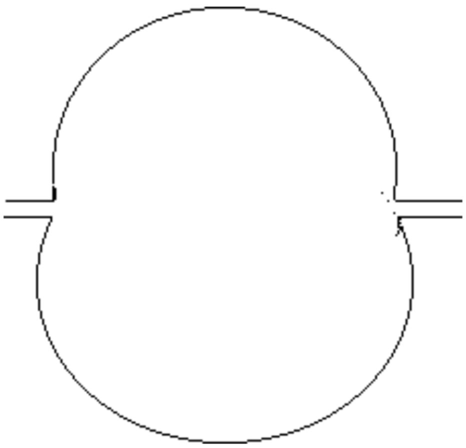


To reduce windage losses the astern turbine exhausts in the same direction as the LP turbine. The Astern casing is located by crossed bars that are able to take the torque reaction from the fixed blading. The bar layout also allows for radial expansion as does the steam inlet which is fitted with a sliding coupling

Thermal Effects

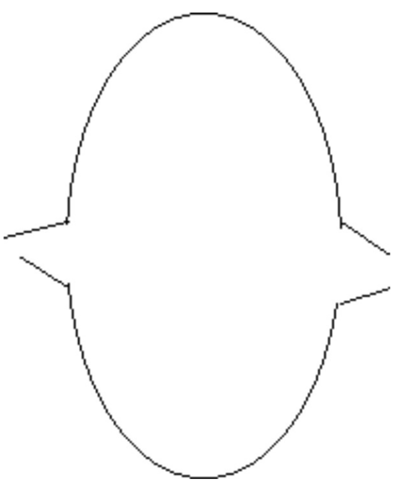


The turbine casing distorts due to the heat differential.



The pressure within the casing distorts casing halves shape to a more cylindrical one, with the high temperature creep results

Hence when the casing cools



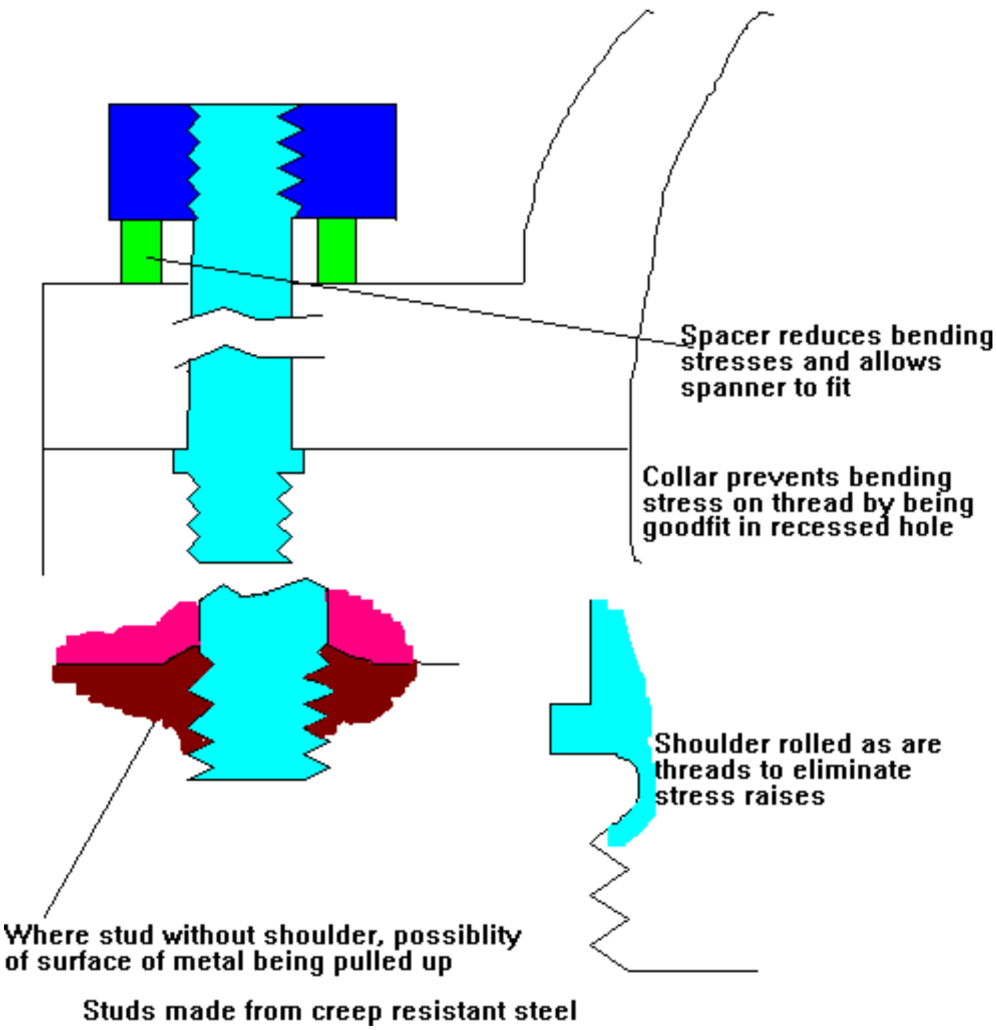
The flanges become warped . This can be checked by laying a straight edge across the casing, measuring with a feeler gauge and keeping a log of the results.
No action should be taken unless absolutely necessary.

The casing may leak during warming through as the bolts fail to close the inner faces of the flange. If the leakage stops when the turbine is up to temperature then this is considered satisfactory.

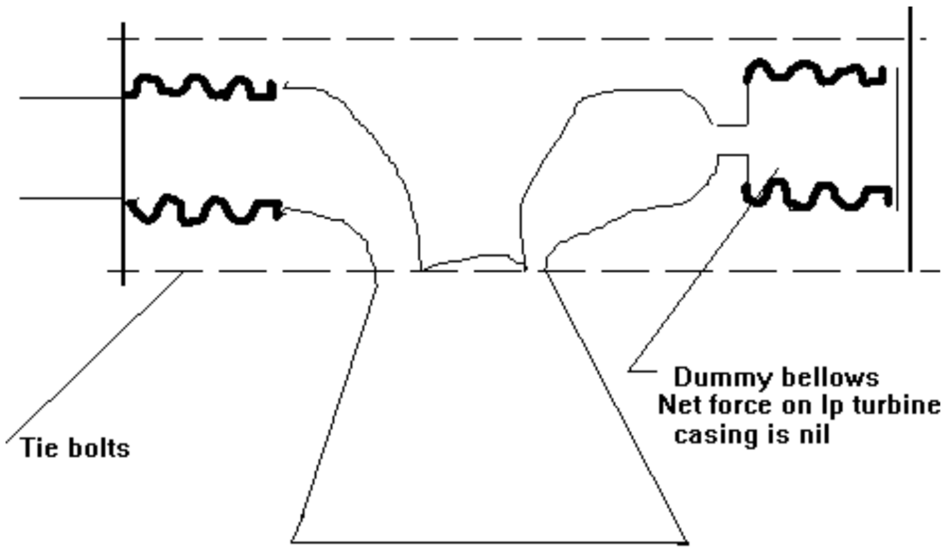
However, if leakage still occurs the some machining must take place. If the leakage is allowed to remain then at high power output damage can ensue.

A temporary repair is with the use of **Phurmanite**, this is a goo which is pumped into the flange, under pressure through a tapped hole.

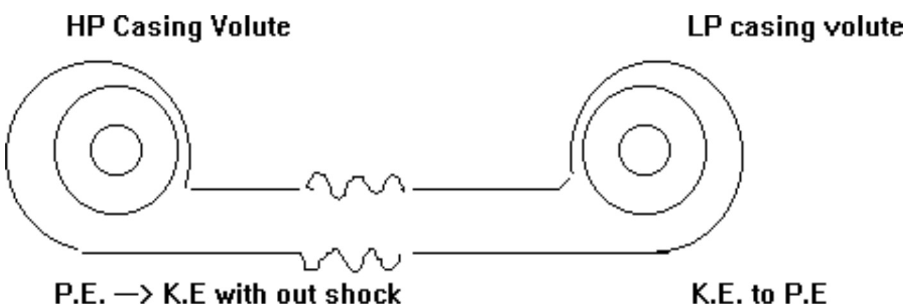
The use of shouldered bolts



Pipework



Long lengths of pipe work should be avoided, as should be tight bends as these can lead to fluid friction losses in the steam and pressure loss.
Hangers and sweeping curves before inlet to casing should be employed to ensure no weight on casing.
For the cross over pipes, to avoid large curves or frictional losses the following is now employed.



The pipes fitted to the casing should have large flexibly supported bends and/or bellows pieces. If not they can give side or top thrusts on the casing and lead to stressing and misalignement.

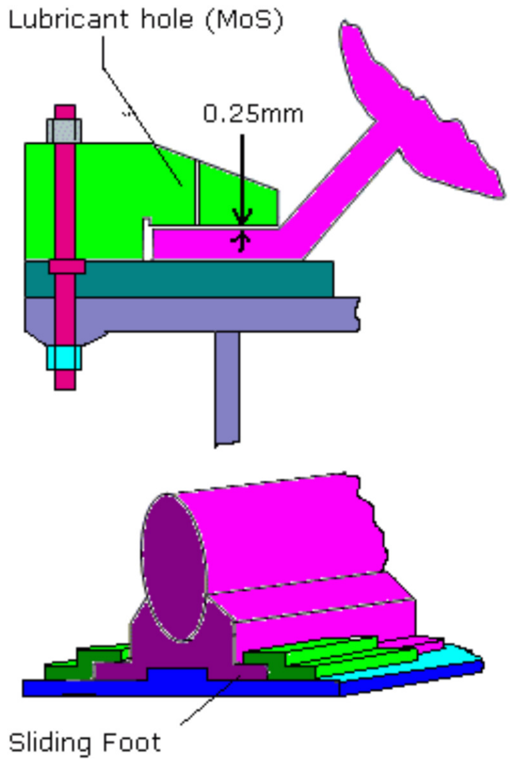
An alternative to sliding feet as shown is to use elongated holes. The holes being elongated in the direction of required expansion. The bolt is then of the loose fit design.

Care must be taken with all sliding arrangements to ensure freedom of movement. Surfaces should be kept clean, lubricated (molybdenum disulphide) and free of rust and paint.

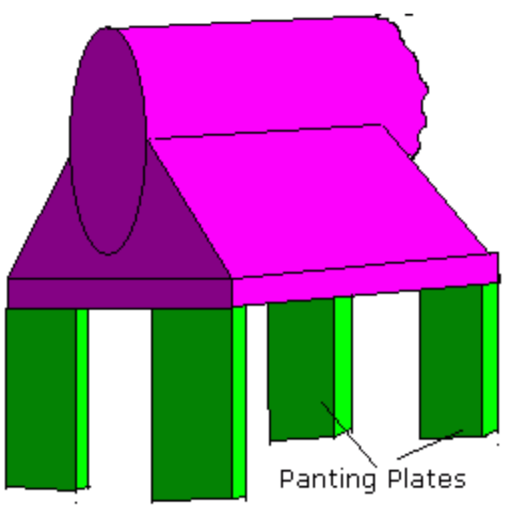
Differing materials may be used for the varying components.

Expansion arrangements

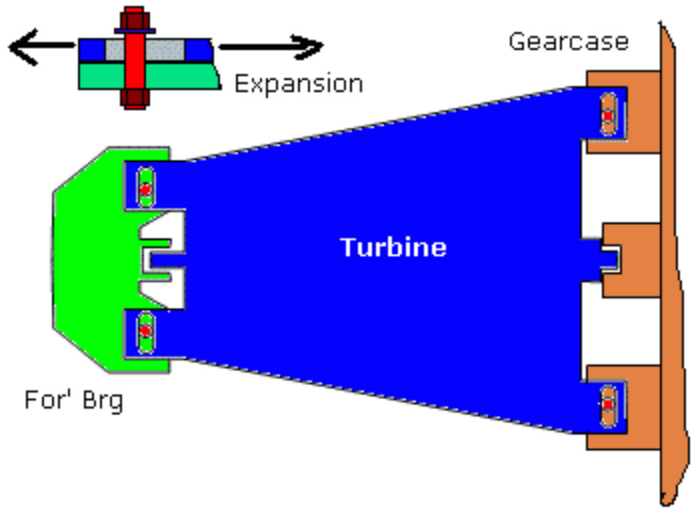
Allowance for expansion over the temperature range in which the turbines operate is essential to reduce thermal stress, mechanical stress and maintain proper tooth contact and blade clearance. This is acheived by securing the turbine at one end and allowing to expand. The free end is normally the hotter end of the turbine where expansion is expected to be greatest.



The turbine is allowed to expand in the fore and aft direction by molybdenum disulphide lubricated sliding feet



An alternative mounting is by 'Panting plates'. This design is particularyly seen in HP turbines and in Turbo-alternators where there is less weight to support.

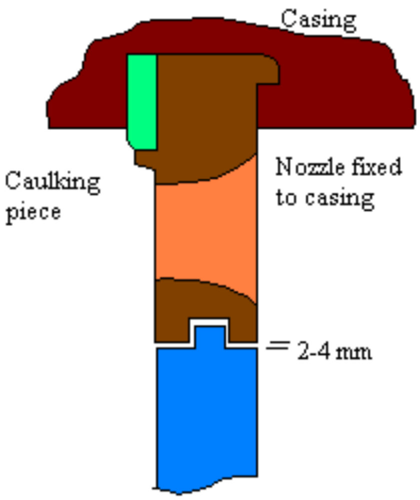


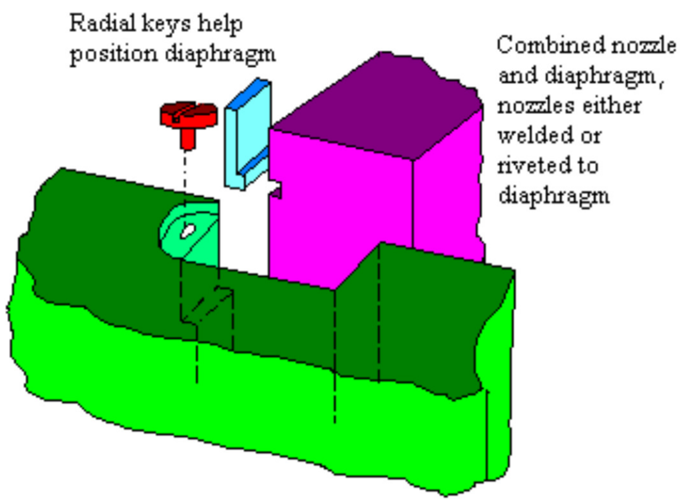
The turbine is rigidly attached to the gear casing or pedestal. The ford end is allowed to expand. The turbine movement is absorbed by the flexible coupling

Diaphragm

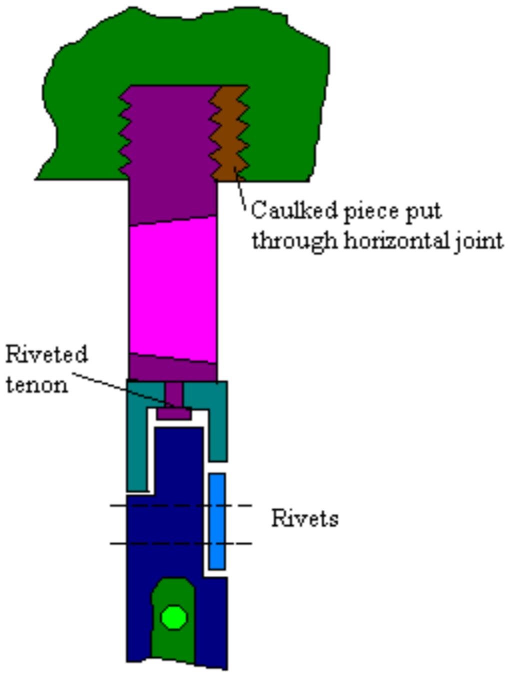
These are found in impulse turbines to create the requisiste number of stages. They locate with a fixed row of blades and are sealed against the rotor shaft by a gland arrangement which must remian effective throughout the working range the diaphragm operates in.
They have a large surface area and so must have sufficient stregth to resist pressure drop across them without being excessively wide which would increase rotor length. Allowance must be made for rapid temperature fluctuations found during manouevring.
Teh take the form of a disc with a row of blades at the circumference and a hole at the centre for the rotor. A horizontal split allows for disassembly, rotation is prevent by a locking plate at the horizontal casing joint.

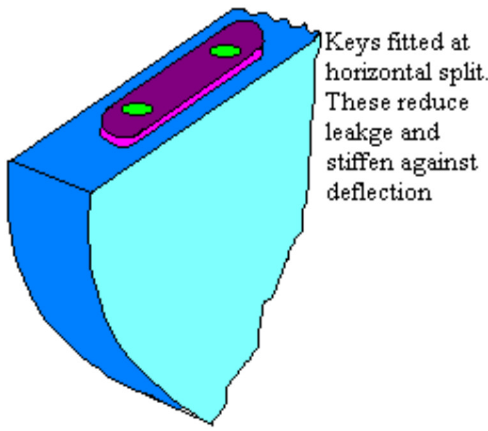
Methods of Diaphragm fixing





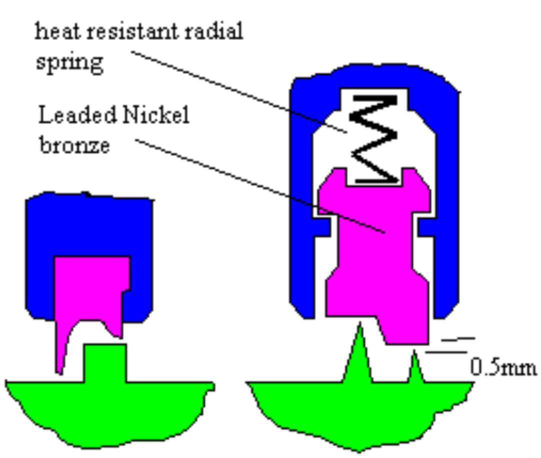
Alternate arrangement





Steam pressure holds the diaphragm plate hard against the downstream face.

Rotor Sealing

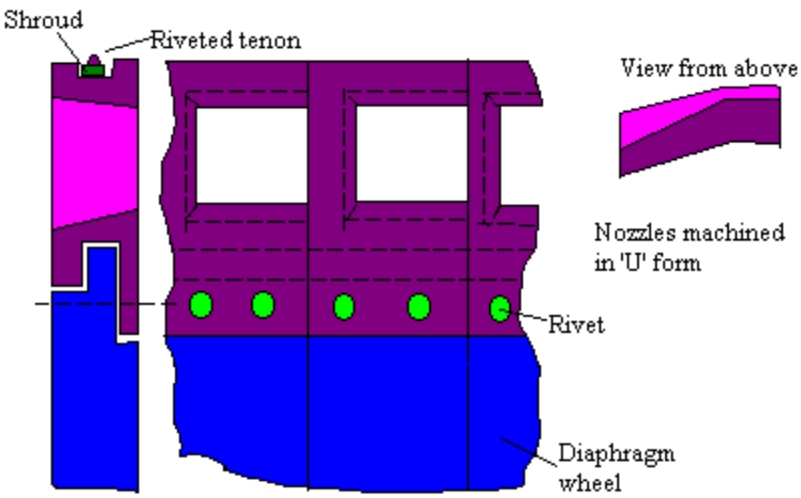


Loading on diaphragm = 207 to 280 NM/m^2, deflection is approximately 2mm

Diaphragm material

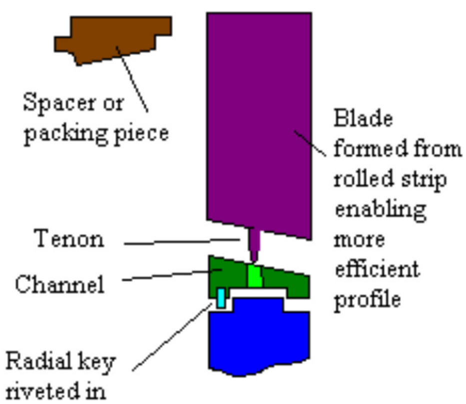
In the high temperature regions typically Molybdenum-vanadium steel all parts. More generally a low carbon steel for the nozzle division plates and spacer bands, mild steel for rest. In the low temperature region cast iron diaphragms may be used. Alternatelychromium or Nickel alloy steel may be used

Construction of Diaphragm Nozzles (all riveted attachment)



Diaphragm is a loose fit in the slot in the casing to allow for expansion.

Construction of Diaphragm Nozzles (partial welded attachment)

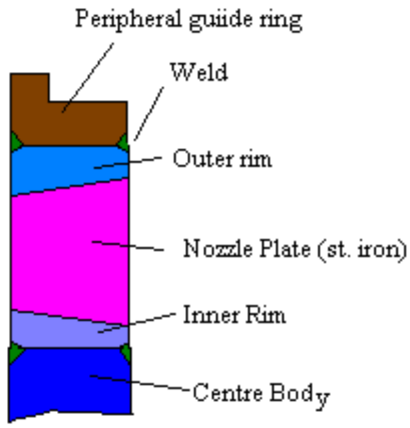


The nozzle is assembled in batches by pushing the tenon of the blade throught the channel hole and riveting. A spacer is fitted and the whole tack welded. The blade batch is caulked into the casing. A small allowance is made for expansion.

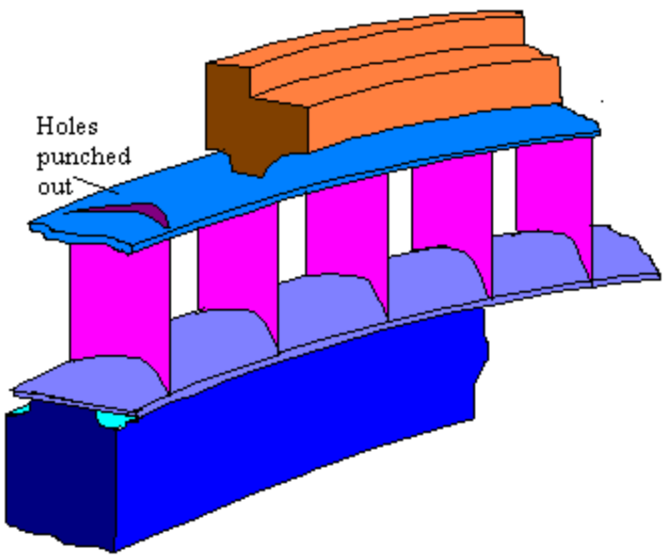
Some sections on the first stages may be blanked where partial admission used.

Modern turbine designs have a curtis wheel first stage which absorbs a large portion of the energy in the steam. The exahust from this stage has a relatively high volume therefore all further stages are full admission.

Construction of Diaphragm Nozzles (welded attachment)

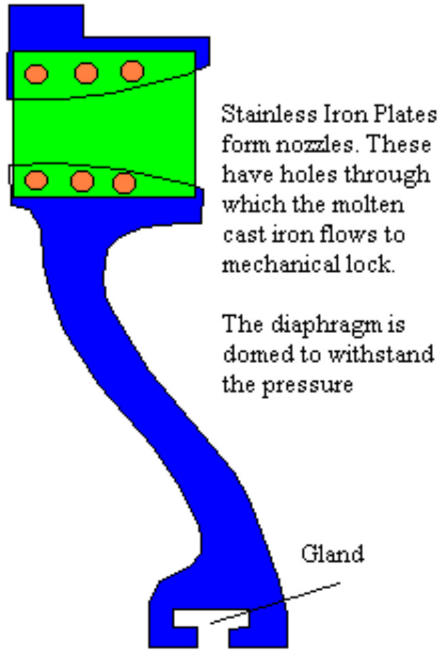


Modern diaphragms are all welded.Nozzle plates or guide vanves fit into slots in the inner and outer rim. The whole is welded to the centre body and perpipheral guide ring. Expansion is allowed for in the casing groove. The Nozzle blades or guide vanes are commonly made from stainless iron. The centre body from Chrome Molybdenum steel in higher temperature regions, mild steel for the lower.



Archaic design

Included for general interest .


Stainless Iron Plates form nozzles. These have holes through which the molten cast iron flows to mechanical lock.
The diaphragm is domed to withstand the pressure
Gland

Turbine Glands

GLAND STEAM SYSTEM

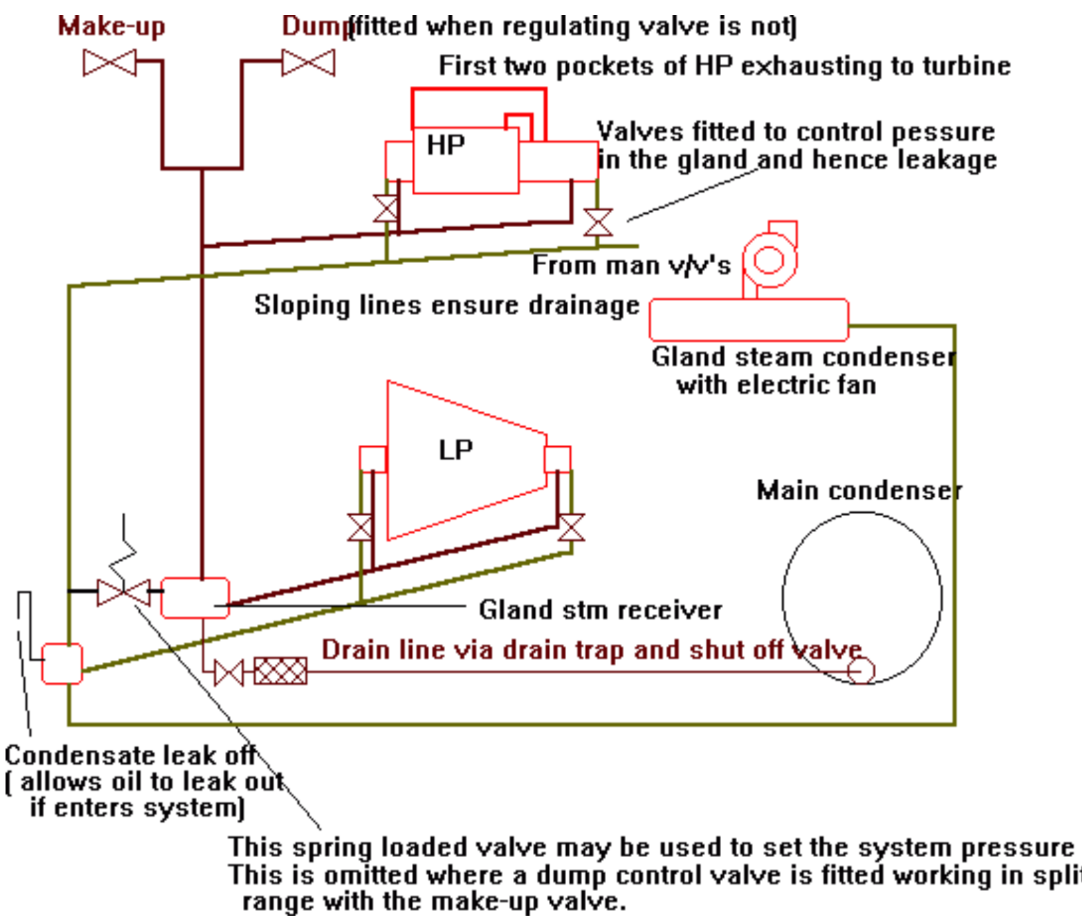
The purpose of the gland steam system is to reduce steam leakage to a minimum and to prevent air ingress.

Steam leakage leads to the requirement for increased make up; this increases the load on the feed and boiler water treatment chemicals and to a deterioration of the working environment surrounding the power plant.

Air ingress leads to a loss of vacuum and hence reduction in plant efficiency , and causes problems of thermal stressing around the gland as well as increases oxygen content of the exhaust steam.

System

The system consists of a set of glands fitted to the turbine, and a steam supply and exhaust system to service them.



The system above shows the two means of controlling the gland receiver pressure; the first is by having a dump in split range with the make-up valve, the second is the use of a pressure regulating valve which dumps excess pressure to the exhaust line. The normal operating pressure is around 0.1 to 0.2 bar.

Gland steam condenser

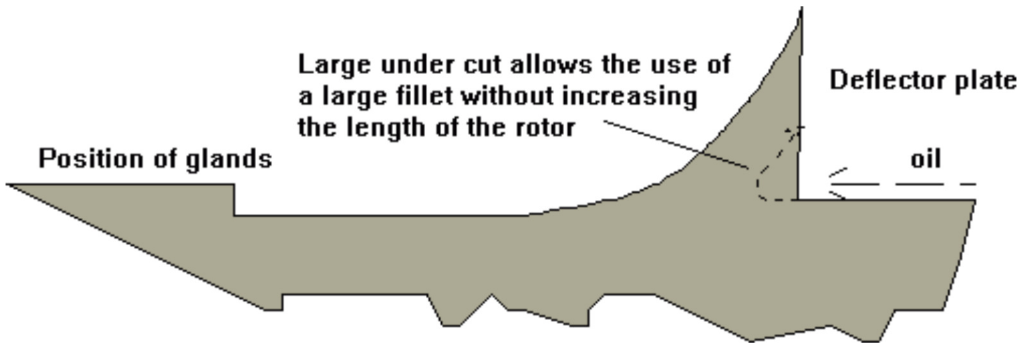
The gland steam condenser is cooled by the condensate extracted from the main condenser and so acting as a feed heater.The gland steam often shares its condenser with the air ejector reducing the cost of having two units

A fan is fitted to induce a flow through the system without incurring a negative pressure in the final pocket as this would allow the ingress of air. This is ensured by the fitting on valves to the exhaust line from the glands so enabling the back pressure to be set.

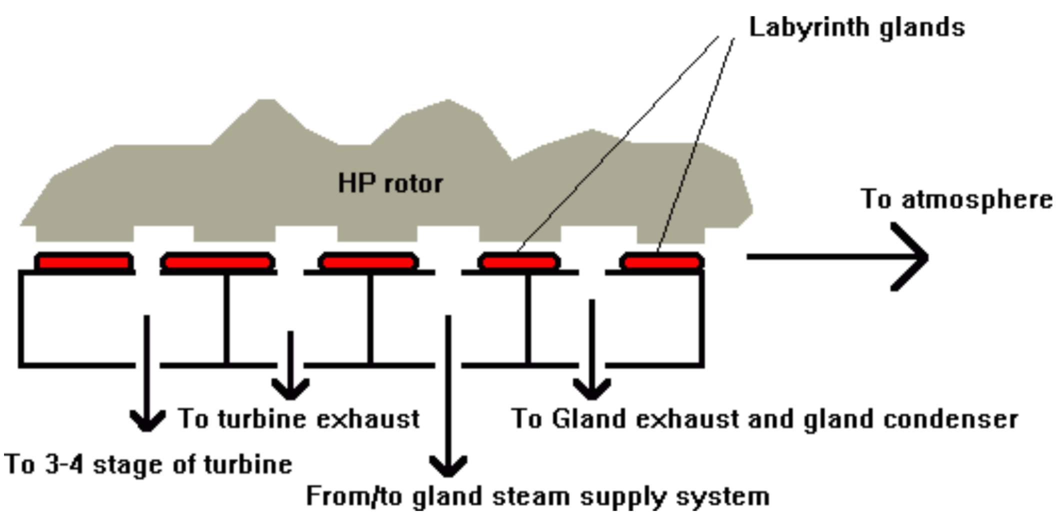
Miscellaneous

A vapour hood is sometimes fitted with extraction at negative pressure reducing leakage still further.

The turbine rotor is shaped to prevent oil which leaks from the bearing traveling down the rotor and entering the gland



Schematic of pockets on inlet end of HP turbine

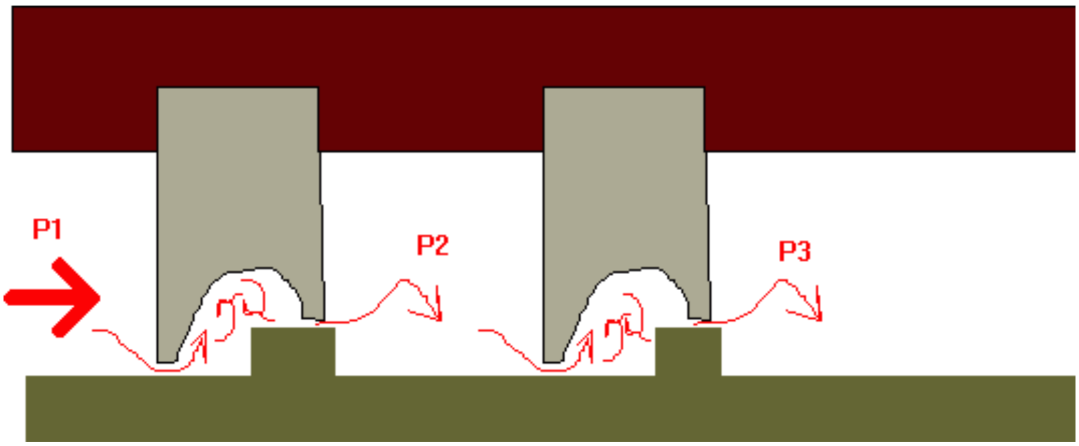


There are two pockets in the glands fitted to all the ends of the turbine; the inner pocket is connected to the gland steam supply and the outer to the exhaust line . The HP turbine has to further inner pockets due to it having to deal with steam at higher pressures and hence increased leakage. The innermost pocket simply passes leakage steam back to the casing a few stages downstream, the next pocket passes the leakage steam to the HP turbine exhaust.

When the engine is stopped the gland steam make-up supplies the system requirements. When the engine is in use the flow of steam to the supply pocket of the inlet end to the HP end reverses and the gland starts to supply the system reducing the quantity the make-up has to provide. At full power the only gland requiring steam will be the exhaust end of the LP turbine, the other will be either supplying the system or supplying themselves sufficiently to not require steam from the system.In this condition the make-up would be shut and the pressure regulated by the dump opening.

Principle of the Labyrinth Gland

The leakage of steam is reduced by the use of labyrinths, these provide a tortuous path for the steam to follow to exit the turbine reducing the pressure across a series of fine clearances to a level that can easily be managed by the gland steam system.



Within the cavity where the flow is turbulent, the velocity of the steam is increased with an associated drop in pressure. The kinetic energy is then dissipated by the change in direction, turbulence and eddy currents.fugal action. Very small heads can deal with large pressure drops

Materials

A typical clearance between the rotor and the fixed gland is about 0.25 to 0.38mm, hence with very little rotor distortion the possibility of rub occurs. This has led to the use of soft, self lubricating materials for the gland segments.

The simplest form of gland consists of carbon rings held on to the shaft by the use of garter springs. Carbon Dioxide is formed with contact with superheated steam making this material only suitable for low temperature requirements.

Brass and Copper led alloys have been found suitable with an alloy of Lead, Copper and Nickel being suitable up to 520^{o}C.

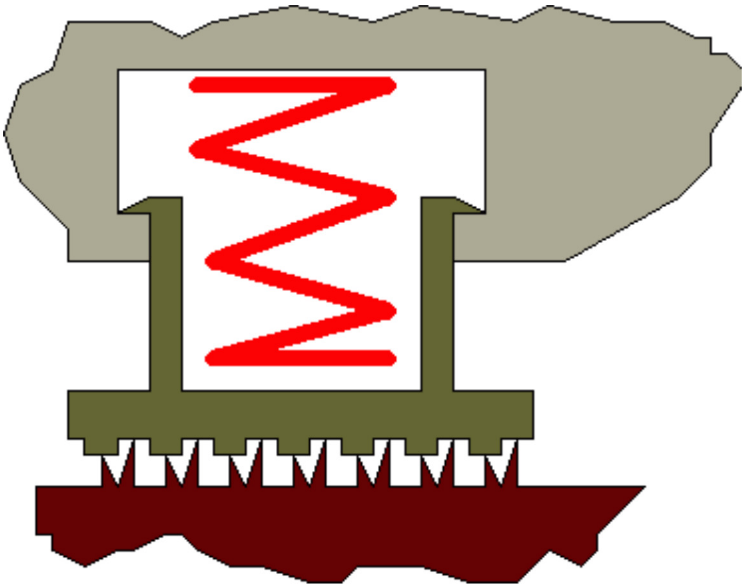
Shaft Rub

Should the rotor bend, say due to carry over the area of rub on the gland will be over a small arc. With successive revolutions the heat generated will increase bend. This increases the area of contact and magnifies the condition by the increased generation of heat.

Plastic flow occurs when the material yields under compression to reduce the stress and on cooling a permanent set occurs.

One side of the gland, typically the stationary part is made up of thinned sections thereby reducing the contact area to a minimum. Spring loaded glands prevent this from happening by giving under contact with the rotor , limiting the heat generated and giving time for the rotor to recover its shape.

Spring backed gland

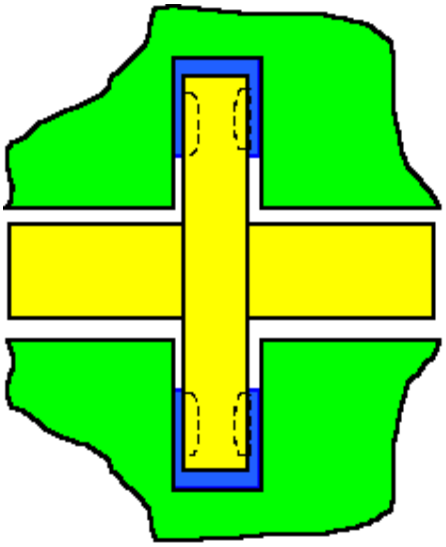


The minimum clearance for a spring backed gland ranges from 0.3 mm fot eh HP inlet to 0.63 mm for the Astern turbine. For fixed glands the minimum is 0.5 mm. With the smaller clearances there is an increase in efficiency

Hydrostatic Gland

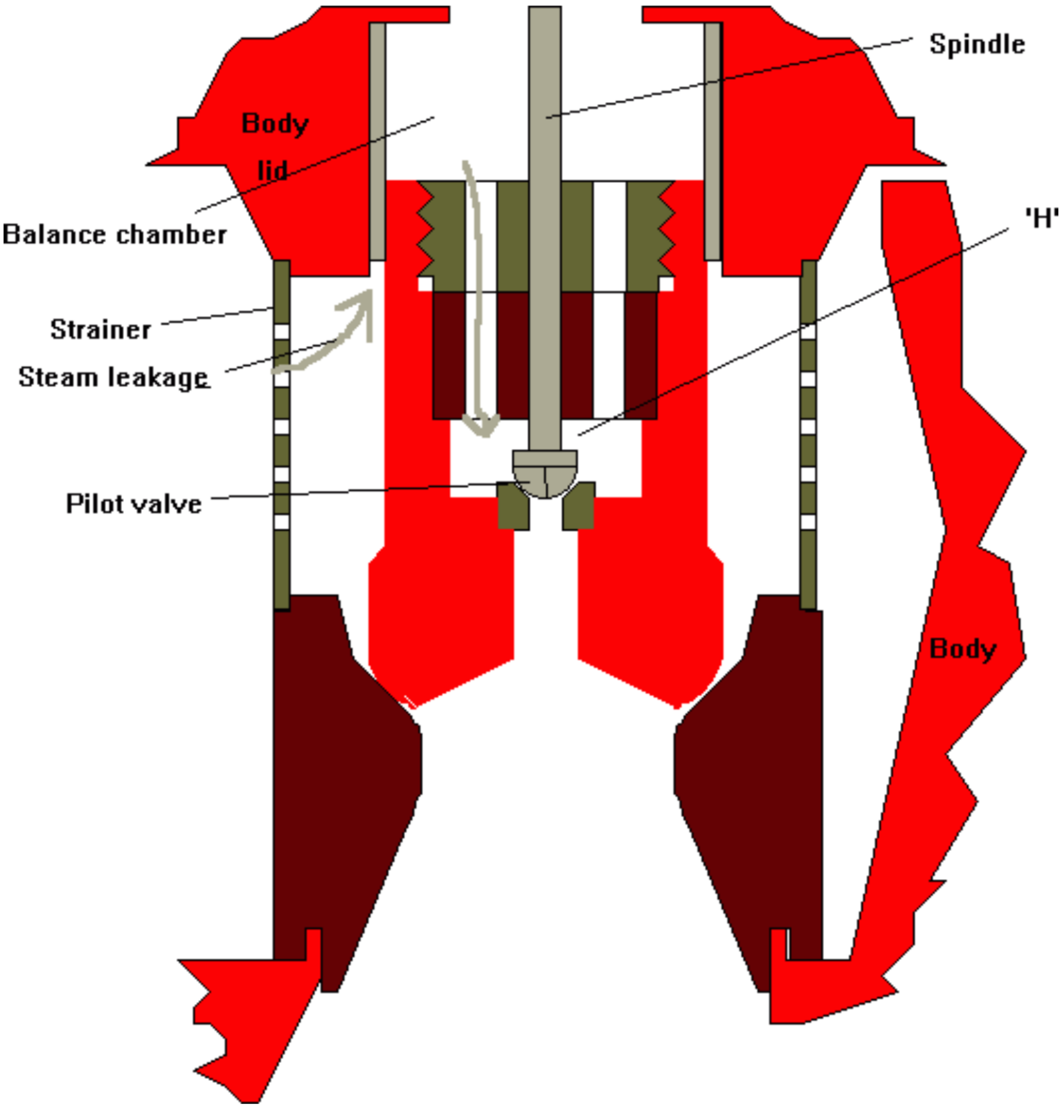
A wheel forged on the rotor ends runs in a water bath. This water is flung out by centrifugal action. The gland only needs to be small as large pressure drops require little head.

The system cannot be used on reversible sets as the seal effect is lost at reduced revolutions. It is more likely to be seen on turbo-alternators.



Manouevring Valves

Obturated manoeuvring valve

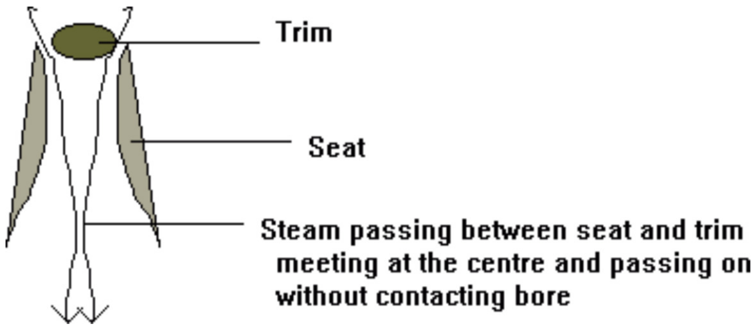


Steam leakage past the side of the main valve trim pressurises the top of the valve and holds it tight on to the seat. The seat and valve trim are stellite coated.

A steam strainer if fitted to remove any large particles such as scale, magnetite flakes etc. traveling on to the turbine.

The height 'H' is important and should be limited otherwise when the pilot valve spindle contacts the valve trim and starts to lift it, steam acting underneath the trim will tend to lift it increasing the valve opening quickly.

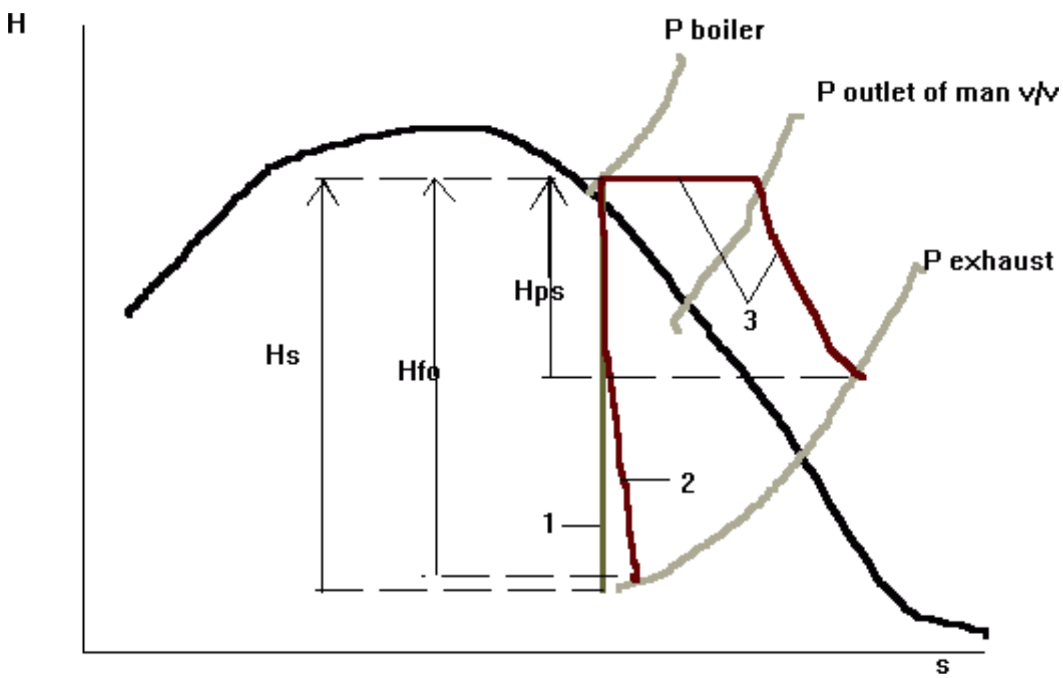
The conical seat and spherical valve trim shape ensures tightness. The seat is shaped to ensure that there is no velocity increase which is associated with the pressure drop leading to losses. The shape also means at low lift the steam stream is designed to meet in the centre and pass on without contacting the sides hence reducing erosion.



The valve operates as follows; The valve is closed with closing force coming from the pilot spindle and the pressure of the steam acting on the top of the valve trim. On open signal to the motor arrangement the pilot valve spindle moves easily opening up the balance chamber to the turbine pipework so releasing the pressure. the spindle travels further to contact the valve trim and hence lift it. The advantage of this system is that the spindle motor does not have to cope with opening the valve against the pressure acting on the back of the valve and hence can be accurately positioned for low lift.

The steam path through the opening valve is designed to give a linear lift/flow characteristic. the stem external to the body often has an arrangement for allowance for thermal expansion. Should the valve be manually over tightened shut or should he arrangement fail then seriously high stresses can be generated in the spindle which can jam.

Throttling



Line 1: Isentropic expansion through the turbine realising an enthalpy of 'Hs'

Line 2: True expansion through the turbine, through an open manoeuvring valve and realising an enthalpy of 'Hfo'

Line 3: Expansion through a partially open man v/v at constant enthalpy to a lower pressure but higher degree of superheat; the steam is then expanded through the turbine. It can be seen that there is an increased slope due to a drop of efficiency of the expansion through the turbine

The amount of heat that is available to do work is determined by the initial conditions i.e.

boiler conditions, and the final conditions i.e. condenser temperature and pressures.
Hence, by varying the flow of steam so can the amount of work produced by the turbines also vary. This is the basis of nozzle control at full power outputs.
However, at reduced loads, even with the additional nozzle groups closed it is necessary to reduce the flow of steam by closing in the man v/v.

Closing the man v/v has other effects other than a reduction in mass flow. With the steam being throttled through the valve in an uncontrolled way and hence with no increase in velocity the steam at lower pressure but containing the same heat energy then exists at a higher degree of superheat (but lower temperature)with a certain amount of reheating due to friction occurring in the turbulent outlet stream. The expansion through the turbine is now carried out at a lower pressure, with the turbine operating at reduced revs due to the reduction in power developed there is a loss in diagram efficiency for the steam being expanded though the turbine.

It can be clearly seen that throttling through a partially open valve incurs a certain degree of superheat at outlet of the turbine. This can lead to overheating the main condenser due to the high exhaust temperature. However, as the mass of the steam is reduced this can generally be ignored.

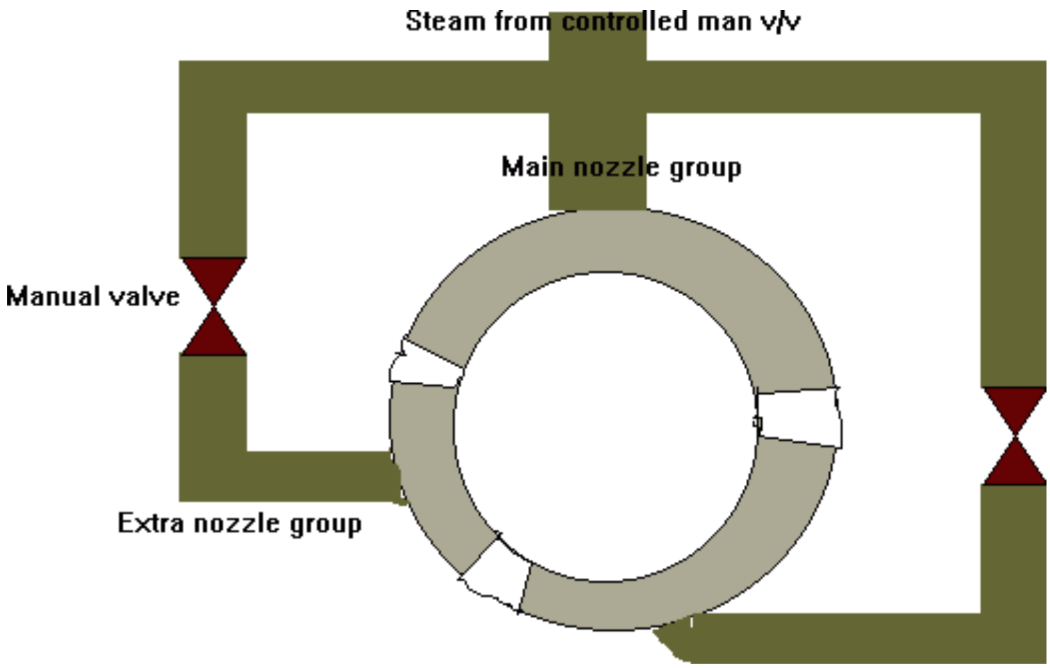
Steam flow control

Throttling

Throttling of the manoeuvring valve leads to an unacceptable drop in efficiency This is caused by the constant enthalpy expansion of the steam passing through the partially open valve; this reduces the pressure and increases the superheat of the steam. The reduced pressure means that less energy is available for conversion to work, and the less efficient expansion through the turbine.

Hence, alternatives are provided whereby the mass of steam passing to the engine, and so power produced, can be altered.

Manual selective

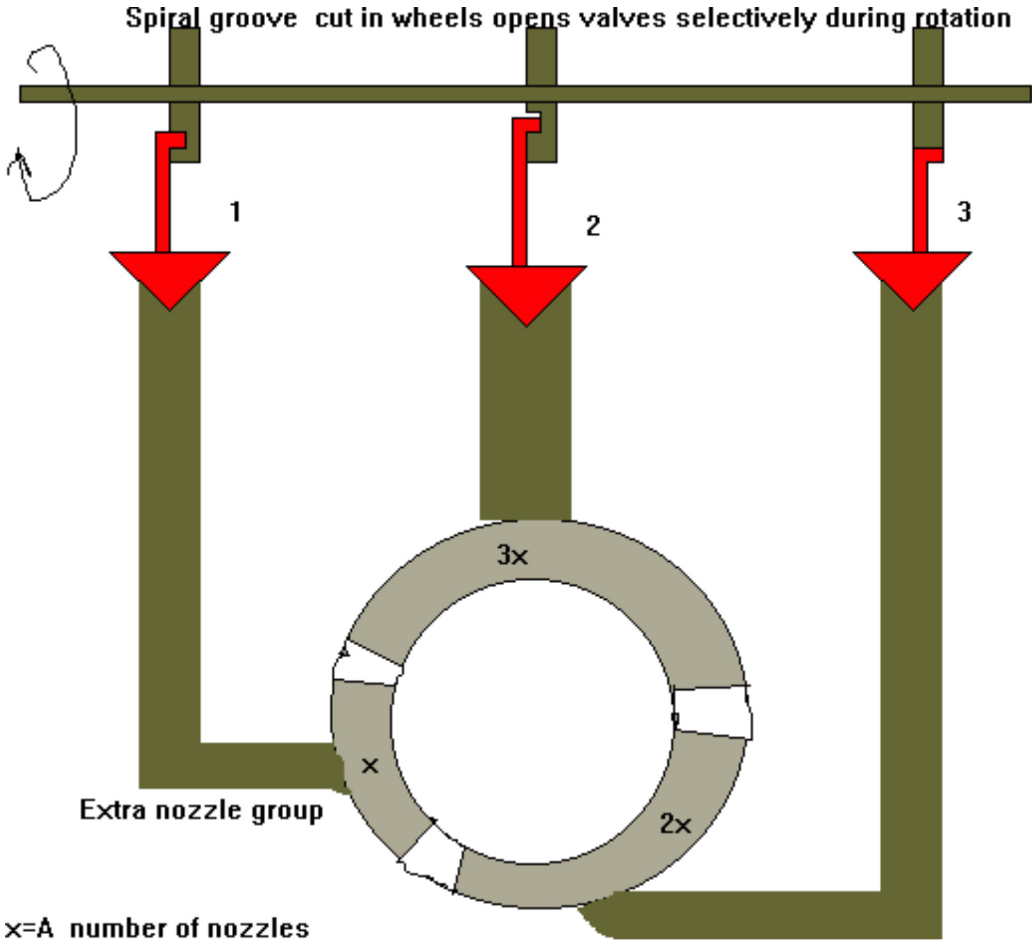


For commercial ships the above system is quite satisfactory, it can be seen that there is no control over the main group and hence losses will occur at lower loads.However, for ships which spend the bulk of their time at high loads between ports this is no a problem. Throttle losses are still incurred at loads between the opening and closing of nozzle groups but is reduced by shutting off the nozzles - opening the man v/v fully and controlling load on the boiler pressure.

Selective Nozzle control

This system works by sequentially opening and closing man v/vs to allow steam to pass to the turbine. The spiral groove cut in the wheels does not simply open on valve then the next. Rather by using the different nozzle numbers contained in the group, it can give variations in the number of nozzles in use by opening and closing groups as the wheel rotates in the same direction. This system would not have the controlled man v/v of the system above.

This system, due to inherent unreliability's, does not lend itself to bridge control.



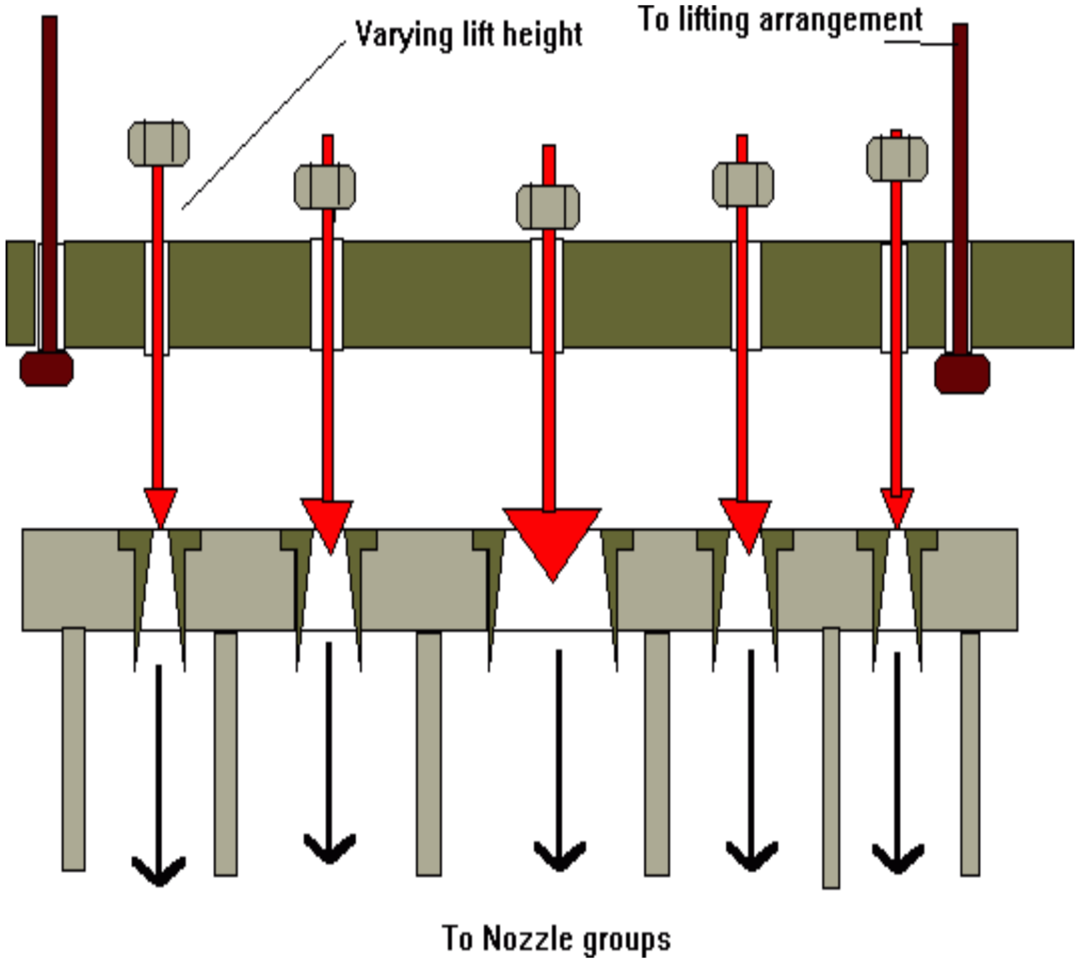
i. *All shut*
ii. *1 open*
iii. *2 open*
iv. *3 open*
v. *1 + 3 open*
vi. *2 + 3 open*
vii. *1 + 2 + 3 open*

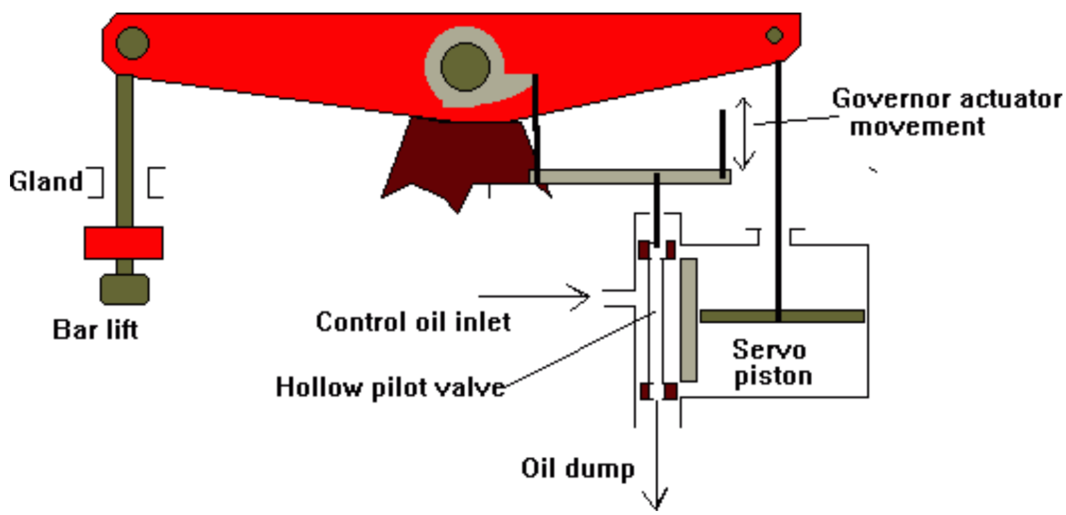
Sequential control - Bar lift type

This system has found much use on Turbo-alternator generator sets and is similar to Selective Nozzle control, but has much increased reliability.

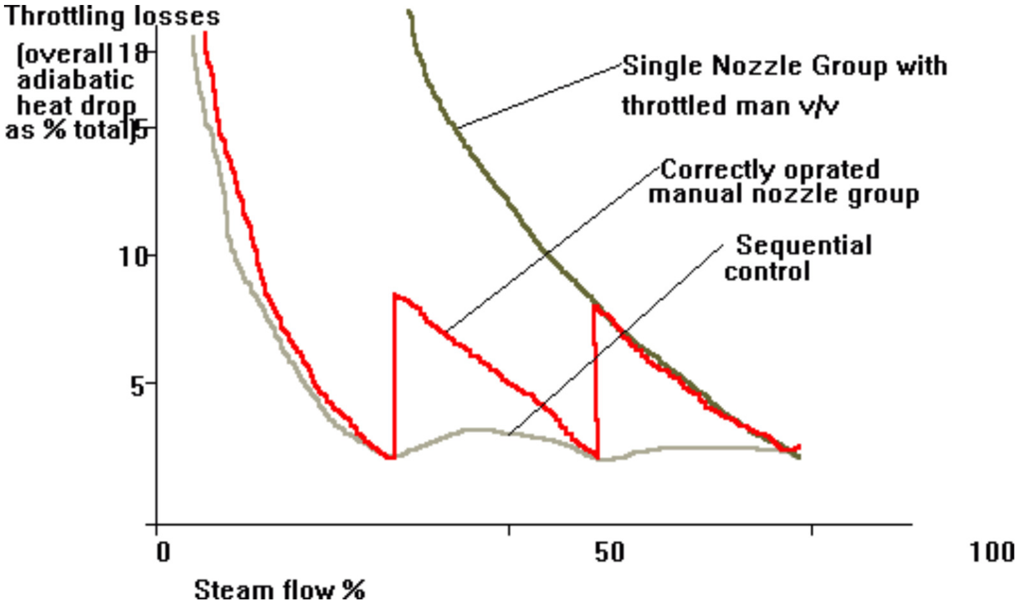
It consists of a series of nozzle groups which are brought into line by the opening of their respective valve. The valves are operated by the lifting of a beam or bar, which is connected via a servo to the governor. Sequential control is gained by the adjusting of the height the bar must lift before contacting with the valve spindle nut; each valve, by adjustment of its spindle nut will start to open at varying bar lift.

Steam flow to the nozzles is at a maximum with little throttling effect.





Some oil is allowed to leak past the servo and pilot valve, this improves the action and gives a cooling effect to these parts which are by necessity located close to the hot parts of the turbine.



All round and partial admission

This refers to the steam flow around the circumference exiting the nozzles and entering the first stage of the turbine.

All round admission- This normally refers to Parsons reaction turbines with no impulse stages.

Steam is led to an inlet belt containing a complete 360^o covering of fixed blades. Power variation is by closing of the manoeuvring valves.

Partial admission- Normally found on impulse turbines or reaction turbines having a curtis wheel first stage.

Due to the low specific volume of the steam at inlet conditions the requisite size of nozzles for full admission would be impracticably small.,p> Hence, the steam enters in sections, those area on the circumference not covered by nozzles are hooded to reduce windage and overheating.

For manoeuvring it is recommended that all the nozzle groups are opened. This reduces the blade loading otherwise all the steam passing through the man v/v would be acting on a small number of blades. Maximum efficiency is achieved with the man v/v full open and hence sets of nozzles are shut off at full away.

However some manufactures recommend that all of the nozzles are opened up to reduce the blade passing vibration caused by the flexing of the blades as they pass the steam jet.

Overload

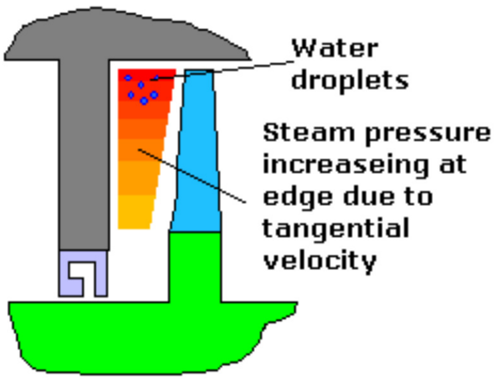
For overload conditions in excess of normal a bypass v/v may be fitted which admits steam a number of stages down from the HP inlet.By introducing the low specific volume steam further down where the nozzle area are greater allows more steam flow. In this condition the main stop is closed and the first few stages idle.

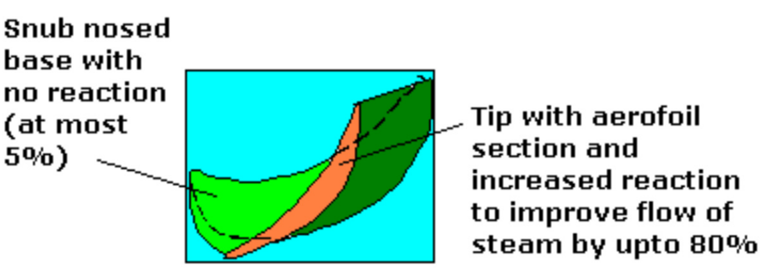
Modern practice however is to leave the man v/v open so a small amount of power is produced over the first stages.

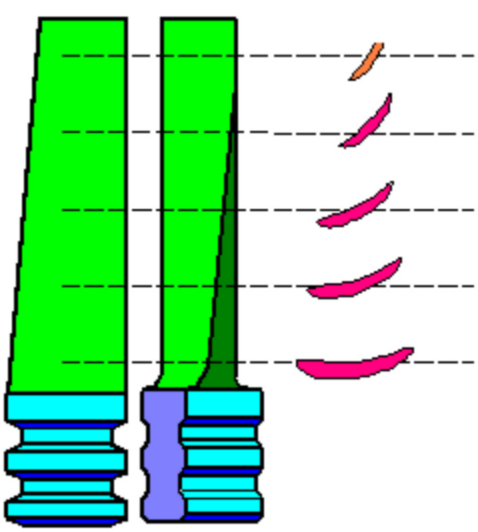
Taper-Twisting of blades

Reasons for taper-twisting of the final stages of LP turbines

- Due to the change in centrifugal velocity with the increase diameter towards the exhaust end the true vector velocity of the steam varies over the length of the nozzle. The blade must be twisted to ensure the steam enters at the correct angle
- The tip has an aerofoil section to increase the reaction to equalise the flow of steam across it which would otherwise be non-uniform due to the pressure difference between the tip and base due to centrifugal action
- The tapered blade design allows an increased distance between the blade and nozzles. This gives water droplets more time to increase in speed driven by the steam flow.
  In addition the tangential velocity is much greater than that of the axial velocity and hence the rotating disc of steam tends to centrifuge out the water droplets
- When viewed as a cantilever beam the tapered design is ideal from a mechanical point of view to resist bending
- The tip aerofoil section increases the reaction to equalise the flow of steam across the bladewhich would otherwise be non-uniform due to the pressure difference between tip and base caused by the centrifuged steam







Negative Reaction

The degree of reaction R is defined as the ratio of the heat drop in the moving blades to the sum of the heat drop in the nozzles and the moving blades i.e.

$R = h_b/h_n + h_b$

The heat drop across the moving blades is manifest as an expansion of the steam during ites passage through the moving blades and thus as increase in steam velocity.

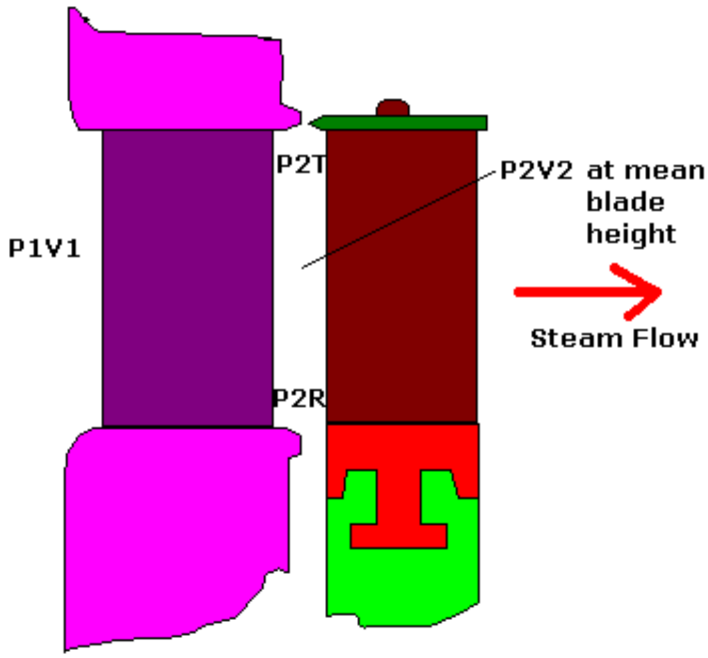
If a compression takes place at the same section along the blade length instead of an expansion thus being equivalent to work done then the term becomes negative, and provided $h_n > h_b$ the expression becomes negative at the section considered.

The actual mechanism where by this occurs is linked to the vortex flow theory.

Simplified this states that because of the oblique angle of the steam flow out of the nozzle the flow path in the gap between the nozzle outlet and moving blade inlet follows a line of flow something like a spiral and that there must be therefore inertial forces set up which cause a variation in steam pressure in the radial direction to the gap.

Where the nozzle height ratio (ratio radial height L of the nozzles to the mean diameter D) is small the effect is limited, but in those stages where the nozzle height ratio is large it has a profound effect on the distribution of heat drop in the nozzles and blades.

Calculation of steam conditions at mean blade height (as be used in the preceding stages) is no longer indicative of flow characteristics.



Shown is a section of nozzle and blade. It is assumed the pressure is sensibly constant in a radial direction i.e. the flow lines are entirely axial in direction relative to the casing. However,there is a pressure gradient in the radial direction in the gap between the nozzles and moving blades so that if the blade profile were calculated on the conditions prevailing at the mean height of the nozzles and blades, based on a pressure drop through the moving blades of P2 - P3, the pressure in the gap near the tip (P2T) would be greater than the mean height inlet pressure (P2) and the pressure near the root (P2R) would be less than the mean height inlet pressure (P2).

If the degree of reaction at the moving blade height were small so that the expansion in the moving blades were small, then P2 would be only slightly greater than P3 and the inlet pressure at the root P2R could in fact be less than P3. This would lead to an apparent increase in pressure through a part of the moving blades or negative reaction. Also, the pressure difference P2T-P3 at the tip could be greater than at the mean height. So the degree of reaction would be positive but larger at the mean height.

Thus, the degree of reaction may increase from negative to positive from root to tip.

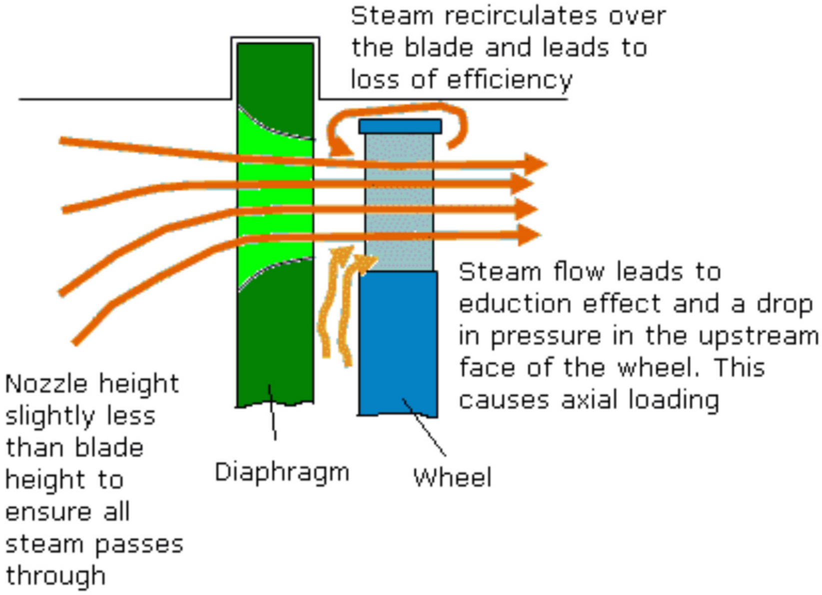
In reality, there is not necessarily a flow reversal at the section where negative reactions occur as would expect but simply an over-expansion of the steam at exit from the nozzles.

Such a blade would be highly inefficient, not only due to the high losses associated with negative reaction but also due to shock losses at entry to the moving blades.

Modern designs ensure a degree of positive reaction at the root of every moving blade and design conditions to avoid negative reaction at all other off design conditions.

Loss of efficiency due to recirculation

Balance holes may be drilled in the blade wheel to reduce the loading caused by this effect. This has the effect of increaseing the amount of recirculation, introduces a stress raiser and increases windage losses. To try to elleviate soem of this the bore is carefully radiused and polished
A certain amount of reaction is put on the blade by casuing a pressure drop across the blade to equal that caused by the eduction effect-approxiamtely 10% (Degree of reaction = Enthalpy drop over blade/enthalpy drop over stage)



Nozzles

Convergent-divergent nozzles

Steam leaving the boiler has high heat energy, low kinetic energy.

The amount of heat energy or enthalpy is dependent on the pressure and condition of the steam (dryness fraction, degree of superheat)

If the pressure is then dropped, then some heat energy must then be released. This heat may be used to perform work or be allowed to manifest itself as an increase in velocity.

Assuming the mass of steam must pass a point at any time, then;

C.S.A is proportional to specific volume of steam/ velocity

At inlet to nozzle the specific volume of the steam is relatively low, and rate of increase is low

Velocity increases at a greater rate

C.S.A is proportional to specific volume/ velocity

Therefore, area required for flow contracts As expansion proceeds, rate of change of specific volume increases to a point where it overtakes the rate of change of velocity and an increase in C.S.A is required

The point immediately prior to this is the min C.S.A and is called the throat.

If the remainder of the path is then kept constant then this nozzle is called convergent and the steam will leave the nozzle with no discontinuity of flow

The amount of steam discharged will depend upon inlet/exhaust pressure ratio.

limit :-

Exhaust pressure = 0.55 inlet pressure (suphtd)

Exhaust pressure = 0.58 inlet pressure (sat)

This is called the critical pressure as no drop in exhaust pressure will increase the flow.

If the steam flow enters a pressure less then the critical then the expansion becomes uncontrollable and there is a rapid dissipation of energy, scattering the stem and causing turbulence in the steady flow. If a divergent section is attached then expansion is controlled by gradually increasing the area making the discharge pressure equal to the back pressure.

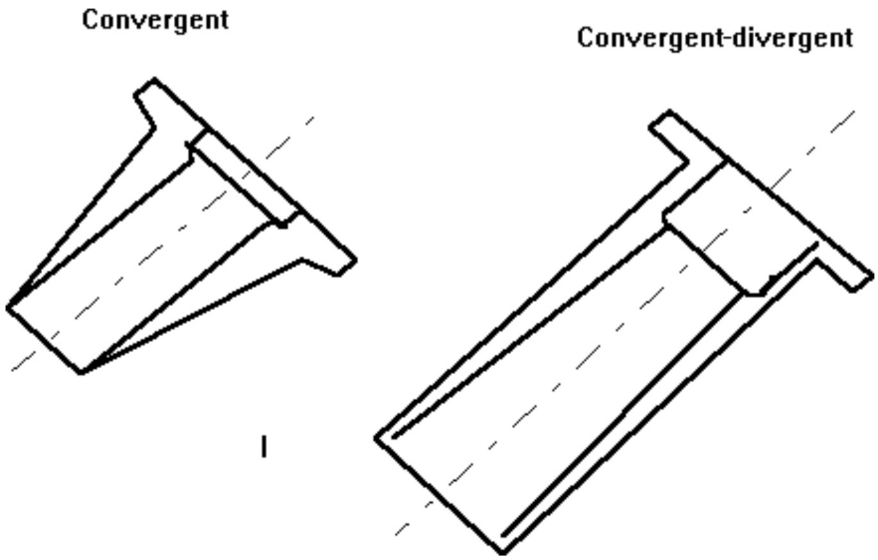
Steam leaves the nozzle without discontinuity of flow.

Divergent section has an angle of divergence of 8 to 10^o to centre line

Converging section made as short a possible as rapid contraction to damp turblence and help stream line for laminar flow.

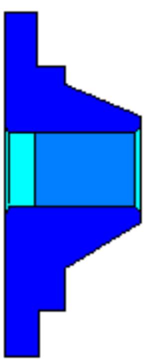
Expansion theoretically adiabatic.

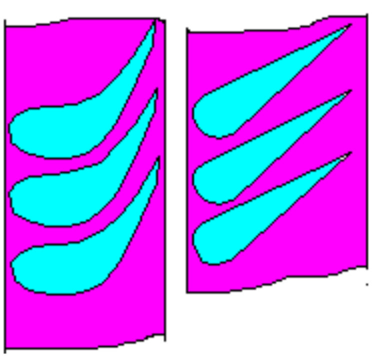
Wear, erosion, deposits create turbulence and reconvert some k.e. back to heat energy.



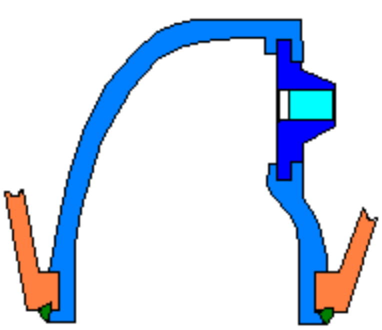
Nozzle plate and Boxes

The nozzles may be formed by machining of the nozzle plate, or by casting in steel partition plates. Alternately, nozzles may be fabricated of vanadium-molybdenum steel and welded into segments. These may be fitted into the nozzle box which is welded to the turbine casing.



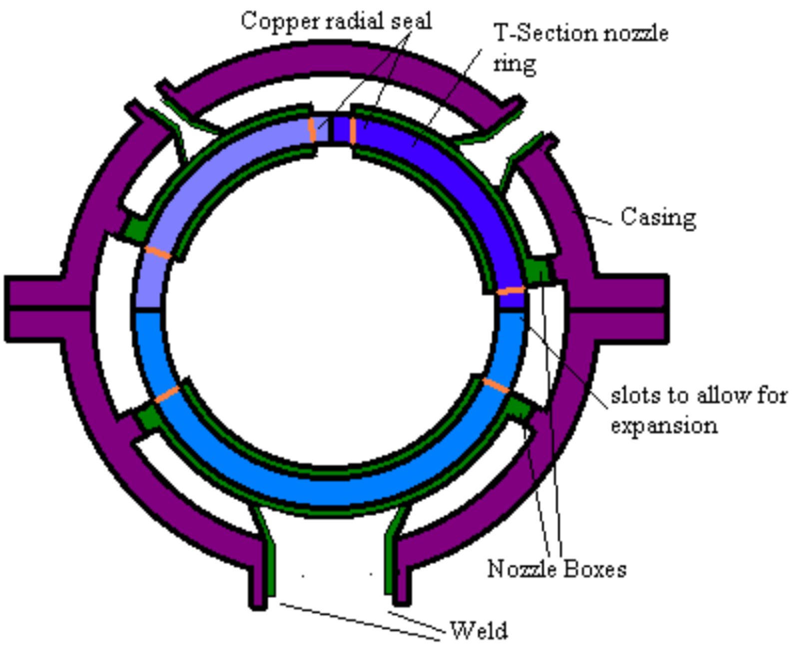


Different nozzle designs



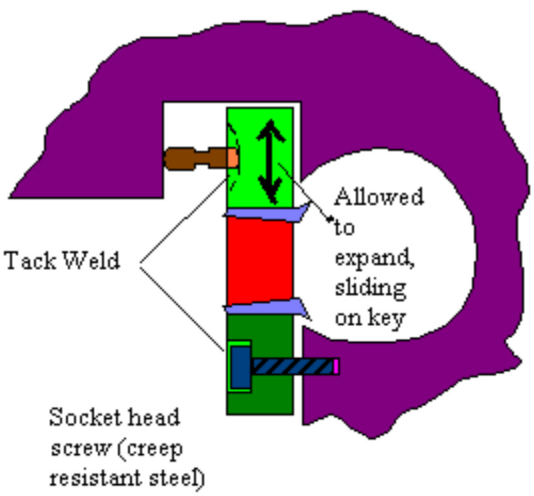
In this instance the T-section nozzle plate is manufactured as a continuous ring, fully stressed relieved, then cut into three sections with gaps to allow for expansion.

The nozzle box is made of a similar material to the nozzle ring and is welded into the casing, followed by stress relieving



The T-Section segments are entered circumferentially into the T-Slots in the nozzle box casting
Copper end seals let into radial recesses in the T-Slot cut down circumferential leakage
Continuous 360' nozzle plate minimises tip leakage over the blades.

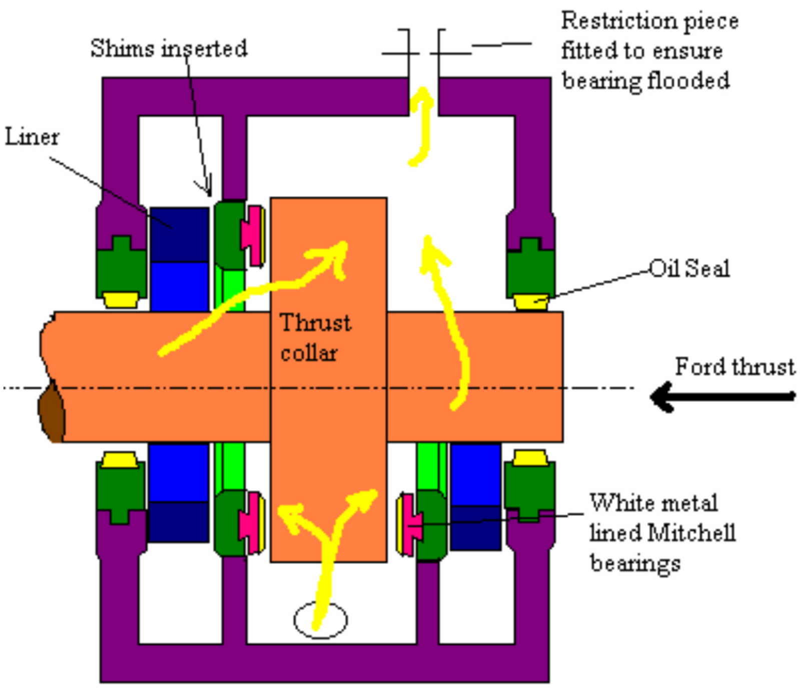
Modern Nozzle Plate



Thrust Bearing

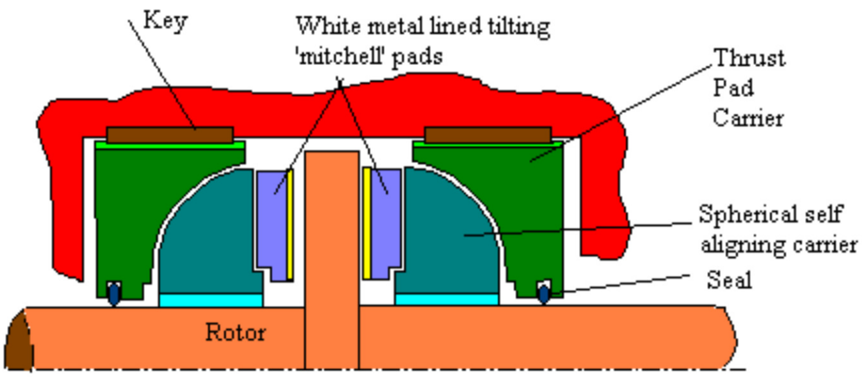
The thrust bearing is placed at the inlet end of the turbine casing as this is the hottest end and hence the most effected by differential turbine/casing expansion. This helps to prevent damage to the glands and also allows the use of reduced clearances, necessary as the specific volume of the steam is at its highest

Standard



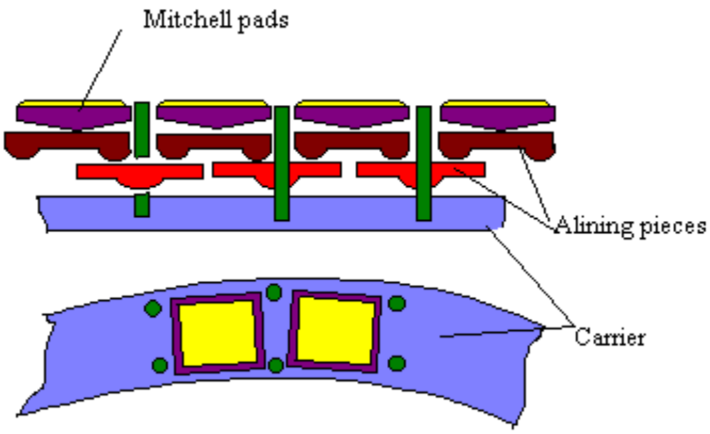
A half set of pads are fitted in the aft thrust direction as these are mainly for location only and do not carry any axial loading caused by the passage of the steam.
Oil enters the lower portion of the bearing and passes up via a restriction to ensure the assembly remains flooded with oil

Self Aligning



The high inertia of the spheical carrier reduces the arragements ability to cope with distortions and imperfections. The key prevent sthe rotation of the carrier.

Modern Self Aligning



This design has less inertia and hence is more effective with dealing with distortion.

Mitchell tilting pad bearings are commonly used due to their self aligning properties. The length of the pads is limited due to lubrication problems at the thin end of the oil wedge.
The pads are formed initially as a single ring then machined to requirements. This is why all pads must be changed following failure

Thrust Bearing Clearance

For inital setting up the rotor is centralised by jacking for'd and aft, and the clearance on the ahead side measured. A complete set of pads with carrier are made up to exactly the correct size. The astern size is measured, a running lube oil clearance subtracted and the astern set built up. The whole lot is fitted and final clearances measured.

The retaining ring is split at the horizontal axis. Stop plates at the joints prevent movement of the mitchell pads, one of these stop plates is extended and prevents the retaining ring moving

On the HP turbine normally only a half set of thrust pads are fitted. For the LP turbine with an astern turbine a full set is used. Shils and liners are fitted to set clearance.

There is a tendency for oil to be flung to the periphery under centrifugal action. ence, the orifice is fitted to ensure flooding, also metering flow from main system.

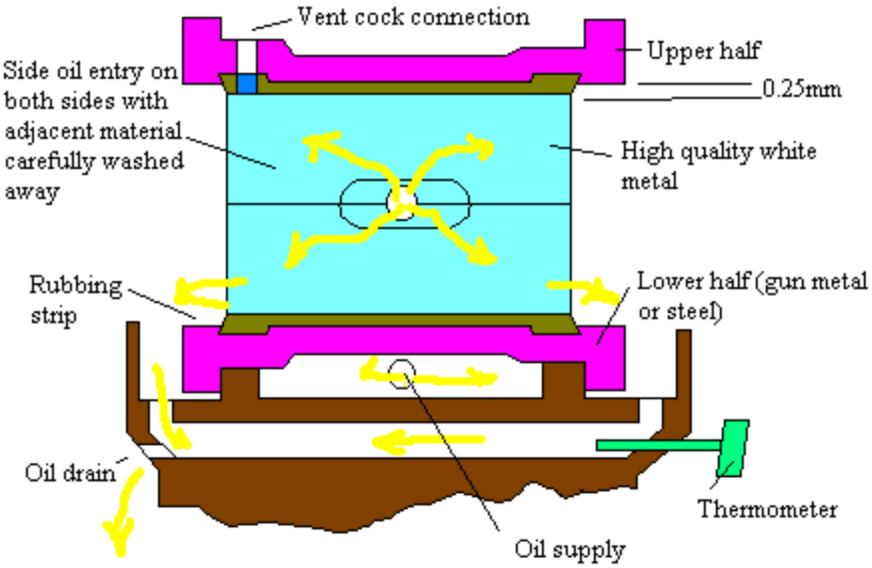
Total clearance = 0.25mm

This may be checked by attaching a finger plate to the casing and jacking the rotor for'd and aft. Poker guages may be used when the turbine is running.

Gun metal or mild steel is used for backing plate. Babbit metal (87% Tin, 8-9% Antimony, 3-4% Copper) for bearing face

An independent thrust collar may be case hardened and fitted using a combination of interference fit, longitudinal key and circumferential retaining ring.

Main Bearing



Teh length/diameter ratio is 2/3 to 3/2, the smaller figure is more relative to modern designs and can help reduce oil whirl. The top clearance is 0.5mm, this is sufficiently large to allow for large quantites of oil flow to aid cooling. No oil ways are provided other than a small amount of metal washed away at the inlt oil ports.

Maximum oil temperature is 83'C

White metal thickness 0.25 to 0.5mm, the thicker this layer the greater the ability to cope with dirt absorbtion. Thicker white metal is required for gun metal backed bearings due to the possibility of copper pick up should the white metal run. The white metal adheres better to the steel and provides better rigidity.

Typical white metal 85% tin, 8.5% Antimony, 6% copper.

An antisiphon device prevents all the oil leaving bearing if there is a failure of oil supply

Dummy bearings must be introduced to allow removal of lower bearing for inspection

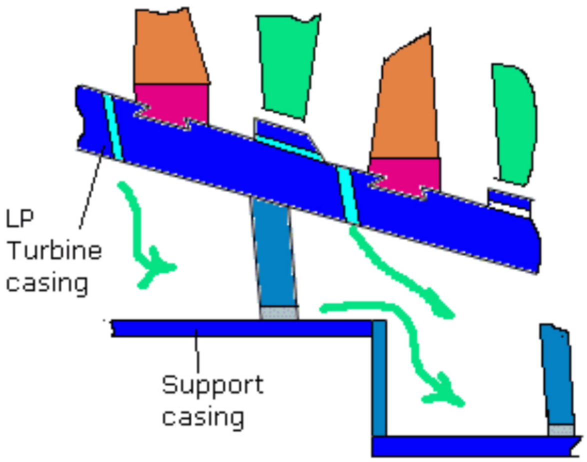
Turbine Drainage

Steam enters the HP turbine dry with superheated. As it passes through the stages the degree of superheat falls to a point in the final stages of the LP turbine they dryness factor is less than one and water droplets are entrained.

When the water droplets form they are very small and travel at the same velocity as the steam. As the stream passes through further stages the water droplets fail to keep in the steam stream with the changes in direction and velocity. The droplet size increases and is removed from the steam by centrifugal action and by contact with the blades.

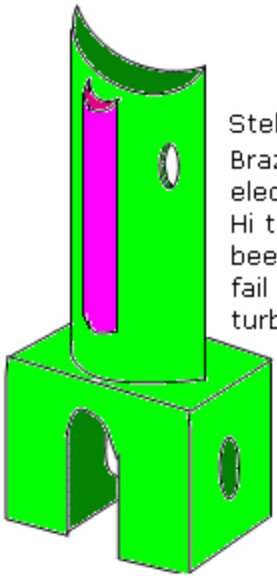
These droplets may impact the leading face of the rotating blades abd lead to erosion and cause a retarding effect. The damage is proportional to the swirl velocity and therefore is 4 times worse at the tip than the root.

The water droplets tend to flow to the tips of the blade and from there passes to the casing or pass on to further stages. The erosion causes pitting, perforations and blade failure.

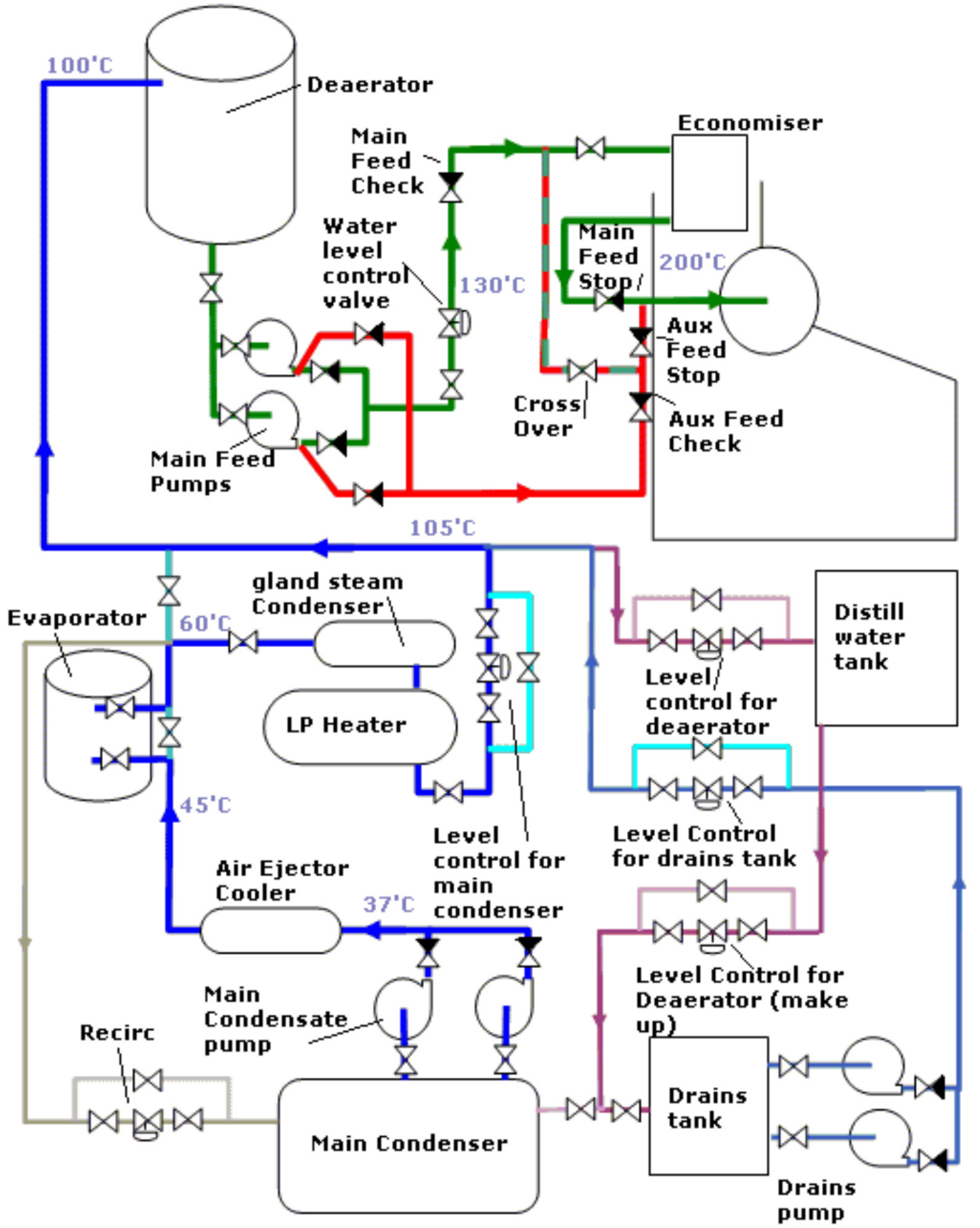


Damage to the blades may be reduced by brazing or electron beam welding on a stellite strip
However these can be undermined by erosion and be thrown off causing considerable damage.

One method of reducing this problem is by reheating the HP exhaust system by passing through the boiler. This has the added effect of increaseig plant efficiency but at increase cost of pipe run. Reducing blade height and therefore speed can lessen effects as can taper twisting the final stages (see seperate page)


Stellite strip
Brazed or more recently
electron beam welded.
Hi temp epoxys have
been used but tend to
fail in the event of
turbine overheating

Feed system



Shown above is a typical feed water system for a modern steam plant. Water is pumped from the main condenser by special centrifugal pumps having an inducer to allow suction from the vaery low pressures without vaporisation of the water. The water passes through the air ejector cooler to the Condensate cooled evaporator. A recirculation valve is available to return some condensate to the main condenser. The purpose of this is to increase the overall flow though the evaporator cooler thereby increaseing water production as well as to ensure a minium flow through the condensate pumps.

The water pass via the gland steam condenser and LP heater which in this case are shown as a combined unit on to the Main Condenser level controller. This prevent s the level in the condenser falling below a set level thereby causing the main condensate pumps to run dry.

Some times mounted after this is a deioniser and feed filter before the water is passed to the deaerator.

The deaerator is mounted as high as possible in the engineroom increaseing the suction head for the feed pump preventing vaporisation in the suction eye of the pump. Not shown is an automatic recirculation valve fitted to the main feed pump outlet to ensure a minimum flow through the pump. The boiler water then passes via the boiler water level controller to the economiser and then through to the boiler steam drum.
An second supply is available for use in emergencies to the drum either vai or by passing the economiser.

The drains tank condensate is pump via the drains tank level controller into the main feed system.

System level Control

Control of the amount of water in the system is by level control of the deaerator. One of the purposes of the deaerator is to act as a reserve capacity of high quality feed for the boiler. Water may be spilled to the feed tank or made up to the drains tank. An emergency filling valve is available for the main condenser the use of which is avoided as it introduces large quantites of gasses into the condenser reducing efficiency

Boiler economisers

Purpose

The purpose of the economiser is to increase plant efficiency by removing heat that would otherwise be lost in the flue gas and use it to indirectly feed heat the water. By heating the feed water it is also helping to prevent thermal shock as the water enters the steam drum.

Description

The flow of water is general counterflow. The exception to this is in the radiant heat boiler where the economiser is mounted immediately above the superheaters. The water flow in these so called 'Steaming economisers' is then parallel flow to decrease the tendency for the economiser to steam excessively above the design limits and lead to steam blockage , this is why these economisers are bare tube with no extended heating surface.

Vent and drains are fitted to header where isolating valves are fitted a safety valve must also be added.

The modern design involves the fabrication of the header and stub tubes which can then be heat treated. The tubes are then site welded to the stubs.

The previous use of expanded joints has now fallen out of failure due to the requirement of a multitude of hand hole doors with associated joints and hence possible area of leakage. The materials used are governed the materials susceptibility to cold end corrosion (see later notes), any metal having a surface temperature below the dew point will tend to have acidic deposits forming on its surface caused by the water absorbing sulphur trioxide and dioxide from the flue gases. Some metals are more resistant to this form of corrosion at lower temperatures, choice of material will initially depend on the minimum metal surface temperature and is calculated as the feed water temperature that is passing through the economiser plus 5^{o}C. For temperatures greater than 138^{o}C solid drawn mild steel tubing is used. Fitted to these are welded on extended surface steel fins or studs.

For temperatures between 115^{o}C to 138^{o}C shrunk on or cast iron gills must be used.

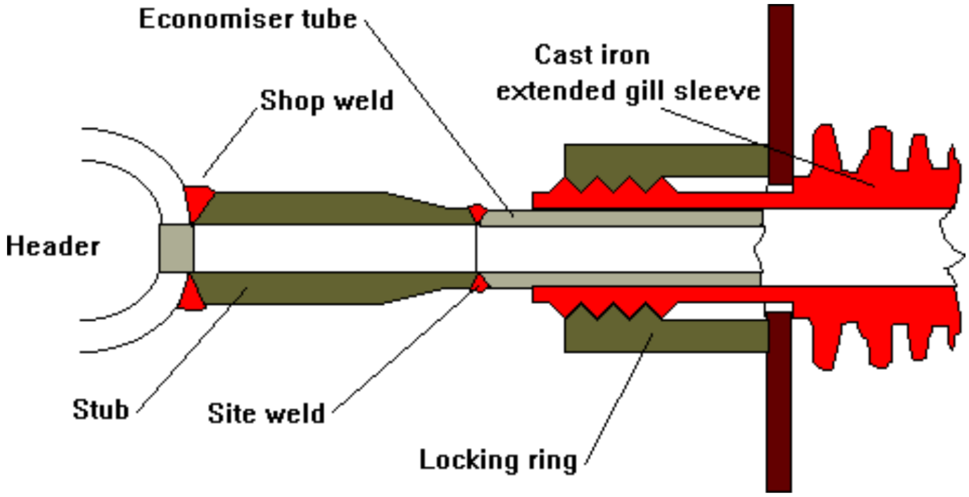
The temperature should not be allowed to fall below 115oC as this can lead to heavy fouling as well as corrosive attack.

Efficient sootblowing is absolutely essential to ensure that surface are kept clear of combustion products which can not only lead to heavy corrosion and a drop in efficiency , but also to the possibility of an economiser fire with potentially disastrous consequences. With this in mind it is not unusual to find provision for water washing, something which is carried out on a very regular basis on a Motor ship with waste heat recovery.

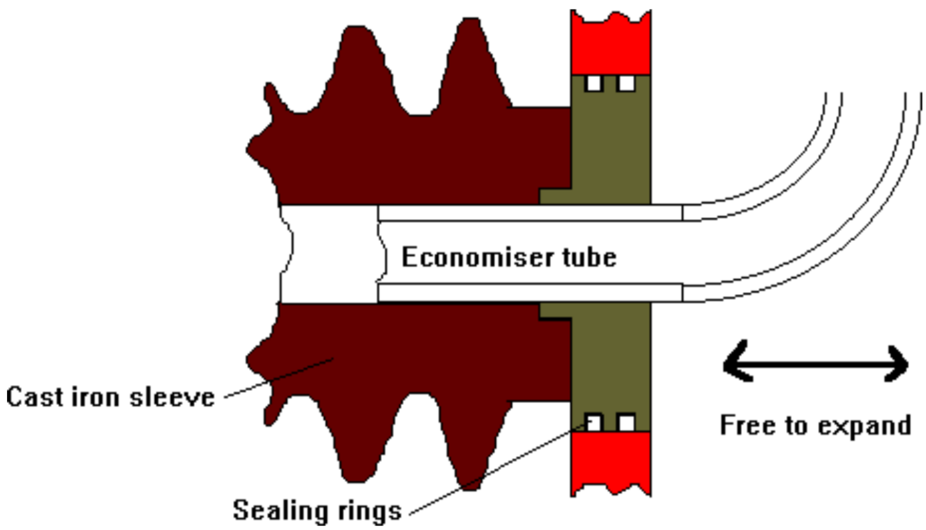
If due to failure it is required to run the economiser dry then the maximum gas inlet temperature should be limited to about 370^{o}C, vents and drains should be left open to ensure that there is no build up of pressure from any water that may be still located in the tubes.

Cast iron extended gill economiser

Inlet end



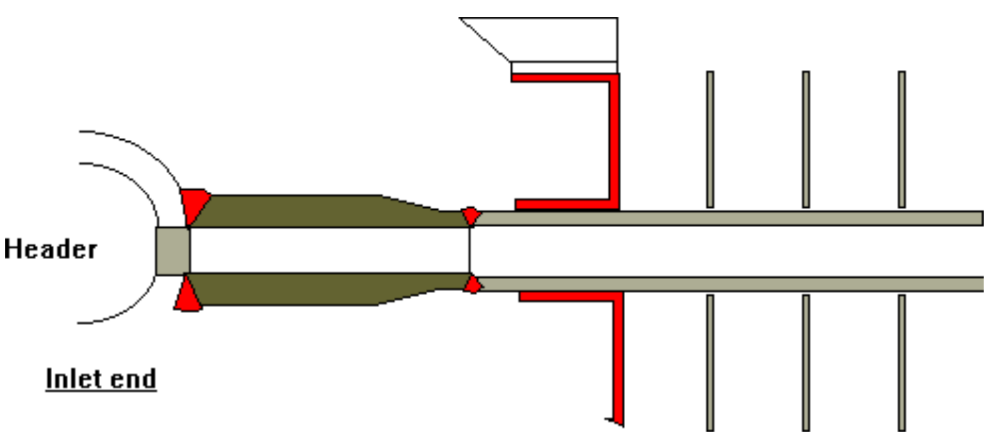
Return end

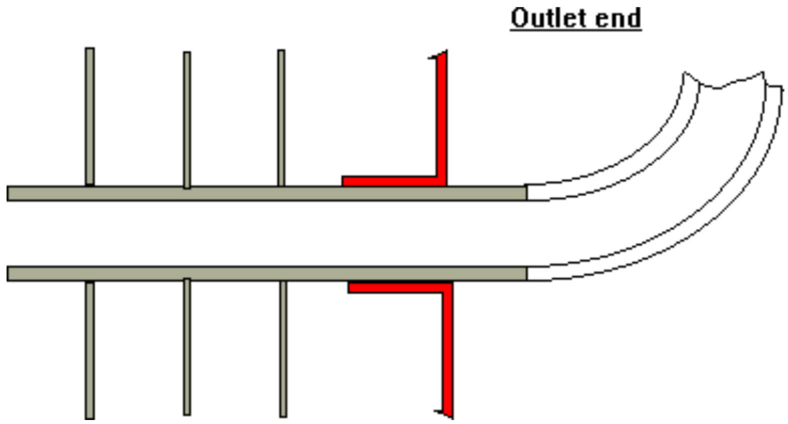


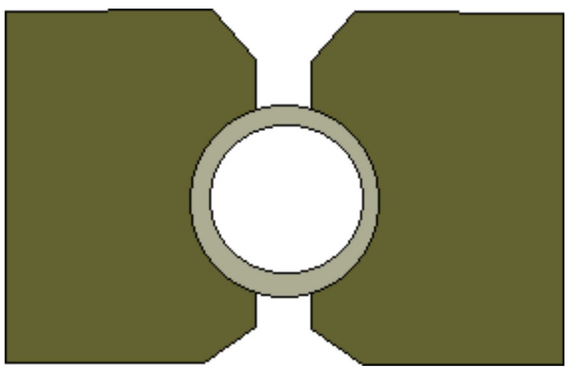
The unit is of the multiple pass 'melesco' style, the sleeves may be slid on before the bends are welded on.

The header is made out of mild steel.

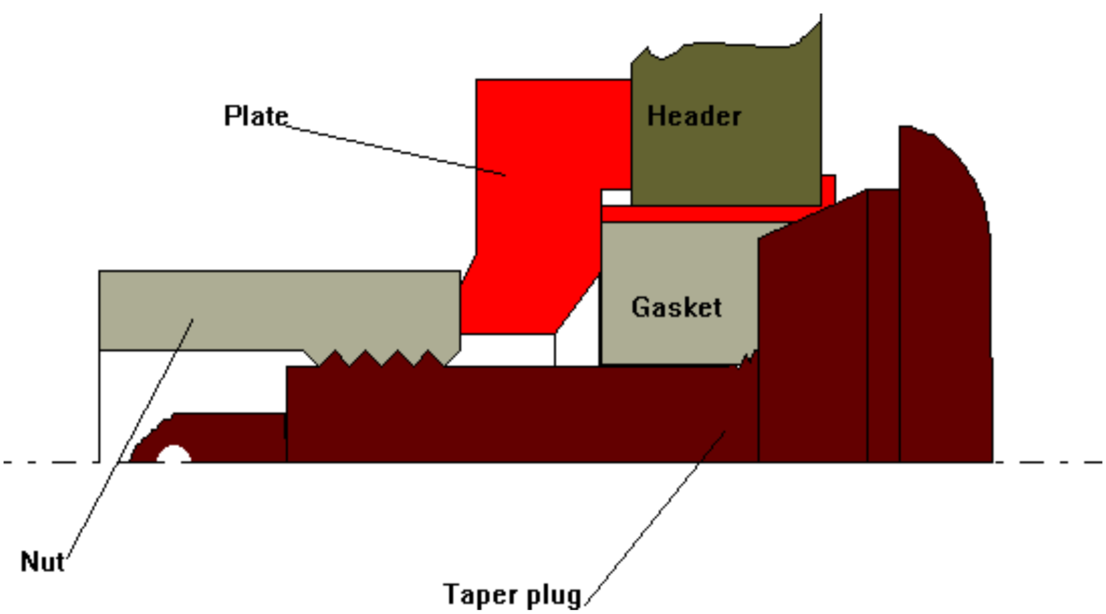
Mild steel fin extended surface economiser





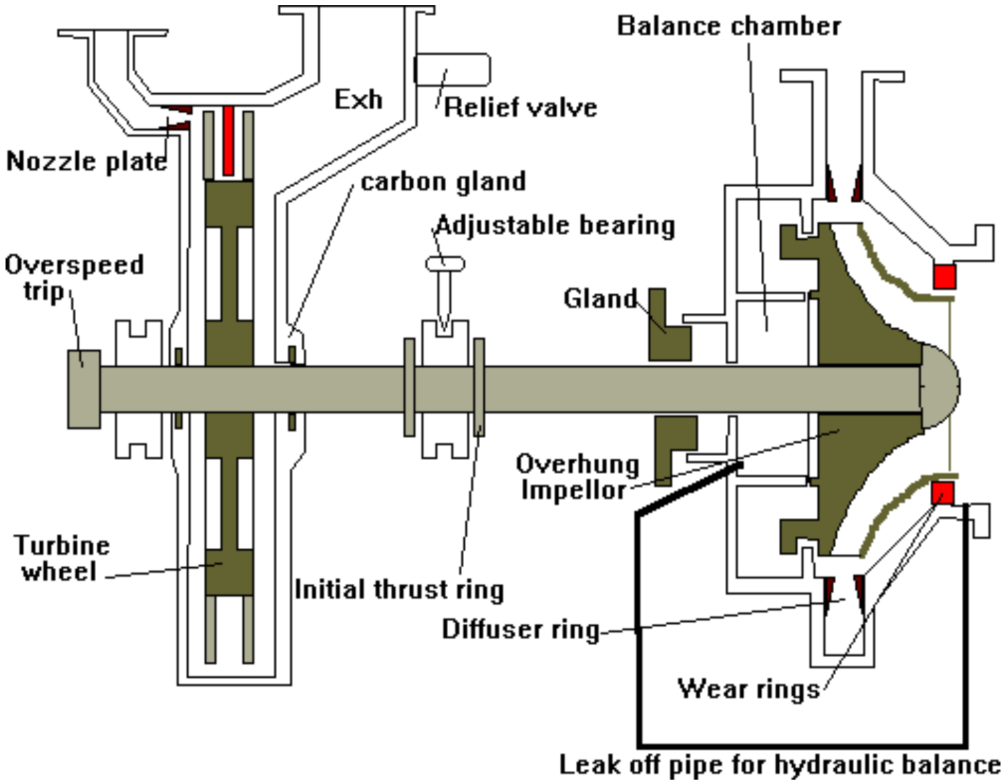


Plug



Boiler feed pumps

High speed , multistage centrifugal pumps are the preferred type due to their ability to supply large quantities of water and to provide it at steady flow avoiding shock loads on pipe lines and valves.



Materials

- Nozzle plate- Creep resistant steel
- Blades-Stainless iron
- Bearings-White metalled (oil lubricated)
- Turbine glands- Carbon
- Turbine casing- Cast steel
- Turbine wheel- Stainless steel
- Shaft- Nickel Chrome steel
- Wear rings- Leaded bronze
- Impeller-Stainless steel or monel
- Diffuser ring- Aluminium bronze

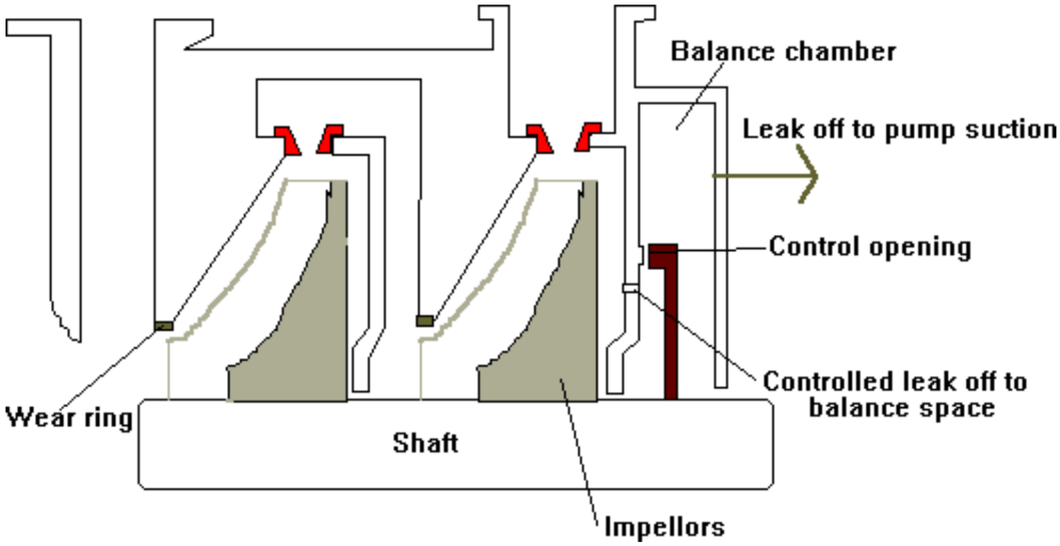
The impulse Curtis wheel (velocity compounded) rotates at speeds of around 7000 rpm. Velocity compounding means that there is very little pressure drop across the stages reducing the need for fine clearances. This allows the turbine to be run up quickly from cold.
The balance chamber must have a diameter greater than the suction wear ring. If the pump is designed to be supercavitating hard metal inducers are fitted which screw into the water. Any cavitation occurs on this which is made sacrificial.

Inlet steam pressure around 60 bar, outlet around 3 bar. Expansion down to lower pressures would require excessively large casings and would lead to problems of centrifugal stresses due to the larger blading required.

Carbon seals are used instead of labyrinths for simplicity and to keep the length of the unit down to a minimum. Due to the different coefficients of expansions between the carbon and the steel a madrill must be used to set the correct running clearance. For multistage pumps an extra end bearing is required and hence additional packed gland.

The pump is dynamically balanced by means of the balance chamber leak off to the suction eye, and the dam edges on the back of the impeller

Balancing of two stage pumps



Feed pumps of this type of balance are best started against either a closed or spring loaded discharge v/v to ensure rapid build up of pressure

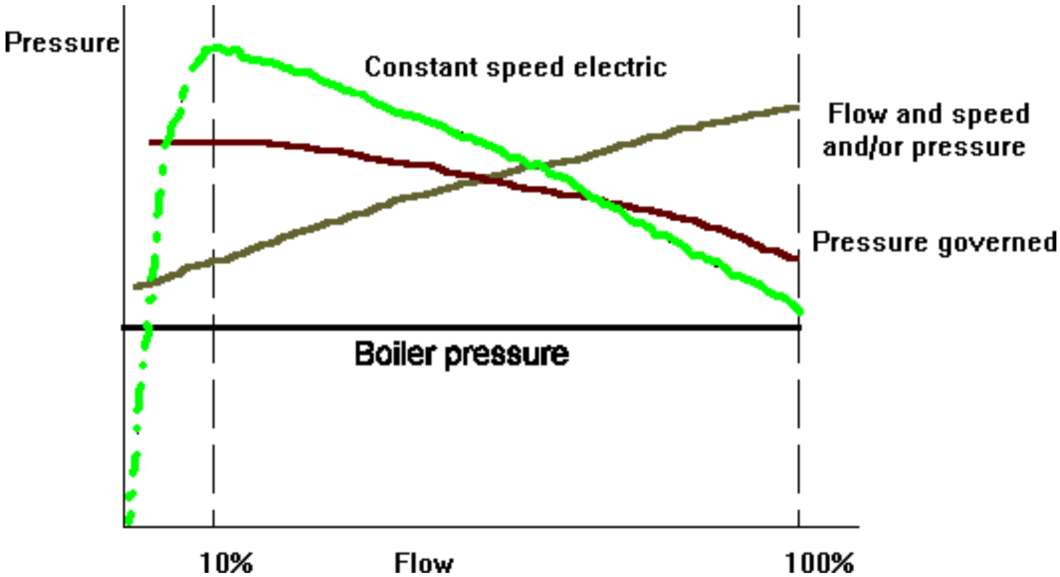
Bearings

Water lubricated bearings- Steel backing onto which is sintered a layer of porous bronze impregnated with PTFE (0.025mm thick). This PTFE is transferred to the shaft so providing very low coefficients of friction

Bearings operate at 115^{o}C with water supplied at 5.5bar 70^{o}C.
Bearing clearance- 0.15 mm
Max- 0.25mm must be replaced
Danger- 0.3 mm severe damage will occur

The bearings should also be replaced if less than 75 % shows on the surface.

Flow characteristics of controlled feed pumps



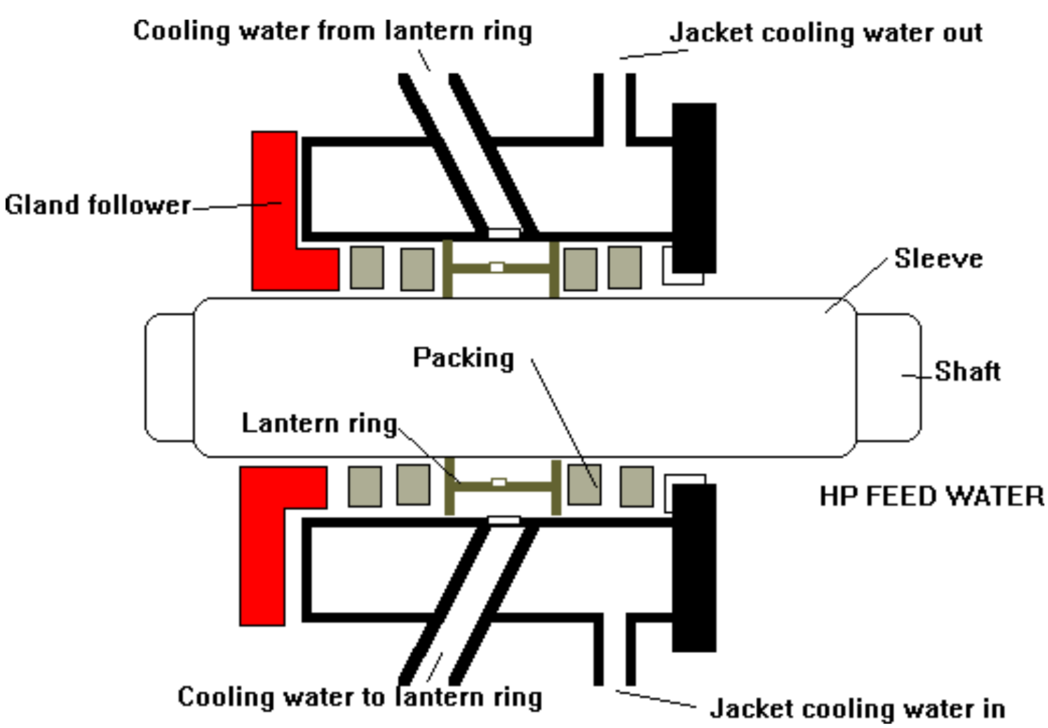
Constant speed (electric)- Below 10% turbulence becomes so great that the pump operates very inefficiently and must not be worked in this range. Hence, a recirc valve must be used. At full flow pressure is only just sufficient to feed the boiler

Pressure governed- Pressure droop designed in to give stable control.

Flow + Speed and/or Pressure- The extra element must be added with the flow otherwise the system becomes unstable. Characteristic can be level or slightly rising giving low pressure at low flow rates conserving energy and preventing water being forced at high pressures through partly open feed control valve.

Gland

Can be operated at very low flow rates due to reduced speed



Dearators

The need for deaeration

In marine water tube boilers it is essential to keep water free of dissolved gases and impurities to prevent serious damage occurring in the boiler

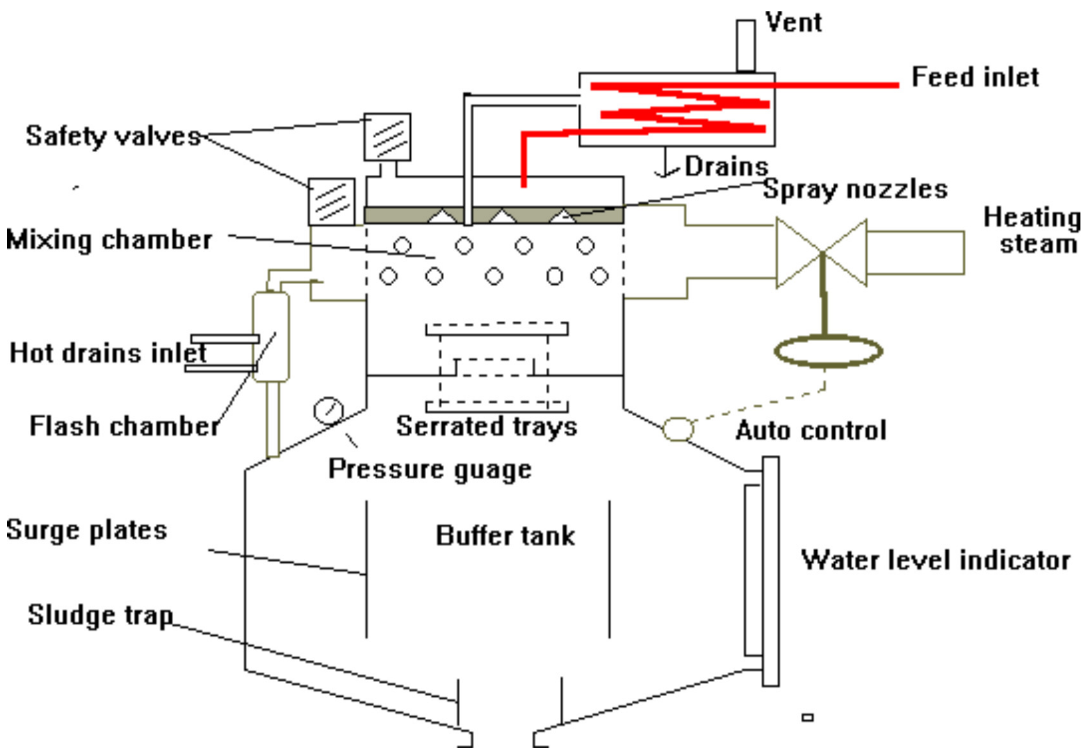
In a closed feed system the regenerative condenser removes the bulk of the gases with a dissolved oxygen content of less than 0.02 ml/l

However, it is recommended for boilers operating above 30 bar and essential for those operating above 42 bar that a dearator be fitted.

Purpose of fitting a Deaerator

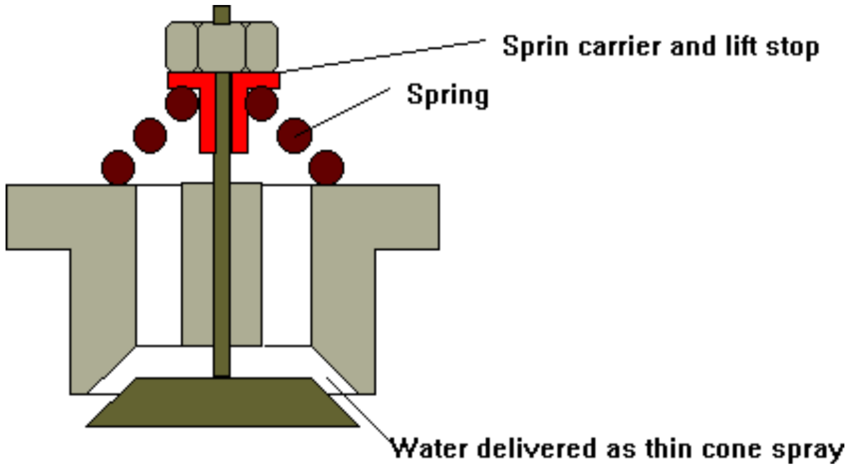
There are four main purposes;

- To act as a storage tank so as to maintain a level of water in the system
- To keep a constant head on the feed system and in particularly the Feed pumps.
- Allow for mechanical deaeration of the water
- Act as a contact feed heater.



Feed water enters the dearator via the vent cooler, here the non condensible gasses and a small amount of steam vapour are cooled. The condensed water is returned to the system. The feed water is sprayed into the mixing chamber via nozzles, for systems with large variations of flow, two separate nozzle boxes may fitted with two independent shut off valves to ensure sufficient pressure for efficient spray.

Alternatively, automatic spray valves may be fitted.



By varying the spring tension the pressure at which the nozzles open can be set at different levels.

The water in a fine spray, and so high surface area to volume, is rapidly heated to corresponding saturation temperature in the mixing chamber by the heating steam. This steam is supplied from the exhaust or IP system and is at about 2.5 bar.

The heated water and condensed steam then falls onto a series of plates with serrated edges, the purpose of these is to mechanically remove any gas bubbles in the water improving the efficiency of the process.

Finally the water falls into the buffer tank, before exiting to the feed pumps; as the water is now at saturation temperature any drop in pressure (such as in the suction eye of the impeller) will cause vapour bubbles to form. Hence, the deaerator must be fitted well above the feed pumps or alternatively an extraction pump must be fitted to supply the feed pumps.

Hot water drains are led to the dearator where they are allowed to flash into steam adding to the heating steam.

The non condensible gas outlet is limited so that there is only a small flow of water from the drain of the cooler. This water should be discarded as it contains not only high quantities of oxygen but also ammonia.

Requirements for efficient operation

- The minimum temperature increase is $28^{o}C$
- The minimum heating steam temperature is $115^{o}C$ which corresponds to a pressure of 1.7 bar; this is to prevent deposits forming on the economiser. To prevent cold end corrosion on cast iron protected economisers this temperature rises leading to the common practice of using steam at 2.5 bar
- The water at inlet should have an oxygen content of not more than 0.02 ml/l

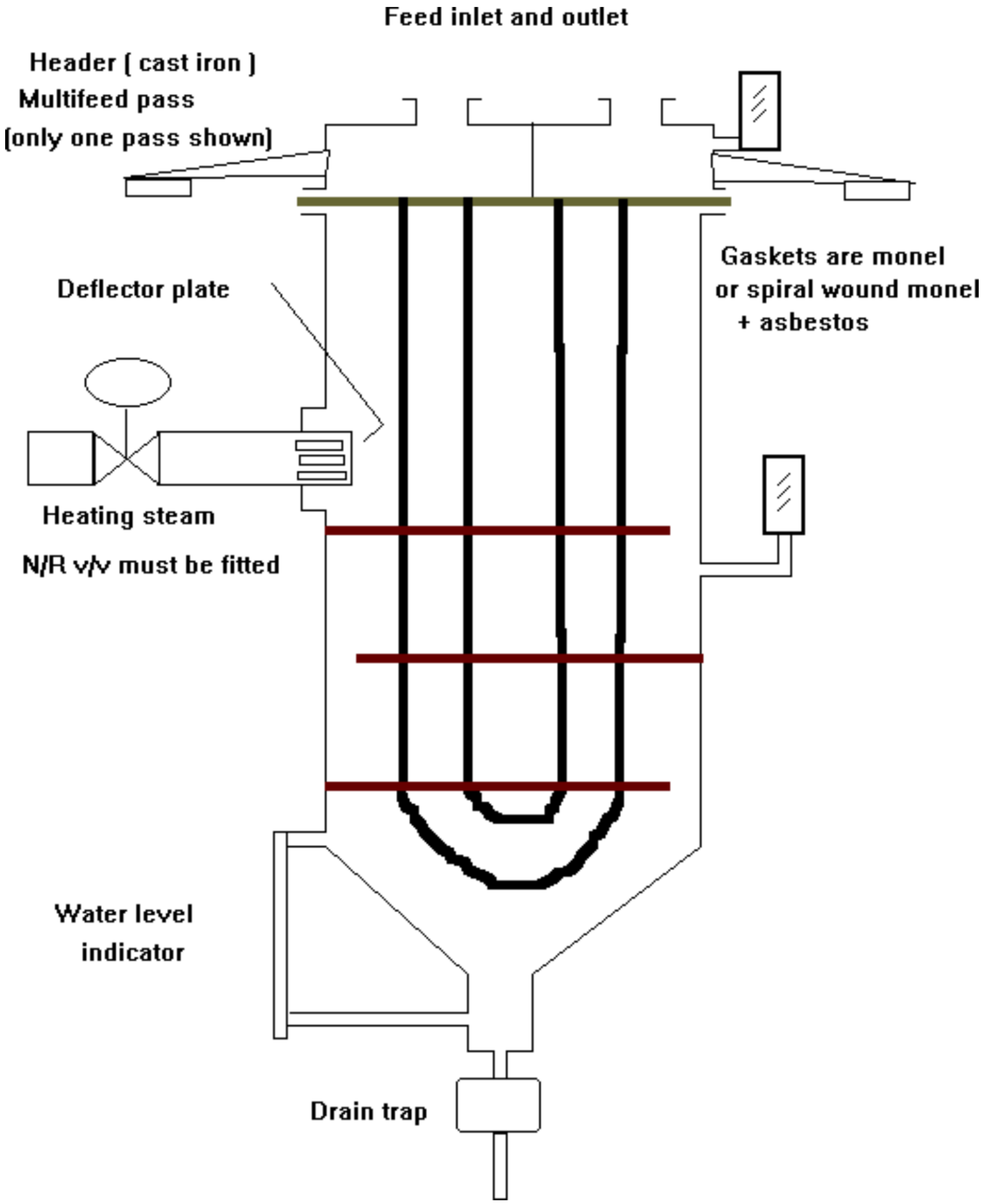
With these parameters met the water at outlet should have an oxygen level of not more than 0.005 ml/l.

A thermometer is fitted to the shell, the temperature should be kept to within $4^{o}C$ of the saturation temperature of the pressure indicated on the pressure gauge. This can be governed by the quantity of heating steam added. If the difference is always greater the partial pressure due to the non-condensable gasses is high and the possibility of redissolving increases. Where fitted the valve on the air outlet should be opened more to limit of too much steam being lost up the vent.

The fitting of vent condensers is not universal and it is not uncommon to see the vent led up the funnel where a small wisp of steam can be seen when correctly adjusted.

HP feed heater

HP feed heater as fitted to cascade feed heater system instead of economiser



- The high pressure tubes are made of copper nickel or steel.
- The casing is made of mild steel

For efficiency it is important that the bottom of the heater does not become flooded.

As a large difference in pressure can be accommodated between the feed and steam , this type of heater can be fitted on the discharge side of the main feed pumps; in a cascade feed heating system this replaces the economiser and the heat in the flue gas is recovered by a regenerative air heater (Lungstrom). This system allows the feed to be heated to a high temperature

The change in temperature is normally about 30^{o}C

The heater, when new, must be able to withstand either or both of the following;

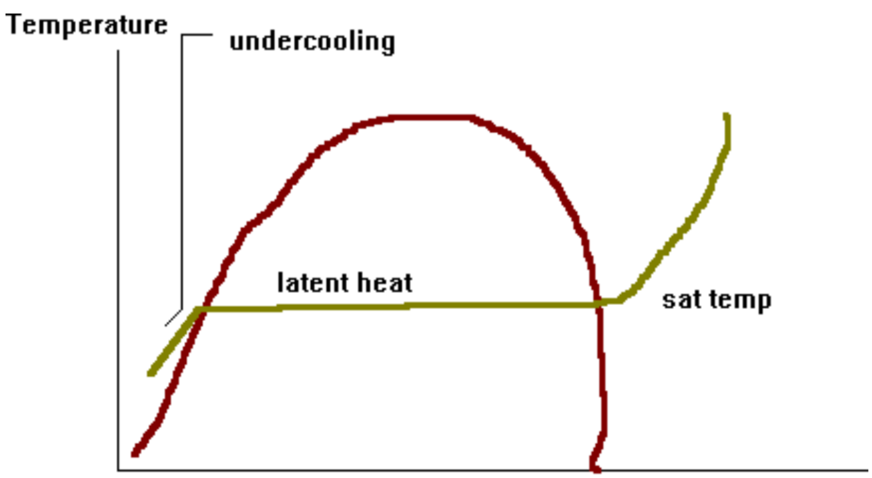
- 2 x boiler press + 20%
- 125 % feed press continuously

Condensors

BASIC FUNCTION

1. *Remove latent heat from exhaust stm and hence allowing the distilled water to be pumped back to system*
2. *Create vacuum conditions assisting flow of exh stm and also allowing for low saturation tempo and hence increasing recoverable heat energy from the stm*
3. *Deaerate*

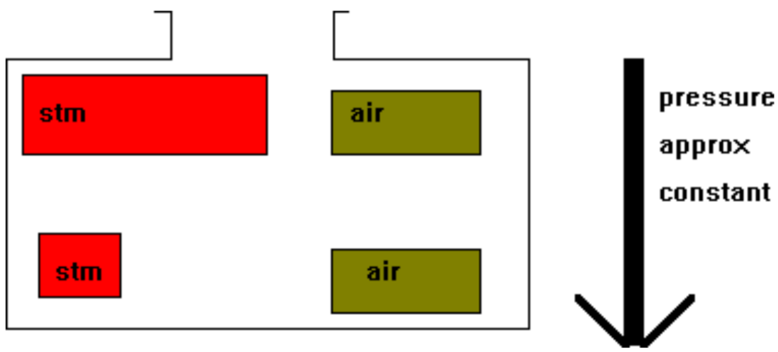
1,Only latent heat should be removed as this increases thermal efficiency



Even when the steam is expanded to vacuum conditions some 60% of the initial enthalpy at boiler conditions is thrown away in the condenser

3, Air must be removed from the condenser because;

- -it dissolves in water
- -it destroys the vacuum
- -poor conductor of heat and forms a thin film on pipes
- -increases under cooling due to the following circumstances



The stm quantity reduces and hence it is responsible for less of the total pressure. Hence it is at a lower pressure ,has lower saturation temperature and so is undercooled with respect to the actual pressure within the condenser (that is to say the condensate should be at a higher temperature equal to the saturation temperature at the pressure measured in the condenser.

Daltons law of partial pressure

Each constituent of a gas mix exerts a partial pressure equivalent to that if it occupied the space alone.

Condensate falling through the lower cooler regions containing the high air content is further cooled and re absorbs gases.

DESIGN

Must have large surface area available for cooling . Hence large number of small diameter tubes.

Cross flow is adopted for ease of manufacture, this allied to the change of state gives a cooling efficiency approaching that of counterflow

Taking into account tube material ,

max sea water flow rate should be maintained so as to;

a. maintain a sufficient steam/ coolant tempo difference across the material along the tube length
b. prevent silting

Circulating system should offer no undue resistance to flow and supply water equally to all tubes.

The tube batches should be so arranged so as to provide no resistance to the flow of steam. There is normally a narrowing inlet space within or surrounding the bank so as the passage area remains constant as the steam condensers.<

Failure to provide even flow leads to ;

a. reduced efficiency
b. pockets on non-condensable gasses being formed in the tube banks.

Allowance in the design should be made for some expanding arrangement.

PROTECTION OF CONDENSERS

Avoid low water speeds which causes silting.

Too high a speed leads to erosion.

Cathodic protection for plates and tubes by using soft iron / mild steel anodes.
> The effect can be increased with the use of impressed current using anodes of larger size and different material.

Alternately coating of the tubes with a 10% ferrous sulphate solution.

Rubber bonding of water boxes.

Marine growth prevention

- -chlorine dosage
- -Electro chlorine generator making sodium hypochlorite (switched off when dosing with ferrous sulphate)

Erosion protection

- -Inlet of tubes streamlined to smooth flow by expanding and bell mouthing

- - the fitting of plastic ferrules
- -for aluminium-brass inserts fitted and glued

When laying up the following procedures should be carried out to prevent damage;

- -Drain sea water side
- -If ferrous sulphate has been used then the SW side should be refilled with fresh water to maintain film
- -Where it is not practical to drain then the SW should be circulated daily

CONDENSER CLEANING

Before draining ensure no special chocking arrangements are necessary to prevent loading on springs or damage to the LP exhaust inlet gasket.

Waterside

- General inspection before cleaning
- Place boards to protect the rubber lining
- Use water jets or balls blown by compressed air through the tubes
- Only brushes or canes as a last resort
- When plastic inserts are fitted work from the inlet end
- Test for leaks on completion
- Clean or renew the sacrificial anodes
- Remove the boards and prove vents and drains clear

Steamside

- Inspect the steam side for deposits, clean with a chemical solvent where required
- Examine the baffles, tube plates and deflectors
- Look for vibration erosion damage of the tubes
- Inspect for possible air leakage
- Box up and remove chocks.

Leakage

The indications that a leak is in existence is that of high salinity measured in the condensate and boiler combined with a rapid drop in pH.

The first aid should be the injection of sawdust followed by a shut down at the soonest possible time.

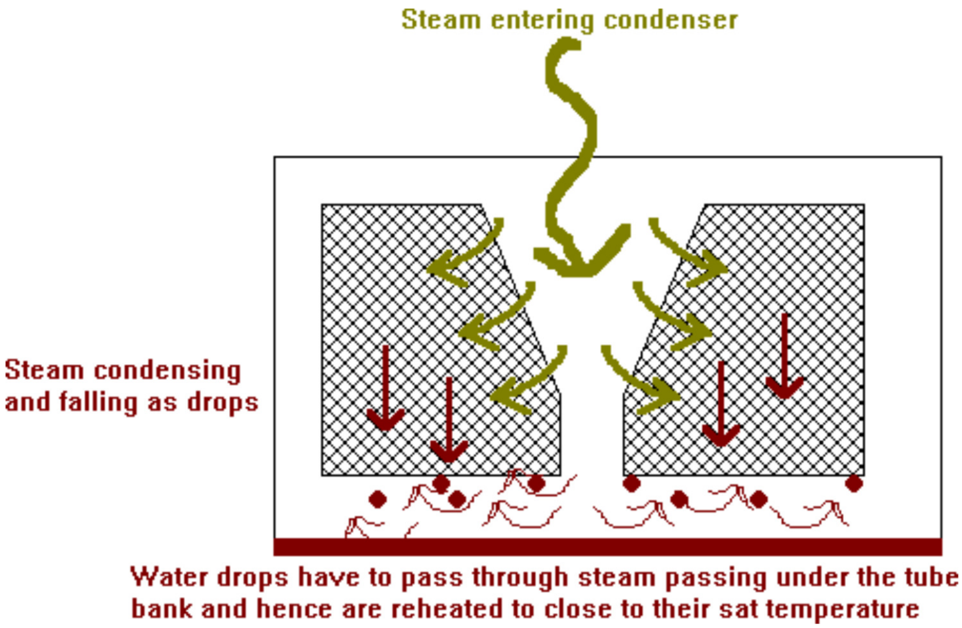
There are three methods for leak detection;

Ultrasonic-Here, electric tone speakers are fitted in the steam space, and a microphone passed down the tubes. Alternately, instead of speakers a vacuum can be drawn with the microphone picking up air leakage.

Fluorescent-The water side is cleaned and dried, chocks are fitted and the steam side filled with water containing a quantity of flourescene. A UV lamp is then used on the water side.

Vacuum test- Draw a vacuum and cover the tube plate with plastic or use the ultrasound microphone.

Regenerative condensers



With the regenerative effect the water is heated to within one degree of the sat temperature so releasing dissolved gases which may have been re-absorbed as the drops where falling.

The dissolved oxygen content should be less than 0.02 ml/litre.

At the air ejector take off for the gasses, a cooling space is so arranged so a to ensure that there is no reheating of the gasses which would lead to expansion and reduce the efficiency of the process.

Drains which are led to the condenser are led to the top so the water is reheated/dearated before extraction.

The increasing use of scoops has led to the single pass condensers with SW velocities of 2 - 4 m/s being the ideal with minimum's to prevent silting of 1m/s.

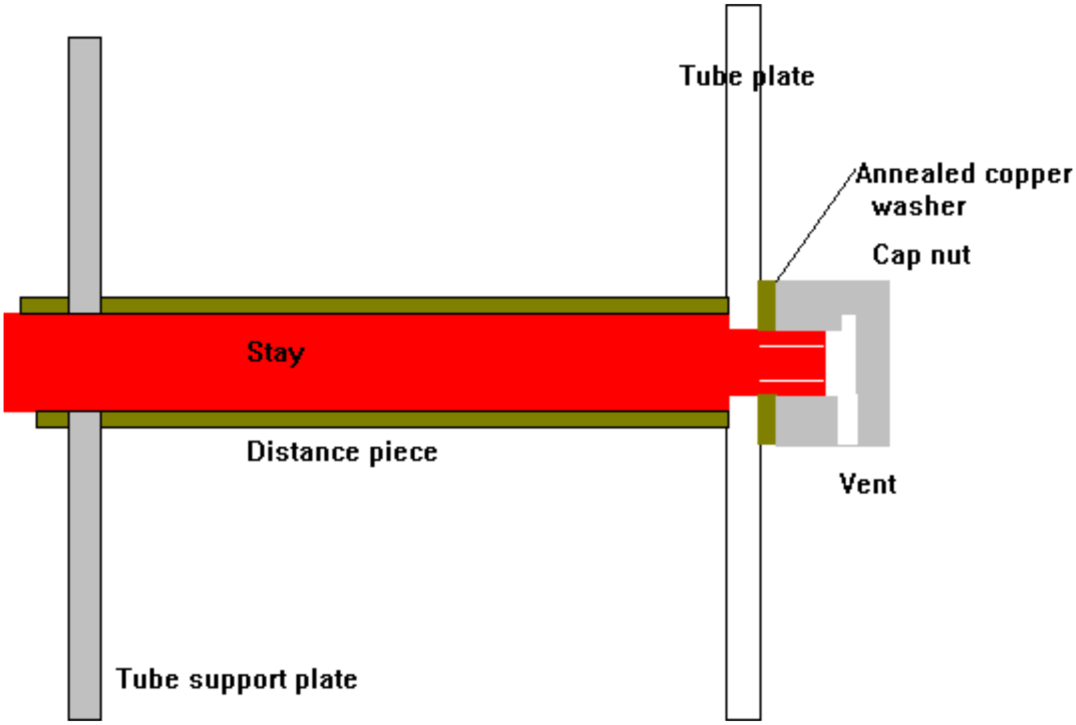
Material of tubes

Cheap aluminium brass has a low allowable flow speed of 5 m/s; cupro-nickel has a higher flow of 10 m/s but is dearer and a poorer conductor of heat.

Tube fitting

This is by expanding and bell mouthing or with by ferrules and alternately fibre and metallic packing at the other end,

Stays



Tube stays cannot be used where the tubes have been expanded at both ends, the tubes must support themselves.

Advantages of the different designs of condenser

Underslung

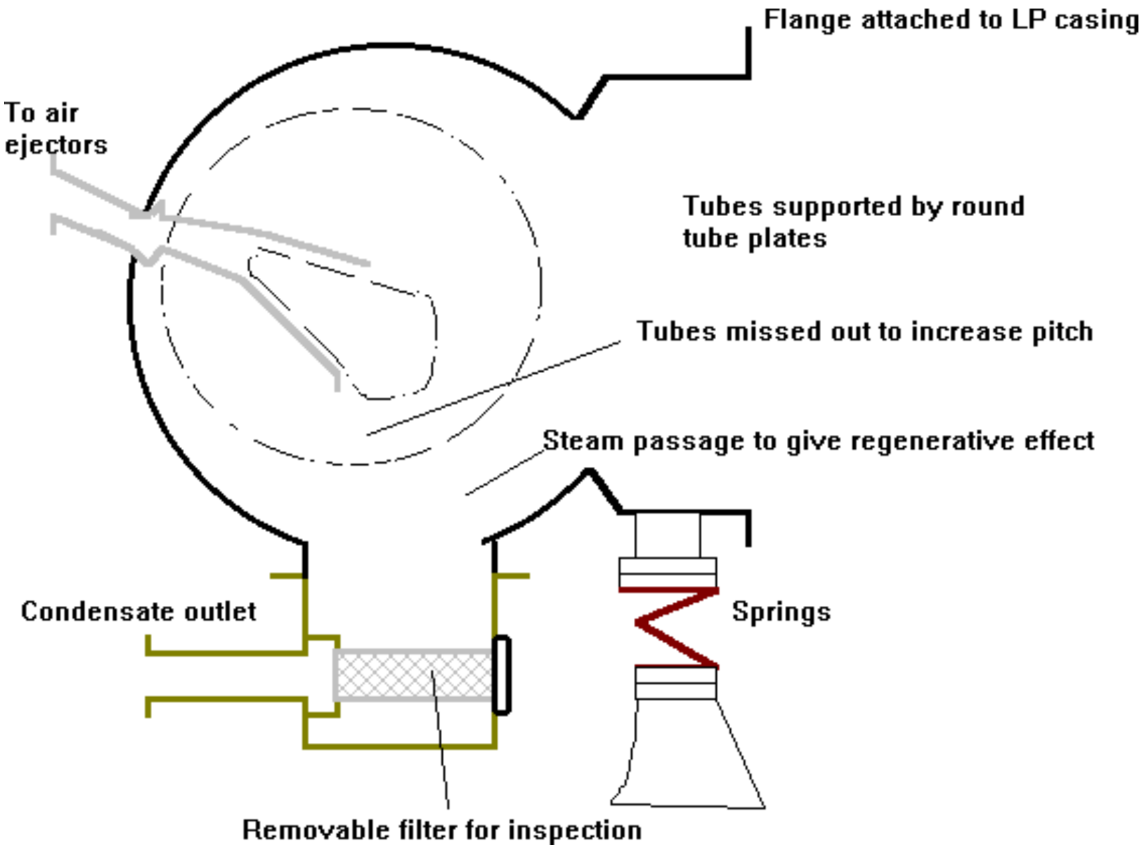
This provides a short path for both the ahead and astern steam, however the steam must turn through 90^o before entering and hence there is a possibility of increased windage losses Windage loss is where the ahead steam is picked up by the astern turbine which recompresses it and heats it up leading to a loss of efficiency, reduced vacuum and heating up of the astern turbine.

The length is reduced but at the cost of increased height. The fitted support springs under the condenser carry two thirds of the weight and allow for expansion.

Axial plane(radial flow)

Reduced height at the expense of length. The ahead and astern both exhaust in the same direction so reducing the chance of windage.As the turbines are situate lower and inline the alignment to the tailshaft is simpler.The big disadvantage is that the condensate level is critical and must not be allowed to spill out.

Axial plane condenser as fitted to the Stal-Laval AP Plant



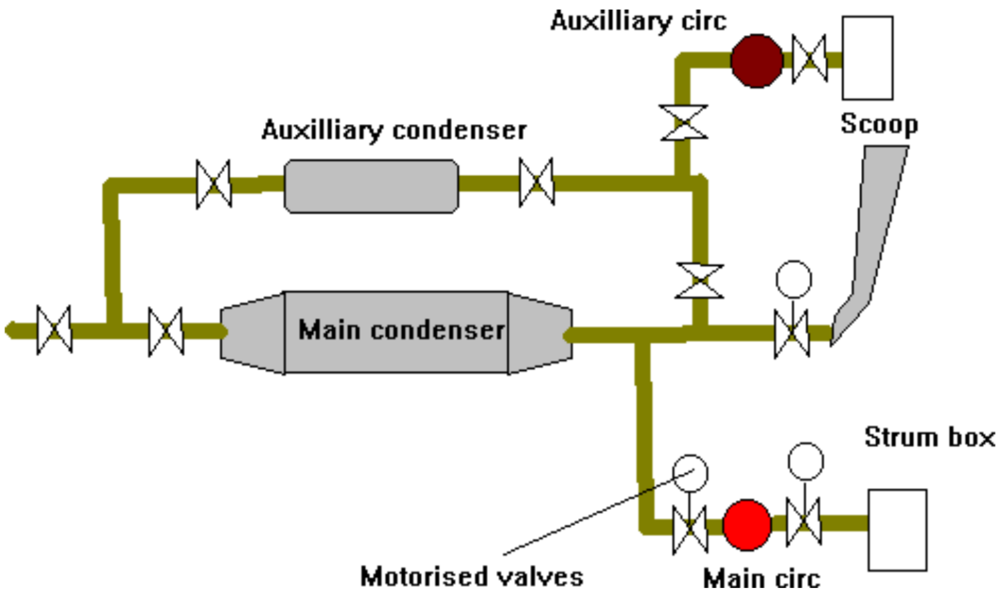
The tube pitch at the bottom of the tube stack is increased by leaving out alternate tubes over the final three rows. This helps to encourage the regenerating effect. A cooling pack of coarse pitched tubes is fitted within the bellmouth for the air extraction to prevent reexpansion of any gases and removal of vapour

The condenser is a dry bottom type with a low water level in the hot well being maintained by the super cavitating pumps

Scoop systems

This single plane design of condenser is of the single pass type and is well suited to use with scoop systems. This is were cooling water flow to the condenser is supplied from an angled inlet pipe on the ships side. For this to operate the engine has to be travelling at a certain speed to give the correct flow of water. Below this speed the scoop must be shut off and a centrifugal main circulating pump in use. The advantage of this system is that the main circ can be of a much smaller size than would be required if it had to supply cooling water requirements for full engine load conditions. In this case it would be normal to fit to pumps of 50% capacity.

Scoop System layout


Auxilliary circ
Auxilliary condenser
Scoop
Main condenser
Strum box
Motorised valves
Main circ

Air Ejectors

FUNCTION

Air ejector units are generally of the steam jet type. Although electrically powered units offer the advantage of ease of installation and slightly improved operating efficiency their maintenance requirements has ensured that the most common type on larger installations are steam powered

Their primary function is to remove non- condensible gases from the condenser

After passing through the nozzle the high velocity stream jet entrains air and vapour , compresses it, and the mixture passes to a condenser section were it is cooled. The air with any uncondensed steam and vapour passing to the second stage were further compression of the air takes place.

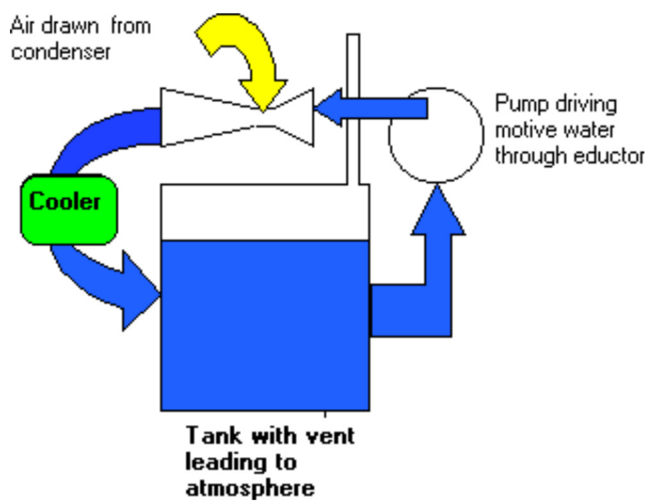
Depending upon the number of stages of the air ejector, the air is now discharged to atmosphere or to a final stage and then to atmosphere.

The condensers are of the surface type and are cooled by condensate, in this way acting as a feed heater.

Either, two complete units or two ejectors mounted on one condenser are used , nozzle diameters are very small typically 1.2 to 4.7 mm and are liable to wear, abrasion and blockage.

When manouevring or at rest provision must be made to ensure that there is adequate flow of condensate through the condenser to provide cooling . This is achieved by means of a recirculating v/v which leads condensate from the outlet of the air ejector condenser outlet (and other low pressure feed heaters such as an evapourator) back to the main condenser. The opening of this v/v should be limited as it leads to a loss of plant efficiency.

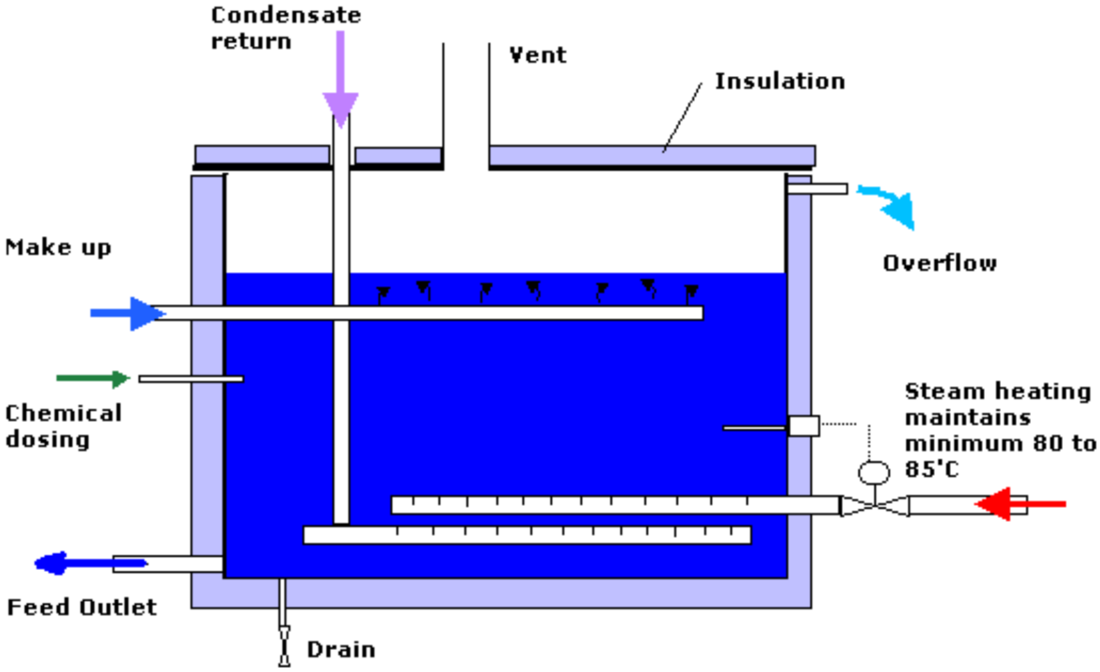
Electric Powered



The position of the cooler can vary; either as shown, incorporated into the tank or on the suction side of the pump.

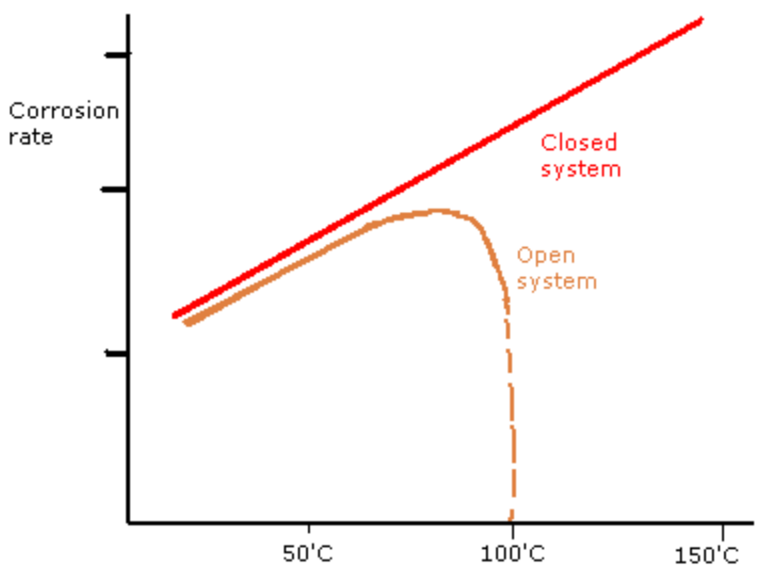
Feed Tank Design

A well designed feed tank should be designed to minimise the oxygen within the feed system. This is especially important with open feed systems.



The following are taken as parameters for a well designed tank

- Adequate ventilation with on or more vent pies determined by the volume of water
- Condensate enters as low as possible via a slotted sparge pipe
- Cold water make up enters at highest point
- Sufficient tank volume to cope with transient flows from normal operations without necessitating spilling back to feed tanks or overflows.
- Tank to have sufficient volume of water at normal working level to allow for 1 hours operation at maximum demand.
- Take off to feed pumps to be at least 75mm from tank bottom
- Tank to be located to provide head requirements at normal working level for feed pumps

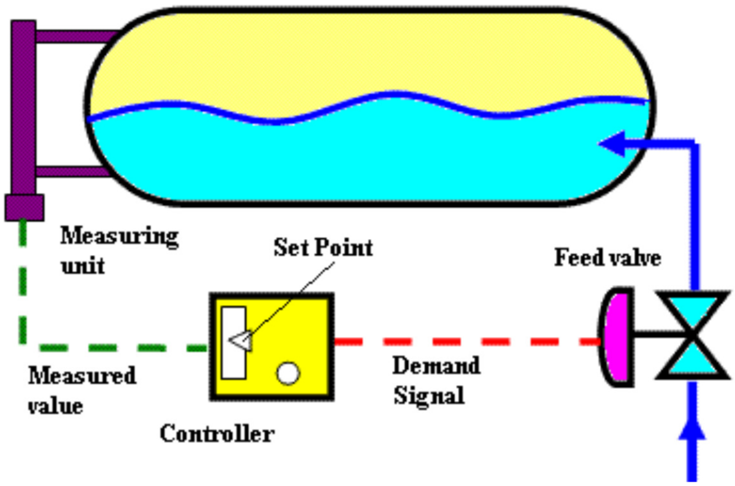


As a rule of thumb chemical reaction rates double for evey 10'C rise in temperature. For feed system this remains true upto about 80'C for open system. After this due to reducing solubility of oxygen the rate of corrosion reduces. Thus steam heating on the open feed tanks have thermostats set at 85'C or higher

Boiler Water level Control

A regulated supply of water must exist for a boiler generating steam. With the system in balance without leaks the flow of water to the boiler will be equal to the flow of steam. When there is a change in steam demand then the flow of water will have to be changed.

One Element



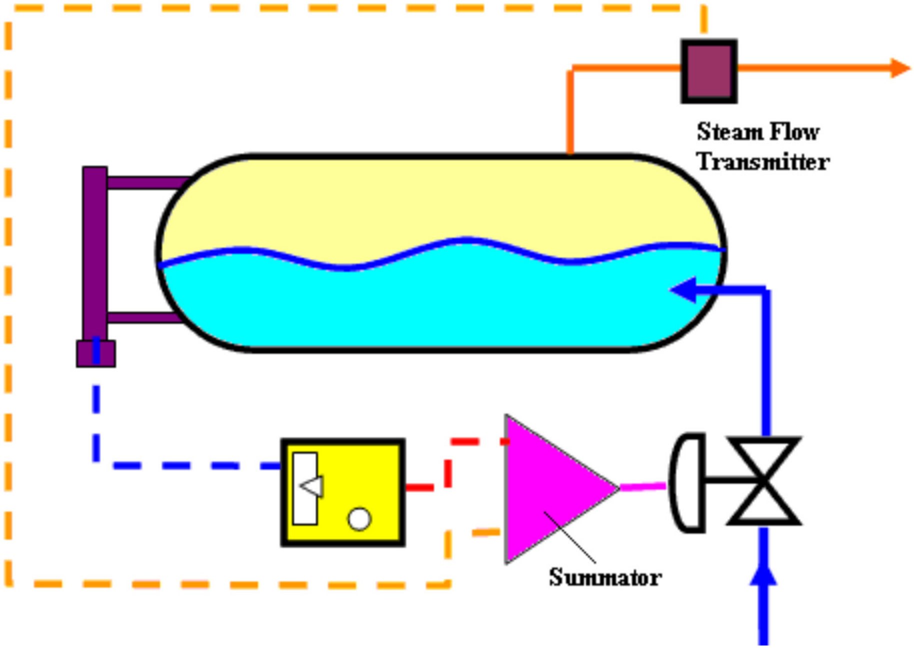
The water level is measured using a suitable device. This level is sent to the controller as a measured value. The controller compares this measured value against a set point. Any deviation from this set point caused a demand signal to be generated.

Two Element

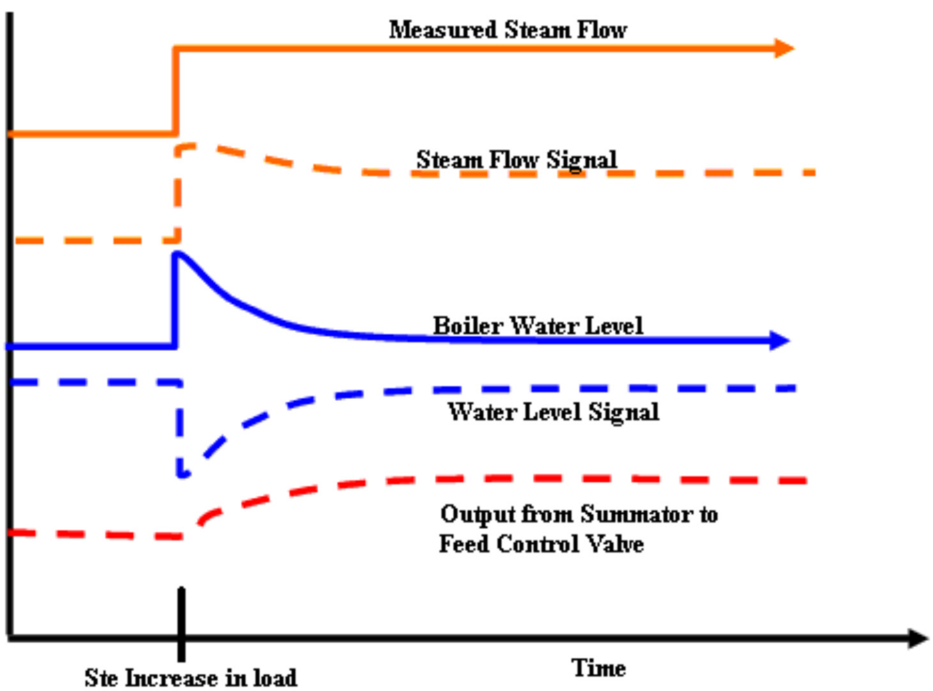
A single element controller is considered suitable for only the smalest of boilers. The reason for this is the effect of stepped load changes

Should there be a sudden demand for increase steam flow there will be a requirement to increase the firing rate. The increased firing rate increases the ebullition or bubble formation in the water and the volume of water increases or **swells**. This will be seen as an immediate increase in the water level.

For a single term controller the tendency will be to close the feed supply valve. However, the increased firing rate will generate more steam flow from the boiler and in reality an increase in water flow would be required

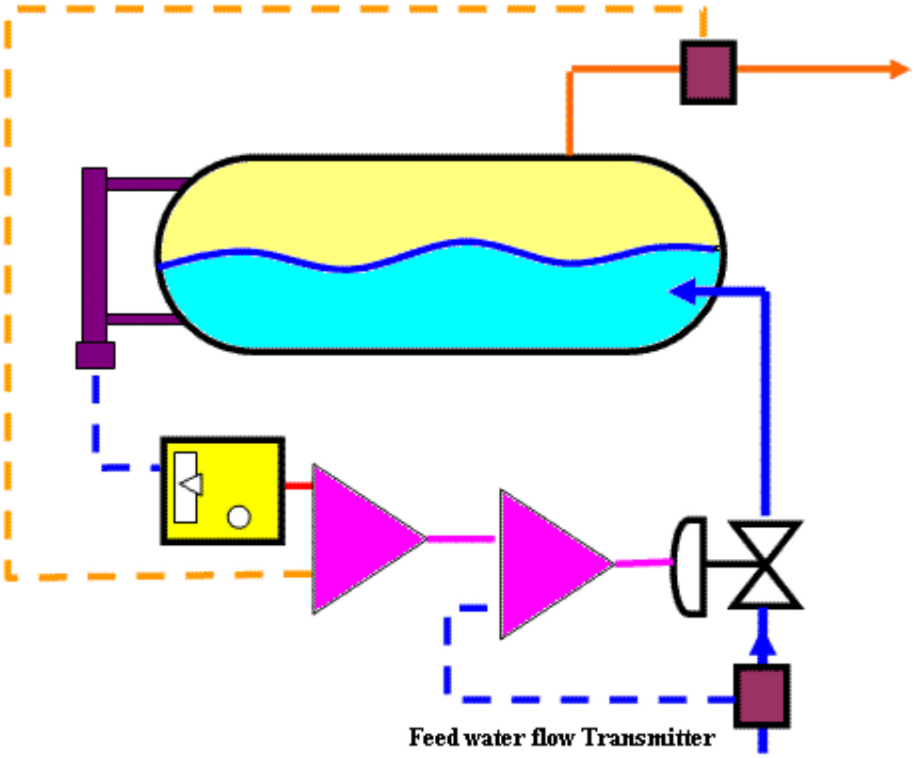


For a stepped load increase there will be tendency for the water level to rise due to swell as described. The Water level controller will give a reduced demand signal. The steam flow transmitter will detect an increase in steam flow and send an increase demand signal via a conditioner which adjusts this signal to suit the system. These two signals pass through a Summator. The resultant effect will prevent any immediate sharp change in the demand signal to the feed flow control valve.



Three Element

Variations in feed pressure will vary the true feedflow rate to valve demand signal. For improved control an additional feed water flow element may be added. This is the case only when the cost and complexity can be justified due to improved plant efficiency and critical water level control.


Feed water flow Transmitter

Cylinder Combustion

Fuel oil is a hydrocarbon consisting of hydrogen and carbon, together with other elements most of which are unwanted.

Hydrogen has a higher calorific value than carbon, therefore, more heat may be obtained from fuels containing higher Hydrogen/Carbon ratios.

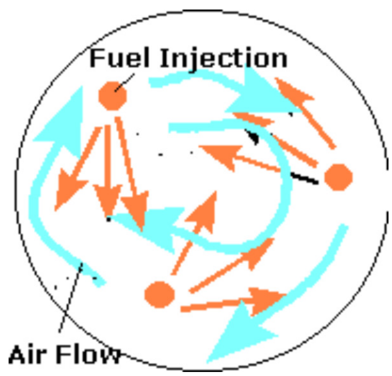
The lower specific gravity of hydrogen than carbon allows a rough rule of thumb to be; the higher the Specific Gravity, the lower the Calorific Value (and quality) of the fuel. The presence of impurities clouds the issue slightly

For efficient combustion an ignition source and sufficient oxygen need be present to completely oxidise the Hydrogen to water vapour and the carbon to carbon-dioxide.

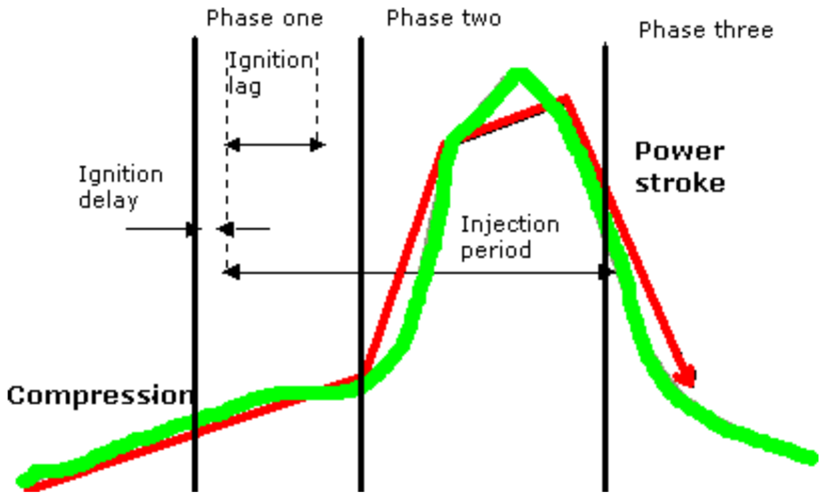
The combustion is required to occur in a short period of time in an internal combustion engine, there are five essential requirements to ensure this;

1. **Correct Air/fuel ratio**-*There must be sufficient oxygen to burn not only the hydrogen and oxygen present but also any other combustibles, such as sulphur. To be effective and efficient all the fuel must be burnt in the cylinder i.e. all the hydrogen must be burnt to water and all the carbon must be burnt to carbon dioxide. As the time for combustion is short excess air must be supplied to increase the possibility of the fuel being in close proximity to the oxygen molecules. The correct maintenance of the scavenge system including turbocharger suction filters is therefore essential.*
2. **Atomisation**-*To ensure that the fuel breaks down into its constituent elements as quickly as possible it is atomised, which means it is injected into the cylinder under pressure through a small orifice (high surface area/volume ratio allowing rapid oxidation).*
3. **Mixing**-*Atomised fuel made up of fine droplets does not penetrate well into the cylinder combustion space , mixing with the air is promoted by giving the a swirling motion.*
4. **Injection Timing**-*As the fuel burns it creates a pressure wave which acts against the piston.*
   If the injection is too late, the piston is travelling down the liner. The pressure wave created by ignition moves rapidly down to meet the piston causes excessive shock loading on the top of the crown (this is the characteristic 'Diesel knock' of engines when started from cold).Less power is derived as the correct pressure does not act on the piston during the early stages of the stroke.
   If the injection is too early then very high temperatures and high peak pressures can be generated caused by the rapid combustion period occurring when the space available is very small. This can lead to increased engine efficiency but also to overloading of the bearings, particularly the top end bearings.
5. **Compression temperature**-*The diesel engine is a compression ignition engine , this means that the ignition of the fuel is reliant on the temperatures generated by the compression of the combustion air.*
   The compression ratio is set at the design stage to give the correct temperature. However, loss of compression, say by a leaky exhaust valve or piston rings can lead to a late timing of ignition. A similar effect can occur if the cylinder parts are not kept at the correct temperature

Cylinder mixing



Combustion chamber pressure curve.



Phase one Ignition delay-Fuel injection does not start immediately the pump plunger begins to lift, there is a delay due to compression of the fuel and expansion of the pipework. Although liquids are often classed as being incompressible, they can be compressed to some extent at the pressures involved. Pipework will expand at these pressures and a certain amount of oil must be delivered in order to take account of these factors. Pump timing can be adjusted to take account of this because the amount remains the same at all engine speeds. When oil pressure reaches a high enough value the injector needle will lift and injection commences.

Ignition lag-The duration of this period is set as a definite period of time, irrespective as to how fast the engine turns, and that period depends upon the chemical structure of the fuel. Basically, the lag period depends upon the number upon the number of molecular bonds which must be broken in order to release atoms of hydrogen and carbon from the fuel molecule. The longer and more complex the molecular chain, the greater will the amount of heat energy required to release the atoms and the longer will be the amount of heat energy required to release the atoms and the longer will be the ignition lag period. Because modern residual fuels result from complex blends of crude oil of many different types, they are complex structures and the ignition quality may be very variable between nominally the same grade of fuel. Formerly the cetane number was used to define ignition quality but cetane is a single element fuel and relating this to the complex nature of residual fuels is not realistic. The general term ignition quality is now used.

Ignition lag is the preparation period of the fuel within the cylinder for spontaneous ignition and beginning of combustion. The physical and chemical processes occurring during this period are characterised by weak ABSORPTION and liberation of heat. Thus there is little if any deviation from the compression curve. The length of the lag period depends on the fuels ignition quality and nothing else. The higher the ignition quality, the shorter will be the lag period, and the lower the ignition quality, the longer the lag period.

The constant nature of the lag period has litle effect in the marine slow speed engine. For an automobile engine operating at much higher speeds this period is a significant proportion of crank angle. As the revs of the engine increase ignition of the fuel will occur later leading to a possibility of 'pinking', a timing retard is therefore required.

Phase two- Uncontrolled or rapid combustion period over a short period (5 to 10 degrees). Initially considerable heat is given off. This causes violent chemical reactions in the air vapour mix which has built up during the first phase. Between 40 to 70% of available energy is released during this phase

Phase three-Controlled burning period. Characterised by a slower pressure rise at the end of the injection period. The physical and chemical processes occurring during this phase are identical to those in the previous phase. The rate of pressure rise reduces as the piston sweeps down the liner.

The time available for combustion is relatively small with higher soeed short stroke engines, but is greater for slow speed long stroke engines. These can ten burn lower quality fuels with higher carbon content.

Heating of residual fuel

When burning residual fuel, heating is required in order to reduce the viscosity at the injectors to approximately that of diesel oil. This ensures good atomisation and brings the temperature of the.fuel closer to the ignition point.

Heating the fuel helps separate solid and liquid contaminants in tanks and in centrifuges, and allows it to flow readily from the tanks to fuel manifold where the final heating for injection takes place. Fuel lines are provided with booster or surcharge pumps on order to force fuel from the tanks through final heaters to the fuel injection pumps, thus ensuring that oil is always available at the pumps. If oil is heated to high temperature it is essential that it is kept under pressure to prevent gassing up of the HP pumps. Heating requires the fuel pump and injector clearances to be increased.

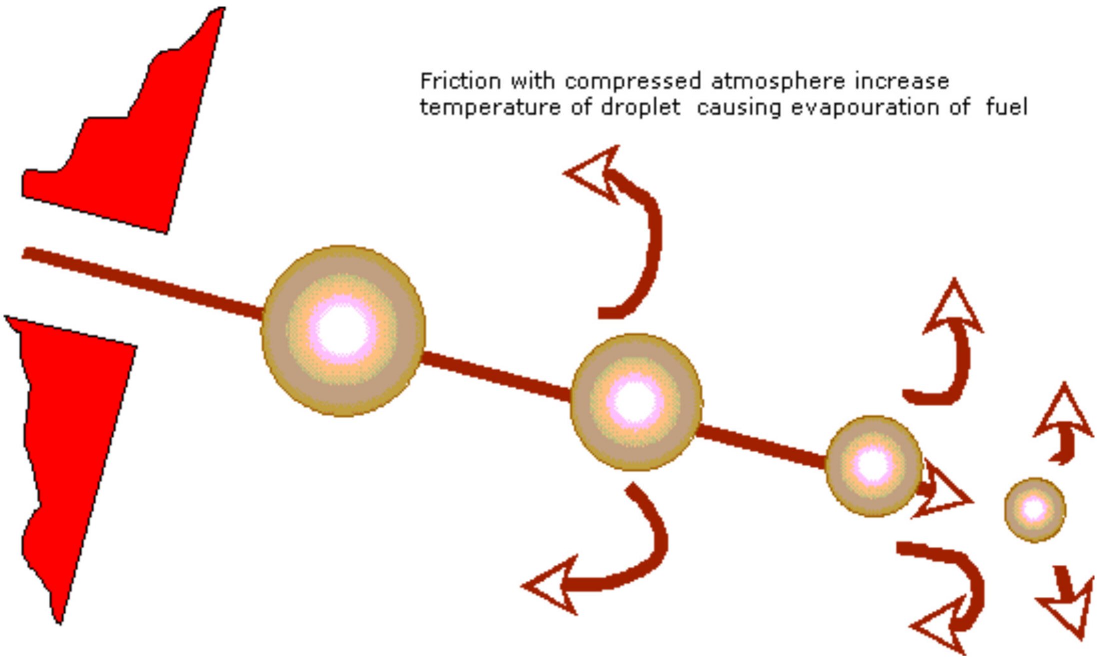
Atomisation

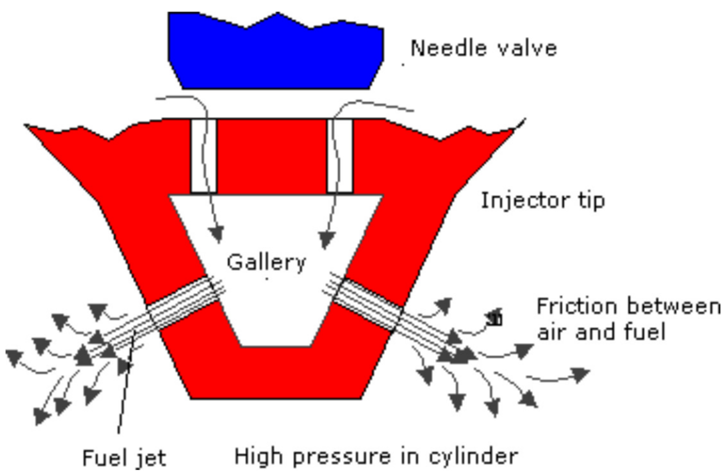
For good combustion the oil droplet size in the combustion space should be at a minimum, and so have a maximum surface area to volume ratio. This ensures rapid heating and an increase in the percentage of fuel molecules in contact with the combustion air. Droplet size should be about 10mm dia.

However, as the droplet size reduces so it ability to penetrate into the combustion space reduces. This is because the droplet has little mass so has little momentum and will be quickly slowed by friction of the dense combustion air. This will produce poor combustion due to the inefficient mixing with the air.

This size must be balanced with the problems of oversized droplets. This is not only with the surface area to volume ratio, also, large droplets can have too great a penetration, still burning fuel can contact with the liners and cylinder wall causing erosion and burnaway. Unburnt fuel can pass down the liner walls where it can mix with the unburnt cylinder liner oil and accumulate in the scavenge risking a potential fire. On trunk piston engine fuel dilution of the crankcase oil can result.

Effect on oil droplet after injection



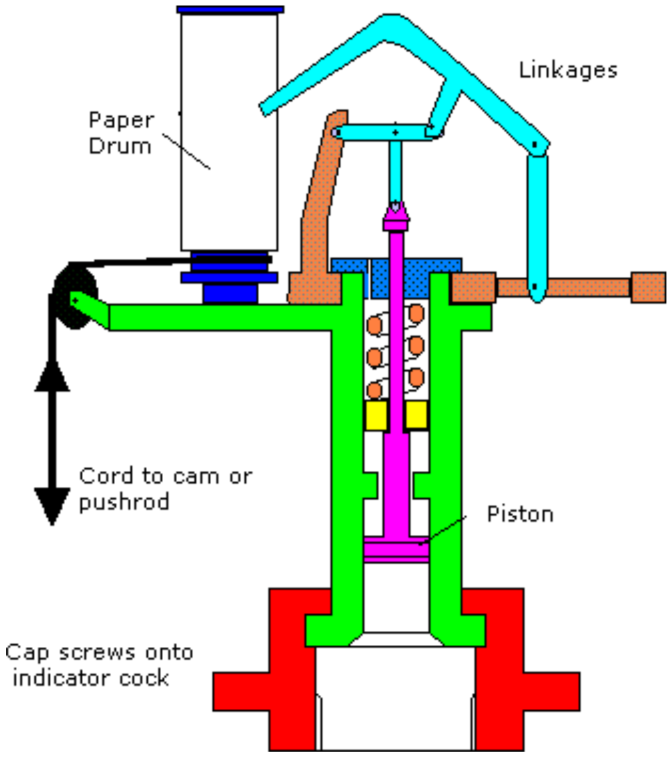


High pressure fuel is forced through small holes in the injector tip and this produces a high velocity jet of fuel. Friction between the fuel jet and the compressed air causes the fuel jet to break down into droplets, the size of which depend upon the density od the compressed air and the velocity of the jet. In order to achieve the optimum jet, fuel pressure and hole diameter must be within well defined limits. In general the length/hole ratio should be about 4:1.

Larger droplets may be produced by enlarging the hole or reducing the fuel pressure whilst smaller droplets may be formed by using smaller diameter holes or higher fuel pressure. Slow running results in larger droplets because fuel rail pressure falls as there is a longer period of time for injection to take place. Slow running for short periods is not a problem, for longer period 'slow steaming' nozzles with reduced diameter holes are used. Over a period of time injector nozzles will wear increasing hole diameter and require their replacement.

Power Cards

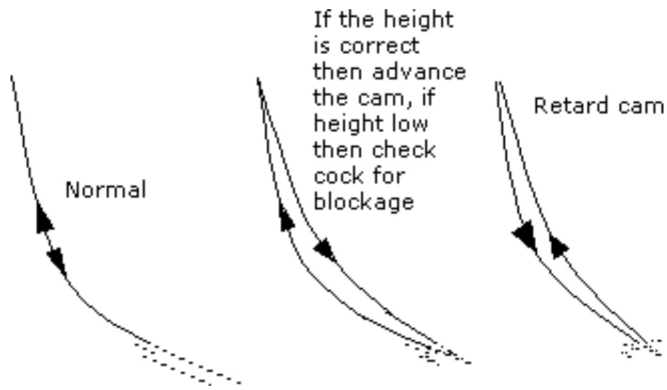
A power card is a graph of cylinder pressure against time, it was originally drawn using a mechanically driven pen onto graph paper mounted on a drum. The drum was rotated by string, via a cam on the camshaft and pushrod. As the drum rotated the pen mounted on the linkages was pressed up to the paper. For clarity the pen is released once a single cycle has passed otherwise slight fluctuations in power demand could lead to several cycles being superimposed on one another blurring the image.



The indicator is a sensitive piece of equipment which can malfunction and so it must be treated with care. It can only be used effectively on an engine operating below 200 rpm due to the difficulty involved in getting only a single line on the card. In addition the inertia in the drum can lead to delays distorting the shape. For higher speed diesels either peak pressure indicators are used, or sophisticated electronic monitoring equipment is required with oscilloscope type displays. The time base for these is off transducers mounted on the flywheel.

It is important that the indicator is kept well lubricated with a light high quality oil . Prior to mounting the indicator the indicator cock is blown through to ensure it is clear. Compression cards are then first taken to check for errors caused by wear or friction/stiction in the instrument.

Compression curves



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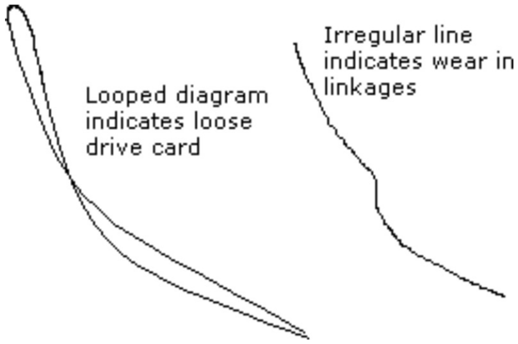
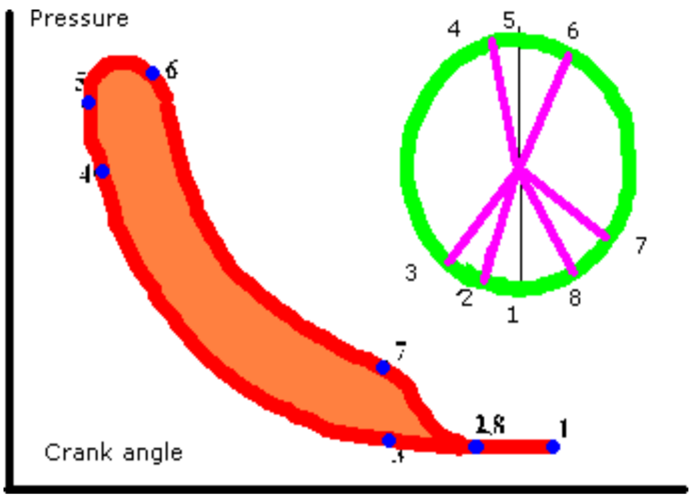


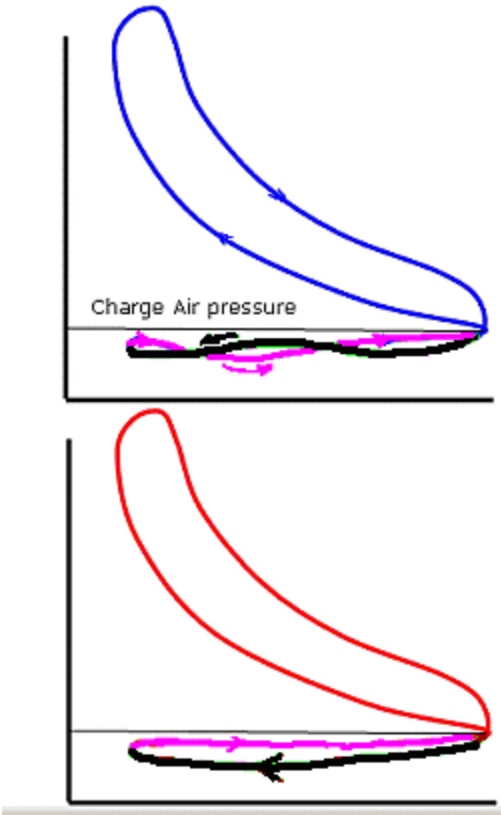
Two stroke cycle power card



Bottom dead centre

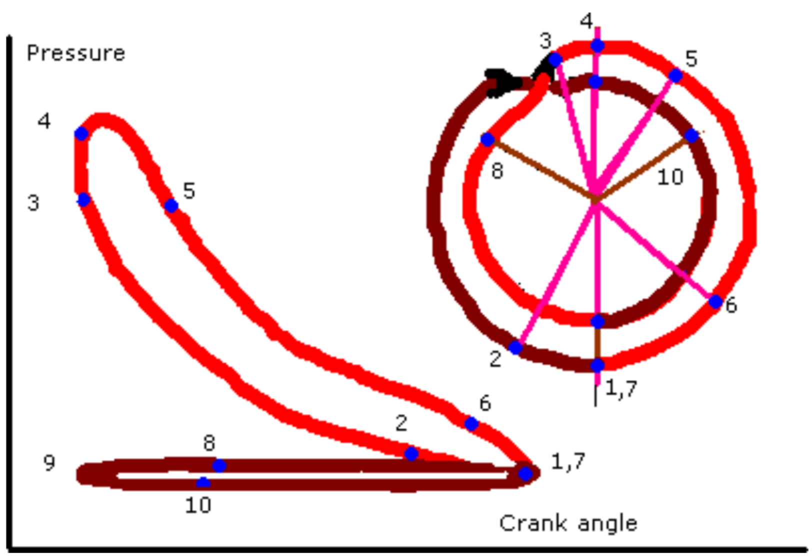
1. *scavenge port closed*
2. *exhaust port shut-commence of compression*
3. *fuel injection*
4. *top dead centre*
5. *7post combustion expansion*
6. *exhaust port opens*

Four stroke cycle



Shown above are typical power cards for 4 stroke engine. The lower one shows the effect of improving turbocharger efficiency. That is some mechanical effort is made by the charge air pressure lowering fuel consumption. Poor timing can negate this effect.

Shown below is a power card drawing taken from an exercise book. it should be noted that the 3rd and 4th stroke indicate power is being abosrbed. It is probable that this drawing was made for a non turbocharged engine although the source is forgotten. The atmospheric line would split the 3rd and 4th stroke



- 3-4-5 fuel injection and combustion
- 5-6 expansion
- 6-7-8-Exhaust valve open

- 8-9-10 overlap, exhaust remains open whilst air enters
- 10-1 aspiration and exhaust valve closes

Power calculation

The area swept out by the power stroke will give the power developed by the engine. It should be noted on a four stroke most of the non-power stroke occurs below atmospheric on a naturally aspirated engine and so gives a net loss of power.

Power = p.A.L.n p - mean average pressure in the cylinder
A-area of piston[m3]
L-stroke [m]
n-revolutions per second

From a power card this is altered to

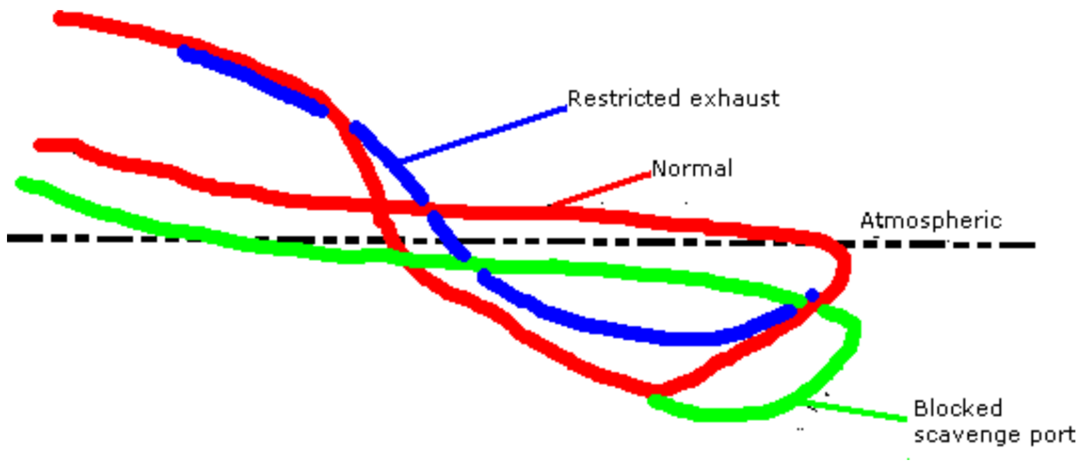
Power = area of diagram/length of diagram x Indicator spring constant

By use of an instrument called a Planimeter the area scribed out by the pen could be measured giving the power generated by the cylinder. In addition, through experience, certain problems could be diagnosed by looking at the shape drawn.

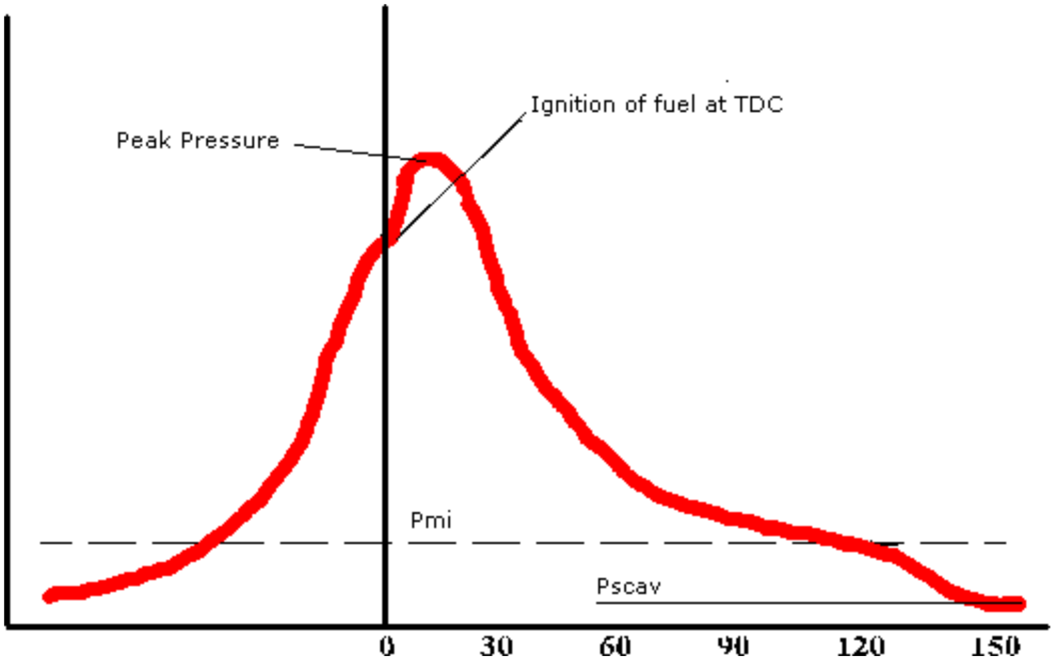
Fault diagnosis

As indicated there are practical difficulties with use of the power indicator instrument on a high speed four stroke engine. Therefore the following is based around the two stroke

The light spring diagram For this, the spring is replaced with one of much lower spring constant. In this way the operation at the lower pressures, i.e. around bottom dead, may be examined. In particular this gives indication of blocked or restricted scavenge and exhausts. To further clarify, the motive effort for rotating the drum is often by hand so only a small part at the end of the stroke is covered.

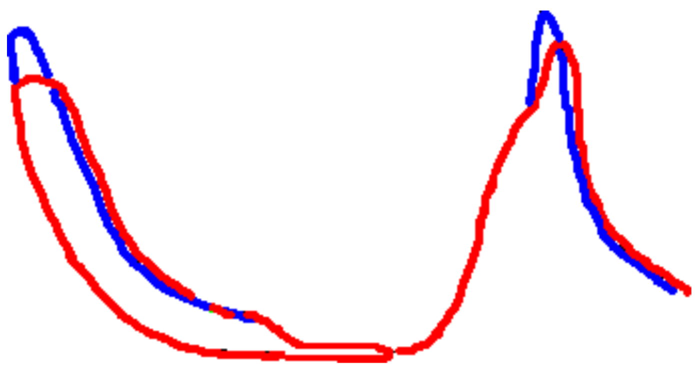


Draw card (90^{o} out of phase)



Scavenge port opens at 140 degrees after top dead and closes 140 degrees before top dead.

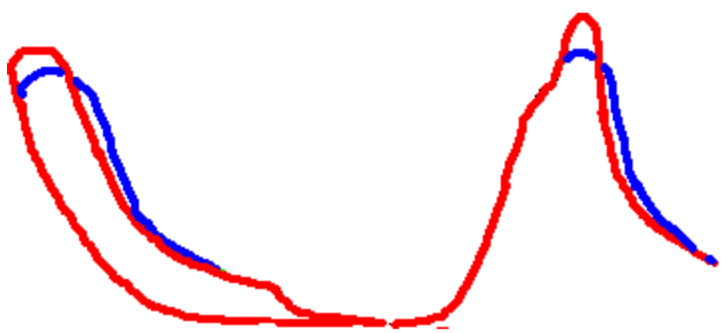
Early injection



Early injection can be caused by incorrect fuel timing, broken or wrongly set up fuel injector, incorrect fuel condition, overheating of parts around the combustion space.

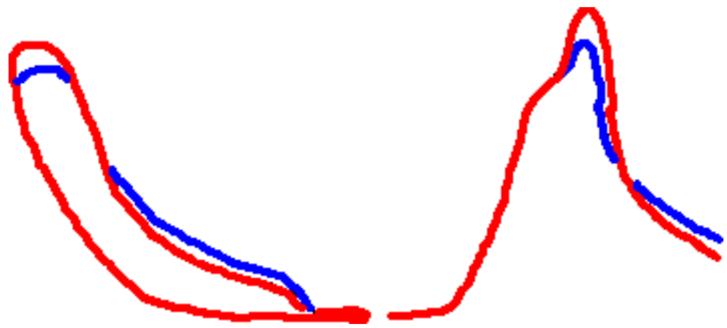
Its effect is to increase the maximum cylinder pressure. There will be an increase in combustion efficiency but the increased peak pressure leads to overload of the bearings and shock to pressure parts.

Late injection



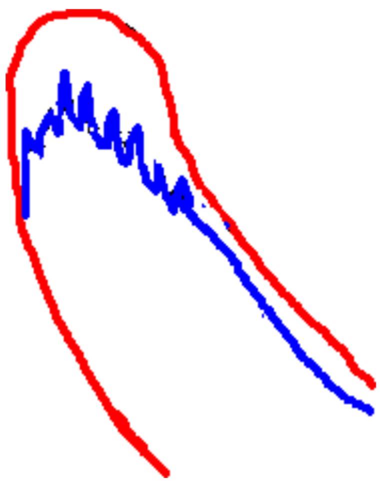
Late injection can be caused by loss of compression, insufficient scavenging, delayed timing, incorrect fuel condition and atomisation, undercooled parts around the combustion space. It results in a condition called diesel knock where the flame front travels rapidly down the liner to strike the receding piston. In addition, leads to afterburning and high exhausts

Afterburning



Causes loss of power, smoke and high exhaust temperatures. Can lead to damage to exhaust valves and seats as well as piston crowns. Fouled turbocharger and waste heat recovery units. High cylinder temperatures causes problems with lubrication

Leaking fuel injector



Detected by loss of power, smoky exhaust and high temperatures. A knock can be heard on the fuel supply system. Can lead to after burning

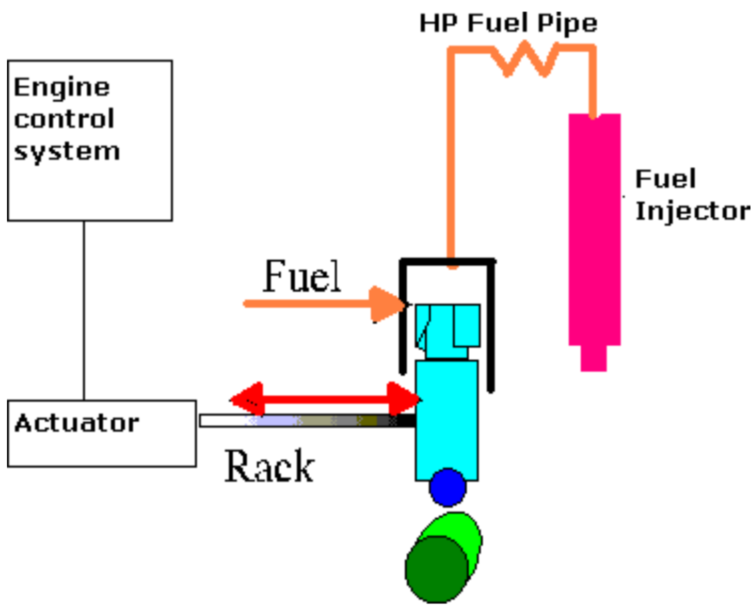
Fuel injection for future high-speed engines

Diesel engine manufacturers in both propulsion and genset applications are concerned with the development aim of low fuel consumption, reliability, and long service life. Other important issues are low soot, NOx, CO, particle emissions, and good dynamic characteristics; noise levels are also becoming increasingly important.

To achieve these requirements more accurate control is required of the timing, quantity and shape of the fuel injection is required.

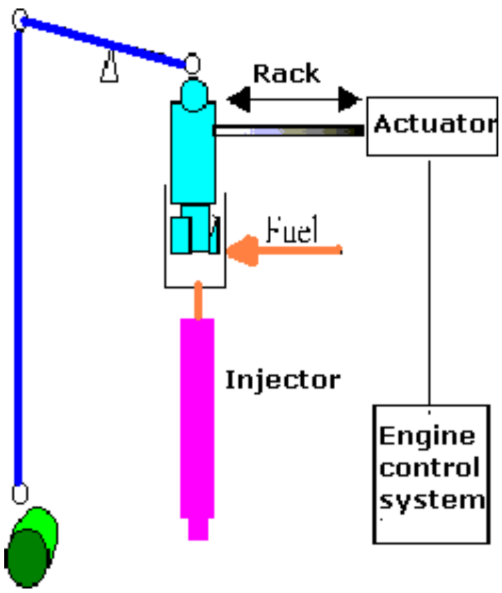
Modern design has moved towards the use of electronics to achieve this.

Unit Injector



Conventional injection systems with mechanical action include inline pumps, unit pumps with long HP fuel lines and injectors. A cam controls the injection pressure and timing, while the fuel volume is determined by the fuel rack position. The need for increased injection pressures in more modern designs means that the variable time lag introduced by distortion of the pipework and compressibility of the fuel cannot be accounted for. Therefore this type of design is losing favour

Unit Injector



A comparison between unit pump and unit injector systems has been made assuming the unit injector drive adopts the typical camshaft/pushrod/rocker arm principle. With the aid of simulation calculations the relative behaviour of the two systems was investigated for a specified mean injection pressure of 1150bar in the injector sac. The time-averaged sac pressure is a determining factor in fuel mixture preparation, whereas the frequently used maximum injection pressure is less meaningful.

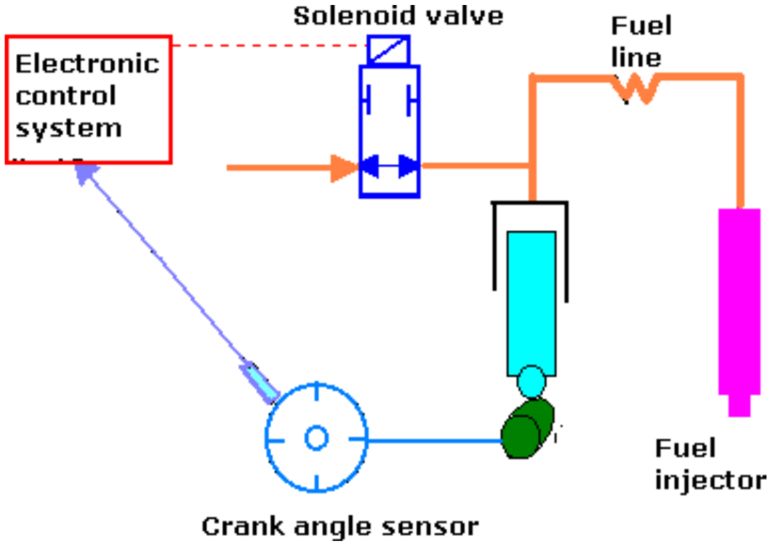
The pressure in a unit pump has been found to be lower than in a unit injector, but because of the dynamic pressure increase in the HP fuel line, the same mean injection pressure of 1150 bar is achieved with less stress in the unit pump.

With the unit injector, the maximum sac pressure was 1670 bar-some 60 bar higher than the unit pump. To generate 1150 bar the unit injector needed 3.5kW-some 6% more power. During the ignition delay period, 12.5% of the cycle related amount of fuel was injected by the unit pump as against 9.8% by the unit injector. The former is, therefore, the overall more stiffer system.

Translating the pressure differential at the nozzle orifice and the volume flow into mechanical energy absorbed, the result was a higher efficiency of 28% for the unit pump, compared to 26% for the unit injector.
From the hydraulic aspect, the unit pump offers benefits in that there is no transfer of mechanical force between the pushrod drive to the cylinder head and less space is needed for the fuel injector which gives better design possibilities for inlet and exhaust systems

With conventional systems, the volume of fuel injected is controlled by the fuel rack, and matching the individual cylinders requires the appropriate engineering effort. The effort increases considerably if the injection timing is done mechanically.

Unit pump with solenoid valve control.



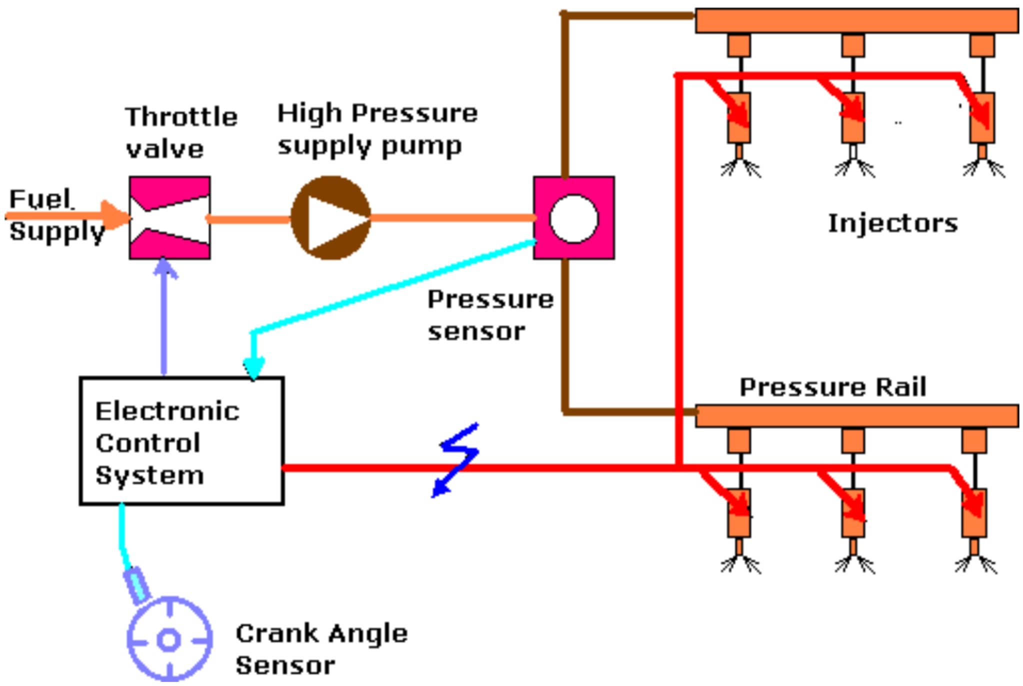
The engineering complexity involved in being able to freely select fuel injection and timing can be considerably reduced by using a solenoid valve to effect time-oriented control of fuel quantity. To produce minimum fuel injection quantity, extremely short shift periods must be possible to ensure good engine speed control. Activation of the individual solenoid valves and other prime functions, such as engine speed control and fuel injection limitation , are effected by a microprocessor controlled engine control unit (ECU). Optional adjustment of individual fuel injection calibration and injection timing is thus possible with the injection period being newly specified and realised for each injection phase; individual cylinder cut out control is only a question of the software incorporated in the ECU.

With cam-controlled injection systems, the injection pressure is dependant on the pump speed and the amount of fuel injected. For engines with high meps in the lower speed and low-load ranges, this characteristic is disadvantageous to the atomisation process as the injection pressure drops rapidly. Adjusting the injection timing also influences the in-system pressure build-up, e.g. if timing is advanced, the solenoid valve closes earlier, fuel compression starts at lower injection pressures which, in turn, is detrimental to mixture preparation.

To achieve higher injection pressures extremely steep cam configurations are required. As a result, high torque peaks are induced into the camshaft which involves a compensating amount of engineering effort regarding the dimensioning of the camshaft and the gear train, and may even require a vibration damper.

So while the solenoid valve controlled system has a number of advantages it retains the disadvantages of the conventional systems. In the search for a flexible injection system this system only represents a half step.

Common rail injection system (CRIS)



With the CRIS the HP pump delivers fuel to the rail which is common to all cylinders. Each injector is actuated in sequence by the ECU as a function of the crankshaft angle. The injector opens when energised and closes when deenergised. The amount of fuel per cycle is determined by the time differential and the in-system pressure. The actual in-system pressure is transmitted to the control unit via a pressure sensor and the rail pressure is regulated by the ECU via the actuator in the fuel supply to the HP pump. For rapid load shedding the pressure regulator restricts the HP pump to a maximum of 1330bar, compared to the specified 1200bar

With this system the injector incorporates several functions. The nozzle needle is relieved by a solenoid valve and thus opened by the fuel pressure. The amount of fuel injected during the ignition delay period is regulated by the nozzle opening speed. After the control valve is deenergised as additional hydraulic valve is activated which ensures rapid closure of the needle valve and. Therefore minimum smoke index. With this servo-assisted injector the opening and closing characteristics can be adjusted individually and effected extremely precisely. It is capable of extremely high reaction speeds for controlling minimum fuel quantities during idle operation or pilot injection.

Compared to a conventional system the pumping force is considerably lower, with pressure generation accomplished by a multi-cylinder, radial-piston pump driven by an eccentric cam. Pressure control is realised by restricting the supply flow. Locating the high-pressure pump on the crankcase presents no problems while the fuel injection control cams are deleted from the camshaft which can therefore be dimensioned accordingly. Fuel quantity injected is determined by the ECU and is a function of desired and measured engine speed. The CRIS allows very fast response times in the region of 10ms

In the event of single injector failure the injector is shut off via the shut off valve. This allows the remaining cylinders to be operated in a get you home mode.

The CRIS system offers the best characteristics and costing for future High speed engine injection systems.

Low Sulphur Fuels

Sulphur contained in the fuel forms metallic sulphides that coat the internal surfaces of the fuel injection equipment including the fuel pumps and the fuel injectors. These sulphides have low shear resistance and act as EP additives similar to that found in lubrication oils. Extremely low sulphur fuels in use on the automotive transport industry have led to the use of lubricity additives. In the marine environment the reduction in sulphur content has been less dramatic.

Marpol Annex VI(regulation 14) and the creation of Sulphur Emission Control Area means it wil be a requirement to use only fuels with a certain maximum sulphur content. In the addition to the increased cost of these low sulphur fuels it is necessary to factor in the possibility of increased wear and tear on the engine components.

Low sulphur fuels are normally low viscosity oils such as gas oil. Carefull planning has to be done both at the design level (to ensure sufficient storage capacity) and at the operational and maintenance levels due to the known difficulties in changing over from a heated fuel to a non heated or one with reduced heating capacity.

Effects of Sodium Vanadium compounds on Marine Diesel engines

Fouling

A not uncommon failure of Marine diesel engines is a fouling of turbocharger nozzle rings and blades with compounds containing sodium and vanadium as well as more traditional carbon deposits.
This leads to increased exhaust gas temperatures, loss of plant efficiency and reduced reliability. The degree and type of fouling is dependent on the constituents and amounts of contaminants in the fuel oil.

Corrosion

More specifically high temperature corrosion directly caused by the presence of compounds of sodium and Vanadium at temperatures over 500'C.

Sodium and Vanadium are found in heavy fuels up to 200ppm and 600ppm respectively forming Vanadium Oxides (chiefly V_2O_5), Sodium oxidises to Na_2O and with sulphur also contained, sulphates $NaSO_4$ which are able to react further with vanadium oxides.

The various compounds that may be formed from these have a wide variety of properties one of the most significant of which is the melting points

At the moment of solidification certain compounds can release molecular oxygen which can attack the metal surface. Oxygen may be re absorbed into the deposition thus forming an oxygen pump which aggressively attacks the surface of the metal during melting/solidification processes at around 530 to 600'C. The iron oxide (or Nickel oxide for Cr-Ni Steels) diffuses into the melting cake. A typical reaction is

$Na_2O.6V_2O_5 <-> Na_2O.V_2O_4.5V_2O_5 + 1/2\ O_2$

The parts of most concern in marine diesels are Exhaust valves, piston crowns as well as components of the turbocharger such as the nozzle ring and blades.

Effects of ratio of Sodium and vanadium in fuel

Composition	Melting Point ^oC
V_2O_5	670
$Na_2O.V_2O_5$	682
$2Na_2O.V_2O_5$	643
$Na_2O.V_2O_4.5V_2O_5$	535
$5Na_2O.V_2O_4.11V_2O_5$	535
$Na_3Fe(SO_4)_3$	543
Na_2SO_4	887
$Fe_2SO_4)_3$	720 (decomposition)

From the table above it can be seen that the ratio of Sodium to Vanadium in the compounds greatly influences the melting point and thereby the corrosive and slagging effect.
The danger zone is taken to be **Na/V ratio of 0.08 to 0.45** of which **0.15 to 0.30** is particularly destructive

Effects of Temperature and SO_2

The temperature of the components in the diesel engine will decisively influence the temperature at which corrosion takes place. In addition the presence of SO_2 causes the formation of sulphates in the melt

$SO_2 + V_2O_5 \rightarrow SO_3 + V_2O_4$

$SO_3 + Na_2O \rightarrow Na_2SO_4$

The sodium sulphate cannot exist in the melted Sodium Vanadates and is released to further attack the metal surfaces. The SO_3 may combine to form sulphurous deposits stripping protective oxide layers from the metal surfaces.

Bunker quality and the effects of Fuel Conditioning

A look at a general cross section of the fuel oils being supplied around the world reveals that a significant portion contain sodium and vanadium in ratios around that considered to be the most destructive.

Passing the fuel through a purifier was the effect of reducing the Sodium content significantly although there is little effect on the Vanadium content.

I have recently been in correspondence with an engineering manager of a large power generation plant. His concern was that the fuel being supplied to the engines had a water content greater or equal to 0.25%.
Water was being introduced into the fuel at an early stage of its conditioning as a method of washing the sodium from the bunkers being supplied in an attempt to reduce the effects of sodium vanadium corrosion.

Vanadium may be found in lubricating oil.

Alteration of the Na/V ratio

As mentioned careful purification can have a significant effect on the amount of Sodium in the Fuel. However Sodium can be re-introduced into the combustion process in the form of salt water spray laden air of due to leakage of sea water cooled air coolers. It should be noted that where ratios are equivalent corrosion processes were the sodium was already contained in the fuel are significantly higher.

Even when Na/V ratios are out of the danger zone it is possible for pockets or 'banks' of products to build up and be released to form these damaging ratios. Typically Sodium deposits may be found in the scavenge areas and Sodium and Vanadium deposits in the exhaust areas.

Fuel additivies

Magnesium salt based additives are available on the market. The effect of these is to increase the melting point of the compounds formed. deposits tend to be loose and easily removed and little corrosion may be evident

Recommendations

An exhaust gas temperature of 530 to 560'C and Na/V ratios of 0.15 to 0.30 are the danger zones. For reasons described it is very difficult to avoid these ratios, however the following recommendations are given which should significantly reduce corrosion and could possibly influence the degree of slagging.

- Use fuels with sodium vanadium ratios outside the critical zone of 0.15 to 0.30 and preferably 0.08 to 0.45
- Ensure efficient separation to reduce sodium content
- Keep mean exhaust gas temperatures below 500'C and turbocharger inlet temperature below 530'C
- Ensure that demisters are operating properly and cure sea water leaks in coolers.
- Use Mg salt based fuel additives

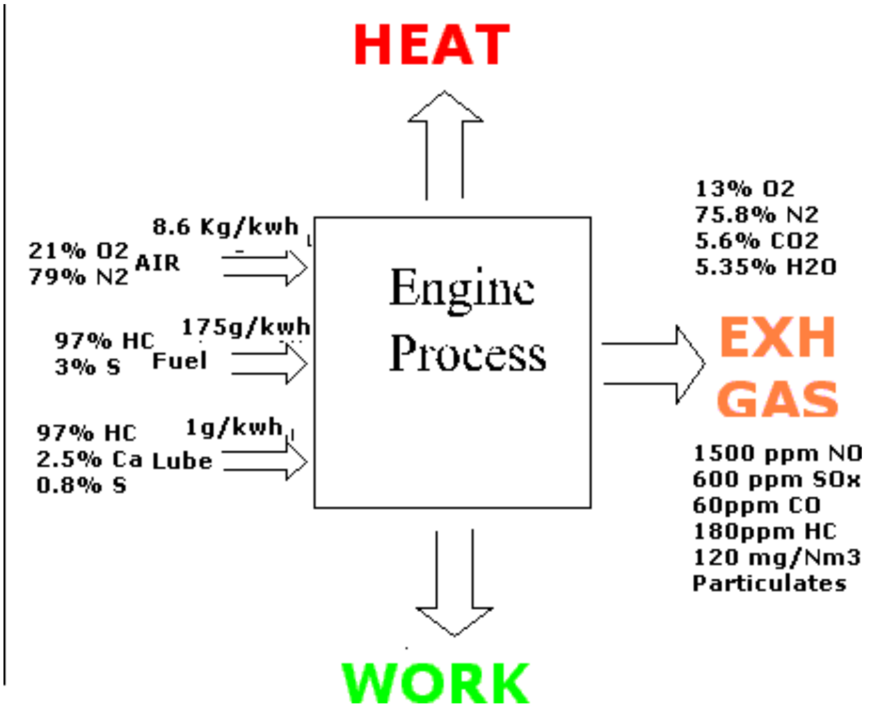
Further Reading:
Mechanisms of High Temperature Corrosion in Turbochargers of Modern Four Stroke Marine Engines:Motoren und Energietechnik GMbh Rostock

Uptake Emission control

Exhaust emissions from marine diesel engines largely comprise nitrogen, oxygen, carbon dioxide and water vapour, with smaller quantities of carbon monoxide, oxides of sulphur and nitrogen, partially reacted and non-combusted hydrocarbons and particulate material. SOx and NOx emissions, together with carbon dioxide, are of special concern as threats to human health and the environment.

Dominating influences in the formation of NOx in the combustion chamber are temperature and the longer the residence time in the high temperature, the more thermal NOx will be created.

Typical emissions from a MAN B&W low speed engine



SOx generation is a function only of the fuel oil sulphur level and is therefore best addressed by burning lower sulphur fuels. Emissions are considered low for a given sulphur level thanks to the high efficiency of large diesel engines.

Emissions of carbon monoxide (CO) , also low for large diesel engines are a function of the air excess ratio, combustion temperature and air/fuel mixture.

During the combustion process a very small part of the hydrocarbons (HC) in the fuel is left unburned: up to 300ppm in large two-stroke engines, depending on the fuel type.

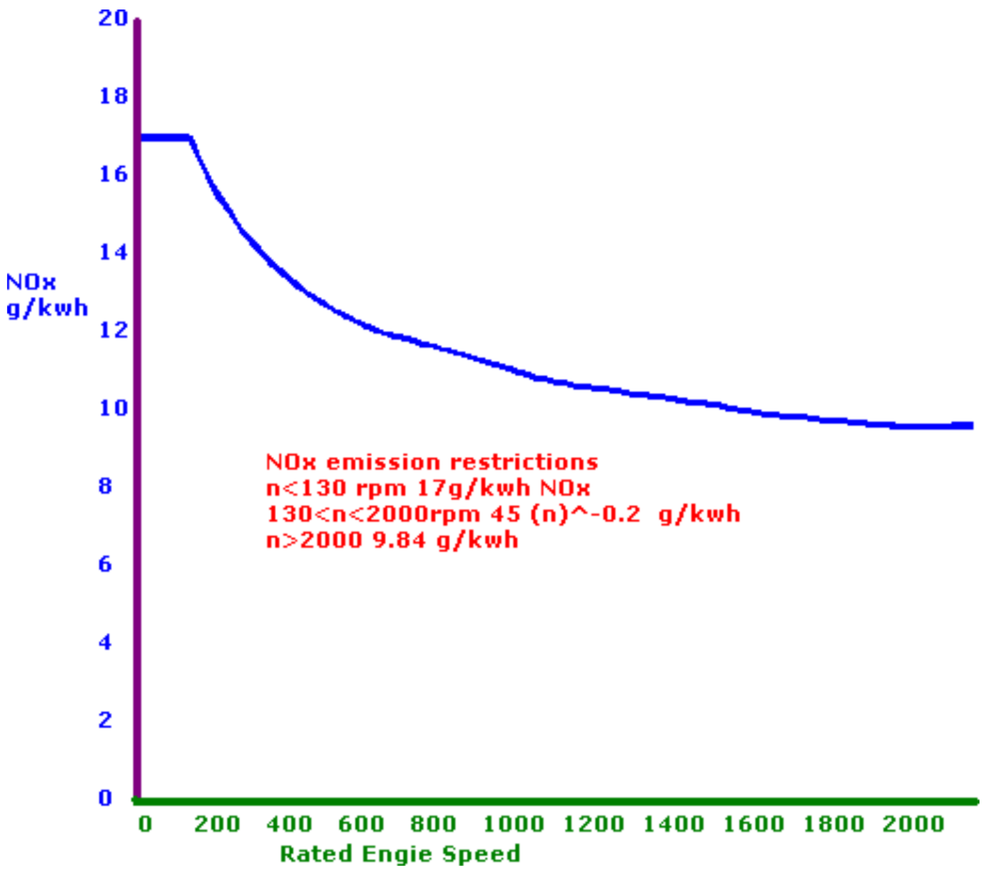
Particulate emissions (typically 0.8 to 1 g/kWh) originate from partly burned fuel, ash content in the fuel and cylinder lubricated oil/dosage; and deposits peeling off in the combustion chamber and exhaust gas system

Emission factors (g/kWh) for marine engines under steady state.

	Low speed engines	Medium speed engines
NOx	18.7	13.8
CO	2.1	1.8

HC	0.5	0.6
SO2	>21.0 x Sulphur content of fuel	

Maximum allowable NOx emissions for marine diesel engines



There are two main approaches to reducing NOx

- Primary methods, aimed at reducing the amount of NOx formed during the combustion process
- Secondary methods, aimed at removing NOx from the exhaust gas by downstream treatment

Primary methods include: reducing the maximum combustion pressure by delayed fuel injection, recirculating the exhaust gas, reducing the amount of scavenge air, injecting water into the combustion chamber or emulsified fuel. And the use of special fuel nozzles.

Reducing the firing pressure via fuel injection retardation readily lowers the peak temperatures and yields lower NOx but also invariably reduces the maximum temperature and leads to higher fuel consumption.

Different fuel valve and nozzle types have a significant impact on NOx generation, as well as on smoke and hydrocarbon emissions, and the intensity of the fuel injection is also influential. The influence on NOx is due to the control by the fuel injection system of the formation and combustion of the fuel/air mixture, the local temperature level and the oxygen concentration in the fuel area.

MAN B&W cites tests with a K90MC engine at 90% load which yielded the following results (NOx/ 15% oxygen):
Standard fuel nozzle 1594ppm
Six hole fuel nozzle 1494ppm
Slide type fuel nozzle 1232ppm

it was verified years ago that water emulsification of the fuel can achieve a significant reduction in NOx emissions with no detrimental effect on engine maintenance costs, MAN B&W Diesel citing long experience with low speed engines in power stations. The influence of water emulsification varies with low speed engine type but generally 1% of water will reduce NOx by 15

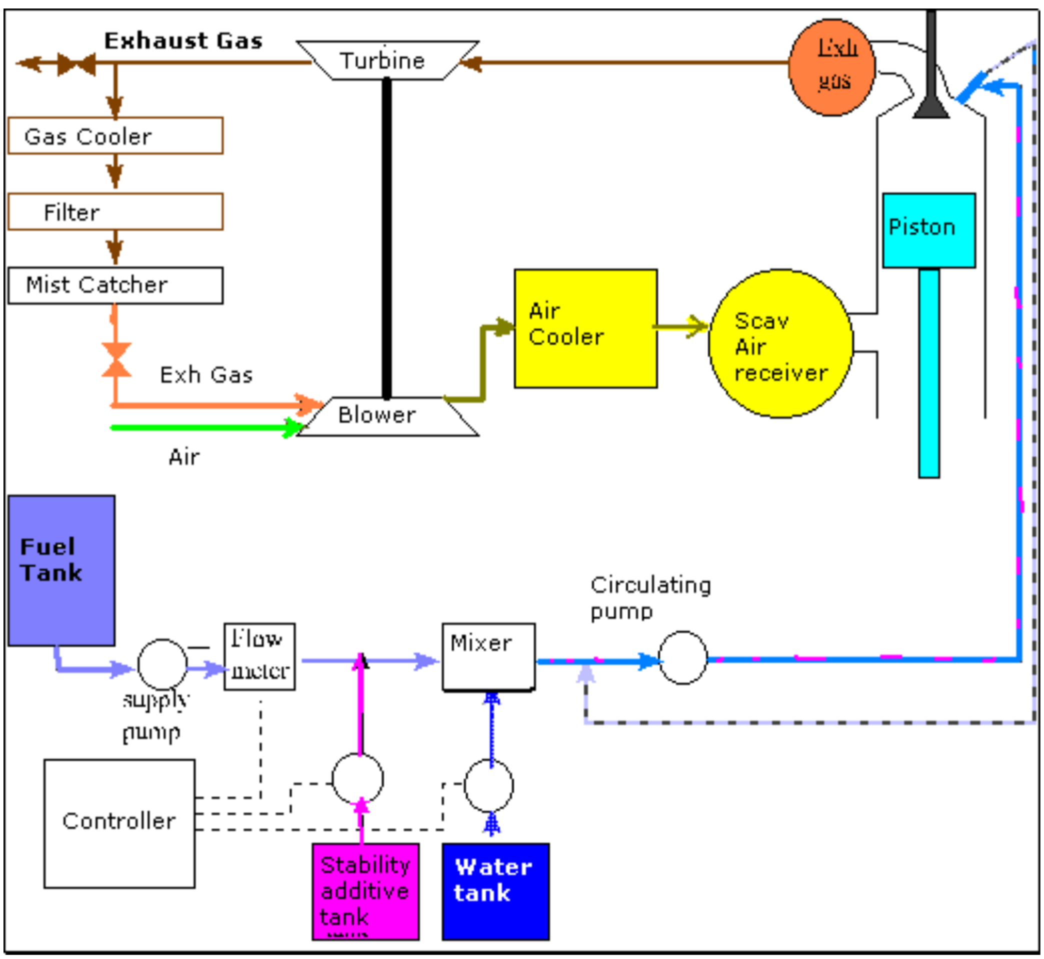
A standard engine design allows the addition of some 15% water at full load, says MAN B&W, thanks to the volumetric efficiency of the fuel injection pumps-but does not represent a limit from the combustion point of view. Larger ratios have been tested - up to 50/50 fuel and water- with the same or similar impact on NOx reduction but this would call for engine modifications.

Emulsification is performed before the circulating loop of the fuel system, in a position in the fuel flow to the engine from which there is no return flow. Thus it is the fuel flow that controls the water flow. The water flow could also be controlled by measuring the NOx in the exhaust, should continuous NOx monitoring be required.

Water can also be added to the combustion space through separate nozzles or by stratified segregated injection of water and fuel from the same nozzle (see SWFI). The results are similar but retrofitting emulsifiers is simpler.

Humidifying the scavenge space id another way of introducing water into the combustion zone though not as appealing since too much water can cause damage to the cylinder conditions.

Schematic of exhaust gas recirculation system and water emulsified fuel system



Exhaust gas recirculation (EGR) can be applied to modify the inlet air and reduce NOx emissions, a technique widely used in automotive practice. Some of the exhaust gas after the turboblower is led to the blower inlet via a gas cooler, filter and water catcher.

The effect of EGR on NOx formation is partly due to a reduction in the combustion zone and partly due to the content of water and carbon dioxide in the exhaust gas. These constituents have high specific heats, so reducing the peak combustion temperature which, in turn reduces the generation of NOx.

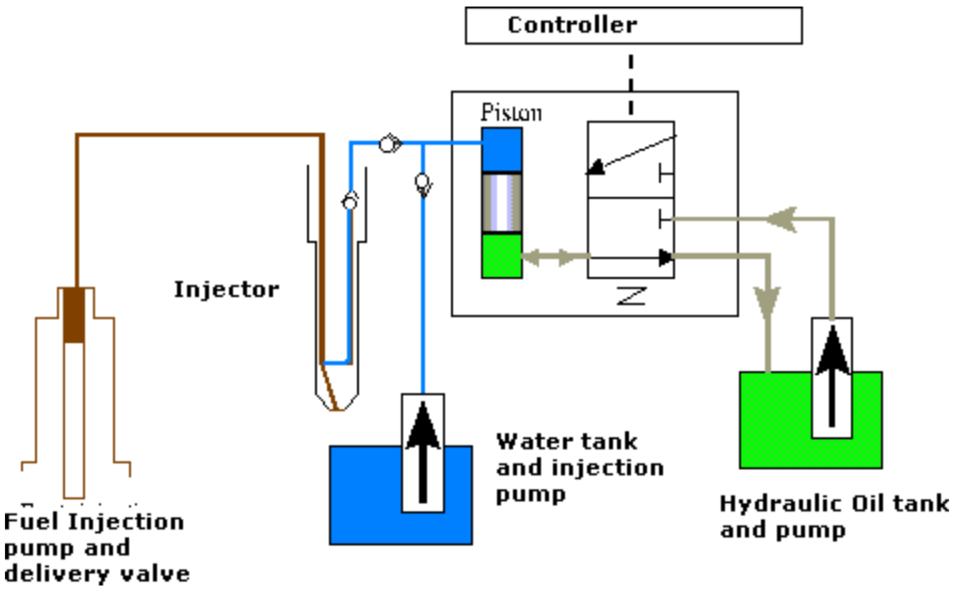
Kawasaki Heavy Industries on a MAN 5S70MC

- Injection timing retard, which can easily be applied in practice, reduced NOx emissions by 10% with a penalty in specific fuel consumption of 3%
- A 20-30% reduction in NOx emissions was yielded by ,modified fuel valves, notably the slide valve. The local increase in heat load has to be taken into account.
- Water emulsified fuel in a 50% ratio achieved a 35% NOx reduction. The method's effectiveness is considered to result mainly form a reduction in the flame temperature caused by a decrease in the flame temperature caused by a decrease in the calorific value. (This is the EGR system)
- Exhaust gas recirculation was confirmed as the most effective method, resulting from a reduced flame temperature brought about by the enlarged theoretical air-fuel ratio. NOx emission was reduced by 69% with an EGR rate of 28%, accompanied by a very small rise in smoke and fuel consumption . (An adjustment of Pmax, however, virtually eliminated the fuel economy penalty for a slight decrease in the reduction of NOx emission.)
  The scavenging system was slightly fouled, however, and Kawasaki suggests that further investigations and long term service testing are necessary to ensure protection against fouling and corrosion before EGR is applied to production engines burning heavy fuel with a high sulphur content.
- Combining several methods yielded greater reductions in NOx emissions. A combination of the slide-type fuel valve , 49% water emulsified fuel and 20%EGR, for example, lowered emissions by 81%, the best result in the test programme

Stratified fuel-water injection (SWFI)

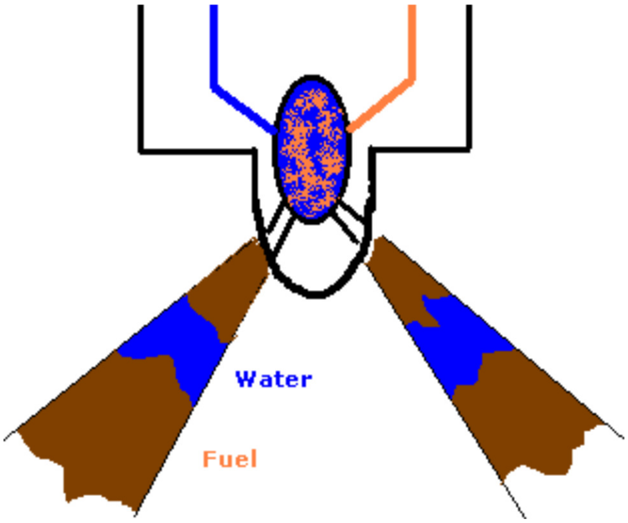
The effects of water addition on diesel spray combustion include a thermal effect due to the large latent heat of evaporation and the specific heat of water and a chemical effect due to water gas reaction with free carbon. It is believed that the lowering of the combustion temperature by these effects in the region of combustion contributes to the suppression of NOx generation.

The aim of SFWI is to add a large quantity of water to the fuel spray after ignitability has been ensured by injecting completely pure fuel oil at the start of injection. Water and fuel are injected separately through the same valve.



The hydraulically actuated piston delivers water via the solenoid at a time when fuel oil injection is not taking place.

Delivered water is at a greater pressure then the oil delivery, it pushes back fuel in the passage between the injection pump and the injection valve. By this process, fuel and water are injected into the cylinder during the next injection cycle while retaining stratification in the sequence: Fuel - water- fuel.



During this cycle the rack becomes higher by an amount corresponding to the amount of water injected.

The following points of note came from an in service trial

- The SWFI system worked in a stable condition throughout in service testing
- Protective devices worked well in the case of abnormalities
- NOx reduced in proportion to water injected
- Engine components did not suffer

Selective catalytic reduction (SCR)

SCR can reduce NOx levels by at least 95%. Exhaust gas is mixed with ammonia before passing through a layer of a special catalyst at a temperature between 300 to 400oC. The lower limit is mainly determined by the sulphur content of the fuel: at temperatures below 270^{o}C ammonia and SOx will react and deposit as ammonium sulphate; and at excessively high temperatures the catalyst will be degraded (the limit is around 400-450^{o}C).

NOx is reduced to harmless waste products nitrogen and water vapour. In addition some soot and hydrocarbons in the exhaust are removed by oxidation in the SCR reactor.

Ammonia is stored as a liquid gas under pressure of 5-10bar in a deck mounted storage tank protected to prevent overheating. A computer controlled quantity of evaporated gas is led to the engineroom via a double skinned pipe. A bypass arrangement allows the SCR to be redundant when away from controlled areas.

A flow of air is taken from the scavenge and used to dilute the ammonia in a static mixer. The ammonia concentration is thus below the L.E.L. before it enters the exhaust pipe. The minimum engine load for NOx control with SCR is 20-30% unless more comprehensive temperature control systems are installed. At lower loads the catalyst is by passed.

Ammonia fed to the SCR reactor can be liquid, water free ammonia under pressure, an aqueous ammonia solution at atmospheric pressures or in the form of urea carried as a dry product and dissolved in water before use.

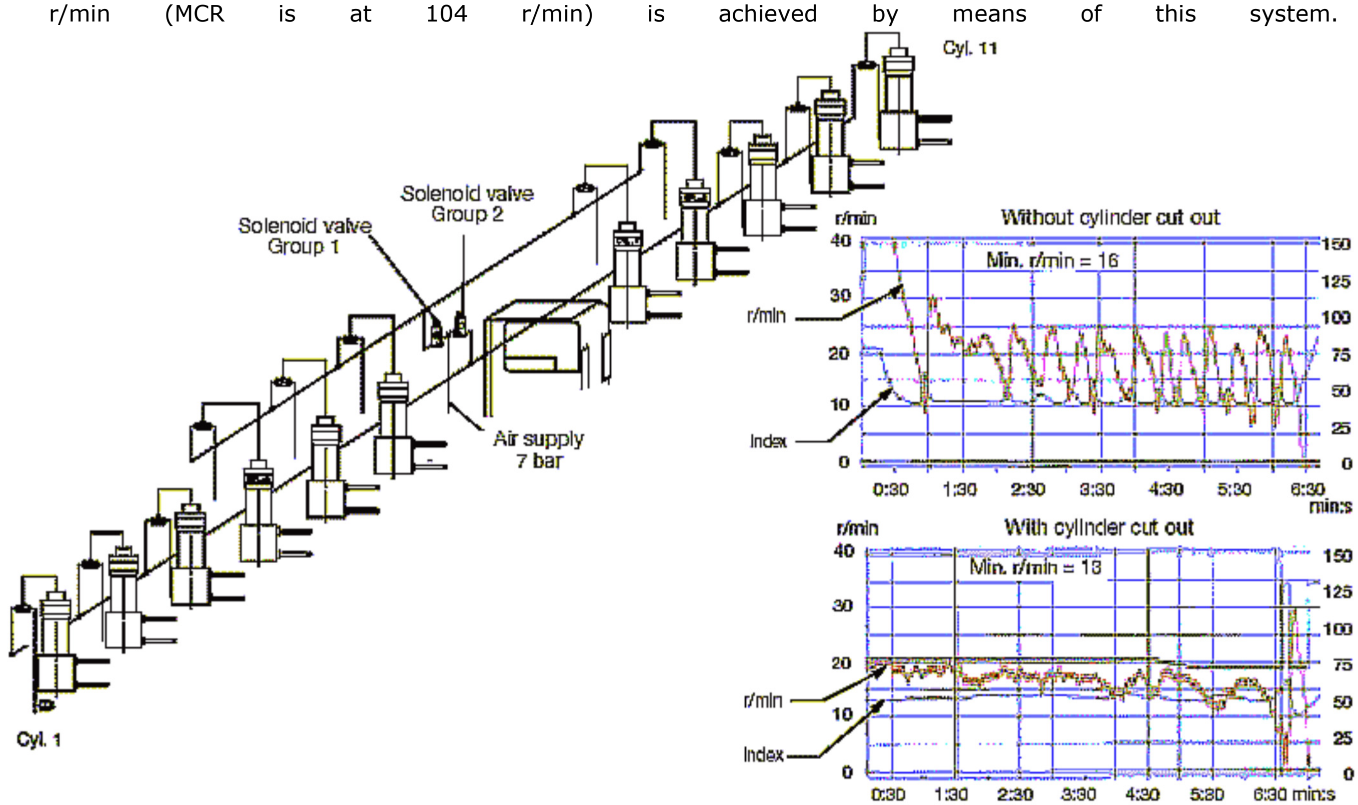
Slow Speed Running Large slow speed Engine

Cylinder cut-out system. In the case of low loads, the traditional problem is fouling of the engine due to irregular injection and atomisation, leading to incomplete combustion.

The irregular injection may be caused by jiggling of the governor, and/or play in the connections in the fuel pump rack control system. The effect in either case is that the fuel pumps, when operating so close to the minimum injection amount, may sometimes just have enough index to inject fuel, at other times just not enough index to do so.

By the introduction of a system where approximately half of the cylinders are cut out at low speed, the injection into the remaining working cylinders is improved considerably, giving more stable combustion and, consequently, stable running and keeping particle emission in the low speed range at a minimum.
To avoid that excessive amounts of cylinder lubricating oil are collected in cylinders that are temporarily deactivated, the cutting out is made by turns between two groups of cylinders in order to burn surplus lubricating oil and keep the same thermal load on all cylinders. Turns between the groups are made on a time basis.
The group separation is determined in order to halve the number of active cylinders and to get the smoothest possible firing order. In order to obtain a safe start, the cutout system is disabled during the starting period and until the engine has been stabilised.

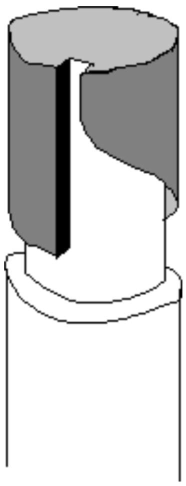
The system has been in service for a year on a series of 11K90MC-C engines, and stable operation down to 13 r/min (MCR is at 104 r/min) is achieved by means of this system.

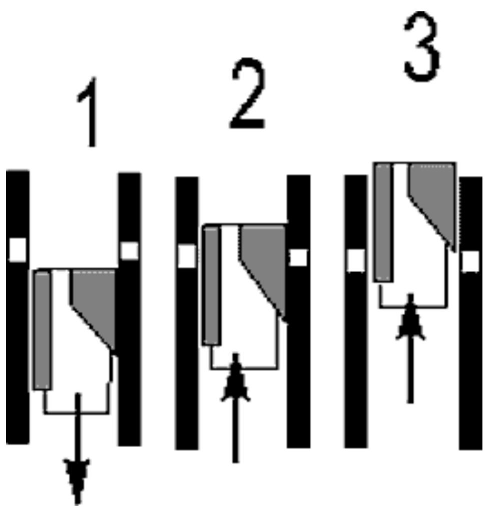


Fuel Pumps

Bosch Scroll pump

The Bosch scroll pump consists of a plunger running in a barrel. The plunger is shaped as per the diagram and is rotated in the barrel by the fuel rack.





Position one-The plunger is travelling down the barrel and the suction and spill ports are uncovered. A charge of oil enters the chamber

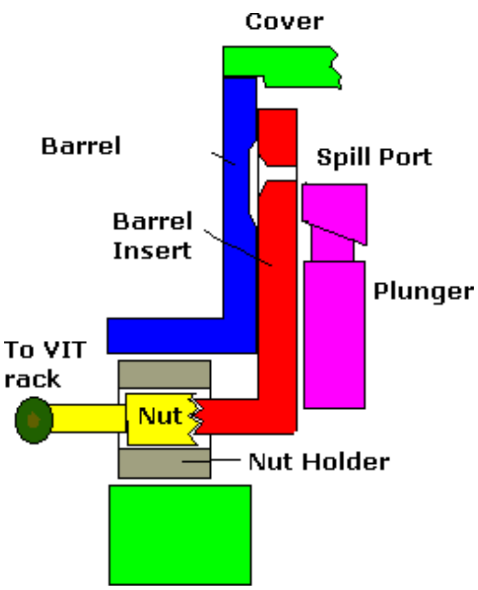
Position two-The suction and spill ports are covered and the barrel is travelling up the barrel. Pressure builds up until the fuel valve opens and injection commences

Position three-the spill port is uncovered, pressure above the plunger rapidly drops as the oil spills out. End of injection

It can be seen that by rotating the plunger the bottom edge uncovering the spill port can be moved. In this way the amount of fuel delivered is varied. On this only the end of injection timing is varied. Start of injection is constant. Some adjustm =481>

A standard bosch fuel pump can be fited wih a profiled plunger. The avantage of this is that the combustion process can be controlled to suit load conditions thereby improving efficiency.

Variable beginning and end-Variable Injection Timing (VIT) control



This allows for ideal matching of load to injection timing for various qualities of fuel. The Barrel insert can be moved up and down by action of the Nut. This has the effect of altering the position of the spill port relative to the plunger stroke. Therefore the beginning of injection is altered. The end of injection is varied by its normal way of rotating the plunger.

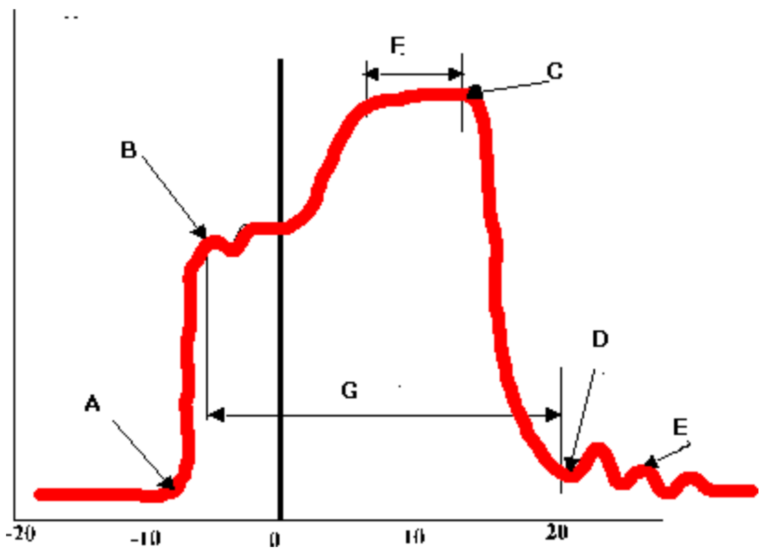
The Nut, which moves linearly, is controlled by the VIT rack, this is altered- continuously by the engine management.

Pump adjustment-Individual pumps may be adjusted in order to account for wear in the pump itself or the entire range of pumps can be adjusted to suit particular loads or fuel ignition quality. Individual pumps are adjusted by means of the screwed links from the auxiliary rack to the nut, just as the main rack adjustment is carried out. Adjustment of all pumps is simply by movement of the auxiliary fuel rack.

Problems associated with jerk pumps-the main problem with pumps of this type is that sharp edges on the plunger and around the spill port become rounded. As injection commences when the spill port is covered by the plunger, this means that later injection takes place. With the variable injection pump this can be accounted for by lowering the barrel insert and hence the spill port, so that it is covered at the required point. In older type pumps, adjustment required washes and shims to be placed between the plunger foot and cam follower or shims removed from below the pump body in order to lower it and the spill port relative to the plunger. Wear also causes leakage between the plunger and barrel but the only solution is replacement. Original timings must be restored.

The period of fuel injection

Typical fuel pressure curve at outlet from pump



A-Pump spill closes (approx. 8^o)

B-Fuel injector opens (approx. -4^o)

C-Spill opens (approx. 12^o)

D-Fuel injector closes (approx. 16^o)

E-Reflected pressure wave

F-Period of partial equilibrium i.e. the rate of delivery from the rising plunger in the barrel equals the flow out of the injector, therefore no pressure rise. Instability of the wave form can indicate too low viscosity fuel supplied.

G- Injection period (approx. 20^o)

It can be seen that the maximum pressure generated by the pump is far higher than the opening pressure by the injector (650 against 350 Kg/cm^2). Engine monitoring equipment can be used to generate this graph allowing diagnosis of the fuel supply equipment. For example, the rate of rise of pressure before the fuel injector first opens indicates wear in the fuel pump.

Period of equilibrium

This is the period between the beginning and end of stroke and can be divided into three periods.

1. *Delivery with no injection- being subject to high pressure the fuel reduces in volume, about 1 %. This causes a loss of effective plunger stroke and hence delays the start of injection. The main factor in this is the length of fuel pipe. The effect must be considered when advancing the fuel cam in relation to engine speed.*
2. *Main injection period-This is directly related to the effective stroke of the fuel pump plunger and consequent engine load. The engine speed can alter the resilient pressure fluctuations in the fuel pipe and so alter the fuel delivery curve and cause irregular discharge from the injector.*
3. *Secondary injection period-This is referred to as 'dribbling' and is due entirely to the resilient pressure fluctuations in the fuel piping and related to engine speed. The fuel oil passing to the injector has kinetic energy. At end of injection a low pressure wave passes through the fuel closing the needle valve in the injector. The kinetic energy in the fuel is converted to pressure energy and a pressure wave is formed. This can be seen below as the 'reflected pressure wave'. Avoided by fitting short, large diameter rigid fuel lines and having a sharp cut off at the fuel pump or an anti dribble device.*

Effects of high speed;

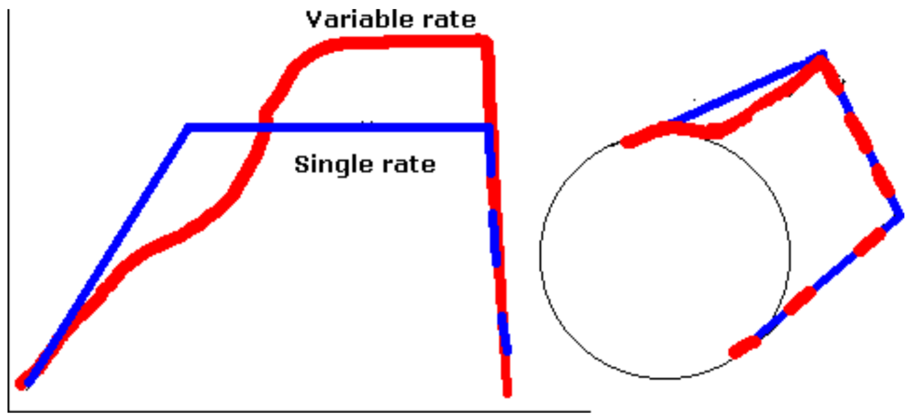
a, start of injection can be delayed 3 to 10^o - counteracted by advancing fuel cam by appropriate amount.

b, fuel pressure can be reduced by half maximum desired

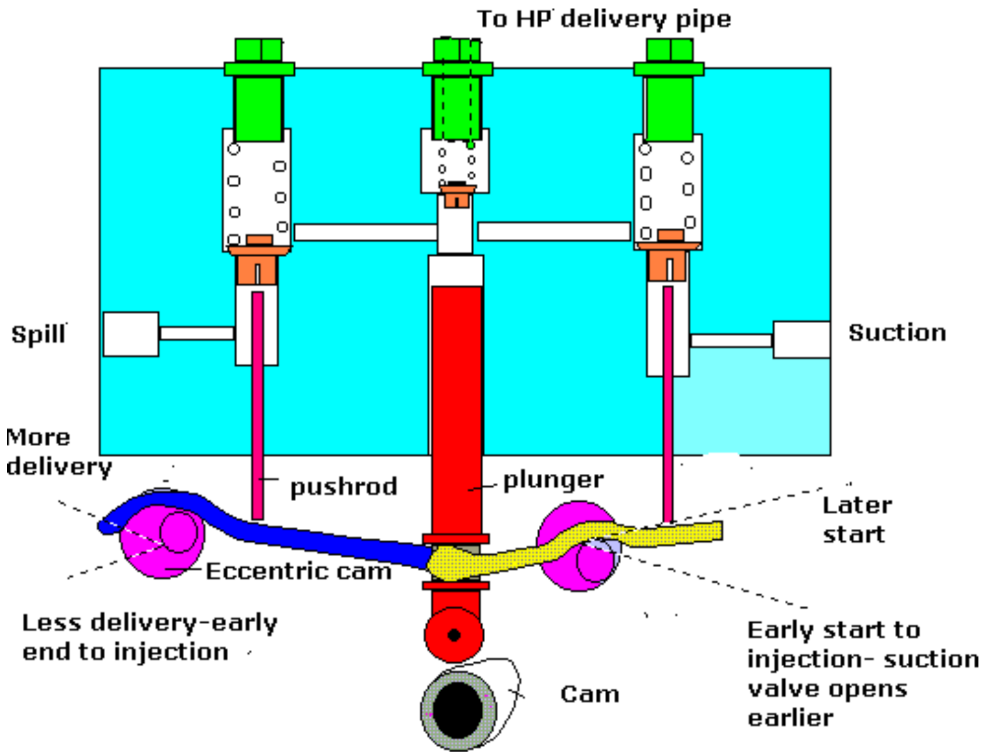
Anti-dribble Non-return valve-fitted to fuel pump discharge

Variable rate injection

In an effort to improve the combustion characteristics of the burn period profiled cams have been used which reduce the initial rate /*of delivery smoothing out the process.



Sulzer Type Fuel pump



The Sulzer differs from the Bosch scroll pump in that it operates with a plain plunger, timing being effected by operation of valves.

The cam, which is driven via gears by the crankshaft forces the plunger up the barrel thereby delivering fuel to the injectors during the period that both suction valve and discharge valve is shut.

The eccentric cam which alters the timing of spill is rotated via the fuel rack driven from the governor. The eccentric cam altering the opening and closing of the suction port, may be altered manually or driven off an engine management system to change the beginning of injection.

Common Rail System

When compared to the jerk system the common rail system is said */to be quieter, gives more accurate control of fuel pressure, has no high torque's or sudden loads transmitted to the camshaft.

High pressure fuel (300 bar) I delivered from a crank driven constant output pump to the fuel main, which supplies all the cylinders. The pump drive is chain driven from the crankshaft. The cam operated timing valves control the start and the duration of fuel injection to each cylinder. The pressure can be controlled by air operated relief or spill valves. The air pressure is controlled by a cam operated reducing valve. The excess fuel is spilled from the HP main and passes to the buffer. An overspeed trip collapses fuel pressure to a drain tank.

Modern common rail system. Modern requirements for very precise fuel injection timing and delivery, varying fuel quality and load/speed variations has led large slow speed engine designers to the common rail system.

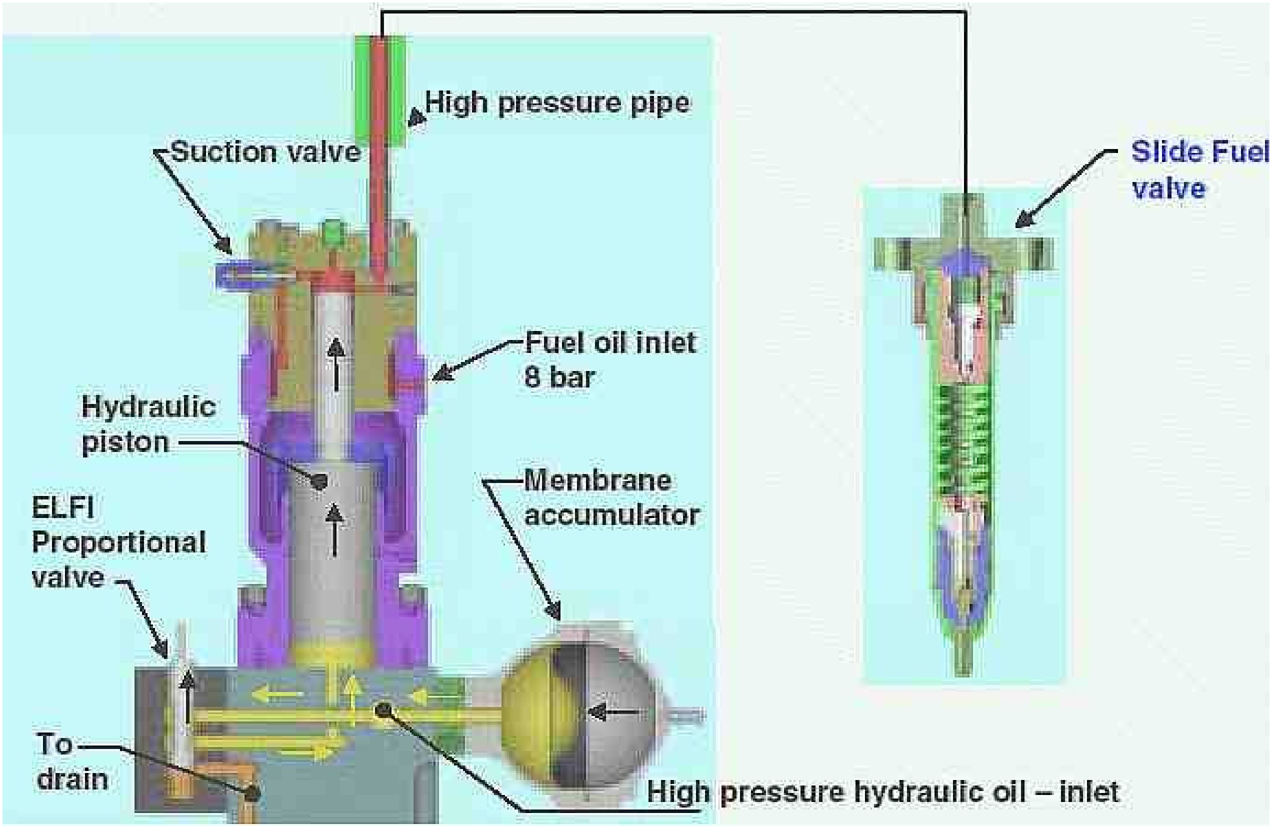
An electric driven high capacity pump supplies fuel to electric operated solenoid valves. One solenoid is fitted for each fuel valve. By computerised control the requirements can be met

Modern Hydraulically driven pump

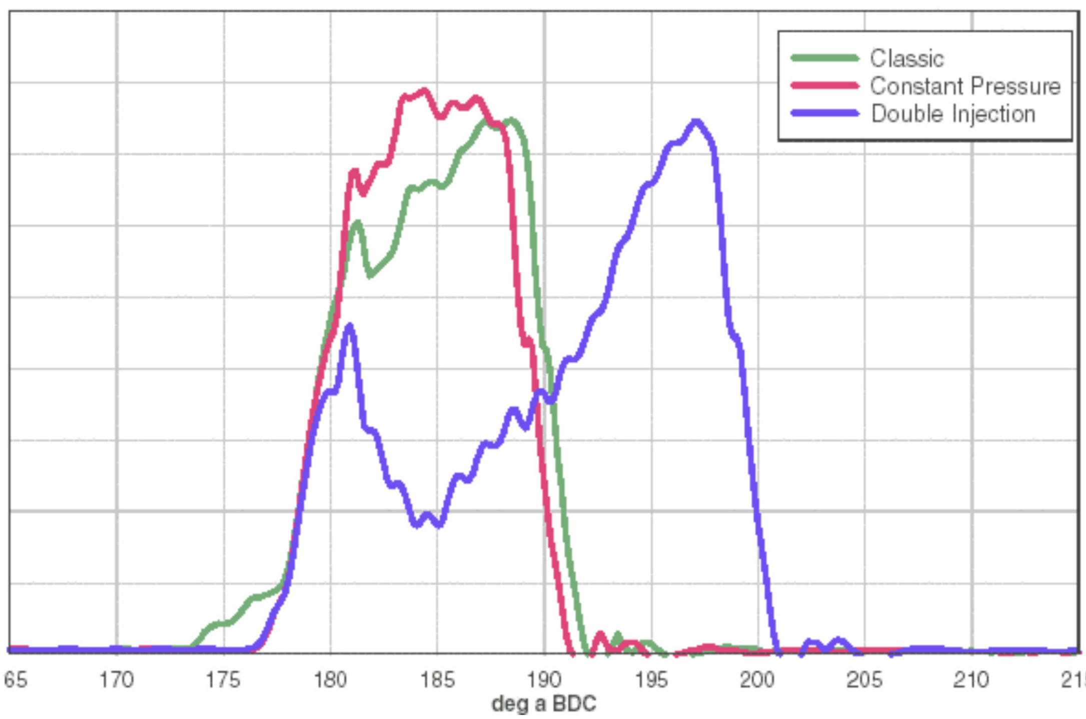
Development of the slow speed engine has lead to the 'camshaftless' design. Here the motive force for the fuel pump has changed from mechanical cam and follower to hydraulic.

Hydraulic oil is suppled via either a dediciated supply or more 8*normally common rail system. Accummulators are fitted on the pumps to smooth the motive oil pressure at the pump.

Hydraulic oil is diverted from the system to the pump actuation piston via an electrically controlled solenoid valve. This valve has three positions the middle being neutral.
The Control of the solenoid valve is carried out by the engine management system and is affected by such parameters as engine loading, engine revs, fuel quality and exhaust gas condition fuel oil flows under 8 bar boost pressure through a non-return suction valve and the piston falls to start of stroke position.



The solenoid valve may be proportioning in that it may control the flow rate to the power piston thereby changing the rate of fuel injection flow. For example, at lower loads a higher rate on injection may be allowed for. This has the effect of increasing Pmax, gives better heat release and thereby improving fuel economy.



Puncture Valve

The puncture valve consists of a piston which communicates with the control air system of the engine. In the event of actuation of the shut-down system, and when 'STOP' is activated, compressed air causes the piston with pin to be pressed downward and 'puncture' the oil flow to the fuel valve. As long as the puncture valve is activated, the fuel oil is returned through a pipe to the pump housing, and no injection takes place. I have also added a few more comments and attached a file to further explain the function(s) of the puncture valve.

MAN B&W reversing: Reversal of the fuel pump follower only takes place while the engine is rotating. If the engine has been stopped from running ahead and started astern, the fuel pump follower will move across as the engine starts to rotate and before fuel is admitted by venting the fuel pump via the "puncture" valve.

WHAT SHOULD i DO IF AN AIR START VALVE STICKS OPEN WHILE MANOEUVRING: The fuel pump of the effected unit should be "lifted" (fuel rack zeroed, puncture valve operated or whatever)...................

Cams

The basic purpose of a cam is to convert rotary motion into reciprocating motion in order to actuate some mechanism. For an engine this usually means the operation of a valve or pump. A cam must be hard enough to withstand the considerable forces exerted upon it but it must also be reasonable resilient. For these reasons cams are generally made from surface hardened steel. The exception is the indicator cam which is usually made from cast iron as the loading are small.

Couplings are provided at each cylinder section of camshaft, these couplings being shrink fits with hydraulic adjustment capability. The advantage of having sections of camshaft is that it allows cams, couplings, to be removed and replaced more easily then would be the case with longer shaft sections.

The Sulzer engines employ a different method of cam fitment. A hub is keyed and shrunk onto the camshaft and the cam fits onto this hub being held in place axially with a nut. The cam is secured against rotation by means of radial teeth on both hub and cam, and since there are 360 of these teeth the cams may be altered in one degree steps. The profile of a cam, including the leading or rsing edge, the dwell period at the op, and the trailing or falling edge are all profiled to give the corect rate and duration of movement for the equipment they are operating .The rate of rise of the leading edge of the cam governs the speed at which the valve or pump operates. Too slight and operation may not be crisp, too steep and undue loading may occur.

Critically profiled cams , especially fitted for operating the fuel pump, may be used. In this the leading edge of the cam is critically profiled to give a requisite flow variation to suit engine makers fuel delivery requirements.

In the case of mechanically operated fuel valves on the Doxford timing block the lift only needs to be small and the cam profile may be designed to suit the rate of change required. With such a system there is no need to provide a usual cam needed. This insert is generally held into place by set-screws and slotted holes in the insert allows the cam to be adjusted.

Some followers do not run on the base circle of the cam, stops being used hold the follower clear. This is said to minimise wear and avoids problems due to the screw holding the cam insert in place.

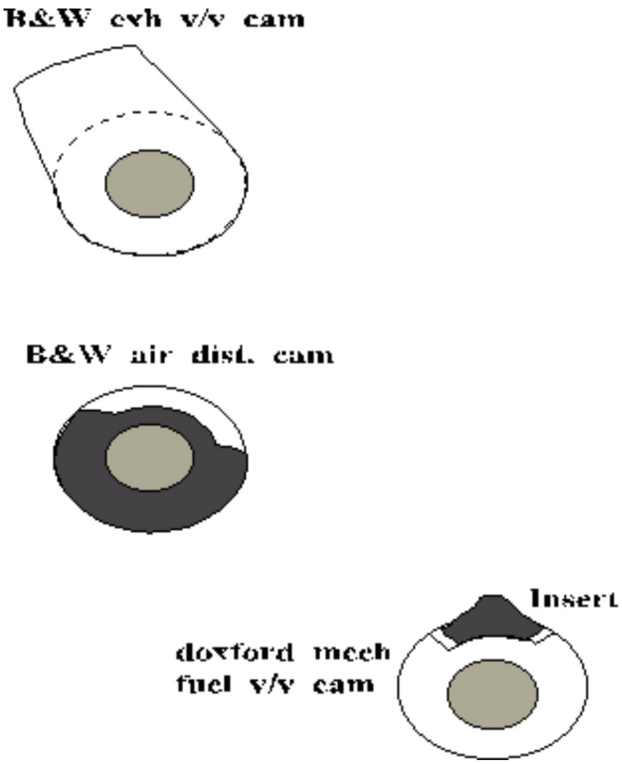
By far the most common method for fixing cams is by hydraulically floating the cams onto the shaft. o-rings seals being provided for that purpose with the high pressure oil supplied from an external pump. When hydraulically floated the cam may be rotated into position.

author note:

on a large bore B&W one of the exhaust valve gear operating cams slipped causing severe engine running problems.No gear was on board for hydraulically floating the cam so the engineers managed to rig a system of chain blocks whereby they where able to drag the cam back into position as an emergency repair. Next port a makers representative oversaw proper repair. He never did accept that it was possible to move the cam by this method!

On a valve operated by direct contact with the cam or via a pushrod and rocker, there must always be tappet clearance in order to allow for thermal expansion of the valve during engine operation. That tappet clearance must be correct, too much and the opening period and timing can be altered, too little and the valve might not fully close.

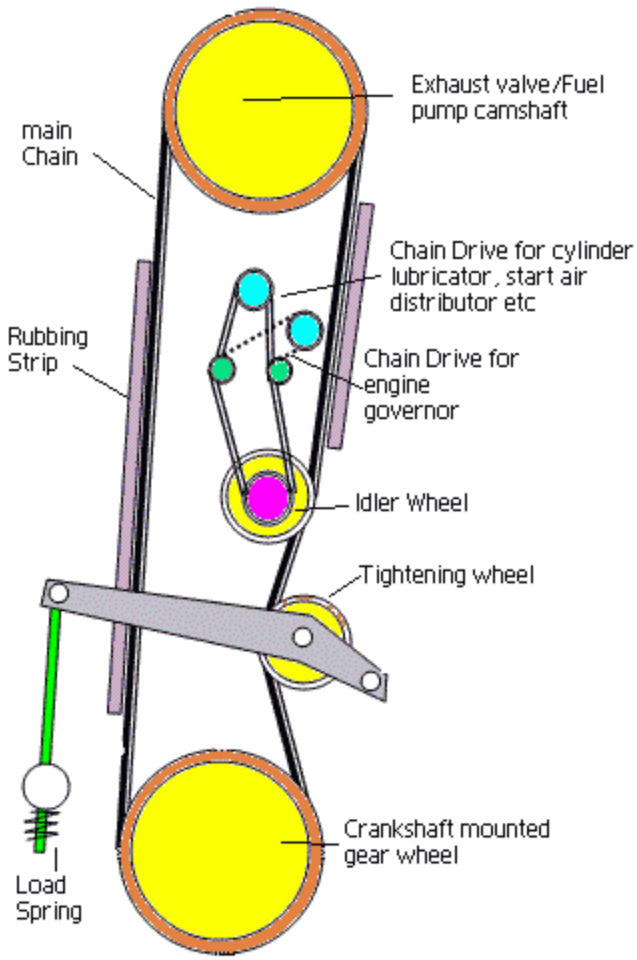
Camshaft bearings for most large engines are of the white metal type. This not only allows for more convenient replacement and adjustment but also allows an oil wedge to build up, that oil wedge restricting the hammering effect on the bearing. Ball or roller races would be subject to considerable brinelling damage. Bearing weardown reduces the effective lift of both valves and pump plungers and so weardown must be corrected as soon as it reaches recommended limits.

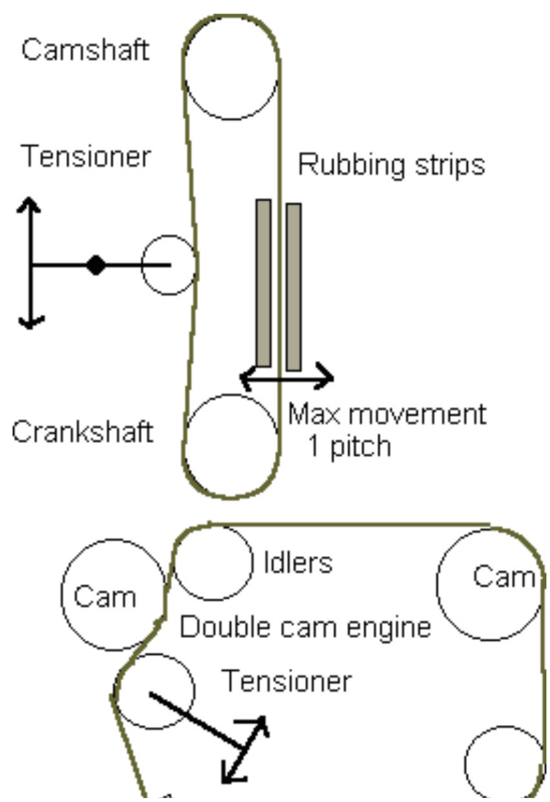


Author note: Spalling damage was noted on what was believed to be the leading edge of cams on a daihatsu medium speed engine. Correspondence with the makers regarding the possibility of damage being caused by the follower slamming down on the trailing edge of the cam drew denials.

It was later found that the damage was actually on the leading edge of the cam. As the damage was so severe as to alter the profile of the cams repair was by replacement. On this engine the cams where mounted on individually sized tapers increasing in diameter away from the end the cams where fitted on. The cams where locked into position and jacked off by nuts fitted on threads located either side of the taper. An excellent system making adjustment to timing very simple.

Chain drives

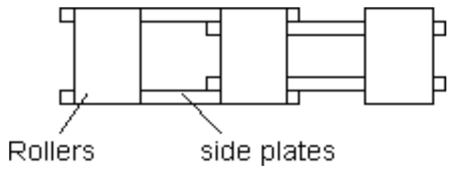


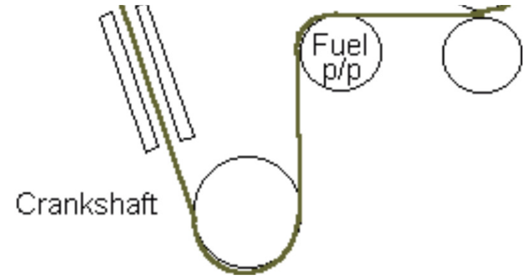


Rotation of camshafts in an engine may be by gears or by chain turned by the main crank. The disadvantage of using gears is difficulty in alignment, lubrication and disadvantage to wear from foreign materials as well as their increased cost.The disadvantage of chains is the requirement for tensioning and their finite life. Although for large installations this can be very long.

Wear on the chain pins, bushes as well as the chain sprockets can all lead to a slackening off of the chain. This can lead to 'slap' and changing of cam timing.This alters the leads of the fuel p[umps and exhaust valves.. The degree of angular displacement by checked using a manufacturer supplied poker gauge.

Chain damage occurs if the chain is too tight or too slack and the result is fatigue cracking of the links. If the tension is too tight, then this adds to the working stress of the chain. Insufficient tension leads to 'slap' with resultant damage to chain and rubbing strips. Vertical misalignment of the sprockets means rubbing at the side plates resulting in reduction of thickness and possible failure.





Chain stretch and hence reduction in tension can be accounted for by movement of a tensioning wheel. The tension usually being checked by movement to and fro at the centre of the longest free length.

Max. is about 1 chain pitch.

Recommended limit on stretch is about 1.5 to 2%, if max. movement of the tensioned is reached before the chain has reached its max. stretch then a pair of links may be removed. When max. stretch is reached, or if the chain shows signs of damage then the chain should be replaced.

The simplest method is to break the old chain and attach the new chain to it. The engine is then turned and as the old chain is paid off, the new chain can be paid in. This maintains approximately the correct timing, the tension of the chain can then be set.

Final adjustment of the timing can be made following manufacturers instructions, this generally means turning the engine until No1 is at top dead, then checking by us of pointer gauges the position of the cam.

The cam drive is adjustable and can be slackened off, by hydraulic means on large modern engines, the section of cams can then be turned relative to the crankshaft angle and the timing restored.

The chains are lubricated by the injection of a jey of oil between the chain wheels and the chain rollers just before the rollers are about to engage the wheel. Thereby an oil cushion is formed to dampen the impact

A question asked by an examiner was to explain the polygon of forces with respect to chain drive. This refers to the forces acting on the chain links as they pass over the chain wheel

Some of these forces are; Bending moment on the link as it travels around the sprocket

Stress changes on the link as it passes from the driving side to the driven

Tensioning of the chain dependent on the number of links between the sprockets varying i.e. related to the pitch

Centrifugal forces acting on the links

Bedplate

The bedplate acts as the main strength member, maintains correct alignment and supports the weight of the components. it must be capable of withstanding the fluctuating forces created during operation and transmit them to the ships structure. In addition it may also collect lubricating oil. In slow speed engine design, it consists of a deep longitudinal box section with stiffening in the form of members and webs.

Transverse members are fitted between each throw of the crankshaft. These support the main bearing saddles and Tie -rod connection. They are attached to the structure by substantial butt welds.

To reduce the engine height the sump of the bedplate may be sunken allowing it to fitted into a recess in the ships structure.

Plate and weld preparation is required with welds of the double butt type if possible. Regular internal inspection of the parts especially the transverse girder is required for fatigue cracking. Tie bolts should be checked for tighteness.

Box girders-A box girder is stronger and more rigid then I or H section girder of the same c.s.a.

From the simple beam bending equation we have;

$M / I = s / y = E/R$

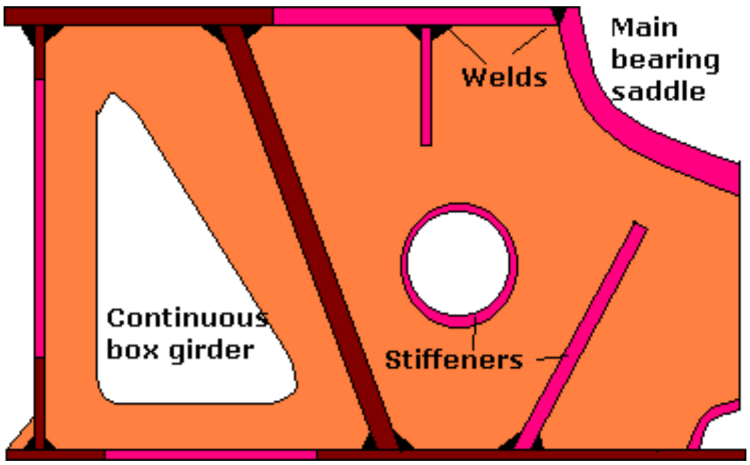
M=Bending moment
I=2nd moment of area of the cross section
s =Stress
y=distance from the axis of bending to the outer face
E= modulus of elasticity
R-radius of curvature of the bending.

This can be arranged into

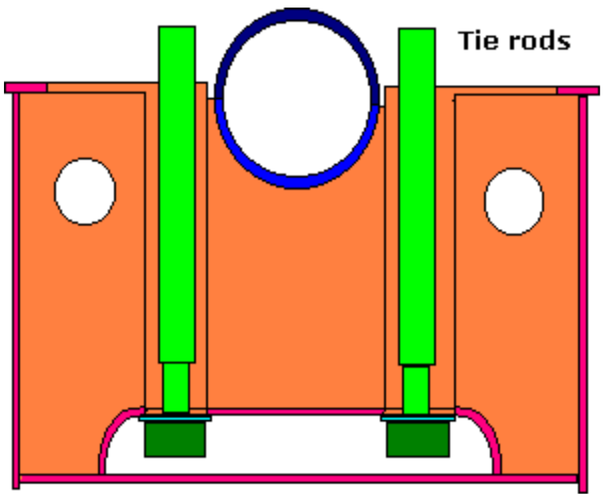
$\mathbf{s = (M/I) . y}$

It can be seen that for the same bending moment on a symmetrical shape of same size, the stress is reduced on the increasing 2nd moment of area. The second moment of area increase with moving of material away from the axis of bending towards the extremes of the section.

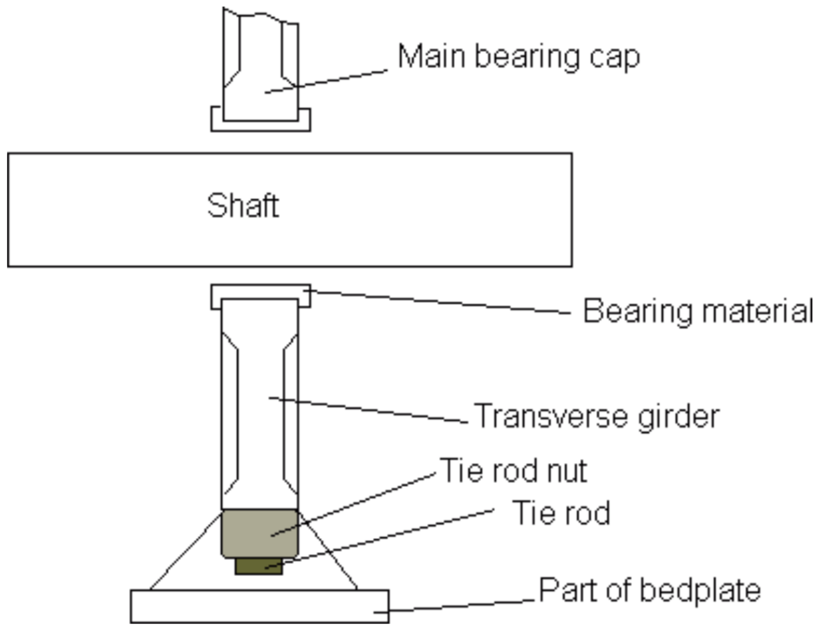
Because of this the commonest way of construction a fabricated bedplate is by creating two box section girders and tie them using transverse girders.



The advent of the small bore slow speed has seen the use of single side bedplates. A box section is then created by using a box section crankcase structure rather than the more traditional A-frame.This has the advantages of reducing width as well as weight and increasing the amount of fabrication so reducing assembly times.

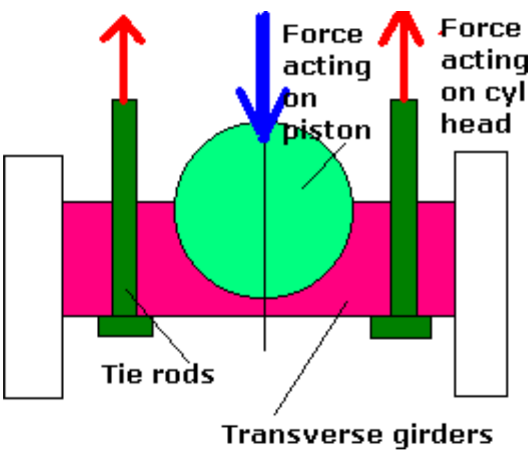


Due to the weight penalty, the use of cast iron is generally limited to smaller units where fabrication becomes impractical. However, cast iron has internal resilience allowing it to dampen down vibrations, this has led to its usage on some medium speed installations, especially passenger carriers, where noise and vibration suppression is important. .

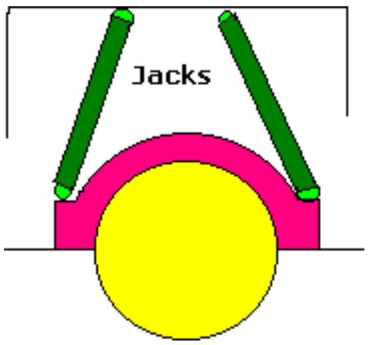


The most highly loaded pat of a bedplate is the transverse girder. Classification societies require that residual stress is removed after construction.

The transverse girder acts as a simple beam with the forces of combustion acting on the piston passing down through the bearing. The forces acting on the head are passed through the Tie rods.



It can be seen that to reduce the bending moment the tie rods have to be brought closer to the crankshaft. The limit to this is the securing arrangement required for the main bearing keep. One method is to use two instead of one bolts which can be made of smaller diameter. Sulzer use an alternative and very successful method in the form of jacking bolts. These jack against the bottom of the A-frame.


Jacks

Cylinder covers

Cylinder heads are exposed to maximum gas pressures and temperatures. They must therefore have adequate strength and cooling. This results in complex structures of strengthening ribs and cooling water passages. The design of heads is further complicated by the need to house various valves, fuel, air start, relief etc.

Where exhaust valves are situated in the head the structure design has to take into account the relatively high local temperatures around the valve which can cause thermal stressing. The combustion chamber may be formed by either shaping the cylinder cover or the piston crown. A flat piston crown is usually used with a shaped cover further complicating design and construction.

As the head runs at a fairly high temperature the cooling water must also be at a reasonably high temperature. This further thermal stressing. It is therefore usual to have the cooling water for the head in series with the jacket. The covers are attached to the cylinder block by means of large diameter bolts. The gas loads acting on the head are thus transferred to the cylinder block from which the tie bolts transfer it to the bedplate and then to the hull of the ship.

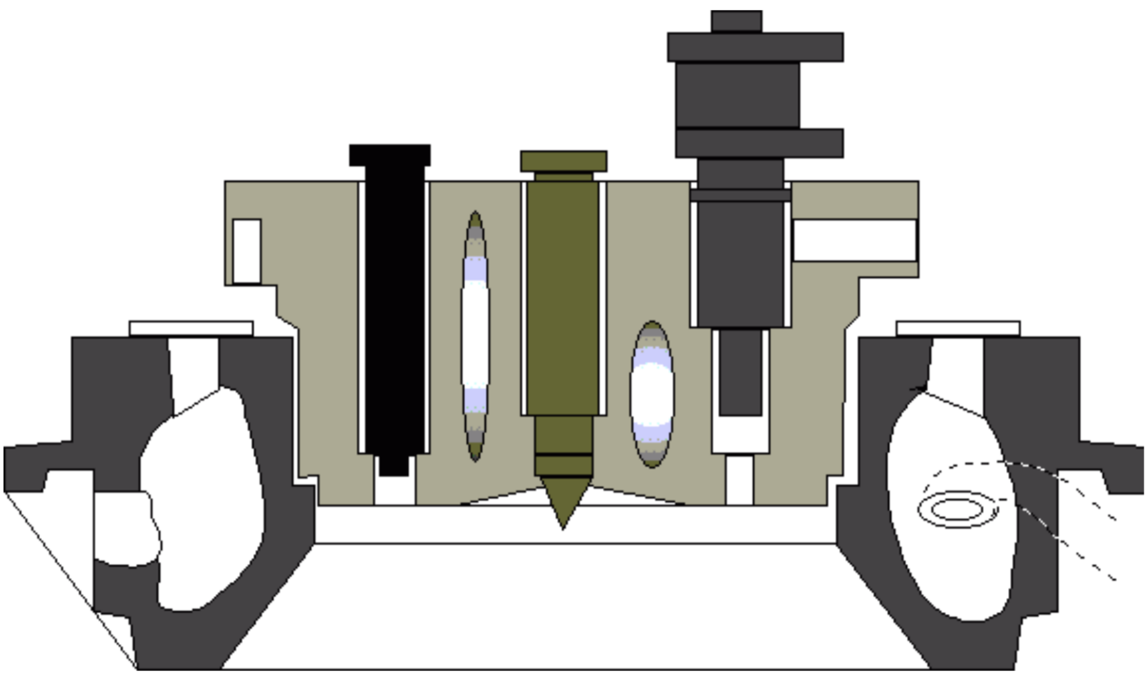
The original Sulzer engines employed single piece cylinder covers, but thermal stress cracks developed in relatively uncooled section were the conical part of the combustion chamber changed to the flat top.

In order to avoid this problem some allowance was required for thermal expansion, and this was provided by having a two part cover with an inner and outer section.

The inner section was of cast iron due to the complicated shape and the outer section cast steel for strength, a soft iron ring provided the joint between inner and outer sections. When the two parts are bolted together the head may be treated as a single unit.

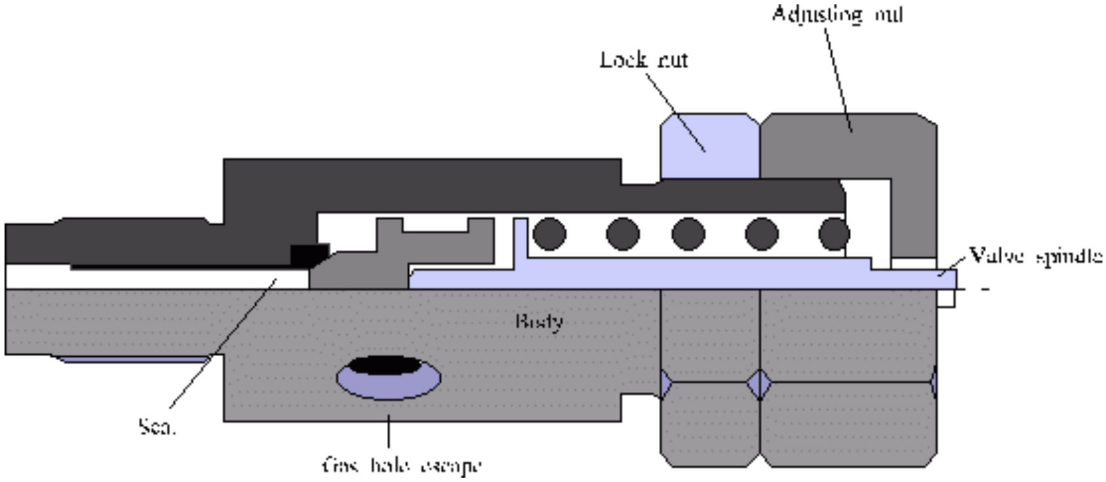
For recent engines the single piece bore cooled steel cylinder cover has been developed and presents no particular problems.

Sulzer RD cylinder cover



B & W cylinder safety valve

This type of valve is suitable for use with the special long studs used in modern engines. The safety valve is small an indicates the onset of over load. To release excessive pressure from the cylinder the cover is able to stretch the studs release the pressure and reseat. Hopefully cleanly.< class



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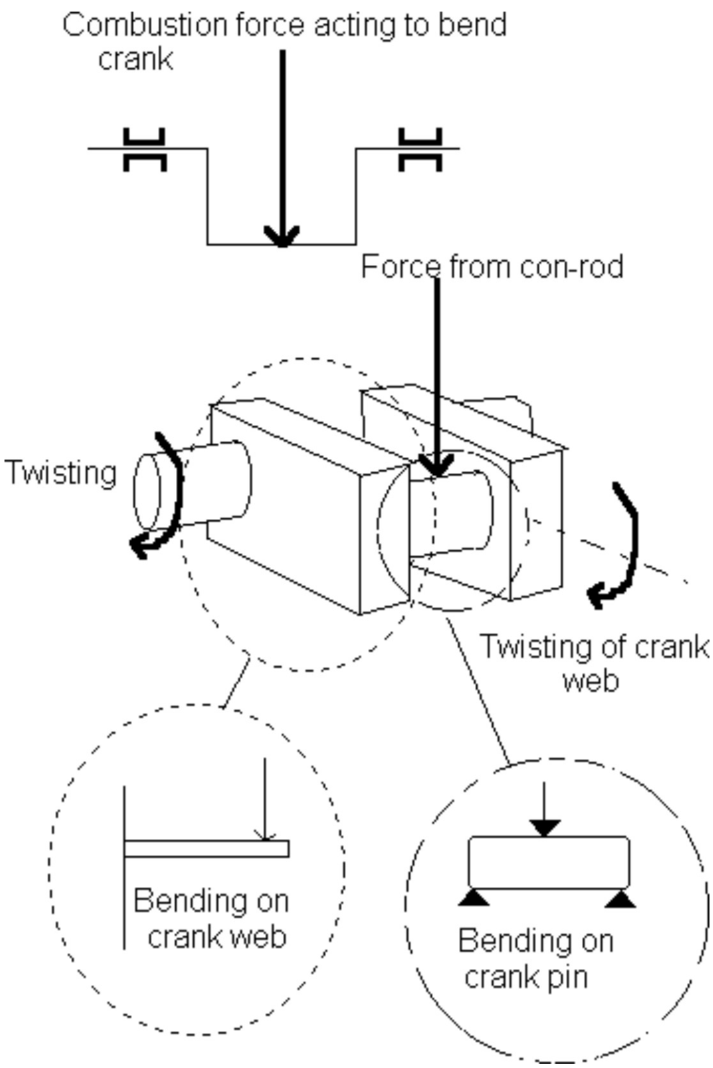
Crankshafts



Bending results in tensile, compressive and shear stresses in the material of the crank web.

Twisting results in shear stresses.

Crankshafts are subject to a complex form of loading which varies with time. In addition shrink fits, oil holes and fillet radii add to the complexity. Pure stress analysis and rules governing crankshaft dimensions are based upon a combination of theory and experience.

The three main loading stresses are;

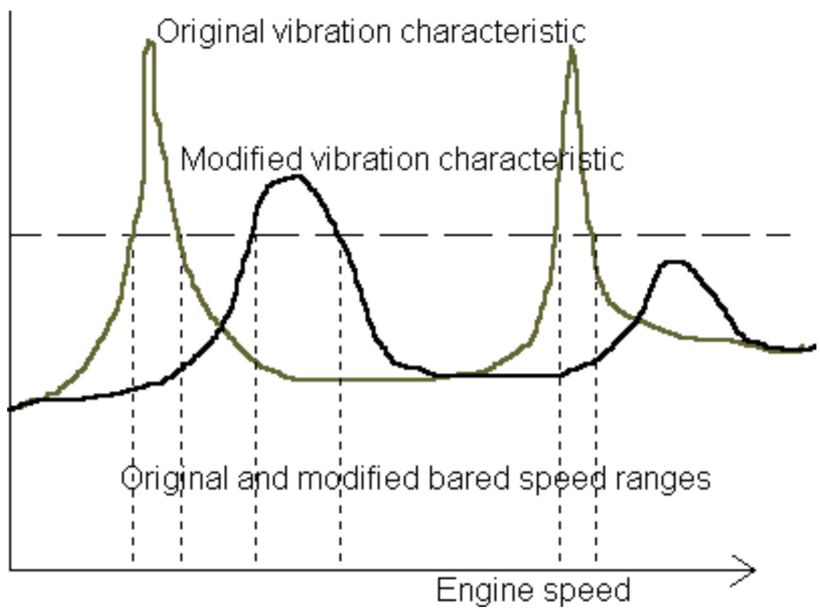
- Gas loads on the crankpin which produces alternating tangential bending of the webs alternating bending of the crankpin and on elements of shearing of the crankpin at the inner web faces
- Torsional vibrations producing alternating twisting of the crankshaft, the journal of which is in any event torsionally loaded by the gas loads via the web
- Axial vibrations in conjunction with the alternating lengthening and shortening of the shaft and in conjunction with local bending. Crankshafts may, in addition be subject to misalignment due to bearing wear or poor chocking. This produces and alternating bending of the crankshaft

All the above alternating stress patterns produce fatigue and so the material must have a built in resistance to it- this is of equal importance to its U.T.S. (Ultimate Tensile Stress). Mild steel is usually the material used but in some cases alloying the steel with a small percentage of nickel, Chromium, Vanadium may take place.

Crankshafts fail usually because of cracks propagating from a stress concentration point.

Vibration

All components vibrate e.g. a weight on a spring, rotating components such as crankshafts can vibrate in a torsional manner. The systems will differ but the principals are the same. The operating frequency caused by the operating speed is known as the forcing frequency. All systems have natural frequencies were the vibration amplitude is excessive (consider out of balanced wheels on a car). Resonance occurs when the forcing frequency and natural frequency coincide and the result is excessive vibration. If it is required to keep the vibration amplitude below a certain value in order to limit stress to prevent fatigue, then speeds coinciding to the natural frequency orders of it must be avoided. These speeds are referred to as the barred speeds (or critical speed ranges).



If the barred speed is located where it is required to operate the engine, say at half ahead, it will be necessary to fit a detuner or vibration damper. These lower the vibration peak and move it slightly higher in the range. The barred speed is either removed or moved away from the area in which the engine is operated. A vibration damper consists essentially of an additional rotating mass driven by the crankshaft and connected to it by a spring or a hydraulic fluid. The energy of vibration is used up in distorting the spring or shearing the fluid.

With constant speed engines employing a CPP propeller, vibration dampers are sometimes required because natural frequencies of the engine and shaft system changes with load due to the pitch of the propeller. In some cases there may even be a barred pitch.

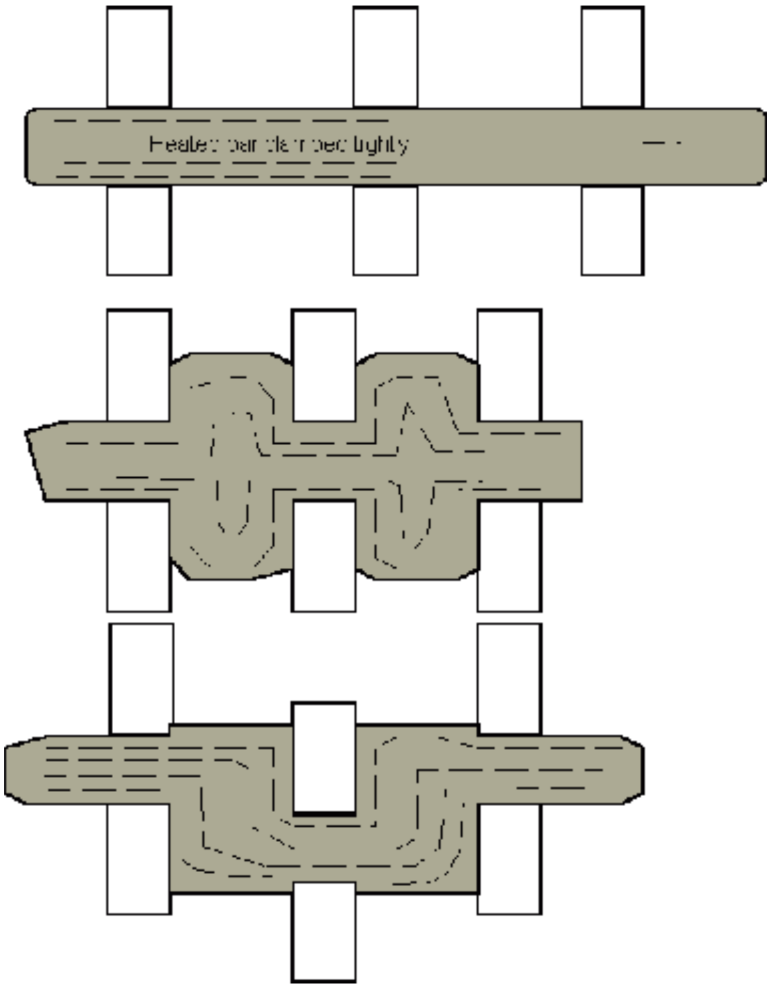
Methods of forming a crankshaft

The ideal arrangement is that of the solid forged structure because there is continuity of material grain flow which allows for smooth transmission of stress.

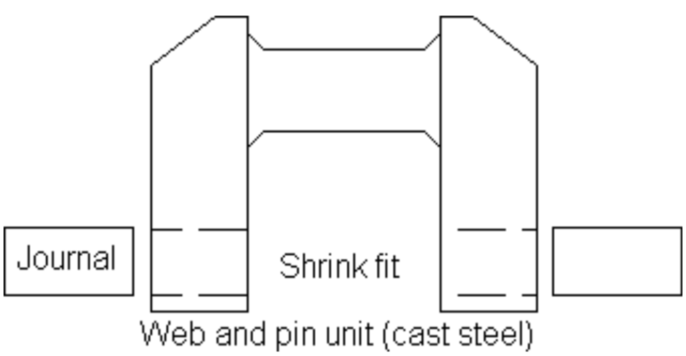
Unfortunately, such crankshafts are limited to the smaller engines because there is a limit to the size of forging equipment and the size of steel bar which can be produced.

Built up crankshafts with shrink fits or welded sections allow very large units to be produced, but they tend to be heavier and less rigid than an equivalent solid forged.

The grain flow method allows solid forged crankshafts to be produced with minimum energy and minimum need for post machining. A heated section of bar is held by three clamps which can be moved hydraulically. The three stages for forming the crank throws are shown. When one throw has been formed the next section of bar is heated, the shaft is held in the clamps again and the next throw formed.

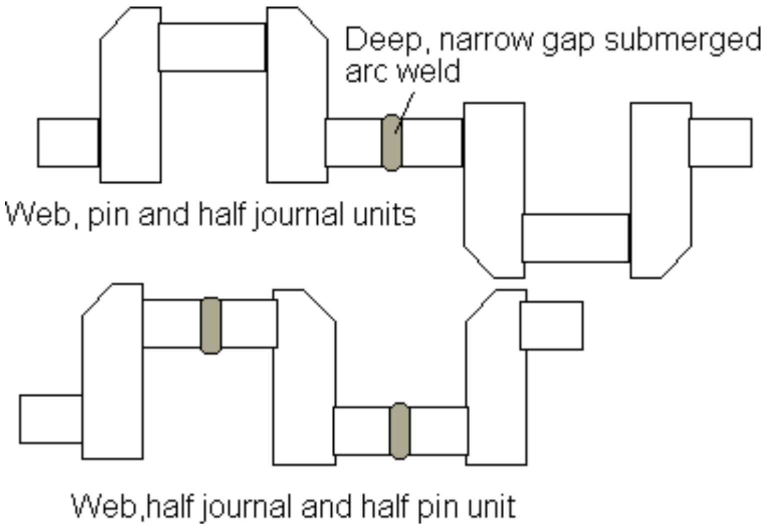


Semi-built up



No dowels are fitted as these can act as stress raisers.

Welded crankshaft



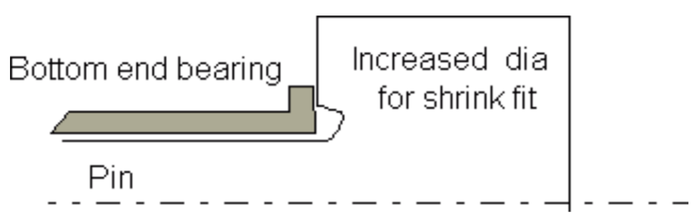
A form of crankshaft construction recently developed is that of welding. Cast web crank pin and half journal units are connected at the half journals by welding. These welds are stress relieved and the pins ground to give the correct finish. This form of construction is suitable for large direct drive engines and it provides strength close to that of the solid forged crankshaft. Any number of units may be connected

The usual form of construction for direct drive engine crankshafts is the semi-built up type. This makes use of shrink fits between the journals and webs. Careful design is required to ensure the shrink fit is strong enough but does not impose excessive shrinkage stress.

The shrink fit must provide sufficient strength to allow necessary torque to be transmitted. The actual allowance is about 1/500-1/600 of the diameter. Too large an allowance produces a high stress which can result in yielding when the working stress is added. Too small an allowance can lead to slippage.

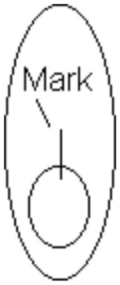
In order to provide for large torque transmission without high stress the area of contact at the shrink fit should be increased.

This is usually by means of an increased diameter (over increase length as this increase the engine length) which allows the fillet radius to be used, as the journal part of the pin does not need to be of the same large diameter. The fillet allows a smooth transmission and is rolled because this produces a compressive stress which provides safe guard against fatigue. The fillet is undercut allowing the web to be positioned against the bearing reducing the engine length and oil loss from the ends of the bearing.



Slippage of shrink fits

Slippage can occur at the shrink fits and this can be noticed by consideration of the reference mark at the end of the web and pin.

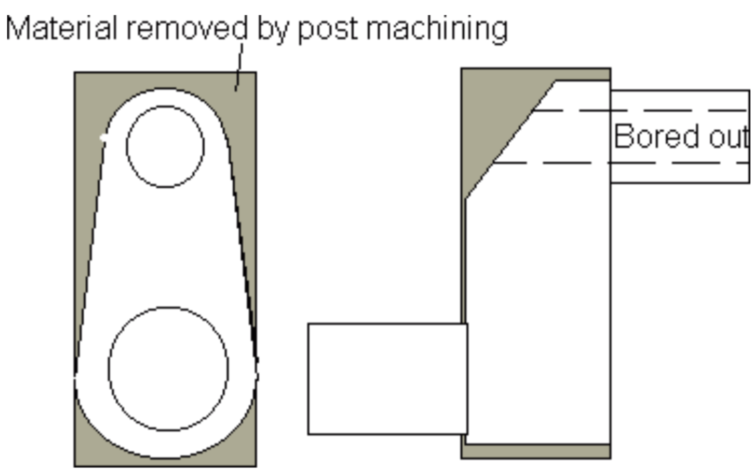


For Slippage upto about 5^o retiming of the effected cylinder can take place so long as oil holes passing through the shrink fit do not become obstructed.

For slippage above 5^o there may be problems of loading on the crankshaft due to firing angles and the relative position of the cranks, this can lead to excessive vibrations and stress. The ideal solution is the replacement of the effected parts, a temporary repair may be carried out. This consists of cooling the pin with liquid nitrogen and heating the web to give a temperature difference of about 180^oC. The web may then be jacked back into position. In both cases the slip fit will have been damaged, the contact faces which originally should be as smooth as possible to give maximum contact area. The engine should be run at below the max. rating until the parts can be replaced.

Most slipped fits are caused by starting the engine with water in the cylinder. But any overload can result in this problem.

Post machining



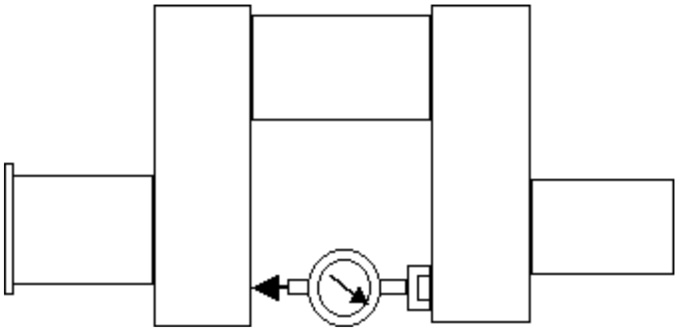
Modern engines designed for high power and weight should have a well balanced crankshaft with a minimum of material. Post machining allows the tapering and chamfering of webs and the counter boring of pins, thereby removing all unnecessary metal. A modern well balanced engine using higher strength steels can avoid the use of balance weights.

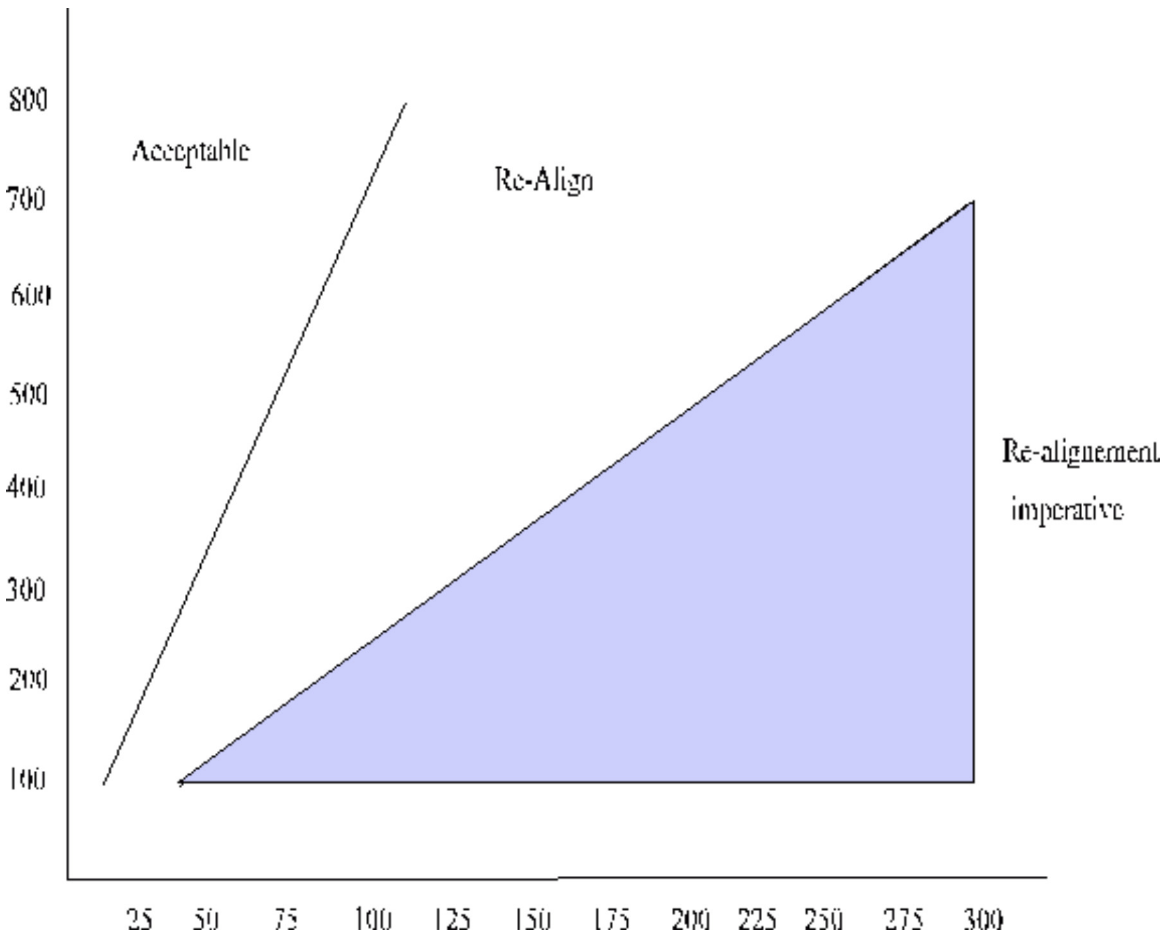
Crankshaft alignment check

If a main bearing has suffered wear then the journal supported by the bearing will take up a lower position, if adjacent bearings have not worn to the same degree then the shaft will take on a bent attitude causing the crankwebs to be subjected to an oscillatory bending action and so fatigue.

It is therefor necessary to check the alignment of crankshafts by the use of special gauges.

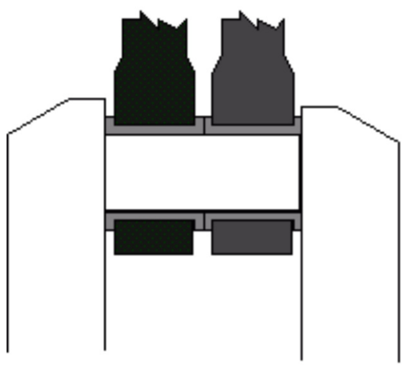
The crankweb will often have a light center punch mark to ensure that the gauge is fitted in the same position at each reading. The trim of the ship, whether loaded or unloaded, whether hogged or sagged are all important factors which can effect the reliabililty of the readings. Ideally the readings should be taken when the ship is drydocked.



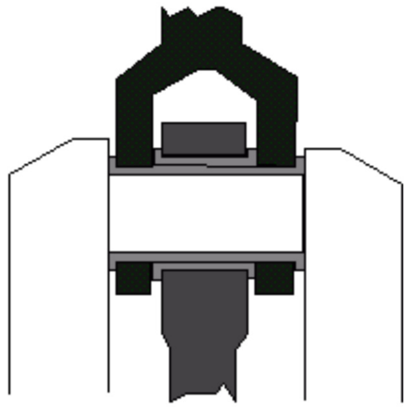


Medium speed vee-type crankshaft layouts

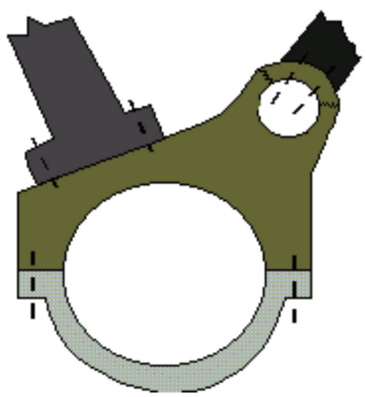
Side by side



Fork and blade



Articulated con rod



With vee-type engines it is necessary to connect two con rods too each bottom end. Three basic arrangements are available as shown. The side by side is the simplest with each bottom end being positioned alongside each neighbour on the crankpin. This requires cylinders to be offset across the engine thus giving a slight increase in length. The fork and blade type allows cylinders to be in line across the engine but the bottom end arrangement is more complicated. The fork may have two bottom end shells with the blade positioned between them. Alternately the arrangement as shown may be used. But in this case the fork shell runs the whole length of the crankpin and the blade shell runs on specially ground outer face of the fork shell.

The articulated arrangement has cylinders in line across the engine and a single bottom end is used. On con rod is connected rigidly but because of piston motions the other rod is connected by means of a gudgeon pin arrangement. Both pistons and con rods can be removed without disturbing the bottom ends.

Modern trends in materials

For a long period most crankshafts were made out of a material known as CK40. This had very good ability to withstand the damage caused by bearinf failure such as localised hardening and cracking. Undersizing by grinding was possible.
The modern trend is to move the chrome-molybdenum alloyed steel of high tensile stress. These may be non-surface hardened (which tend to bend and have localised hardening when reacting to an overheated bearing) or hardened (tends to loose its hardeness and due to changes in the molecular structure will crack). In both these cases grinding is generally nnot an option for repair.
For modern material cranks subject to normal wear grinding may be carried out.

Piston Rings

Rings must have sufficient spring so that they will provide an initial seal with the liner. As pressure builds up gas acting on the back face of the ring increase the sealing effect.

The spring must be retained under normal operating temperatures. They must not crack under high temperature and pressure ranges. Rings are generally of spherical graphite cast iron because of the strength and limited self lubricating properties. With modern long stroke engines the rings do considerably more rubbing than equivalent sections of the liner and so the rubbing faces are usually made slightly harder. This is achieved by a case hardening process (usually Nitriding) some rings are contoured on the rubbing face in order to promote faster running in. Copper or carbon coatings are sometimes provided for the same purpose. When running in cylinder l.o. is increased to provide an additional flow to carry away metallic particles and a straight mineral oil without antiwear properties is used.

The ring axial depth must be sufficient to provide a good seal against the liner but it must not be so great so that an oil wedge does not form. The ring actually distorts in the groove to form the wedge but if they are too deep they cannot do so. Thin rings will distort easily and scrape the oil from the surface. Radial depth must be sufficient to allow adequate support for the ring in the groove when the ring is on max. normal wear for its self and the liner.

Rings must be free in their grooves and the correct clearance is required. Excessive clearance can allow rings to twist while insufficient clearance can cause jamming and prevent the gas pressure from acting behind the rings. Also the rings may tend to twist excessively. Radial clearance must be sufficient between groove and ring back to allow a gas cushion to build up. The butt clearance must be sufficient to allow for thermal expansion. If insufficient the rings may seize and if excessive can lead to excessive blowpast

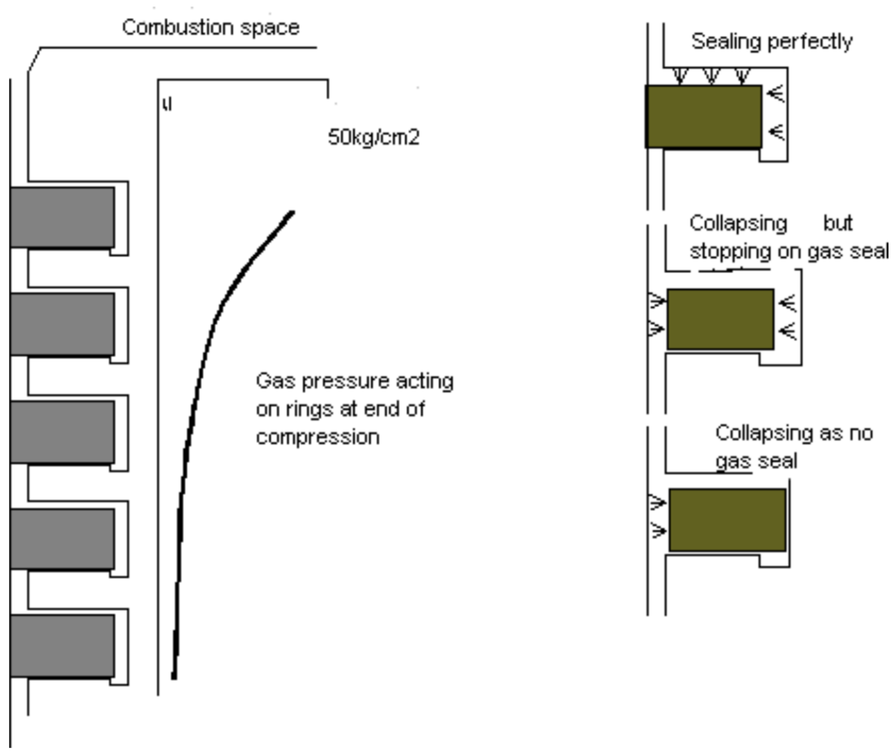
Grooves are sometimes coated with chromium to restrict deposit build up. For reconditioning the bottom face of the groove is generally provided with a replaceable steel wear ring.

As the rings maintain the gas seal there is a desire to position the top or firing ring as close to the piston crown as possible. However ,since the crown is highly stressed, thermally, this results in distortion of that zone. There is thus a desire to position the ring a long distance away from the crown. A compromise position is decided upon in each engine design.

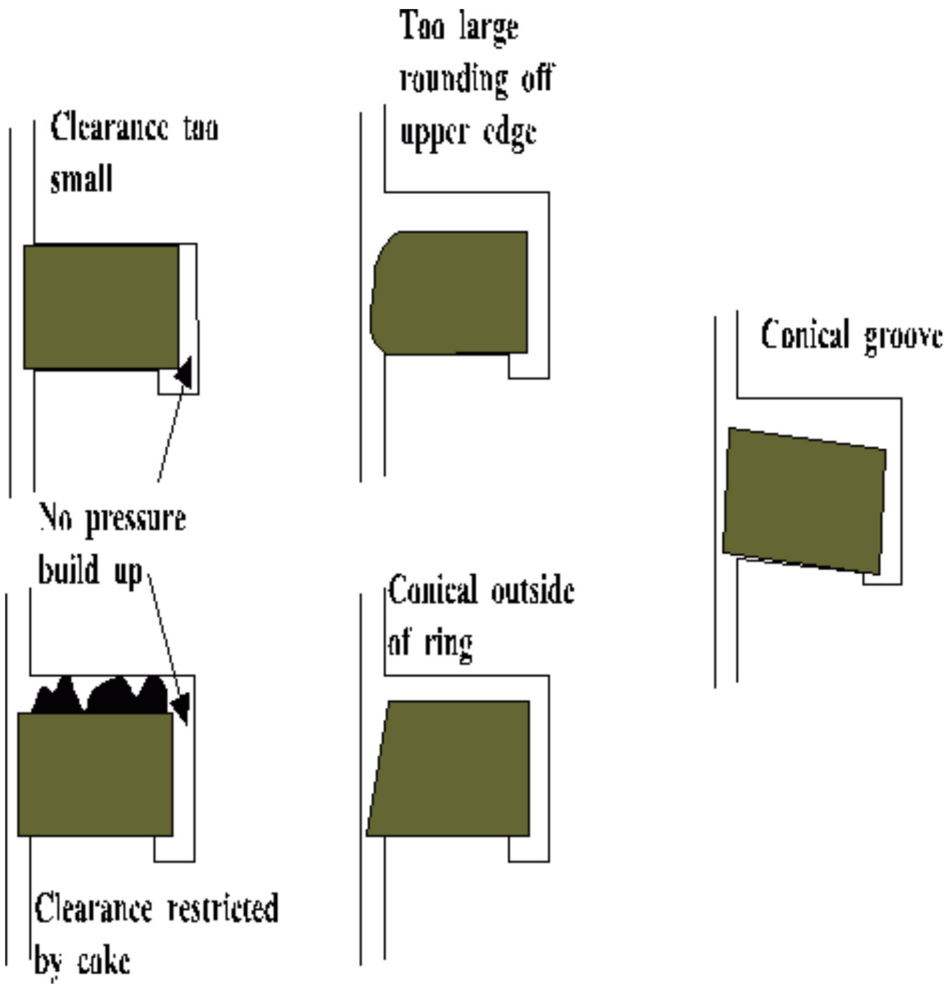
In order to minimise wear, a film of lubricating oil must be maintained between the moving parts i.e. the rings and liner, and rings and groove. Also the lubricating oil must spread over the liner surface by the rings, this helps to combat acidic products of combustion.

Skirts fitted to pistons on some designs perform the function of sealing the exhaust ports at T.D.C. these extended skirts have bronze rubbing rings inset to provide a bearing surface during the running in period.

Piston ring sealing and collapse.



Faults leading to ring collapse



Material History

Improvements to ring longevity before the 1970's were mainly concerned with design changes to improve lubrication.

Chromium plated rings running in unhardened liners were brought in but found to be susceptible to seize and burn marking with above average loading.

At the end of the 70's very hard plasma jet weld coatings were applied to the rings which gave excellent wear rates and resistance to burn marks. However running in unhardened liners gave high liner wear rates. Laser hardening of the liners gave improved life with acceptable maximum cylinder pressures of 145bar for medium speed engines. With increasing pressure requirements modern designs utilise a ceramic coating which gives excellent wear characteristics negating the need for laser hardening of the liner.

Stuffing box

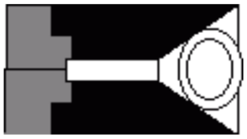
In the bore for the piston rod in the bottom of the scavenge air box a stuffing box is mounted to prevent lubricating oil from being drawn up the crankcase into the scavengeing air space. The stuffing box also prevents scavenge air from leaking into the crankcase.

The stuffing box is mounted on a ring which is bolted onto the underside of the scavenge air box. The stuffing box is taken out together with the piston rod during overhaul of the piston, but also can be disassembled for inspection in the crankcase with the piston remaining in position.

The stuffing box housing is in two parts, assembled by a flanged joint. In the housing five ring grooves have been machined out of which the two uppermost ones accommodate sealing rings that prevent scavenge air from blowing down along the piston rod. In the lowermost grooves scraper rings are fitted which scrape the lubricating oil of the piston rod. The oil is led through bores in the housing and back to the crankcase.

Between the two uppermost ring grooves, for the sealing rings, and the three lowermost grooves, for the scraper rings, a cofferdam has been machined out which, through a bore in the housing and a connecting pipe, communicates with a control cock on the outside of the engine. It can be checked by opening this control cock that the scraper and sealing rings are functioning correctly.

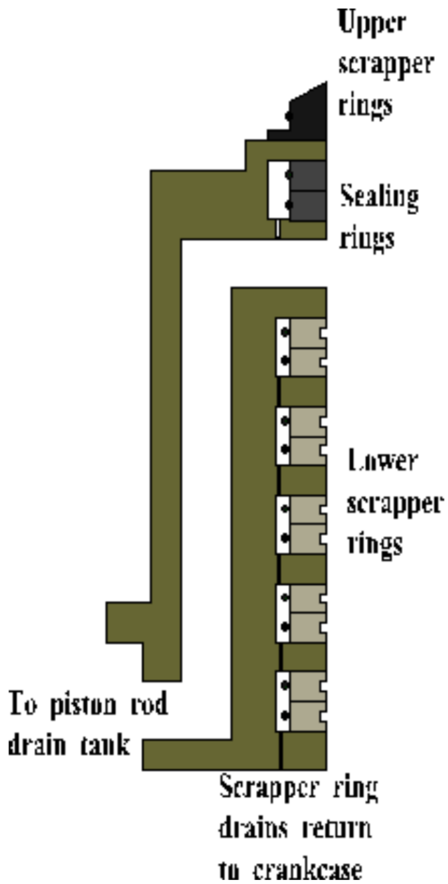
Sealing ring section



The two sealing rings each consist of a four piece brass ring which accommodates eight brass sealing segments, two per base, guided by four cylindrical pins. The parts are pressed onto the piston rod by a helical garter spring.

Scrapper ring section

The three scraper rings are made up of three steel base parts into which two lamellas are fitted into a grooves machined in each part. A garter spring keeps the ring in contact with the piston rod. Scraped off oil is led through ports in the base ring back to the sump.



A clearance is given at the ends of the parts to ensure contact with the piston rod as the rubbing face wears.

Author note:

Extremely high wear was noted on a class of vessels with B&W gfca engines. Balls of wire wool where removed from between the segments at overhaul.

Repair was to send the piston rods for machining from their cloverleaf shape back to circular. When fitting new lamellas emery paper was wrapped around the rod and the lamellas 'bedded' in. This prevented the segments from canting and the ends of the lamellas digging in.

Liner

Cylinder liners are generally made from grey cast iron because it is easily cast and has self lubricating properties due to the graphite flakes for, some modern engines spheroidal graphite or nodular graphite is used. This has greater mechanical strength, but has the same self lubricating properties.

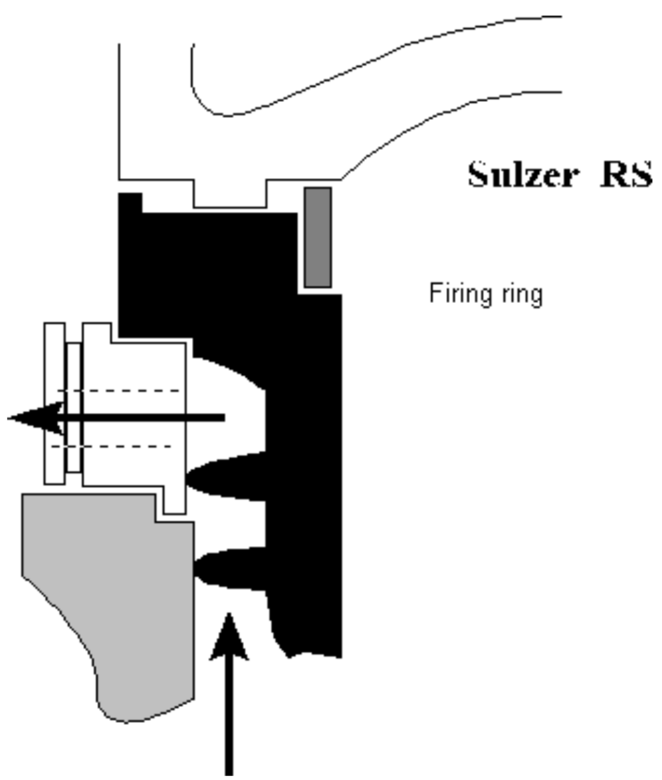
The critical part of any liner is the upper section were the temperature and pressure conditions are at their most difficult. Cooling is required to maintain strength and the temperature variations must be maintained within set limits in order to avoid cracking. Rapid change of temperature due to the rapid variation in cylinder condition or cooling water temperature can result in cracking.

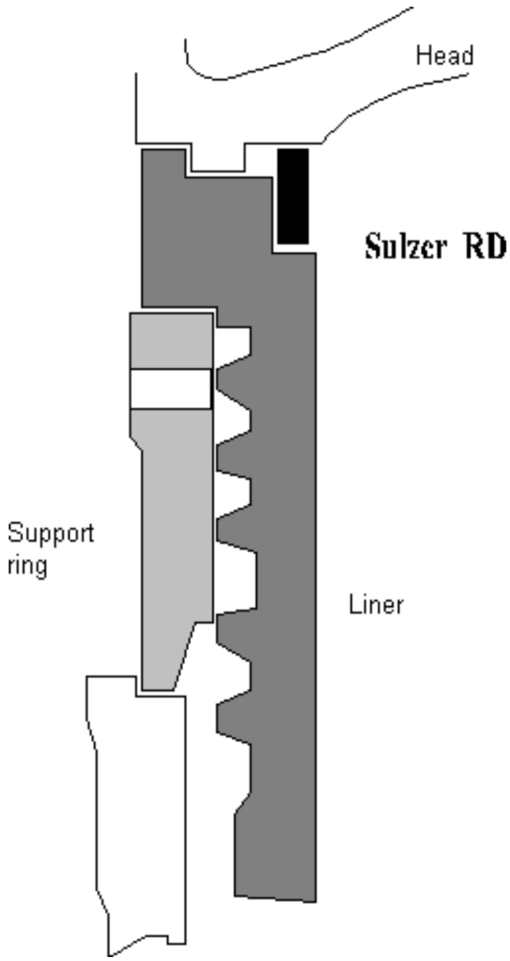
Early engines e.g. Sulzer R's were lightly loaded and thin section liners could withstand the pressure , the thin sections avoided any problems of thermal stresses. Fire rings were often fitted to protect the inner face of the liner from impingement by the combustion flame.

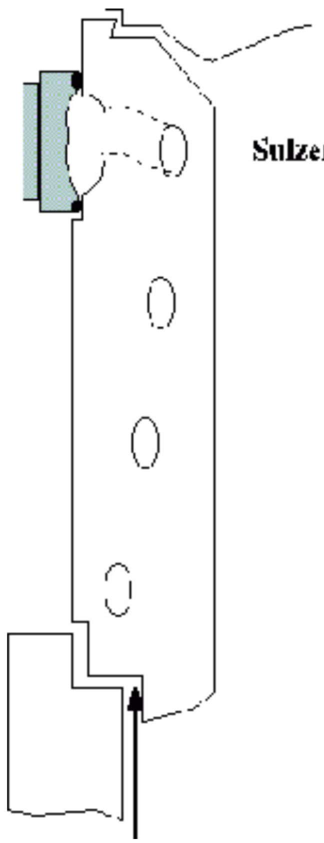
With the advent of turbocharging e.g. Sulzer RD, it was necessary to provide strengthening in order to withstand mechanical stress increasing the wall thickness would have resulted in thermal stress.

Shrink rings or support rings were used to strengthen the upper section of the liner and the cooling space was provided , the support ring took about 50% of the load, between the liner and the strengthening ring.

For modern highly rated engines support or shrink rings are not suitable and thick section bore cooled liners are employed




Head
Sulzer RD
Support ring
Liner



,p> A typical cast iron as used in liner construction begins to lose its strength at a surface temperature of about 340°C . A liner must therefore be either alloyed with expensive elements or cooled to about 80°C below this temperature.

A typical cylinder lubricating oil forms a lacquer at about 220°C . A liner must therefore be cooled to about 40°C below this temperature in service, to reduce formation of carbon deposits.

A liner must therefore have a maximum temperature in the thickened region, of about 260°C and a max. temperature in the thinned section of about 180 °C . This produces large temperature gradients axially in the liner and also across the walls of the liner. This could produce component failure due to high thermal stress if the material was too thick or failure by low metal strength if the material was too thin.

The design that has been adopted is to have the cooling surface around the combustion zone formed by a large number of hole drilled at an angle to the vertical axis of the liner. This produces a fully machined cooling water surface close to the combustion side of the liner, thus keeping thermal stresses low.

It is usual to allow the liner to expand freely in the axial direction away from the combustion zone. The cooling spaces may be sealed by neoprene rubber rings fitted in the grooves in the liner. The rings and grooves being closely matched to ensure a positive seal. Alternately copper rings may be fitted

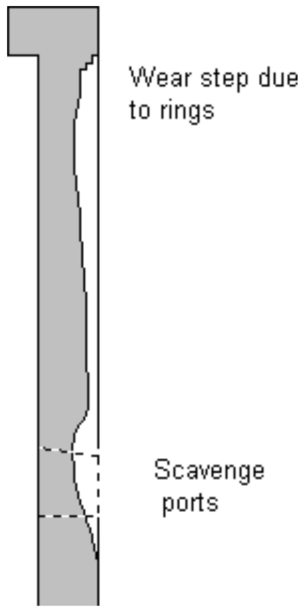
Wear of cylinder liners

There are three main cause of damage to the liner material;

Corrosion-caused by the acidic products of combustion

Abrasion-caused by solid particles breaking through the lubricant film

Friction-Break down of the lubricating oil film leading to metal to metal contact



Normal liner wear exists for the reasons given above. Wear rates are greatest towards the top of the stroke due to the high temperatures thinning out the oil film and high gas pressure behind the piston rings forces the land into contact with the liner wall. In addition, piston is moving slowly at the end of its stroke and a good oil wedge cannot be formed.

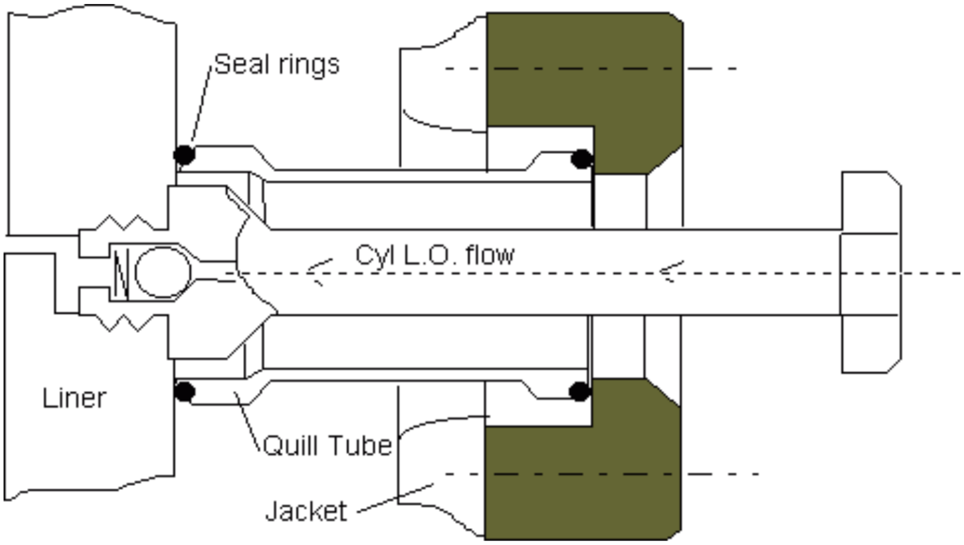
Wear rates reduce lower down the stroke because pressure and temperature conditions are less arduous and piston speed has increases. At the bottom end of the stroke wear rate increases again due to reduce piston speed, but also due to the scouring effect of the in coming scavenging air. The reduced temperature increases the viscosity of the oil so reducing its ability to spread evenly. Long stroke engines are sometimes provided with quills at the bottom of the stroke.

Cylinder Lubrication

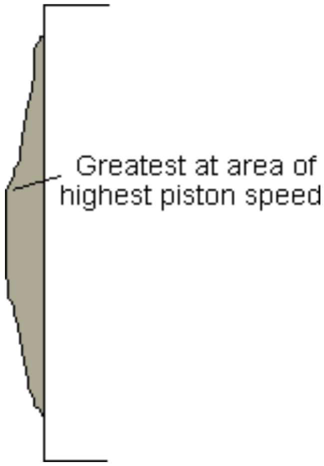
Cylinder oil is injected by means of quills positioned in the liner, the number of which is governed by the diameter of the liner and ensures sufficient oil to be injected. The use of grooves in the liner helps spread and retain the oil film.

Vertical positioning of the quills is important and the oil should be injected so that it is spread upwards by the top two piston rings. If injected too early the top ring will scrape the oil upwards to be burnt. If too late the oil will be scraped off the liner by the next downstroke. Injection timing is therefore critical, too much so as experiments to inject the oil precisely have failed. The remedy has been to over supply the quantity of oil and provide extra quills at the bottom of the stroke

Cylinder Lubrication quill

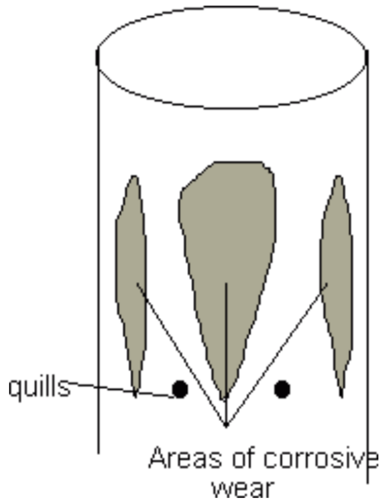


Abnormal Liner Wear



a,Scuffing- This occurs if the cylinder lo quantity is insufficient. A complete oil film is not obtained and rings contact the liner surface. Local seizures takes place producing a hardened glassy surface on the rings and liner and as the rings rotate in their grooves scuffing speeds around the liner. If scuffing is extensive the only solution is to replace rings and liner. Minor scuffing may be corrected by replacing the rings and braking don the scuffing area on the liner with a rough stone to provide a key for the cylinder l.o.

It is necessary to determine the cause of scuffing and correct it. As stated the most likely cause is insufficient quantity of l.o.



b, Cloverleafing-if the cyl l.o. has inadequate acid neutralising properties for the fuel being burnt or if there is insufficient quantity of oil injected then cloveleafing can occur.. This is basically regions of corrosive wear midway between the quills and upwards towards the top of the liner. These areas may be visible due to the corrosive effect and they are cloverleaf shaped. Eventually the rings become unsupported in these areas, gas builds up on the front face and the ring is subject to collapse.

There are consequences of over lubrication, particularly with sticking rings and choked ports due to carbon build up. Excess unburnt oil can also accumulate in the scavenge space risking fire.

Ships which operate for long periods in the 'down by the stern' trim mat exhibit an increased wear in the for'd to aft direction over the athwartships direction. Athwartship wear is aggravated by the reaction forces from the piston and rotation of the crankshaft. Although the bulk of this is removed by the crosshead on slow speed engines, this resultant force still causes the athwartship direction to have the greatest wear rate.

Maximum allowable liner wear is determined by the manufacturer but generally is between 0.7 to

1.0%.

Piston

Manufacturing and materials

Materials

Piston crowns attain a running temperature of about 450^{o}C and in this zone there is a need for high strength and minimum distortion in order to maintain resistance to gas loads and maintain the attitude to the rings in relation to the liner. The heat flow path from the crown must be uniform otherwise thermal distortion will cause a non-circular piston resulting in reduced running clearance or even possible contact with the liner wall.

In addition to this thermal stress they are also subject to compressive stress from combustion and compression loads, as well as inertial loads.

Materials such as pearlitic, flake and spheroidal cast iron, alloy cast irons containing Nickel and chromium, and aluminium alloys may be used.

The determining factor is the design criteria for the engine.

For a modern slow speed engine steel forging or castings of nickel-chrome steel or molybdenum steel are common. The weight of the material is not normally a governing factor in this type of engine although resistance to thermal stress and distortion is. Efficient cooling is a required to ensure the piston retains sufficient strength to prevent distortion.

For medium and high speed engines the weight of the material becomes important to reduce the stresses on the rotating parts. The high thermal conductivity of aluminium alloys allied to its low weight makes this an ideal material. To keep thermal stresses to a reasonable level cooling pipes may be cast into the crown, although this may be omitted on smaller engines.Where cooling is omitted, the crown is made thicker both for strength and to aid in the heat removal from the outer surface.

Hard landings are inserted into the ring groves to keep wear rated down.Composite pistons may be used consisting of an cast alloy steel crown with an aluminium-alloy or cast iron body.

Annealing

After casting or forging the component is formed of different material thicknesses. The thinner parts will cool more quickly thereby setting up internal stresses. Annealing removes or reduces these stresse as well as refining the grain structure.

Cooling

Water Cooled	Oil Cooled
High specific heat capacity therefore removes more heat per unit volume	Low specific heat capacity
Requires chemical conditioning treatment to prevent scaling	Does not require chemical treatment but requires increased separate and purification plant
Larger capacity cooling water pump or separate piston cooling pump and coolers although less so than with oil	Larger capacity Lube oil pump, sump quantity and coolers

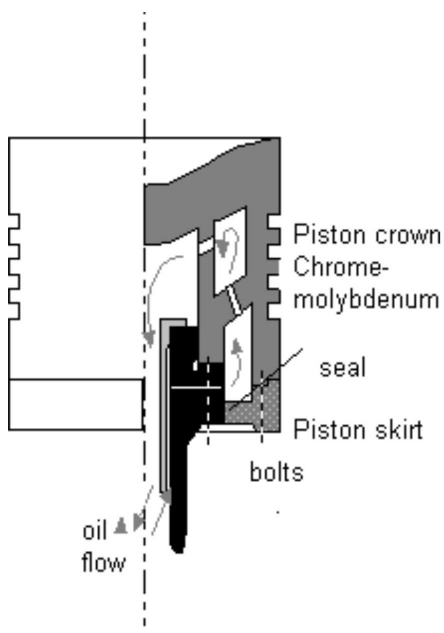
Special piping required to get coolant to and from piston without leak	No special means required and leakage not a problem with less risk of hammering and bubble impingement.
Coolant drains tank required to collect water if engine has to be drained.	Increased capacity sump tank required
Pistons often of more complicated design	Thermal stresses in piston generally less in oil cooled pistons
Cooling pumps may be stopped more quickly after engine stopped	Large volumes of oil required to keep oxidation down and extended cooling period required after engine stopped to prevent coking of oil

Wear rings

Wear rings are found on some slow speed engines employing loop or cross flow scavenging although they may be found in most designs. They are made of a low coefficient of friction material and serves two main purposes. To provide a rubbing surface and to prevent contact between the hot upper surfaces of the piston and the liner wall.In trunk piston engines wear rings to negate the distortion effect caused by the interference fit of the gudgeon pin .

The ring may be inserted in two pieces into the groove then lightly caulked in with good clearance between the ends.

B&W LMC oil cooled piston



The piston has a concave top. This is near self supporting and reduces the need for internal ribbing. It prevents the cyclic distortion of the top when under firing load. This distortion can lead to fatigue and cracking

Pistons may be cooled by oil or water. Oil has the advantage that it may be supplied simply from the lubrication system up the piston rod. Its disadvantage are that maximum temperatures is relatively low in order to avoid oxidised deposits which build up on the surfaces. In addition the heat capacity of oil is much lower than that of water thus a greater flow is required and so pumps and pipework must be larger. Also, if the bearing supply oil is used as is mainly the case a greater capacity sump is required with more oil in use.

Water does not have these problems, but leakage into the crankcase can cause problems with the oil (such as Micro Biol-Degradation). The concave or dished piston profile is used for most pistons because it is stronger than the flat top for the same section thickness

Sulzer watercooled piston (rnd)

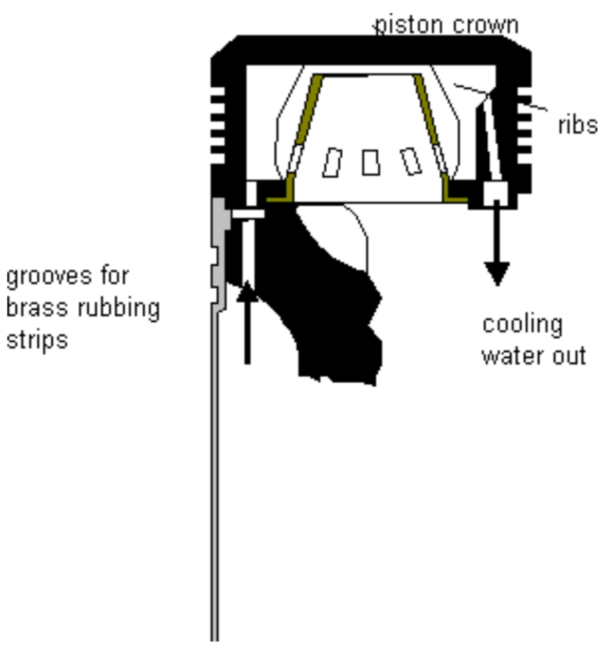
Increasing section thickness would result in higher thermal stress.

Sulzer piston require a flat top because of the scavengeing and exhaust flow arrangement (loop scavengeing of RND etc). in order to avoid thicker sections internal support ribs are used. However these ribs cause problems in that coolant flow is restricted. The flow of water with an RD piston is directed to and from the piston by telescopic pipes. The outlet is positioned higher than the inlet within the cooling cavity and on the opposite side of the support rib in order to ensure positive circulation.

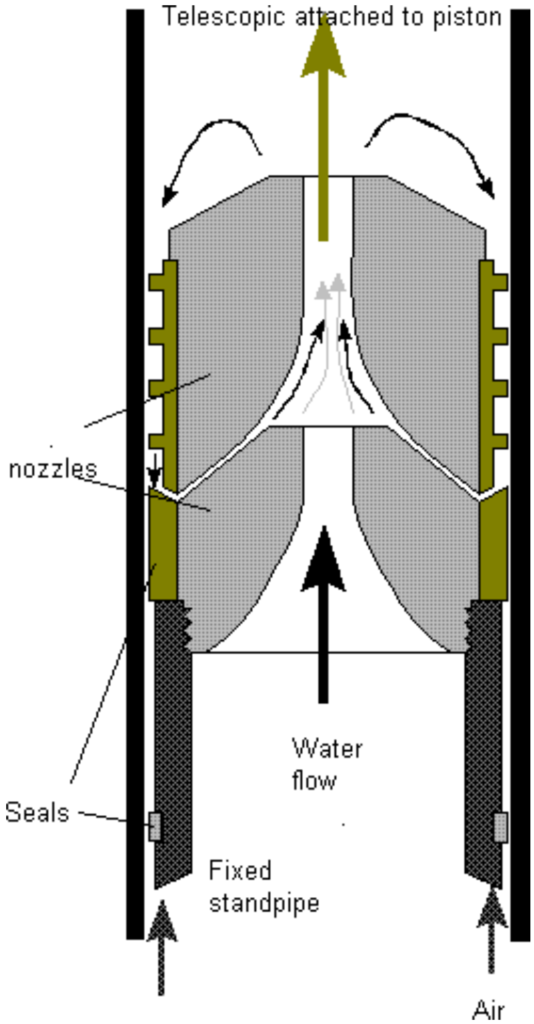
With highly rated engines overheating occurred in stagnant flow areas between the ribs and so a different form of cooling was required. The cocktail shaker effect has air as well as water in the cooling cavity as the piston reciprocates water washes over the entire inner surface of the piston just as in a cocktail shaker. Unfortunately air bubbles become trapped in the water and flow to outlet reducing the air content and removing the cocktail shaker effect. To avoid this problem air must be supplied to the piston some engine builders use air pumps feeding air to the inlet flow. The sulzer engine allows air to be drawn into the flow at a specially designed telescopic transfer system.

The telescopic arrangement is designed to prevent leakage and allows air to be drawn into the coolant flow to maintain the cocktail shaker effect. Consider the inlet telescopic, a double nozzle unit is fitted to the top of the standpipe. Small holes allow connection from the main seal to the space between the nozzles. Water flowing through the lower nozzle is subject to pressure reduction and a velocity increase. The space between the nozzles is therefore at a lower pressure than other parts of the system. Any water which leaks past the main seal is drawn through the radial holes into the low pressure region and hence back into the coolant flow.

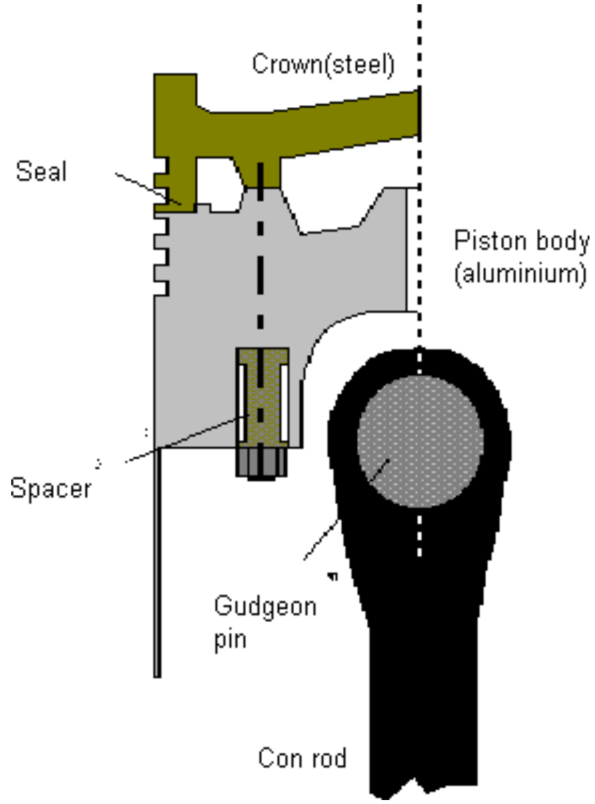
The pumping action of the telescopic draws air past the lower seal and this is also drawn through the radial holes into the coolant flow. This maintains the air quantity in the piston and so maintains the cocktail shaker effect.



The sulzer water cooled piston differs from that of the Oil cooled variety by the method it uses for distributing the cooling medium. In tis case the piston is not continually flooded but instead contains a level governed by the outlet weir. Cooling of the crown occurs during change of direction at the top of the stroke by so called 'Cocktail shaker' action.



Composite pistons

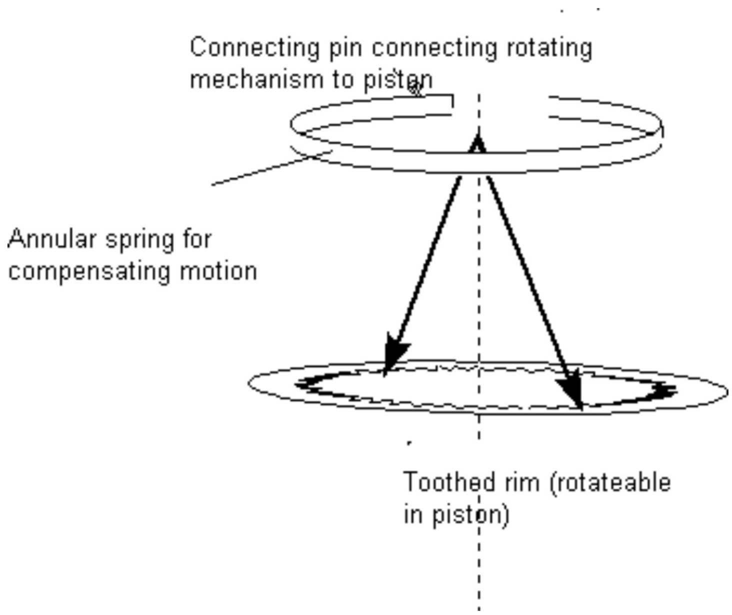


With medium speed and higher speed engines considerable inertia forces are placed on the conn rod and bearings as the piston changes direction at the ends of the stroke. The amount of force is a factor of the speed and rotating mass. To reduce this force whilst maintaining the same engine speed it is necessary to reduce this rotating mass.

Aluminium, with its lower density than steel is used when alloyed with silicon for extra strength. Even alloyed the aluminium has less mechanical strength than the steel, therefore damage is possible due to gas pressure acting on crown and piston rings. The piston could deform sufficiently to prevent proper operation of the rings in their grooves. Some engine manufacturers fit cast iron inserts into the grooves but more generally the piston is made in two parts with a cast steel crown containing two grooves.

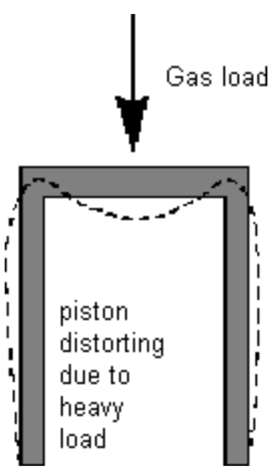
Aluminium has a better coefficient of heat transfer than steel thus overheating is not a problem. Its lower coefficient of friction avoids the problems of fitting bushes for the gudgeon pin, thus a floating gudgeon pin may be used. The higher coefficient of expansion could lead to the need for greater piston/liner clearance. However, as the main body is not subject to the high temperatures of combustion this expansion is not a problem.

Sulzer rotating piston



This piston rotates as it reciprocates. The rotation being brought about by the swing of the con rod. This causes two spring loaded palls located in the spherical top end to oscillate. These palls engage with a toothed rim which is connected to the piston by means of a compensating spring. As the conrod swings the palls act on the toothed rim causing it, and hence the piston, to rotate. The amount of rotation is limited to one tooth pitch every engine rev and the action is similar to that of a ratchet mechanism. The advantage of this is that local overheating of the piston or the liner due to blow past is prevented. Running in characteristics are improved and liner wear are improved. There is a better spread of oil brought about by the piston rotation. A spherical top end is required but this provides better support for the piston which does not distort as much as one fitted with a gudgeon pin. Piston to liner clearance may therefore be reduced.

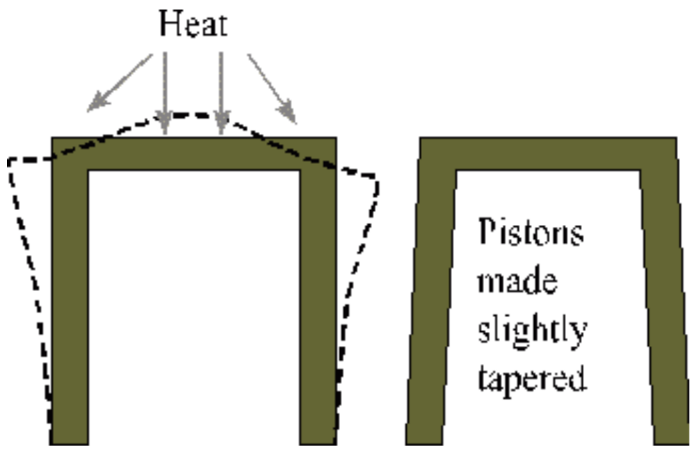
Transfer of gas loads from crown to piston rod



Is usually transmitted from the reinforced crown to the piston rod by internal mechanism avoiding possible distortion of the ring belt.

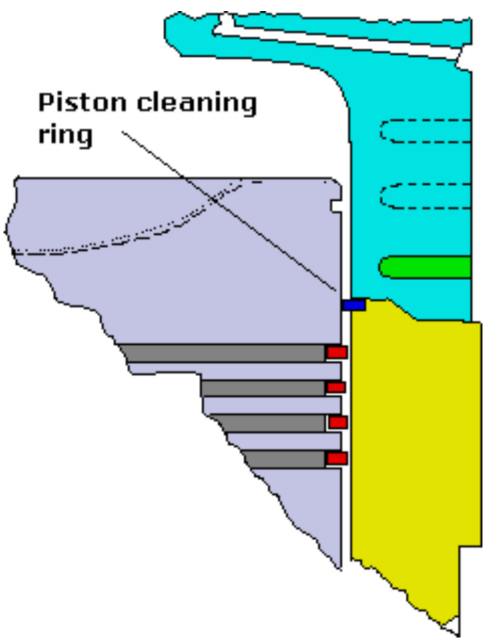
The tops of pistons are made dome shaped or have strong internal ribbing.

Thermal distortion of Piston

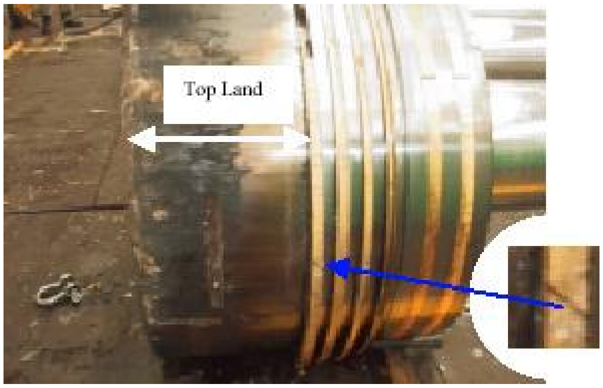


Anti-Polishing rings

High topland (the 1st piston ring is positioned will below the upper surface of the piston) with asociated reduced ring heat load has given better ring pack performance by improving working conditions for the cylinder lube oil. The disadvantage of this system is that a coke build up can occur aboth the piston which leads to 'bore polishing'. This polishing reduces the ability of the cylinder lube oil to 'key' into the liner therefore increased cylinder lube oil consumption/increased liner wear can result. To combat this **piston cleaning rings** are incorporated into the liner. These slightly reduce the bore removing the depoisits.



Modern Design



The top piston ring is moved further down the piston. This allows the crown to enter deeper into the crown reducing temperature and pressure on the liner. The top piston ring is a 'Controlled Pressure relief' (CPR) ring. This design has several oblique shallow grooves in the piston ring face allowing some gas presure to pass through to the 2nd ring thereby reducing load on the top ring. To reduce blowpast an 'S' type joint is formed n the ring ends

Tie bolts

These are positioned at each transverse girder. They are intended to keep the transverse girder in compression at all times thus minimising risk of fatigue cracking. Correct tension is therefore important and this should be checked regularly in accordance with the engine manufacturers instructions, this normally means retensioning the bolts in pairs from the center of the engine. alternately for'd and aft.

Tie-rods are often in two parts for ease of manufacture and fitting when head room is restricted. This also makes changing the bolt in the event of breakage simpler

Pinch bolts are fitted at certain points to prevent vibration which can induce stress and cause fatigue.These must be released before the bolts are retensioned

Tension should be checked at set intervals, following a scavenge fire, after application of an excessive load, following grounding or collision, or where the landing face have become suspect. Tiebolts are susceptible to fretting, often indicated by the presence of red dust (sometimes called cocoa) around the nut. In the event of this it is important to check the condition of the nut landing and to ensure before retightening that the surface is clean and free from moisture.

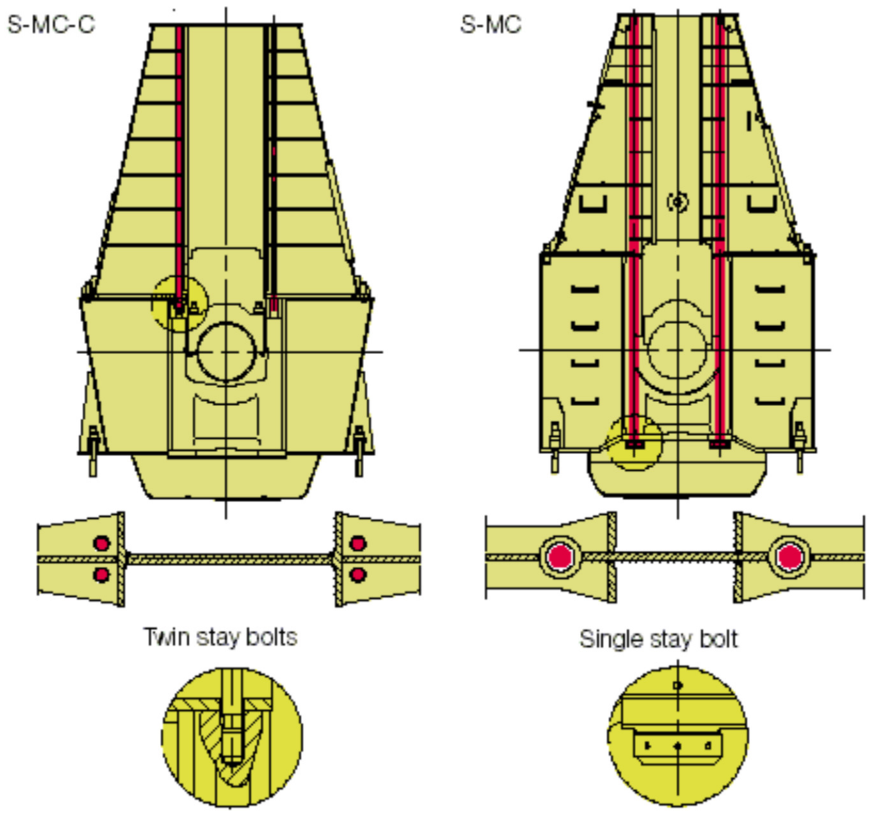
The most common method for applying the correct tension to the bolt is by use of hydraulic jacks. These are mounted on the tiebolt thread above teh nut. The jack stretches the bolt by acting on a removable sleeve surrounding the nut. Once the bolt has been extended the nut may be rotated via slots cut into the sleeve allowing access. Pressure is applied as per manufacturers requirements which extends the bolt within its elastic limit, the nut is screwed down hand tight and the pressure released. A second method involves the nut turning to handtight, then by use of a gauge the nut is rotated a further angle.

Tie-rods are nor required on medium speed engines generally because the relatively thick sections used means that stress is lower.

Opposed piston engines do not require tie-rods because combustion load is transmitted from the crankshaft to the bedplate is very low.

Modern trends

The traditional through tie bolt is being supersceeded by shorter twin stay bolts which have the advantage of reducing distortion of the main bearing keep


S-MC-C
S-MC
Twin stay bolts
Single stay bolt

Holding down arrangements

The engine must be firmly in position in the ship in order to preserve alignement between the crankshaft and the propeller shaft.

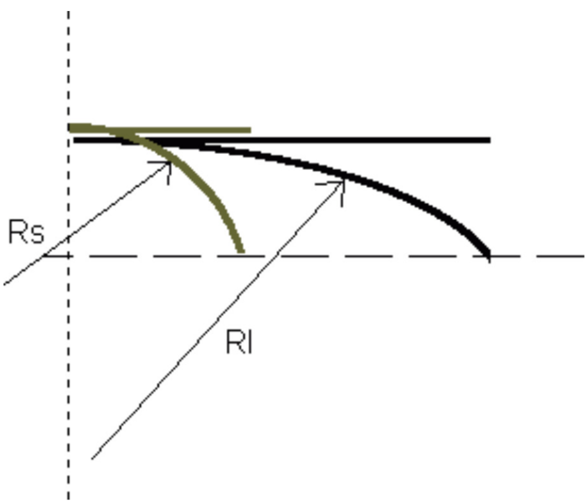
Vibration, rolling and pitching will tend to move the engine from its original set position.

The bedplate is aligned and individual chocks are used to maintain that alignement. Holding down studs which are preferred to bolts because they are cheaper are then used to hold the engine firmly to the tank top.

The bedplate must be as rigid as possible in order to keep the crankshaft straight. The ships structure, which includes the tank tops will distort as the ship rolls and pitches. Modern bulk carriers are constructed of high tensile steel because thinner plates may be used, thus reducing the deadweight and allowing more cargo to be carried. Thinner plates are more flexible and this increases the relative movement between tank top and bedplate.

This relative movement between the rigid bedplate and flexing tanktop leads to bending of the stud and possible fatigue failure.

One solution is to use spherical washes but these are expensive. A better solution is to use longer studs. When these bend the radius of curvature is grater and so reducing the bending moment for the same relative movement. A large radius of curvature means a lower stress and the risk of fatigue failure is reduced.



M /I = s/y = E/R

M=Bending moment
I=2nd moment of area of the cross section
s =Stress
y=distance from the axis of bending to the outer face

E= modulus of elasticity
R-radius of curvature of the bending.

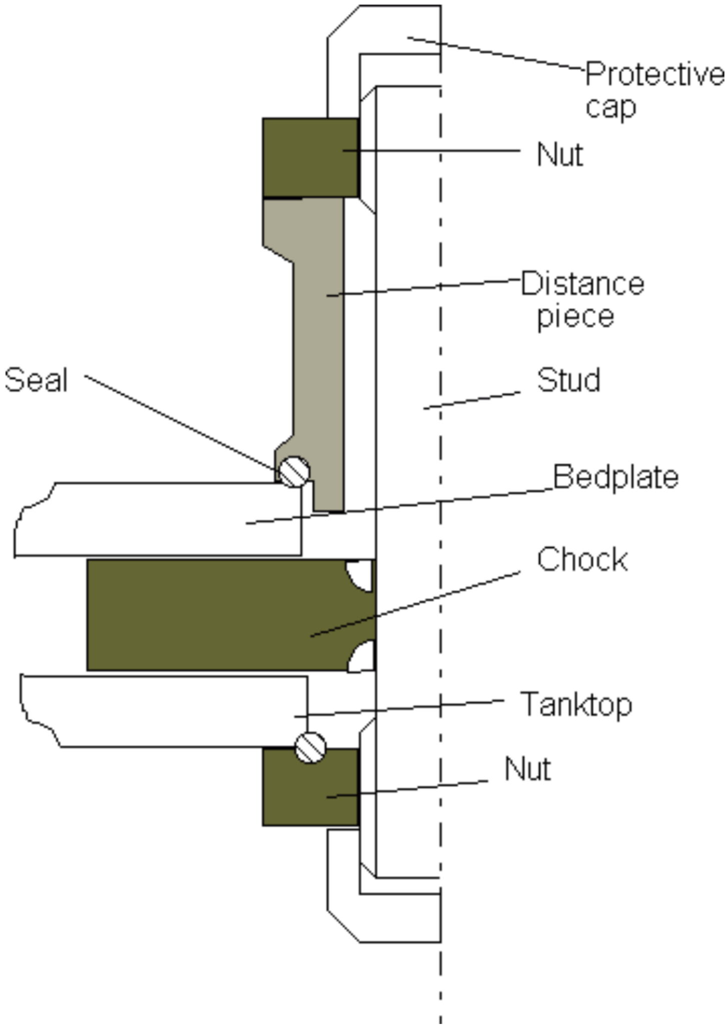
This can be arranged into

s = E . y /R

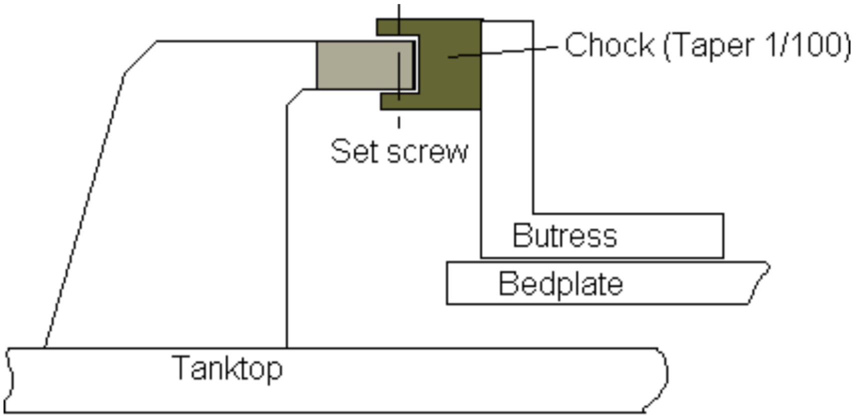
or s = k. 1 /R

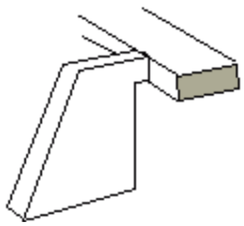
where k is a constant

that is, stress is inversely proportional to the radius of curvature.

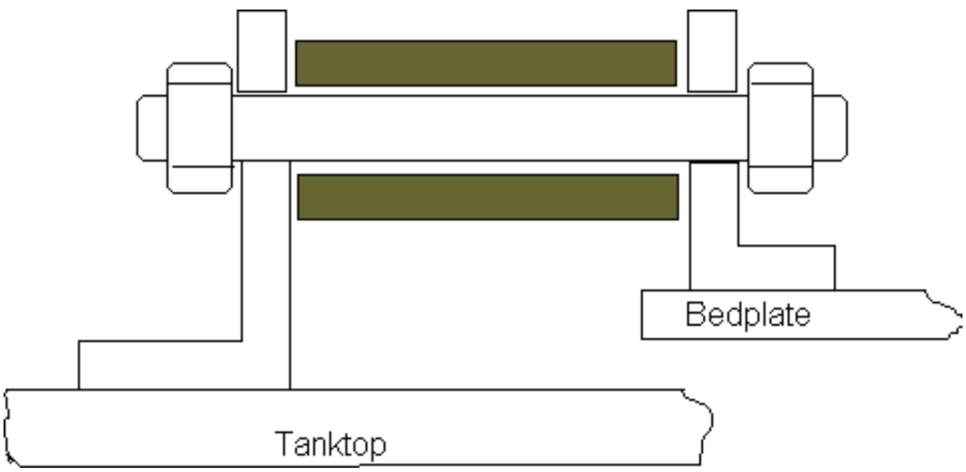


Side Chocking





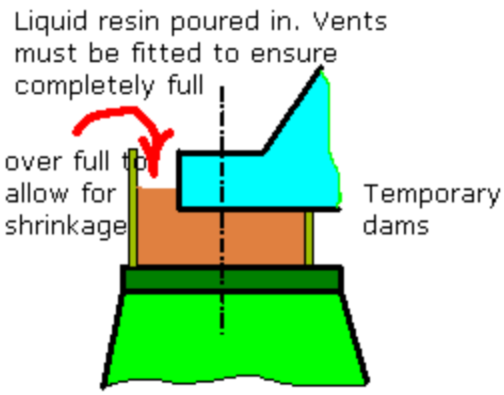
End Chock (aft end of the engine only)



Resin Chocking

Steel chocking has the disadvantages that each block must be individually fitted, a time consuming process, and after fitting are susceptible to fretting and wear. Resin chocks are poured and therefore are much quicker to apply. They form into the shape of the clearance and key into surface imperfections. This much reduces damage due to fretting and removes bending momemts on the holding down bolts.

The disadvantage is that the resin creation must be precise and that it is less straight forward to replace in the event of damage of misaligenement.



Properties

The material used for the rsin chocking is Class tested to ensure minimum standards.

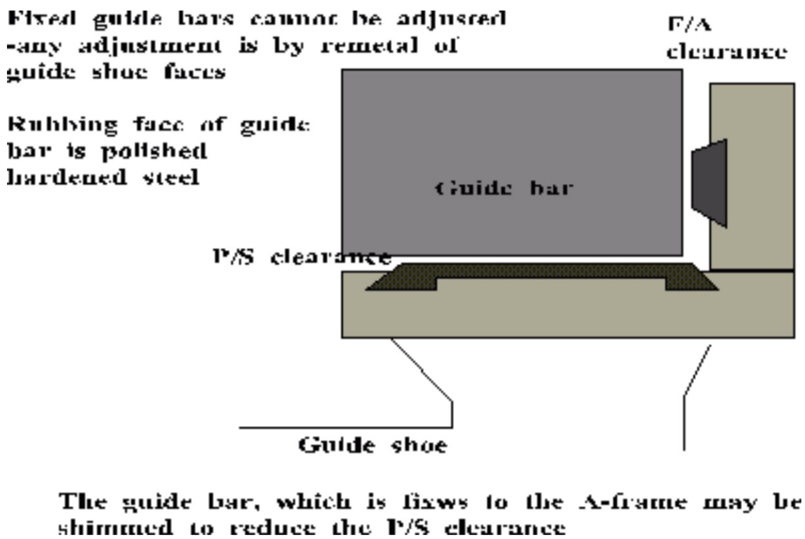
A sample cured in the correct way is tested for the following;

i. *The impact resistance*
ii. *Hardness.*
iii. *Compressive strength (stress at maximum load) and modulus of elasticity.*
iv. *Water absorption.*
v. *Oil absorption.*
vi. *Heat deflection temperature.*
vii. *Compressive creep*
viii. *Curing linear shrinkage.*
ix. *Flammability.*

Crosshead

The purpose of the crosshead is to translate reciprocating motion of the piston into the semi rotary motion of the con rod and so bearings are required. It is also necessary to provide guides in order to ensure that the side thrust due to the conrod is not transmitted to the piston. This also ensure the piston remains central in the cylinder thus limiting wear in the liner.

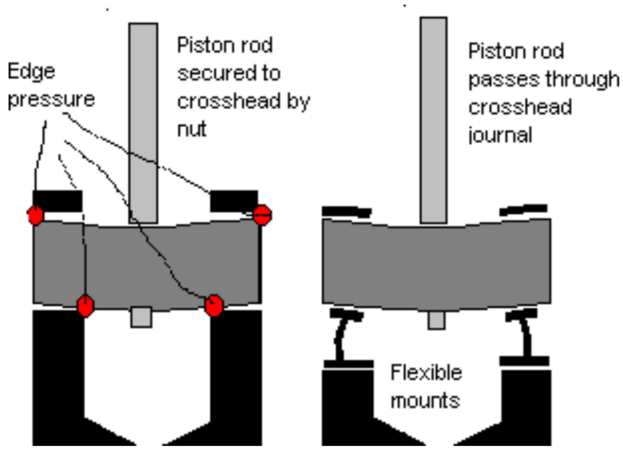
Two faces are required as the thrust acts in opposite directions during power and compression stroke. Guide shoes positioned at the extreme ends of the crosshead pin provided a large area and minimise risk of twisting. The doxford engine uses a centrally positioned shoe because there is no room at the ends of the pin due to the side rod crossheads.



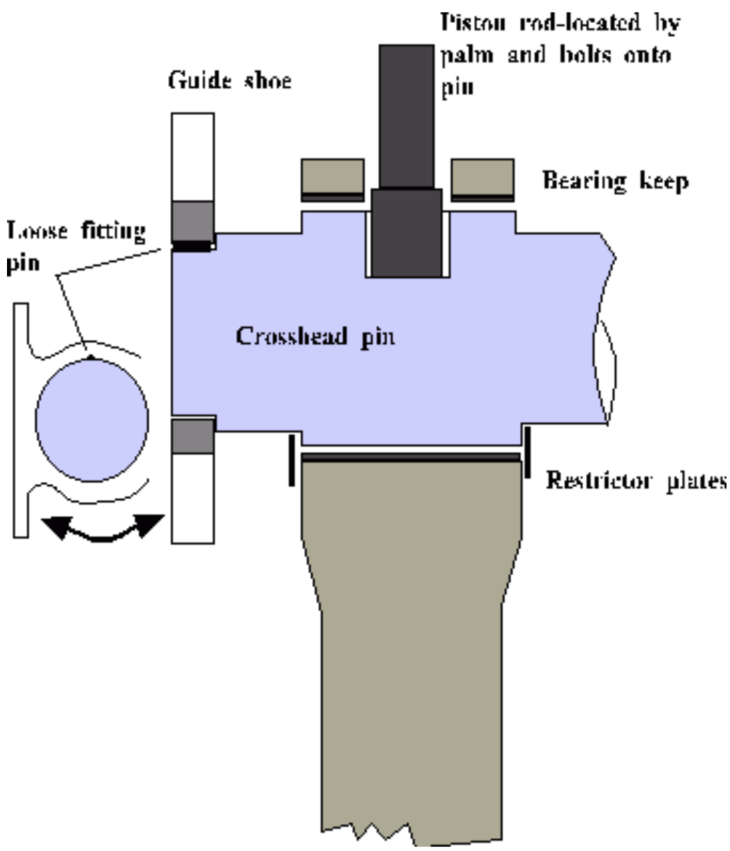
The usual way of checking guide clearance is by means of a feeler gauge with the piston forced hard against one face and the total clearance taken at the other face. This gives a reasonable estimation as wear should be approximately the same in the ahead and astern faces. A more accurate idea can be gained by chocking the piston centrally in its bore than measuring the clearance at each face. This will also give the athwartships alignment. The edges of the guide shoes are also white metal faced and these run against rubbing strips. Clearance at these faces can be checked with feelers and this gives the fore and aft alignment.

Guide clearances are usually adjusted by means of shims between the hardened steel guide bars and the mounting points. Bolts are slackened off allowing slotted shims to be inserted or removed. Note, care must be taken when handling these shims.

Crosshead pins are supported in bearings and the traditional way has been to mount the piston rod at the centre of the pin with a large nut and having two bearings alongside. This arrangement is like a simply supported beam and the pin will bend when under load. This gives rise to edge pressures which break through the oil film resulting in bearing failure. The Sulzer solution is to mount the bearings on flexible supports. When the pin bends the supports flex allowing normal bearing contact to be maintained.



In order to minimise the risk of bearing failure the actual force on the oil within the bearing should be kept within reasonable limits this can be achieved by having as large a bearing area as possible. Increasing the diameter of the pin and hence the bearing will minimise the problems as this not only allows for a large bearing area but it also avoids the problem of pin bending. Pin bending is further prevented by means of a continuous bearing. This also avoids the loss of oil which can take place with short bearings. Most modern engines tend to have single continuous bearings. Oil loss from the ends of bearings is prevented by means of restrictor plates. Some engine builders provide booster pumps which increase the oil pressure to the crosshead during the critical firing period. Cross heads do not have complete rotary motion and so a complete oil wedge does not form. The use of means for preventing oil loss are therefore useful in maintaining an oil film between pin and bearings.



The crosshead pin is fitted with a loose fitting pin. This pin allows a small degree of movement (about 1mm) between the guide shoe and the pin giving better alignment.

Types of damage associated with the crosshead bearing

There are two possible types of damage which may be sustained;

1. **wiping**-*this is where part of the white metal contact faces are wiped out so that machining marks and oil grooves disappear, the material is displaced into the lubrication grooves where it forms 'stubble' or may fill them completely. Providing adequate lubrication this may be caused by two high a degree of roughness of the crosshead journal. Possibly due, if occurring after trouble free operation, to particles in the lubricating oil. Roughness may also occur due to corrosion by weak acids forming in the lubricating oil. A water content above 1% can attack the white metal and cause formation of SnO which has the appearance of dark smudges on the surface. This must be removed whenever possible as the tin oxide can become harder than the metal of the journal causing obvious distruction of surface finish.*
2. **cracking-** *these may appear as individual cracks, hair line cracks, or densely cracked or crackled areas.*

   The latter may be so dense as to give the appearance of segregated grains. This can lead to scratching on the journal. The reasons for cracking may be insufficient bonding of white metal to the steel.

   Densely nested networks of cracks is due to fatigue fractures.

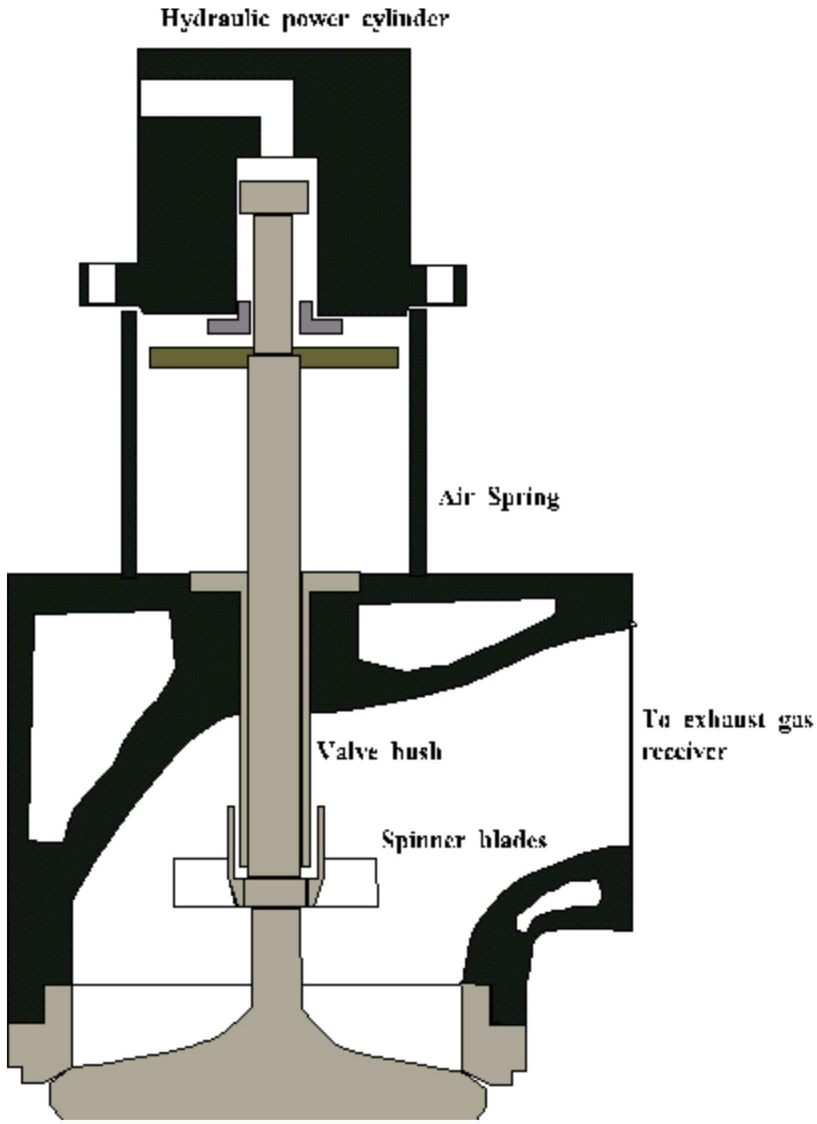
Exhaust valves

Large exhaust valves are provided with detachable seats made form molybdenum steel. The main parts of the valve casing is of cast iron and water cooled, there being no particular strength requirement for this part. It is the seat area which is subject to high temperatures and wear, hence the use of better materials. The seat is detachable in order to allow removable for machining and replacement.

Rocker operation of valves presents certain problems;

1. *a tappet clearance must be allowed to suit thermal expansion of the valve stem. Insufficient clearance may result in the valve not fully closing whilst excessive clearance can effect timing and the period the valve is open. Hammering will also take place at the tappet face. (The use of self adjusting hydraulic tappets went some way to alleviating these problems)*
2. *A side thrust is imparted to the valve stem when the valve opens. Thus causing wear at the stem bushing and subsequent leakage*
3. *wear takes place at the pushrod and valve contact face, additionally the rocker bearings require constant lubrication.*

To avoid these problems hydraulic valve actuation is used there is no tappet and no tappet clearance to set. Thermal expansion is accounted for by allowing the oil to escape at a relief valve on the pump unit. Oil loss is made up at the pump unit from the cam lube oil supply system. The opening face is always axial. Note: The hydraulic pipe must be sheathed to avoid the risk of fire in the event of pipe failure.



With modern fuels, vanadium and other deposits can build up on valve faces leading to damage. These deposits can be hammered into the seating faces. If the valve is rotated and reseats in a different place then the same dmage does not occur. Rotating the valve also prevents localised overheating due to a faulty atomiser.. If the valve is set spinning and is still rotating as it reseats a light grinding action takes place. This removes deposits and ensures a good seal. Such rotation is induced by spinners on the valve stem upon which the escaping exhaust gas acts.. To allow for this effect the frictional effect of the springs and valve/cover must be removed. The removal of springs means that a closing force by some other means is required. Air springing can be used. This consists of a piston fitted to the valve stem below the hydraulic unit. As the valve opens air below the piston is compressed and this compression provides the upward force of closing the valve. The space above the piston is vented to atmosphere and the pressure below the piston maintained at 5 bar from an air supply via a non-return valve.

An additional advantage with this system is that when the engine is stopped the valves will all close after a short delay. This prevents the flow of cool scavenged air through units which with a rocker system would otherwise be open.Preventing this allows all cylinder to be equally warm and stops the rotation of the turboblower which can occur.

Springs

Springs of sufficient force must be provided in order to ensure that the valve closes when the tappet force is removed. Once the valve is closed, the pressure in the cylinder will increase the sealing force on the valve seat.

Springs have natural frequencies and if the engine operating frequency is close to the natural frequency of the spring then vibration will take place and valve bounce will occur. Springs also twist when they are compressed and this causes wear at the landing faces. To avoid problems, double springs may be fitted one inside the other in parallel. These springs must be of different size and so have different natural frequencies. Valve bounce due to spring vibration is thus avoided.

The springs are wound in different directions to prevent twist and also to prevent one coil entering the other in the event of breakage, thereby locking it up.

Long springs tend to bow out when they are compressed and this increases the risk of stress failure. A solution is to have two springs in series, one above the other and separated by a centre disc which is located via a pivoted arm arrangement so that only vertical movement is allowed. Series /parallel arrangements are available.

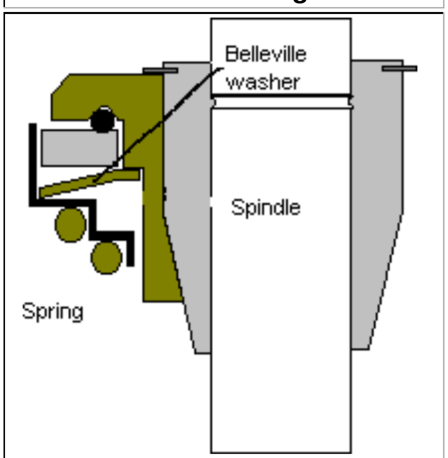
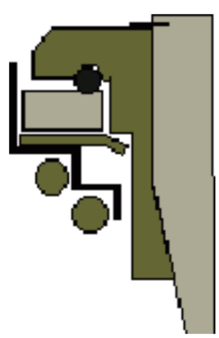
Modern engines use pneumatic springs. Thisi both eliminates the problems of valve bounce , spring brakage and also the need for rotor caps. As the valve is free floating spinner vanes fitted on the spindle allow the valve to be rotated by the flow of exhaust gas.

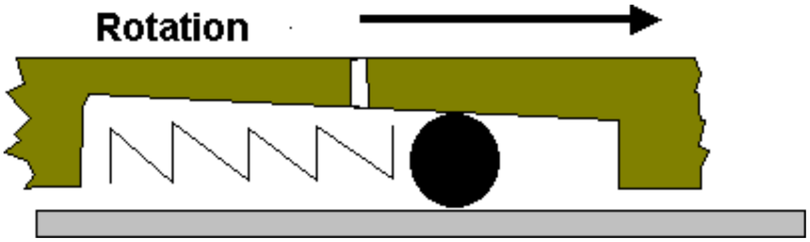
Rotocap

The rotocap is a mechanical device which produces valve rotation by a small amount as the valve opens. The valve rotation is about 8^{o} when the unit is in good condition.

Rotation to a new position avoids deposits from being hammered into the seat and repositions the valve thus preventing local overheating. Frictional contact is provided through the springs to the valve cover via the belleville washer which contacts at point A and C. As the tappet force increases to open the valve, the belleville washer is collapsed thus removing that frictional contact. Further increase in tappet force acts on the spring loaded ball bearings and the ramped slots tend to slide over the ball bearings. These slots are in the valve cover which is connected to the stem thus as the cover moves it rotates the valve.

As the tappet force is removed when the valve closes the belleville washer restores frictional contact and prevents further rotation. Springs return the ball bearings to their original position ready for the next stroke.

Valve closing	Valve opening
	


Rotation

Comparisons of cross head and trunk piston engines

There are two basic types of connecting a piston to a crankshaft;

1. *Crosshead construction-used by all slow speed two stroke engine manufactures*
2. *Trunk piston construction- used in smaller four stroke engines*

Crosshead construction

The piston is rigidly fixed to the piston rod. The rod passes through a gland to a cross head to which it is attached via a flange , or shoulder through bolt and nut. The crosshead consists of an rotating element which is attached to the connecting rod. It is through this bearing that the vertical load is transferred from the combustion space and converted into the rotary motion of the crankshaft via the connecting rod and big end bearing. Horizontal thrust generated at the crosshead are absorbed by white metal surfaced shoes which run up vertical athwartships mounted guides.

The advantages of the crosshead design are

1. *guide faces take side thrust, this is easily lubricated, wears little and takes side forces off the piston and liner running surfaces.*
2. *Uniform clearance around piston allows for better lubricating oil distribution reducing wear*
3. *simplified piston construction designed for maximum strength and cooling. Extended load bearing skirts found on trunk pistons unnecessary*
4. *due to gland lubricating oil may be optimised for crankcase and cylinder. High alkalinity oils used in cylinder allow poorer quality fuels to be burnt.*

Trunk piston construction

The piston is directly attached to the connecting rod by a small end rotating bearing. Side thrust is absorbed by extended skirts on piston.

The main advantage is reduced engine height

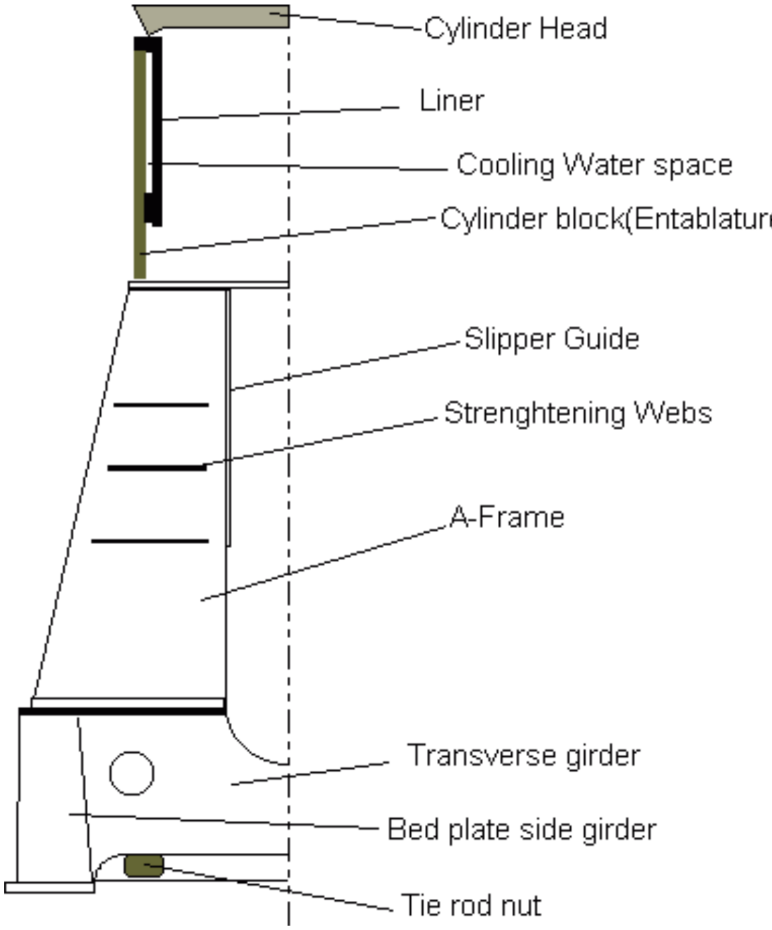
Opposed piston engines

Mainly built by doxford and consisted of two opposing piston moving in a common liner. Fuel injection occurred at the centre where the piston met. Construction is of the crosshead design with the upper piston connected to the crankshaft via two side rods and transverse beam. Timing was approximately 180^{o}C except for a small angle of advance for exhaust timing.

Advantages are;

1. *Perfect primary balance by balancing*
   i. *upper reciprocating masses and lower velocity side cranks against*
   ii. *lower reciprocating mass and the higher velocity centre crank*
2. *No gas loading transvered to bed plate (normally via head and tie rods) on engine meaning that construction could be lighter*

Overall arrangement



Description of the salient parts

Modern engines designed for increasing power to weight ratios are reliant on not only stronger materials but also on careful design. Each component design must not only be optimised for its own purpose, but also in some cases, to provide strength to the overall structure.

An example of this is how the bedplate and A-frame combine to create a strong rigid box able to resist the forces of combustion and maintain essential alignment for the crankshaft and over moving parts.

The entablature not only supports the cylinder liner and head it also creates areas for cooling water and scavenging air.

Fabrication techniques are extensively used simplifying castings and speeding assembly times by reducing the number of fastening.In order to obtain ideal strength transfer between components the fastenings must have intermit contact with the surfaces of the components and hence fitted bolts are used.

Cylinder blocks must be cast, due to the difficulties in casting large components generally single cylinder blocks are created joined to each other and to a common fabricated A-frame/bedplate box.

Bedplate

The bedplate acts as the main strength member, maintains correct alignment and supports the weight of the components. it must be capable of withstanding the fluctuating forces created during operation and transmit them to the ships structure.

In addition it may also collect lubricating oil.

In slow speed engine design, it consists of a deep longitudinal box section with stiffening in the form of members and webs.

Transverse members are fitted between each throw of the crankshaft. These support the main bearing saddles and Tie -rod connection. They are attached to the structure by substantial butt welds.

To reduce the engine height the sump of the bedplate may be sunken allowing it to fitted into a recess in the ships structure.

Plate and weld preparation is required with welds of the double butt type if possible. Regular internal inspection of the parts especially the transverse girder is required for fatigue cracking. Tie bolts should be checked for tighteness.

Box girders-A box girder is stronger and more rigid then I or H section girder of the same c.s.a.

From the simple beam bending equation we have;

$M / I = s / y = E/R$

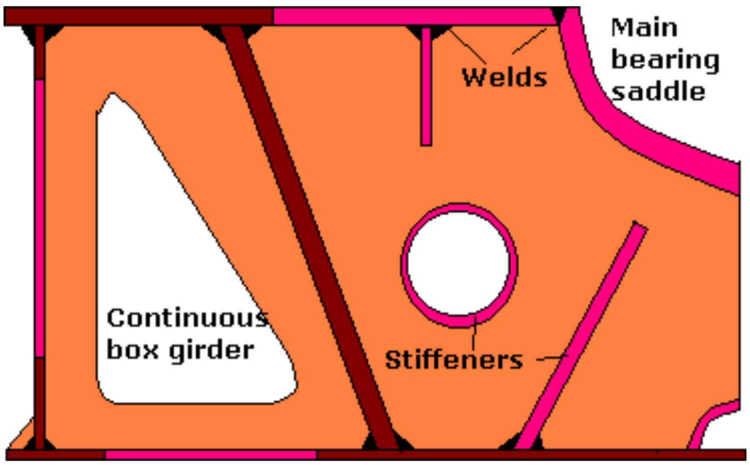
M=Bending moment
I=2nd moment of area of the cross section
s =Stress
y=distance from the axis of bending to the outer face
E= modulus of elasticity
R-radius of curvature of the bending.

This can be arranged into

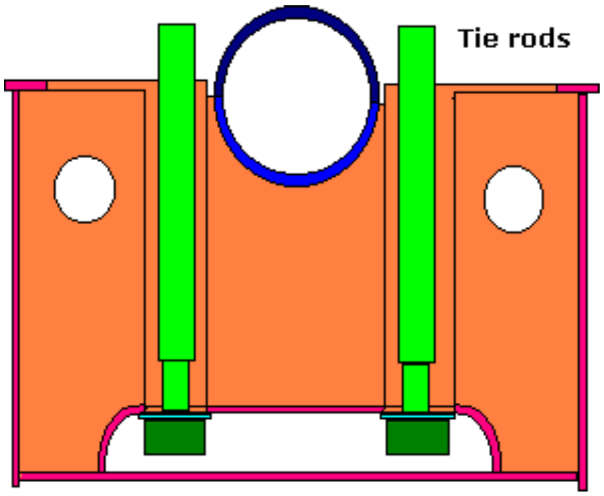
$\mathbf{s = (M/I) . y}$

It can be seen that for the same bending moment on a symmetrical shape of same size, the stress is reduced on the increasing 2nd moment of area. The second moment of area increase with moving of material away from the axis of bending towards the extremes of the section.

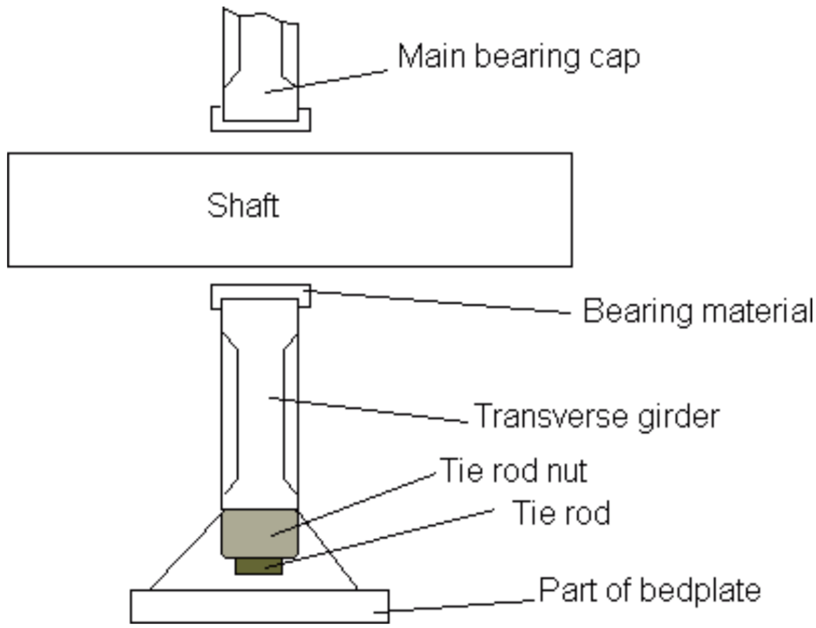
Because of this the commonest way of construction a fabricated bedplate is by creating two box section girders and tie them using transverse girders.



The advent of the small bore slow speed has seen the use of single side bedplates. A box section is then created by using a box section crankcase structure rather than the more traditional A-frame.This has the advantages of reducing width as well as weight and increasing the amount of fabrication so reducing assembly times.

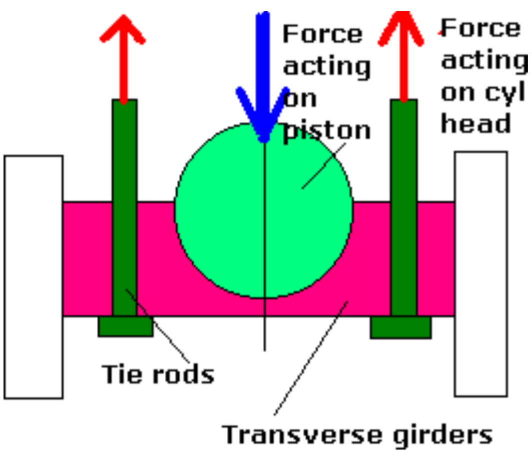


Due to the weight penalty, the use of cast iron is generally limited to smaller units where fabrication becomes impractical. However, cast iron has internal resilience allowing it to dampen down vibrations, this has led to its usage on some medium speed installations, especially passenger carriers, where noise and vibration suppression is important. .

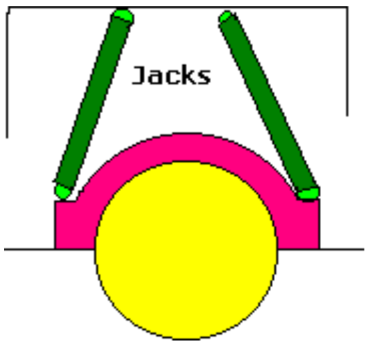


The most highly loaded pat of a bedplate is the transverse girder. Classification societies require that residual stress is removed after construction.

The transverse girder acts as a simple beam with the forces of combustion acting on the piston passing down through the bearing. The forces acting on the head are passed through the Tie rods.



It can be seen that to reduce the bending moment the tie rods have to be brought closer to the crankshaft. The limit to this is the securing arrangement required for the main bearing keep. One method is to use two instead of one bolts which can be made of smaller diameter. Sulzer use an alternative and very successful method in the form of jacking bolts. These jack against the bottom of the A-frame.



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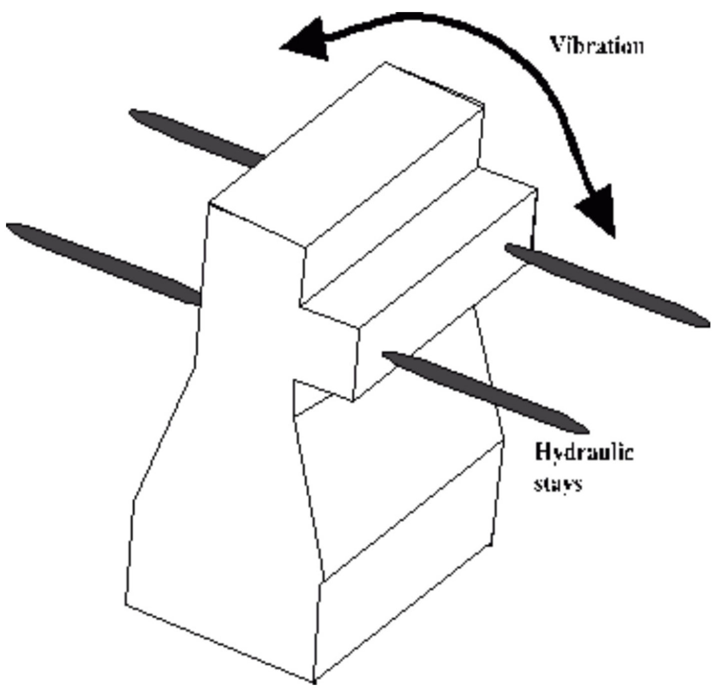
Superlong stokes

The increasing stroke to bore ratio has led to several problems not least of which is cylinder lubrication, thermal gradients over stroke, starting etc. I addition there is a necessity to dampen rotational vibrations over the engine height by means of hydraulic stays attached to the ships structure. These reduce the movement of the engine without allowing excessive vibration to be transmitted to the hull.



Camshaftless engines

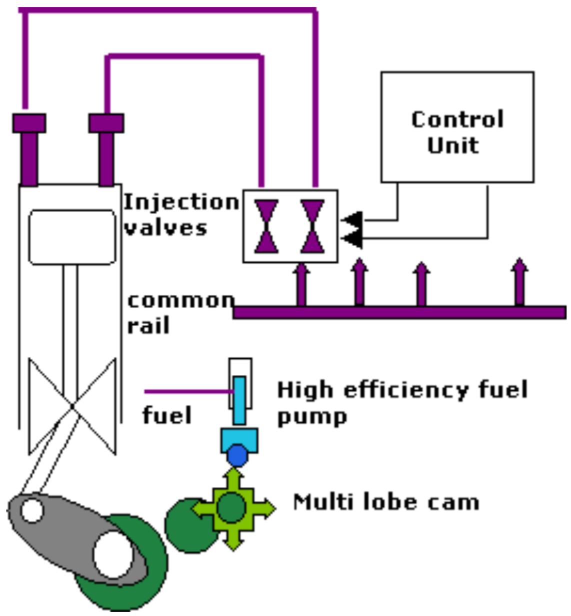
The camshaftless two stroke crosshead engine has two main advantages;

Firstly it simplifies engine design in particular negating the need for chain or gear driven camshafts. This allows a net reduction in weight, simplifies engine erection and removes some physical constraints for future engine design.

Secondly, it allows for finite control of parameters such as fuel delivery volume and timing, and exhaust valve opening and closing times.

Traditionally fuel, exhaust valve opening, starting air and cylinder lube oil delivery are all controlled by camshaft lobe design. It is possible now to control these using high reliability solenoid valves. This method is used on the sulzer RT-flex engine

Fuel control



Fuel is delivered to a common rail by a high efficiency fuel pump operated by a multilobe cam driven off the main engine crankshaft.

A control unit activates electric solenoid valves to deliver fuel to the appropriate cylinder injectors.

This allows control of fuel volume, fuel delivery progression (that is the shape of fuel delivery- e.g slow than fast) and precise timing. It means that fuel ignition quality and condition at delivery can be taken into account.

Exhaust valves

Exhaust valves are operated in the normal way via hydraulic pushrods. However hydraulic oil delivery is not by individual pump but by common rail supplied by a high capacity, high pressure servo pump. The engine management control unit operates the exhaust valves by energising the appropriate solenoid valve. Other starting air valves and cylinder lube oil are all similarly controlled by the engine management control unit via solenoid valves

Modern developments

The modern trend has followed the smaler and lighter rule with an ever increaseing power to weight ratio. In addition to this simplified maintenance and production proceddures have been incorporated.

Intelligent engines without camshafts are being introduced enabling increased efficiency with reduced fuel quality. Intelligent engines also allow for increased efficiency when running at part load.

Liners

Modern requirements for the design and contruction of a cylinder liner include;

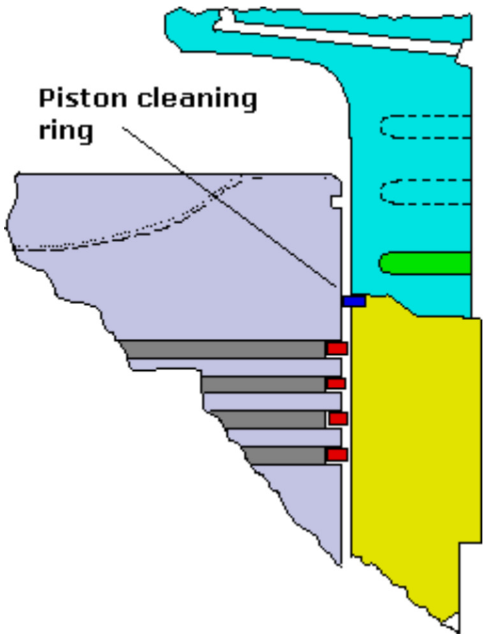
- Material with sufficient hard phase and ductility
- Smooth surface finish
- Full honing of running surface
- Bore cooling of liner and components surrounding combustion chanmber- the insertion of insulating

tubes into the bore cooling holes of liners is sometimes necessary to prevent undercooling and allow a standard liner to be used with different ratings.

- Critical profiling of liner wall thickness to stabilise temperatures and prevent corosion attack
- Multi-level cylinder lubrication with variable speed (load dependant) pumps
- Efficient water removal from scavenge air

Pistons

High topland (the 1st piston ring is positioned will below the upper surface of the piston) with asociated reduced ring heat load has given better ring pack performance by improving working conditions for the cylinder lube oil. The disadvantage of this system is that a coke build up can occur aboth the piston which leads to 'bore polishing'. This polishing reduces the ability of the cylinder lube oil to 'key' into the liner therefore increased cylinder lube oil consumption/increased liner wear can result. To combat this **piston cleaning rings** are incorporated into the liner. These slightly reduce the bore removing the depoisits.



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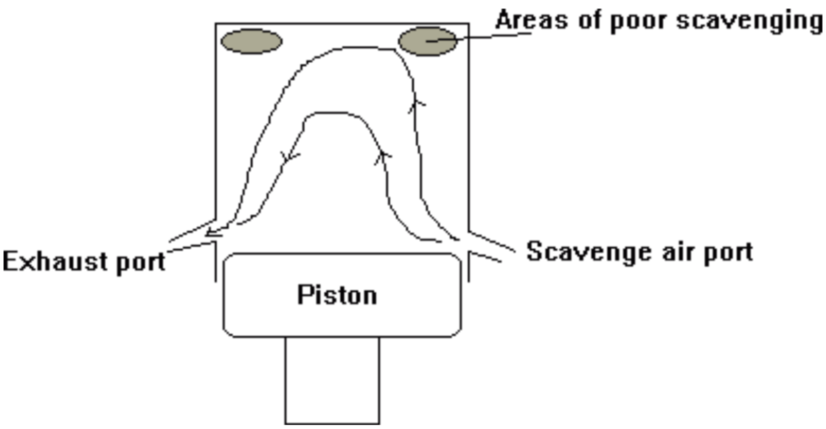
Types of scavenging

There are two distinct types of scavenging arrangements;

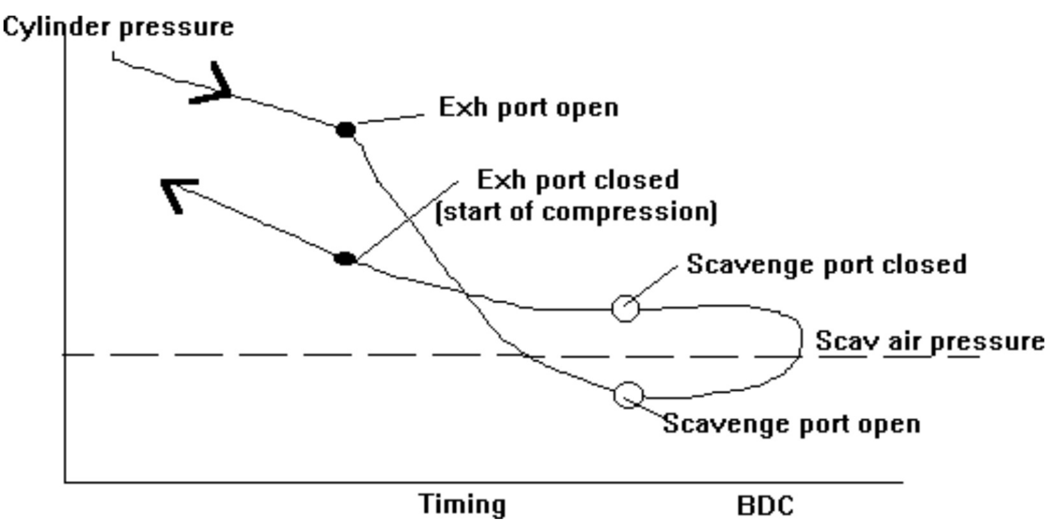
- Loop or cross scavenge
- Uniflow.

The main difference between the two types is that uniflow requires an exhaust valve or piston to operate. Loop or cross flow relies on the piston to open and close exhaust ports

Cross flow

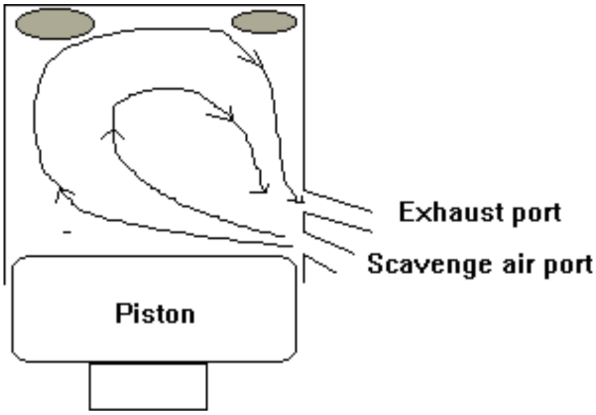


After ignition of the fuel the piston travels down the liner uncovering firstly the exhaust ports. The exhaust gas at a pressure above atmospheric is expelled. This is often referred to as blowdown and its effect can be seen on the power card for all the types of scavenging as a rapid drop in cylinder pressure towards the end of the cycle.

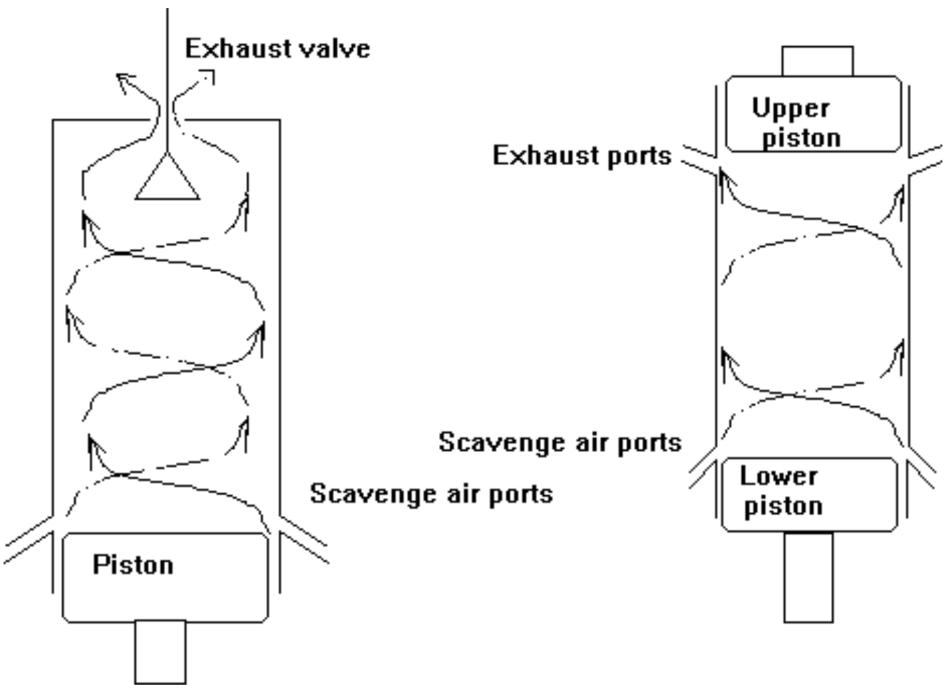


Loop

The method of loop scavenging is similar to the cross flow except the exhaust and scavenge ports may be found on the same side



Uniflow



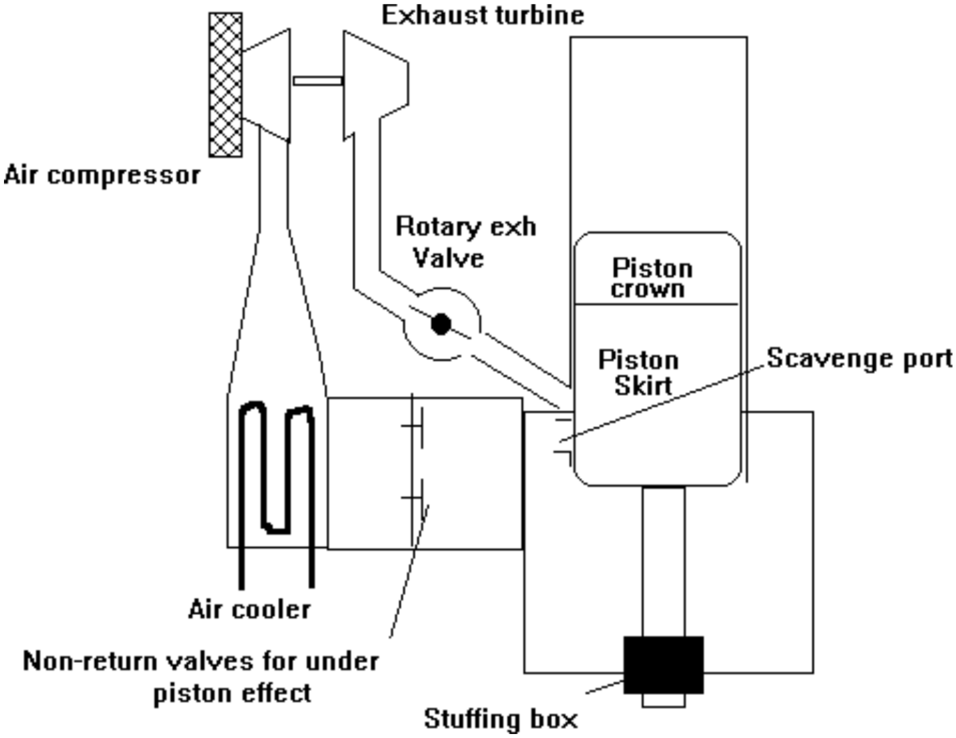
The scavenge air enters through the scavenge ports in the lower part of the cylinder liner, the exhaust gas is expelled through the centrally mounted exhaust valve in the cylinder cover. The scavenge ports are angled to generating a rotational movement of the rising column of air.

Air is forced out of the cylinder by the rising piston leading to low flow resistance, the effect is often compared to squeezing the contents out of a tube.

Disadvantages of the loop/crossflow method of scavenging

The greatest disadvantage of this system, and the one that has led to the abandonment of its usage where once it was widespread is its inefficiency in clearing the cylinder of all combustion products. Following the exhaust blowdown the scavenge ports are opened. The period available for scavenging is limited to the recovering of the exhaust ports and is only at its most effective until the closing of the scavenge ports. Therefore, high air velocities are designed in, the air entering through steeply angled shaped ports. The possibility exists for the scavenge air to shortcut directly to the exhaust ports, a situation which worsens with blockage of the scavenge ports due to carbon build up. Due to the inefficiencies above there is a high volume of scavenge air requirement with this design. This has led to the complicated underpiston effect designs to augment the turboblower output with some engine power being absorbed dropping cycle efficiency.

A problem with having fixed ports is that difficulty is encountered with port timing. On the piston down stroke the exhaust port is opened followed by the scavenge port to make effective use of blowdown. However, the same timing for closing the ports means that the effective compression stroke is reduced. To try to remedy this differing means of closing the exhaust ports before the piston covered the ports was tried, One such method was by engine driven rotating valves which opened and closed the exhaust ports. All the designs increased complexity and often proved unreliable due to the arduous conditions they had to operate in.



To prevent exhaust gas entering the cylinder under the piston as the piston moves up to TDC, extended piston skirts are fitted. This adds to the reciprocating mass and increases load on the crosshead bearing. The small amount of side thrust not absorbed by the crosshead is spread over the larger of the skirt reducing loading and wear on the liner, however, problems of increased lubrication requirements for the increased surface area largely negate any advantage.

The requirement for both the exhaust and scavenge ports being fitted into the liner makes for a more complicated design with increased liner lubrication difficulties especially in way of the exhaust ports. This region suffering not only the washing away effect of the gas flow but also contamination from combustion products and increased temperature. Cylinder lubricating oil volume demand is therefore higher with this design.

In an attempt to improve the scavenge efficiency shaped pistons have been used which produce a combustion chamber shape not the best for efficient combustion. Asymmetrical piston designs can also lead to excessive thermal loading and complicated strengthening and cooling designs.

One advantage of the Loop method of scavenging is that it does away with the requirement for an exhaust valve or opposed piston. This means that all the extra running gear associated with this can be omitted. That means, simpler cylinder cover design, simpler and less stressed camshaft and camshaft drive train, and a shorter piston reducing reciprocating mass.

Where an exhaust valve is fitted in the cover, there is increase thermal stressing especially in way of the valve where higher temperatures are encountered.

Additional advantages of the Uniflow method

The fitting of an exhaust valve does give a major advantage in that the timing of opening and closing of the valve can be altered which is used to its fullest with modern designs with 'Variable exhaust timing' control fitted. This means that the effect of the scavenge air inertia entering the cylinder, and optimising the closing of the valve to increase the effective compression (which starts when the exhaust valve is closed) can all be taken into account for the varying loads and engine speeds.

The increased scavenging efficiency with this type of scavenging creates greater scope for increased economy and so all modern designs are based on this design. The opposed piston design once in favour due to its inherent dynamic load balancing has now largely disappeared due to its increased mechanical complexity.

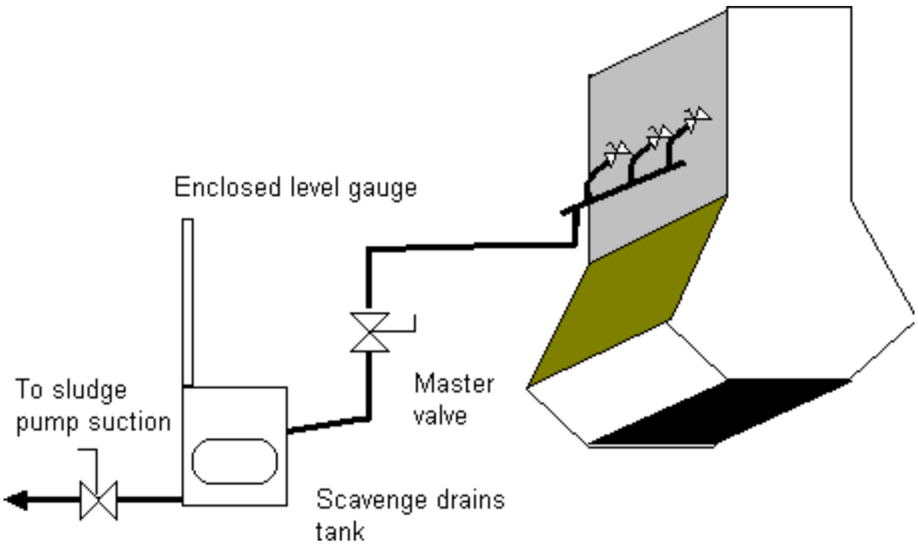
There is a minimum air demand as the ingressing air pushes the combustion products ahead of it with little requirement for scavenging by dilution. As the air flow is symmetrical rising up the liner the thermal influencing on the liner walls, cylinder covers and piston crowns is also symmetrical. this allows simpler oil cooling of the piston crown

The reduced number of ports (no exhaust ports), and reduced size of the scavenge ports (due to reduced air volume requirements), this reduces the problems of liner lubrication allowing reduced oil consumption.

Scavenge fires

Oily carbon deposits build up in the scavenge trunking during normal operation of the engine. Drains are provided in order to remove such deposits and so help keep the scavenge trunking reasonably clean

Scavenge drains system



Under certain conditions the deposits may dry out and ignite. Piston blow past due to sticking or broken piston rings, or even excessive liner wear, is a major cause of the problem. Faulty combustion due to late injection or incorrect atomisation may also be responsible as may blow back through the scavenge ports caused by a restriction in the exhaust.

Some of the smaller bore RND engines has sighting ports fitted to the scavenge air space under the piston. The amount of blowpast could be seen and a close watch kept on the condition of any deposits.

On the occasions when the blowpast started to become excessive, slowing the engine down for a short period would settle the engine. Subsequent speeding often went with much reduced blowpast. In this way many potential fires where averted. Unfortunately these sigthting ports are no longer fitted.

In all cases the increased temperature leads to a drying out of the oily deposits in the air box and subsequently ignition takes place. A scavenge fire can cause serious damage to the piston rod diaphragm gland as well as leading to possible distortion of the air box and cracking of the liner. Tie rod tension will almost certainly be affected.

The worst case scenario for a scavenge fire is it leading to a crankcase explosion.(B&W on some designs fit a cooling jacket between the air box and crankcase to help prevent this.)

The fire may also spread outside the scavenge box due to relief doors leaking or oil deposits on the hot casing igniting. For these reasons a scavenge fire should be dealt with as quickly as possible.

B&W and other engine builders recommend that in the event of a fire the engine should be slowed as soon as possible and preferably stopped. The turning gear should be put in and the engine continuously turned to prevent seizure. Air supply should be cut off by enclosing the turbocharger inlets, for mechanically operated exhaust valves the gas side should also be operated, (hydraulically operated exhaust valves will self close after a few minutes). The individual isolating valves on the scavenge drains line are close to prevent the fire transferring to other boxes. Boundary cooling may be employed.

Fixed extinguishing mechanism should be used at the earliest possible time. When the fire is extinguished the air box is allowed to cool, then the air boxes should be well cleaned, the tie-rod tension checked. The causes of the fire should be ascertained and remedied.

Fire fighting media

Carbon dioxide- will put out a fire but supply is limited. Susceptible to loss if dampers do not effective prevent air flow

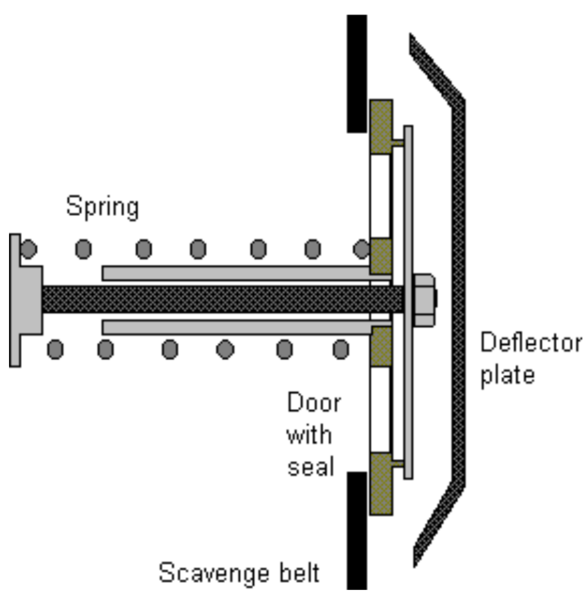
Dry powder- will cover the burning carbon and oil but is messy. As the fire may still smoulder below the powder care must be taken when the scavenge doors are removed as the powder layer may be blown away. **Steam**-plentiful and effective

Water spray- perhaps the ideal solution giving quick effective cooling effect to the fire.

Indications that a fire is imminent are a reduction in flow through the drains and a temperature rise in the scavenge. This temperature rise can be detected by temperature wires or mats.

When a fire is in progress there is a slow down of the engine with the blowers surging as the fire consumes the oxygen. Sparks are seen issuing from the drains and there is a temperature rise in the scavenge space.

Scavenge belt relief door



Fitted to both ends of the scavenge belt and set to lift slightly above the maximum normal working scavenge air pressure

Turbochargers

For Combustion of a fuel, an adequate quantity of air is required. For a Turbocharger system capacity should be sufficient to ensure that the air demand is met when the turbocharger is not at its optimum.

In a four stroke diesel engine, this air is induced during a down stroke in one of the two engine cycles per power stroke. The exhaust gasses are removed by the preceding upstroke .

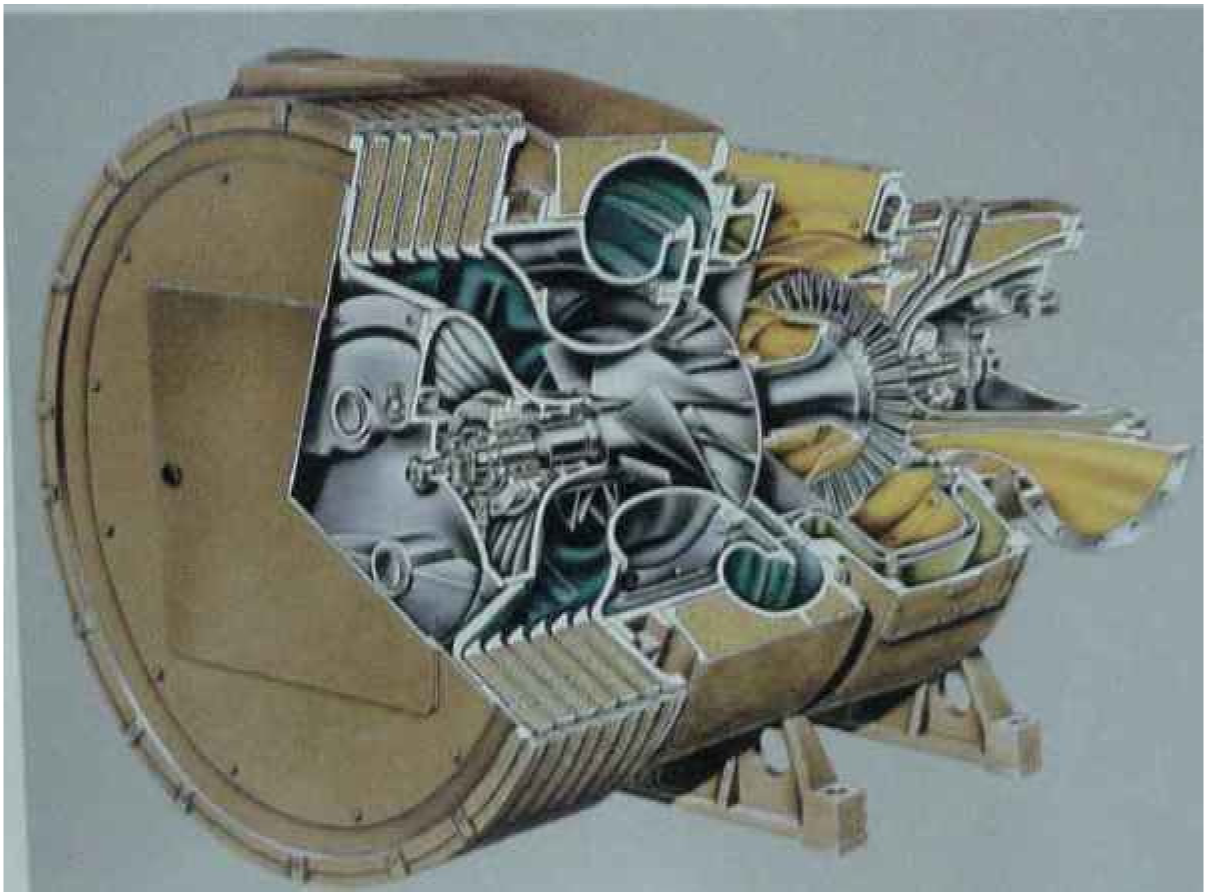
For a two stroke no such cycle for scavenging and air replenishment exists. Instead, air under pressure is supplied at the end of the power stroke providing a new charge of air and removing the exhaust gasses. The period allowed for scavenging is limited as the longer the exhaust port or valve remains open so the shorter the travel of piston is available for compression. The greater the mass of air that can be supplied, the more efficient the scavenging process will be, and also the greater mass of air will be available for the combustion of an equally greater mass of fuel. The mass of air is increased by increasing the pressure at which it is supplied.

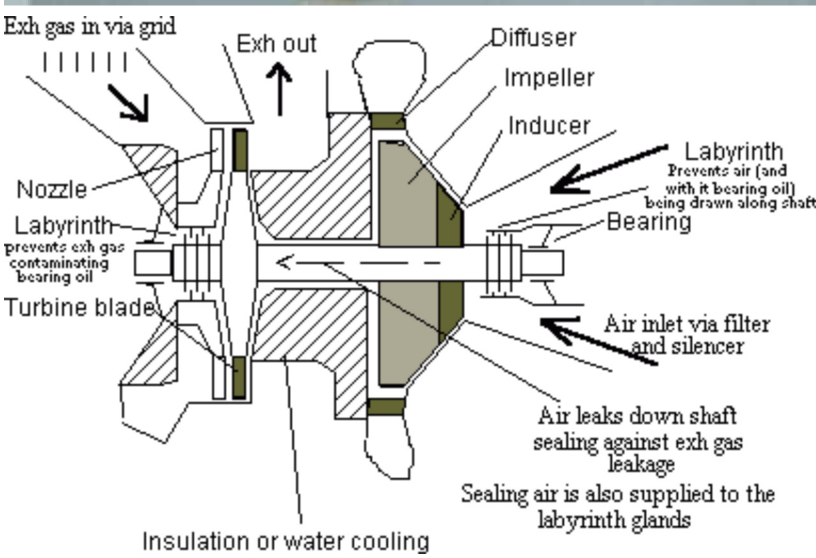
Pressure charging can be obtained by a number of means including scavenge pumps, chain driven rotary blowers and exhaust gas driven blowers.

Exhaust gas driven blowers or Turbochargers make use of gas in the cylinder which theoretically could be expanded further, the power that would be developed could be used for driving an engine driven scavenge pump. In practice it is more efficient to use this exhaust gas in the turbocharger as further expansion of the gas would require an increased stroke. Increased stroke would mean increased engine height with problems of crankshaft construction, cylinder lubrication and effective scavenging coming into play. The work that could be extracted from this low pressure gas would be limited and more efficiently extracted in a rotary machine.

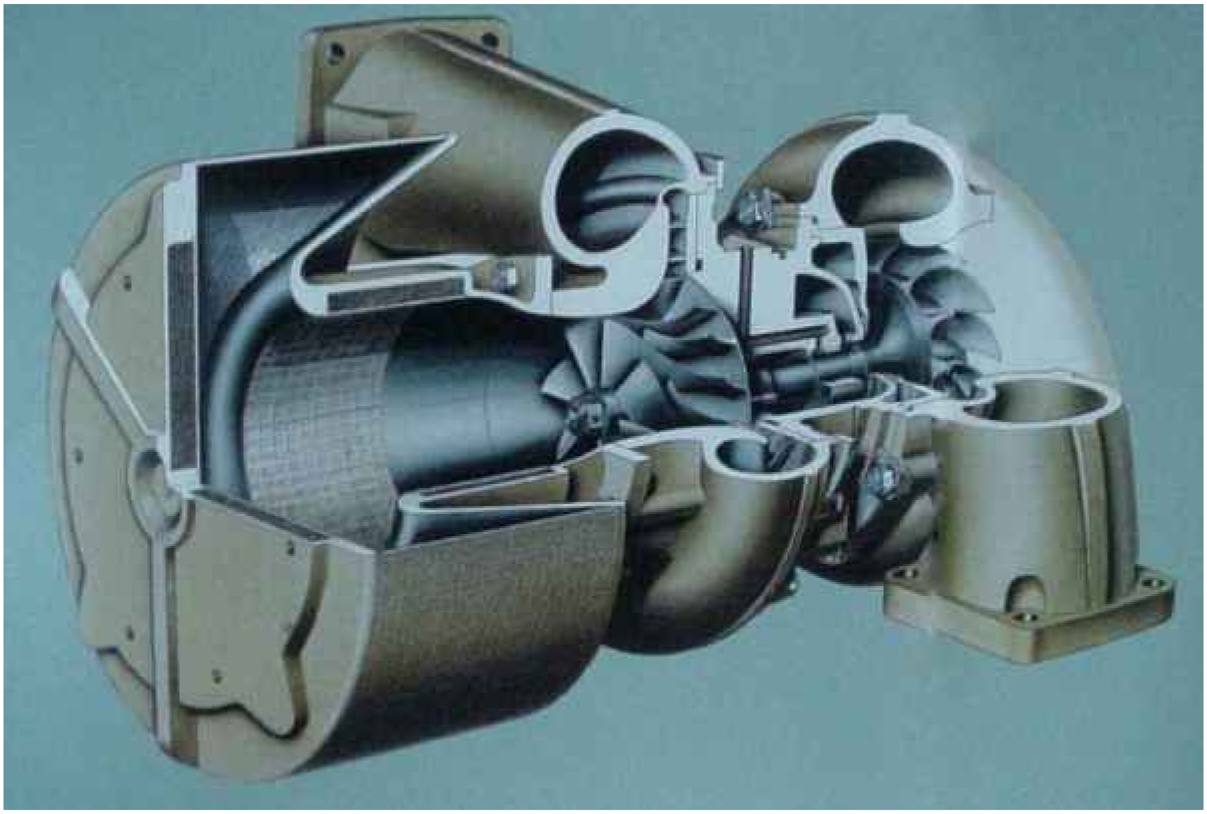
Construction

Axial





Centrifugal



Centrifugal turbochargers are generally cheaper to produce than axial flow. In addition for smaller sized radial units the effects of blade leakage are less important They are very common in automotive systems were lthey are suited to the manufacture of large volumes of standard design. Axial flow may be selected even when there are centrifugal alternatives as it is better suited to individual modifiactions and is able to operate better on heavy fuels.

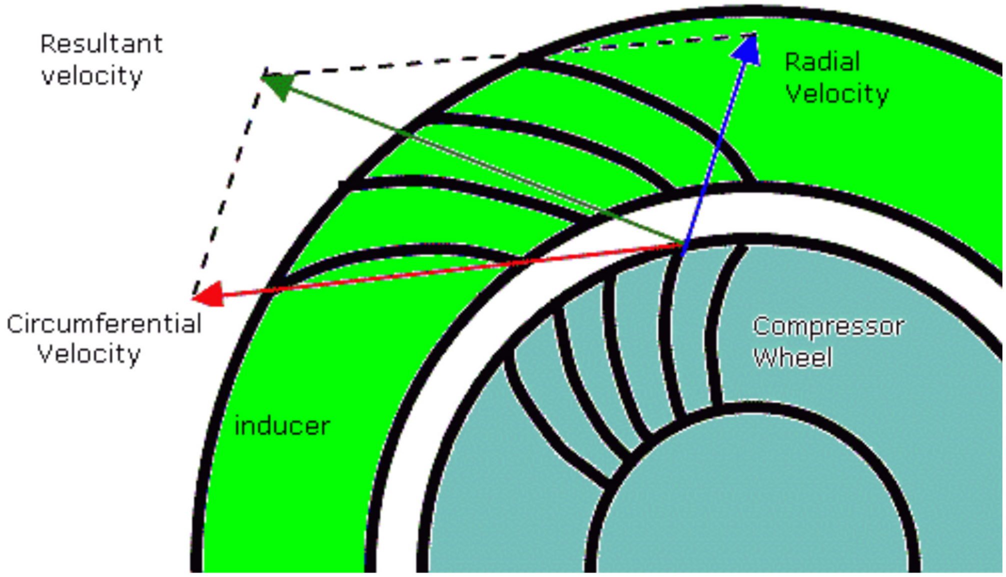
A turbocharger is made basically in two linked parts, the gas side and the air side.

The **gas side** is made out of cast iron, is in tow parts and is generally water cooled. The turbine inlet casing carries the nozzle blade shroud ring and forms the bearing housing. The turbine outlet casing forms the main part of the blower which includes the mountings. In addition it forms a shroud for the shaft and contains bled air passageways for supplying air to the labyrinths seals.

Compressor

The **air side** casing is also in two parts but is made of aluminium alloy. The inlet casing may be arranged to draw air form the engine room or from the deck , both methods via a filter and silencer arrangement. The advantage of drawing air form outside the engine room is that it will tend to be cooler and less humid. An advantage of drawing from the engineroom would be simpler ducting arrangements and that the engine room tends to be slightly pressurised.

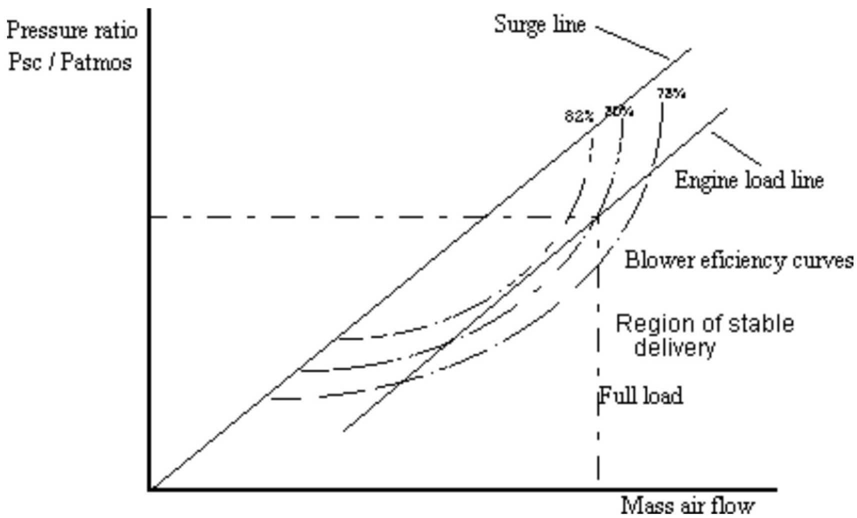
The main parts of the Compressor are the Compressor wheel (made up from a serpate Inducer and Impeller on larger designs), the diffusor, and the air inlet and outlet casing.



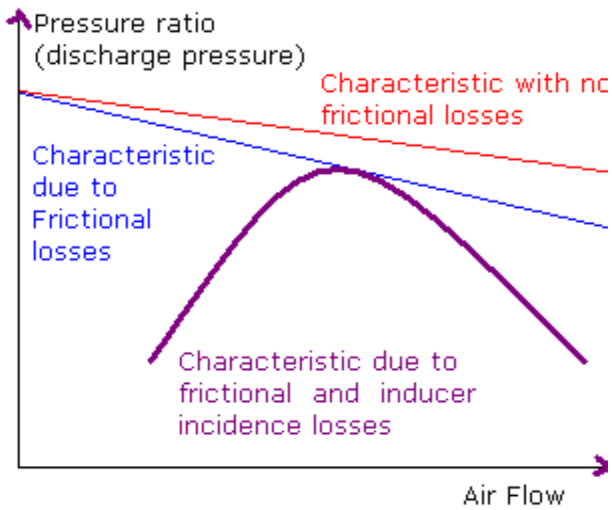
With the wheel rotating a unit of air massin the compressor wheel experiencesa circumferential velocity (v)at its distance from the wheel centreline (radius r). A radial velocity is experienced of value v^2/r which causes it to move radially outwards. The unit of air leaves the compressor with a resultant velocity the angle of incidence of which should, by careful design, match the inducer inlet angle. This leads to maximum compressor efficiency.
The effects of frictional losses, whether due to surface imperfections or fouling of the compressor wheel will result in changing the angle of incidence and thus a drop in efficiency

Surging

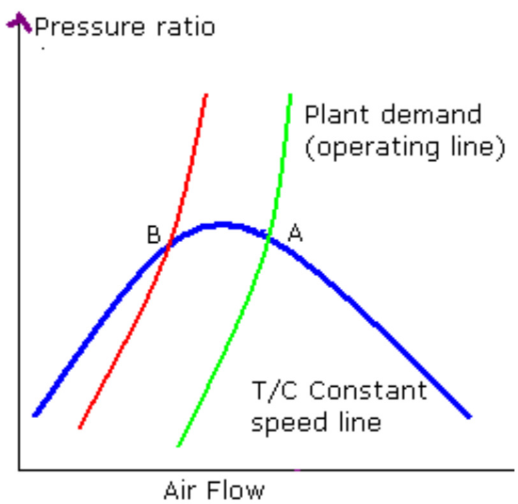
Takes place if the air mass delivered by the blower falls at a faster rate than the air pressure of delivery. With all blowers it is possible to produce a graph showing the effect. Surging gives an unpleasant noise. The initial action in order to prevent a blower surging is to reduce engine load. Blower efficiency is highest closer to the surge line and so if a high efficiency is demanded there is little leeway against surging. In practice the fitting of blowers is a compromise between a reasonable blower efficiency and an acceptable degree of safeguard against surging.



Surging is a condition whereby an imbalance in demand and supply of air from the turbocharger causes a rapid decelleration. This is accompanied by a loud barking noise and vibration. It was not uncommon on pulse systems in heavy weather, it is less prevalant in modern constant pressure designs but may begin due to reasons explained later.



The normal characteristic of a turbocharger running at constant speed is one of reducing possible pressure ratio for increasing air flow demands. This characteristic is exagerated when frictional losses are taken into account. As described above from maximum efficiency the air leaving the compressor wheel should enter the inducer at an optimal angle. Failure to do so leads to losses and a characteristic shown. It should be noted that this shows a relationship at a specific instant of Turbocharger speed. It would be possible to plot many lines of constant speed on the graph. The point at which surging occurs could be plottd for each and a surge line drawn. Moving the plant operating line towards the surge line can lead to an increase in turbocharger efficiency.



The stable operating point is at A though which passes the respective engine operating line (this line indicates the relationship the engine requires between Air flow and pressure), the unstable point leading to surging is at B.
If the air flow through the turbocharger reduces The effect would be a decrease in pressure at the receiver. However the pressure ratio of the turbocharger (running at constant speed) would Increase. The effect of this is to return the system back to its stable point A.

For an engine operating on the line passing through B then the effects of a reduced air flow wil be a corresponding reduction in compressor pressure ratio. The engine however requires increased air flow which the turbocharger cannot supply and the result is surging. Theroretically this effect begins where the constant pressure line is flat.

Conditions leading to Surging

Turbochargers are generally specified in relation to set ambient operating conditions and then matched to engine load requirements. Deviation away from this due to such things as changes

in ambient conditions and changes in engine speed/load relationship has to be taken into account.
It is very unusal for a moden turbocharger to such. However surging may begin after several years of stable operation.

Some possible reasons are

- For multi blower installations surging can occur due to a difference in maintenance of cleaning causing one or more to operate at pressure ratio's above its capability
- Similarly difference in blower component wear, this is particularly true for such things as increased blade tip clearance
- change in engine speed/ load reltionship- say due to hull fouling
- cylinder power imbalance
- faulty injectors or timing
- dirty air filter
- dirty air cooler (air side)
- High air cooler cooling water temperature
- dirty turbine nozzle ring
- deposits on blades or impeller
- damage to blades
- It is also possible that components downstream from the blower exhasut such as a fouled exhaust gas boiler can also lead to surging

The above is a very simplified description of the operation of the compressor and how surging occurs. No doubt I wil be receiving barrages of complaints from turbocharger specialist. In case you still cannot get it try to understand you are looking at a specific point in time and looks only at the turbocharger running at a constant speed

Rotor

This may again be thought of two parts; the gas side and shaft and the air compressor side. They are usually made of two materials as the conditions that the wheels operate in is very different. The advantage of making the compressor end of a lighter aluminium alloy material rather than using the same material throughout, is that it reduces the total mass of the rotor , is more easily cast into intricate shapes, and the rotational inertia is reduced.

Must be capable of maintaining strength at high temperatures so material is usually a chromium steel. The rotor for a smaller blower may be a single piece forging but for a larger blower it may consist of two separate sections of shaft and turbine wheel with bolted connection.

The impeller is made of an aluminium alloy and for larger compressors may have a separate inducer section at the eye. Whatever the form of construction it must preserve the rotor balance and that means refitting in the same position after removal from the rotor. This is usually achieved by having one of the connection splines larger than the others.

Blades

The blades shown above are twisted and tapered to allow for the increased blade velocity with increased radius Blades must be capable of withstanding the high exhaust temperatures and also the highly corrosive environment of the exhaust gas. Stainless steel is frequently used. They are mounted axially in the disc using inverted fir tree root or similar e.g. 'T' piece or bulb roots. Locking strips are provided to prevent axial movement of the blades in the disc due to the axial gas force.

The blades are not force fit into the disc but are relatively loose.

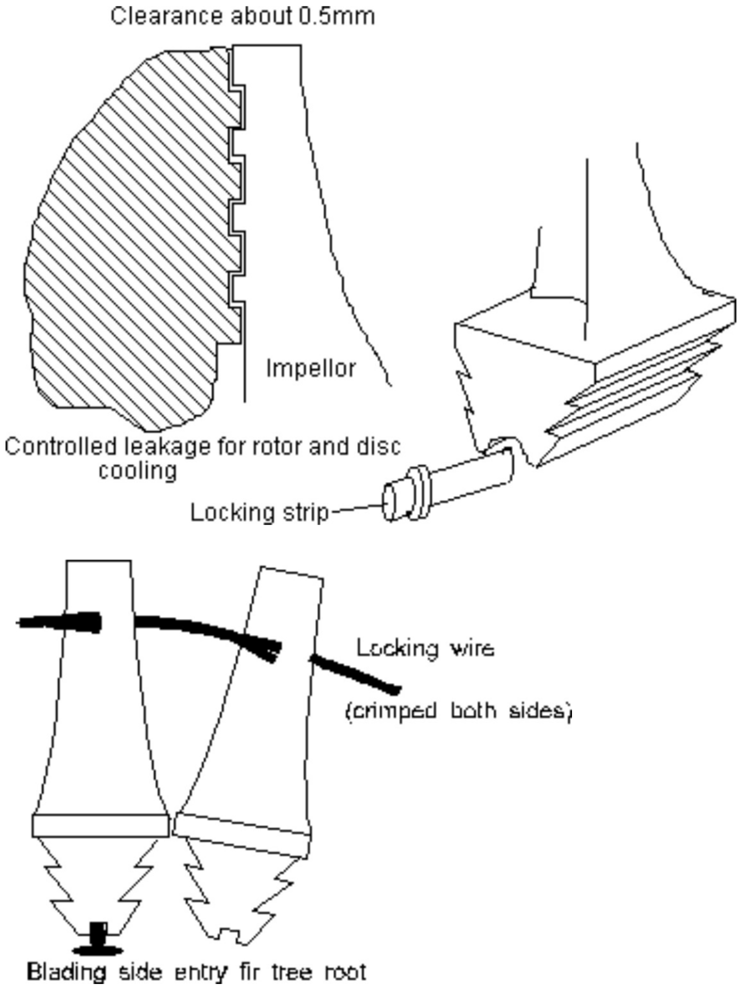
The blades are made lose fit for the following reasons;

- To allow for thermal expansion
- To prevent force fit stress adding to centrifugal stress (stops the material 'yielding')
- Help dampen vibrations from the gas pulses as the blades pass the nozzles (especially when partly or wholly blocked)

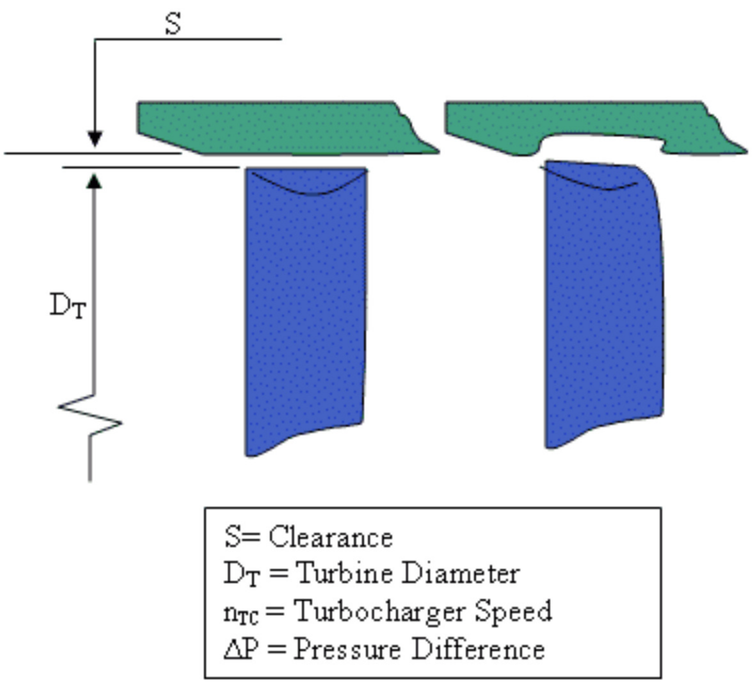
For larger blades lacing wires are used as a means of dampening vibration by the friction acting between the wire and the blade material at the hole. The wire is normally fitted about 1/3 of the way from the tip, it may pass through all blades or batches and is crimped to hold it in place. Dampening due to friction and stiffening up because of the connection of a number of blades avoid vibration.

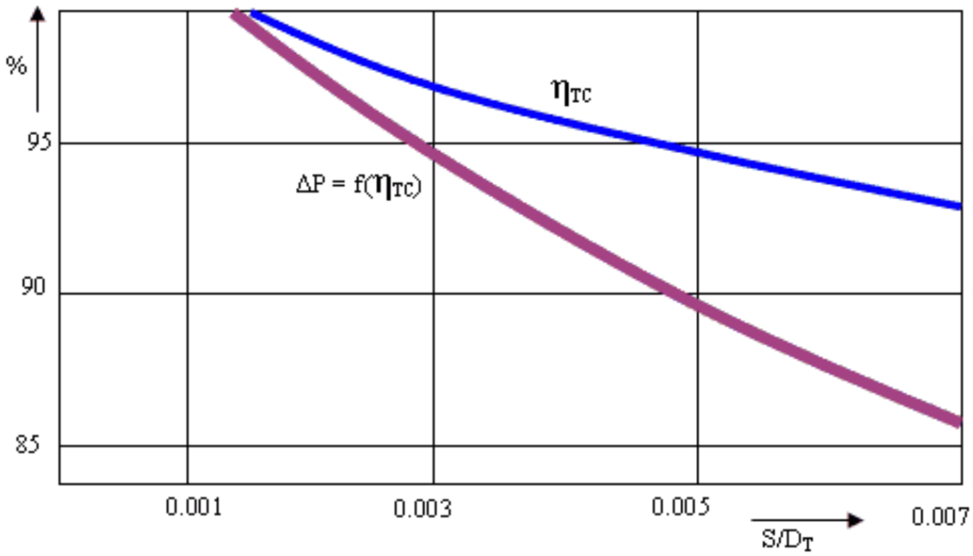
The main problem with lacing wire, usually of wrought iron, is that it breaks and sections fall out resulting in an unbalanced rotor.

Balance of the rotor is essential in order to avoid vibration and blade damage due to impact, corrosion, erosion and deposit build up all cause problems.

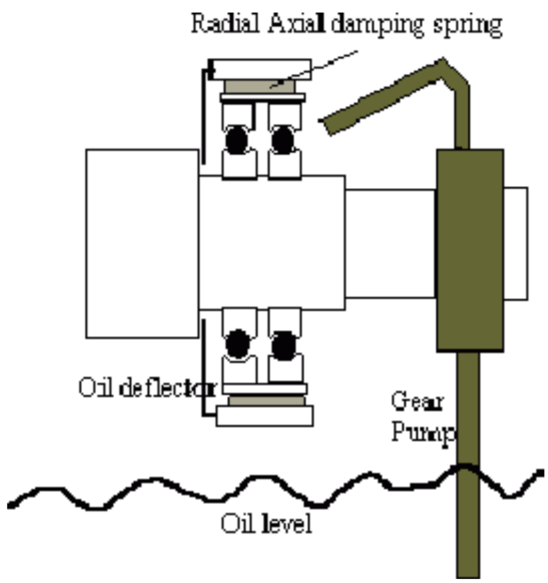


Blade Wear and its affect of blower Speed





Bearings

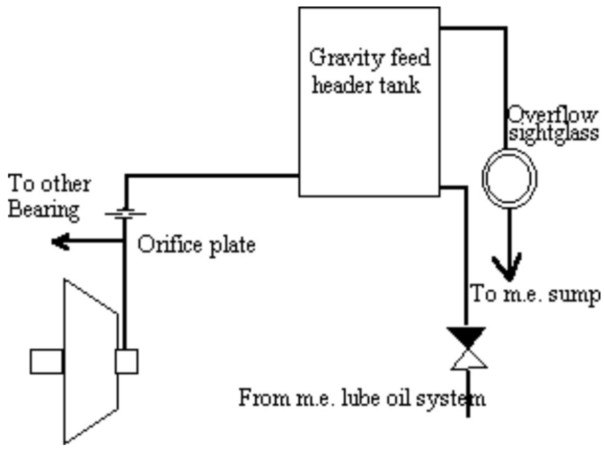


Most main engine turbochargers are water cooled in order to keep temperatures reasonable. On the most modern of turbochargers this cooling water has been reduced in quantity to that is required for cooling the bearings. The space between the compressor and turbine being filled with insulation material.

There are some smaller blower designs which by design can be cooled by air flow. As no cooling jacket is required it is convenient do place the bearings in between the turbine and compressor wheels. this allow for better rotor support. The larger blowers have the bearings placed at the coolest part of the charger, at the ends of the rotor within cooling jackets. This has the advantage of making them more readily accessible.

Plain white metal bearings may be used , these have an indefinite life but require lube oil to be supplied at pressure. they also require a header system to supply oil in the event of the main supply pump failure. A common system is by supplying from the main engine lube oil system via a header system similar to that employed with steam turbines.

Plain bearing Lube oil system



Care should be taken to ensure that the bearings are adequately protected when the engine is stopped as the blower is liable to turn due to natural draught (although modern engines having hydraulic exhaust valve actuation are not susceptible to this as the all valves close after a short period of inactivity). Locking the blower, isolating the blower from the scavenge belt by use of a slide valve, putting covers over the blower suction or continuation of supply of lube oil after engine stoppage may be used.

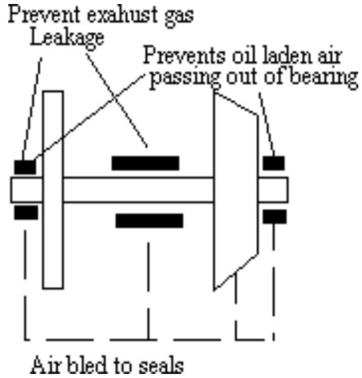
Ball or Roller bearings require elasto-hydrodynamic lubrication and may be supplied by means of a shaft driven gear pump from an integral sump. The gear pump is operated by rotation of the rotator. The bearing housing as a cooling water jacket.

ball and roller bearings have a definite life and must be changed on a running hours bases, typically every 15,000 Hrs. This means that they should be placed in a readily accessible position. The transmission of vibration is dampened out by the use of radial and axial springs between the bearing carrier and the casing.. These can consist of leaf springs wrapped around the bearing and fitted at the bearing ends.

An axial thrust is generated by the passage of the exhaust gas over the turbine . This must be balanced out . For turbochargers fitted with plain bearings a double-sided thrust is fitted at both ends. This takes the form of a collar on the rotor acting on white metalled 'Mitchell' type segments. Double-sided thrusts are fitted to locate the turbine during rolling and pitching. Generous oil quantities are supplied to bearings in order to allow for cooling as well as lubrication

Labyrinth Seals

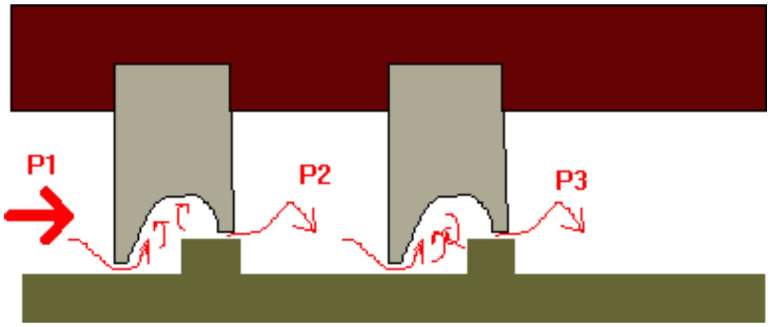
These are provided at each ends of the rotor and between the turbine and compressor and serve to prevent the passage of exhaust gas and also to prevent oil laden air being drawn into the eye of the impeller from the bearing. Oil seals in the from of thrower plates are also fitted at the bearings to prevent the passage of oil along the shaft.



Labyrinth seals consist of projections on the rotor which almost touch the casing.

Principle of the Labyrinth Gland

The leakage of steam is reduced by the use of labyrinths, these provide a torturous path for the gas to follow to exit the turbine reducing the pressure across a series of fine clearances



Within the cavity where the flow is turbulent, the velocity of the gas is increased with an associated drop in pressure. The kinetic energy is the dissipated by the change in direction, turbulence and eddy currents.

Air is bled from the compressor end into the middle of the Turbine glands, this air expands in both directions and provides a very effective seal. The flow of air in the centre gland also aids cooling and minimises the heat transmission form the turbine wheel.

Care must be taken to ensure that deposits do nit build up in the seals otherwise its effectiveness is lost. Also there is a possibility of 'rub' occurring

Timing of scavenging on ported liner on two stroke slow speed

The scavenge and exhaust period can be divided into three periods starting as the piston travels down the cylinder and uncovers first the exhaust port followed by the scavenge air port.

1, Blowdown-Exhaust port is open and cylinder pressure falls to or below the scavenge pressure
2, Scavenge- Incoming air forces the exhaust gasses and any unburned fuel out
3, Post scavenge- Exhaust only is open, some air is lost during this period. For ported exhausts this is unavoidable due to design of the liner with the exhaust ports above the scavenge. Some loss of compression therefore occurs, on the Sulzer RD an attempt was made to limit the blowdown by the use of a rotary exhaust valve. This proved very unreliable and was omitted on the later RND.

Modern Slow Speeds make use of exhaust valves, and with the most modern the exhaust valve timing is variable dependant on load and to some point fuel type.

Blower corrosion

Blower corrosion can take place on the gas, water or air sides. As most water cooled blowers make use o the engine cooling systems the same problems and solutions exist as in the jacket water system. In general with modern systems there are few problems if treatment quality and quantity is maintained. On the gas side deposits depend upon the quality of fuel and combustion. Carbon from poor combustion, sulphur products from the fuel, Vanadium Pentoxide from the fuel and Calcium Sulphate from the alkaline additives in cylinder oil all result in deposits and/or corrosion. Correct attention to operating conditions and matching of cylinder oil alkalinity to sulphur content will minimise the problem. Pitting corrosion and scale formation will lead to imbalance. On the air side there is a lesser risk but pitting oxidation of aluminium can take place in the prescience of salt spray. If air is taken from the deck there is greater risk than if it is drawn from the engine room because the oil mist in the engine room causes a protective film to form on the aluminium surface. Regular cleaning of parts is essential to maintain efficiency, minimise corrosion and ensure balance.

Out of service cleaning is relatively straight forward but requires the blower to be stripped down and time might not allow that. Light deposits on the air side may be easily wiped away, but gas side deposits require the rotor and nozzle blades to be 'boiled' for about 12 hours in clean water or water containing chemical; care must be taken in handling chemicals and 'special shipboard mixtures' should be avoided as they can be highly corrosive resulting in damage tot he rotor. In service cleaning provides an alternative.

For the airside this usually consists of injecting a limited quantity of water into the eye of the impeller, the water droplets then wipe the oily film from the surface but often deposits this on the cooler from where it must also be removed. If heavy deposits do form on the impeller and volute and then the risk of surging will increase. The usual in service cleaning method for blower gas side employs water but it is also possible to make use of ground rice or walnut shells, Whichever method is used care must be exercised.

In service water washing of the gas side requires the blower speed to be reduced to half or below (3000 rpm for a medium sized slow speed), in order to avoid impact damage by the water droplets

The casing drain must be open and known to be clear. Water is injected via an air atomiser nozzle into the gas flow. The flow rate is controlled by means of a pressure gauge and orifice plate. The basic principle is that the water droplets impinging on the blades has a shot blasting effect. Observation of the water flowing from the drains will indicate when sufficient water has been injected. On completion the blower speed should be increased gradually to prevent thermal shocking, ensure all the water in the gas side casing is removed , and to prevent damage due to any unbalance caused by partially dislodged deposits.

The injection of nutshells and rice can take place at full load.

Modern trends in Turbocharger design for Large slow speeds

With the search for ever increasing plant efficiency and power/size ratios, greater demands are made of the Turbocharger. Some manufactures have answered this by the use of totally water free blowers , these are fitted with plain bearings and supplied from the main engine lubrication system.

Running the aluminium alloy impeller above the aging temperature (190-200^{o}C) threatens a reduction in material strength. This temperature can easily be reached at pressure ratio is of 3.7 and above depending on suction air temperatures.Progressive creep deformation can occur above 160^{o}C requiring carefull consideration of stress on the blades. ABB turbos have available an aluminium compressor with a pressure ratio of 4.6 units new designs.

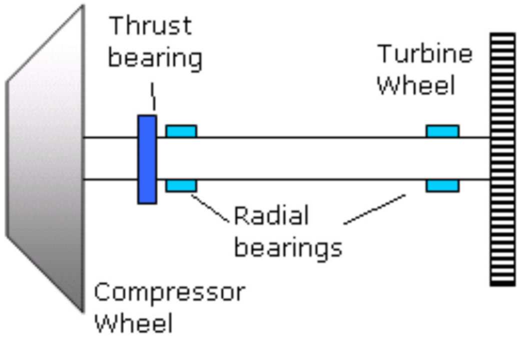
For higher pressure ratios stainless steel or Titanium is used where pressure ratios of up to 5.2 have been possible.

A typical modern design has plain bearings supplied by oil from the main lubrication systesm or from a dedicated external system. The casing is entirely uncooled relying instead on the lubrication oil to be splashed around the generously sized bearing space to cool the areas adjacent to the bearings

Vairable geometry nozzle rings are available which adjust balde angles depending on load.

The blades are high chord (thick section) meaning that lacing wires can be omitted. Special attention has to be made on the shaft fitt arangementalloyed aluminium compressor wheel as the rotational speeds of 500m/s create high centrifugal stresses. The number of blades in the volute is matched to the number of blades on the compressor to reduce noise

The thrust bearing which is subjected to high loading is mounted outside the radial bearing on the compressor end fo ease of maintenance

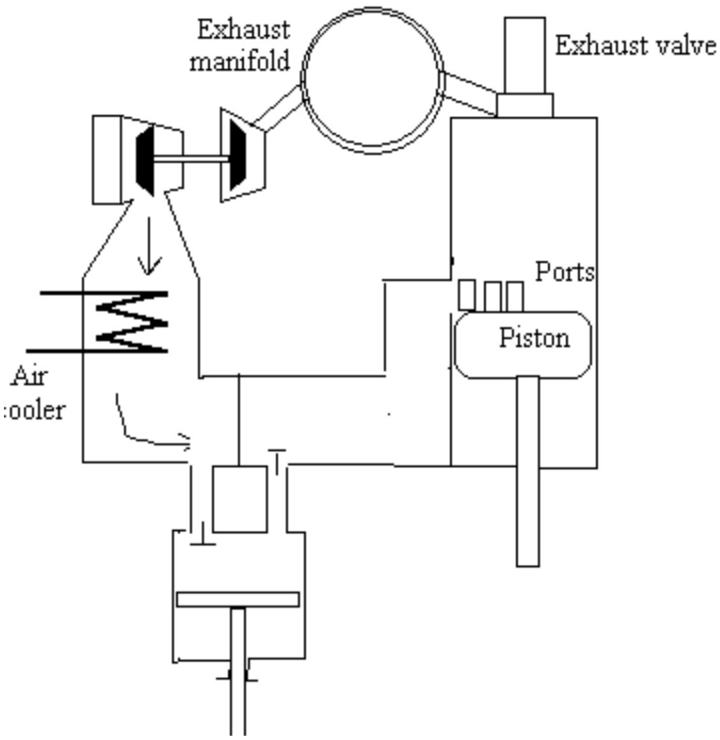


Turboblower arrangements

History

The idea of supplying air under pressure to the engine dates back to Dr Rudolf Diesel in 1896. The use of a turbocharger to achieve this dates to 1925 to work on 'pulse system' carried out by A.Buschi. This system feeds exhaust gas through small diameter pipes to the turbocharger turbine. Cylinders whose timing and firing ordermeans there is no effect on each others scavengeing can be connected into a single entry

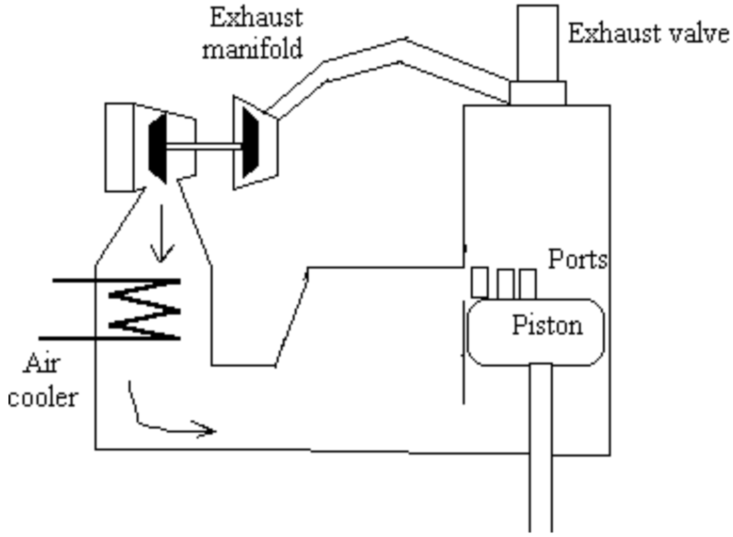
In the early days turbocharger efficiency was not high enough to supply the scavenging needs of two stroke engines and engine driven scavenge pumps had to be used



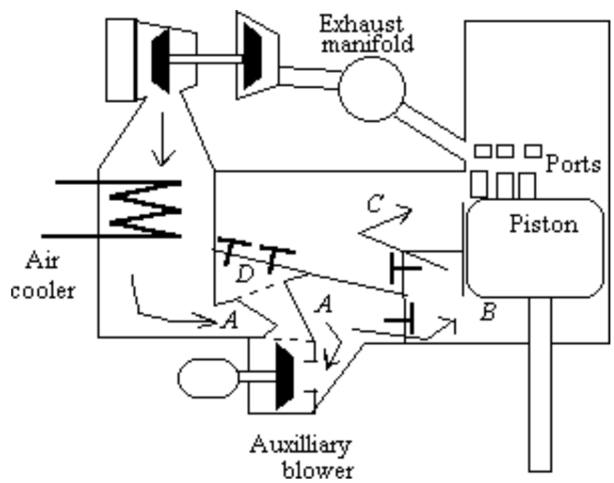
Shown above is a constant pressure turbocharger in series with a scavenge pump. This system saw use in Gotaverken engines aound 1970. The scavenge pump is a double acting LP air compressors driven either by the main engine crosshead through levers or by an additional crank section in the main crankshaft. There capacity is about 1.5 times the swept volume and they absorb about 5% of the engine power. They have a low mechanical efficiency and increase the length of the engine.

A rotary compressor of the positive displacement type (Rootes blower) is directly connected to the engine by chain drive. It absorbs about 6% of the power and increases the charge air pressure by about 0.3 bar.

Gas driven blowers rely on the available enthalpy of the gas so there operation is very much load dependent. They absorb no power from the engine but slightly effect operation by causing a back pressure on the exhaust.

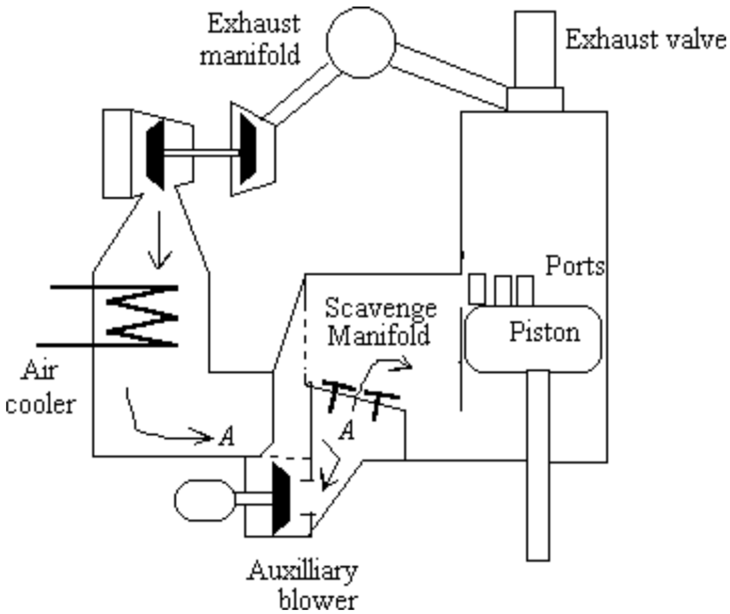


The pulse (constsnt volume) system was employed at the same time by B&W. The advantageous of this system is that no scavenge assist is needed at part loads. The disadvantage is reduced turbocharger efficiency as the blade and nozzle angles have to be a compromise because of the varying gas velocity and pressure at inlet.



Shown above is a variation on the scavenge piston assisted engine. In this the underside of the piston is used as the scavenge pump. In full load conditions air passes through the cooler, into camber A, the pressurerised air then passess through the non-return valves into chamber B, additional compression as the piston travels down the liner occurs and the air then passes onto the scavenge manifold indicated by C. In low load conditions the auxilliary electric diven blower operates drawing air from A and passing it out via non return valves in chamber D.

The use of uniflow scavenging and smaller (and thus with a lower rotational inertia) high efficiency turbochargers has meant that the requirement for energy sapping underpiston effect is negated.

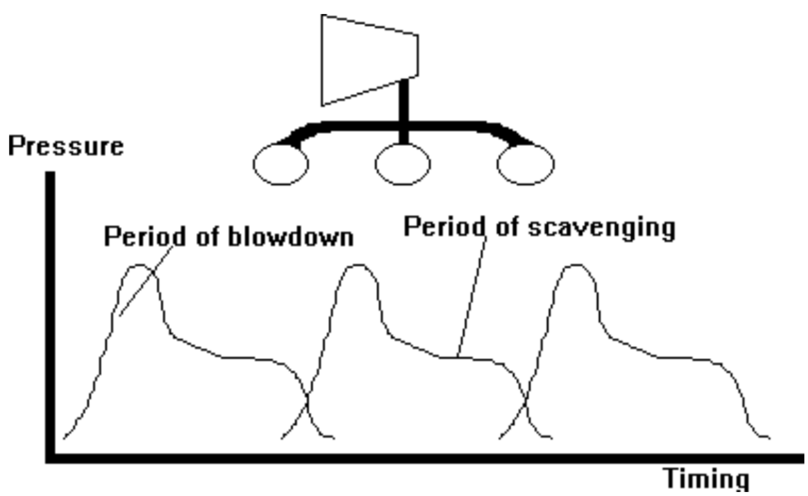


This is the modern layout with an auxilliary blower assisting the turbocharger at lower loads. In addition starting air may be supplied to the larger sized blowers to start them turning when the engine is first started.

Impulse(pulse,blowdown,constant volume)

This is the oldest turbocharger system for marine diesels, and can trace its lineage back to the conversion from mechanically driven to exhaust gas driven superchargers.

In the impulse system, the exhausts from each cylinder is led to the turbocharger via short length small diameter pipes. The small volume of this pipe means there is a large variation in exhaust gas pressure over the cycle.



Best use is made of the high temperature and pressure gas during the blowdown period. On opening of the exhaust valve this hot gas is expelled forcing the cooler gases through the turbine, following this initial surge the scavenged gas being forced out by the scavenge air is of lower pressure and temperature. There is therefore, a wide variation in conditions of the gas at entry to the turboblower. Due to the restricted outlet of the exhaust, the exhaust valve must be opened relatively early to ensure that the pressure has fallen sufficiently before the scavenging air is introduced.

By connecting three cylinders to each blower a 10% increase in the useful energy is extracted form the gases. It is essential that the pulse do not interfere with each other and hence careful attention has to be paid to firing order (which can lead to problems of torsional vibrations on the crankshaft). The graph above shows the ideal where three cylinders are led to the turboblower, the cylinders are firing 120^o apart, and the exhaust valve is open for a longer period leading to overlap. Often complicated exhaust geometry is required to ensure maximum efficiency.

The main advantage of this system is that best use is made of the available energy from the exhaust gas at part load to a point that auxiliary blowers of any sort are usually omitted except where fitted for emergency use. The system also responds rapidly to load changes

Due to the fact that maximum efficiency occurs when only three cylinders are connected to a turboblower, several blowers are required for multiple cylinder plants. This leads to increased cost and maintenance requirements. Where four cylinders are fed to a turboblower, it is normal to use 'Split entry' where the cylinders are split into pairs each feeding a separate inlet and nozzle chamber in the blower. Where say five blowers feed two turboblowers the central cylinder gases are split feeding both blowers simultaneously. This system is often called the 'Balanced' system as the turboblowers are kept the same size rather than having a large and small blower being fed by three and two cylinders respectively, so reducing spare gear requirements.

There are three main points of note with this system;

The energy available at the turbine can be increased by 2% by advancing the point of exhaust port/valve opening by one degree. Therefore it is essential that exhaust valves should open as rapidly as possible

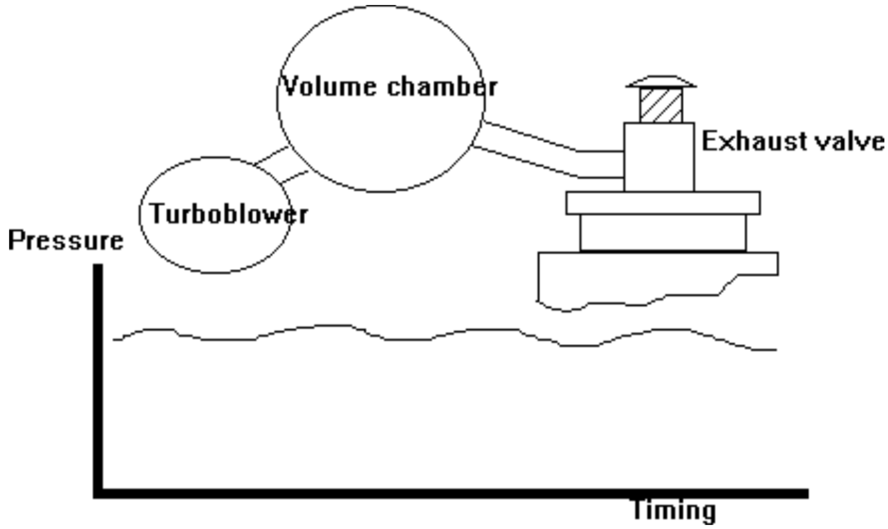
As the exhaust gas pressure drop between the cylinder and the exhaust pipe increases, so throttling losses increase. So the manifold is kept as small as possible.

As gas pressure builds up in the pipe so the period of blowdown is increased.

Tuned system-This refers to a pulse system designed to reduce air loss from the cylinder when the scavenge air valves/ports are closed and the exhaust valve still open. On opening of an adjacent cylinder the blowdown causes a shock wave ahead of it, by careful attention to pipe geometry and timing this shock wave can be utilised in pushing back the scavenge air into the cylinder without the exhaust gas from the adjacent cylinder actually entering the scavenged cylinder before the exhaust valve shuts.

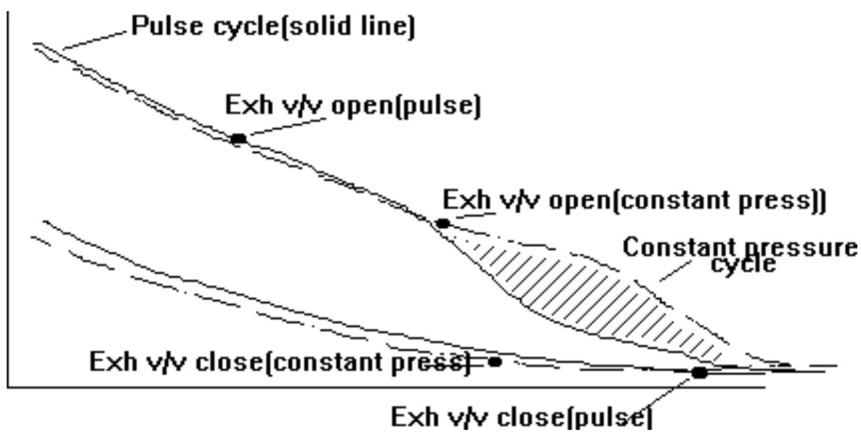
Constant pressure

The pulses of the exhaust gas are evened out by leading the gases into a volume chamber. Therefore the gases enter the turbine with little fluctuation in temperature and pressure. The exhaust manifold must be well insulated and the turboblower can be sighted at any convenient location. Also the pipework leading from the exhaust valves can be very much simplified so reducing costs.



Due to the stability of the conditions of the gas entering the turbine, the blades and blade angles can be optimised for maximum efficiency. Due to this, a constant pressure system can offer about a 5% increase in efficiency over a pulse system fitted engine, also due to the increased efficiency of the blower more energy is available at outlet from the blower for utilisation in the waste heat recovery or power turbine. The stability in the gas flow has an added advantage in that the loading on the rotating parts and the bearings is reduced.

Another reason why constant pressure systems are more efficient is that exhaust valve opening can be made later in the stroke as the high pressure blowdown of the exhaust gas is not required and also there is less resistance to the outflow of the exhaust gas. These effects can be shown on the working diagram;



It can be seen from the diagram that more work is available with the constant pressure process as indicate by the shaded area. Scavenging will take place at a higher pressure for the constant pressure process, however, compression work is reduced as indicated by the lower curve as the cylinder has been purged with the scavenging air longer and so the charge is at a lower temperature. Due to this reduced temperature of the charge, the final compression pressure is lower. This means that fuel injection can be retarded so increasing the pressure rise for the same peak pressure. As the period of this pressure rise is reduced so thermal efficiency is increased.

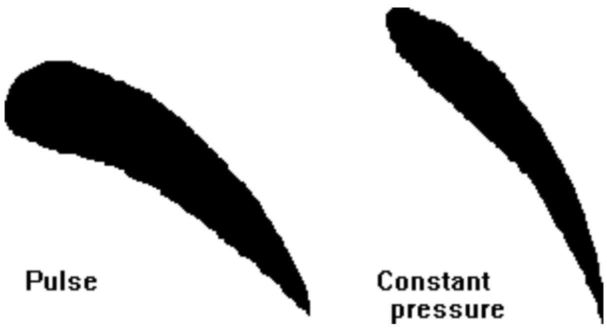
The main disadvantage of this system is that some means of assisting the scavenging is required at part load. This normally takes the form of an electrically driven blower which is sighted in the scavenge manifold. This blower draws air in over the turboblower compressor and compresses it discharging directly in the scavenge manifold. Drawing air in over the turboblower assists with inertia. Another disadvantage is the possibility of back leakage into the cylinder under low load conditions.

Although it would be possible to design a constant pressure system using only one Turboblower, more generally more than one is fitted for the following reasons;

- Mechanical breakdown
- Mounting difficulty with a large and heavy blower
- Cylinders furthest away from the blower would receive air at reduced pressure leading to power imbalance

It can be note that improvements to efficiency can not be gained by altering the exhaust opening timing

Comparison of blading of the constant pressure and the pulse turbine



It can be seen that the blades of the pulse turbine have a very pronounced 'Bull nose' which is required to cope with the varying relative gas inlet angles caused by the varying gas speed at outlet from the nozzle. The blade is also made thicker to cope with the shock loading at each pressure pulse.

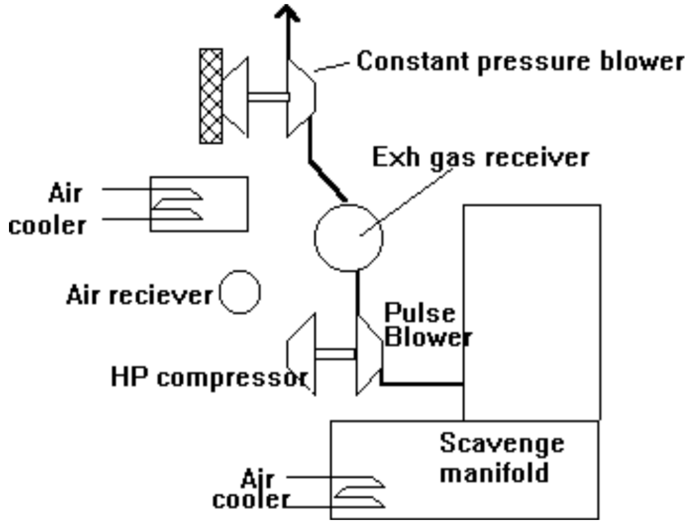
Timing variation due to supercharging

Unsupercharged four stroke

Air inlet opens	25^o BTDC	
Air inlet closes	25^o ATDC	
Exhaust opens	42^o BBDC	
Exhaust closes	TDC Overlap occurs at the beginning of the cycle with exhaust open until TDC and air inlet open from 25 degrees before this, allowing cooling of crown and exhaust valve	
Supercharged four stroke	Air inlet opens	55^o BTDC
Air inlet closes	28^o ATDC	
Exhaust opens	42^o BBDC	
Exhaust closes	35^o ATDC	

Valve overlap has increased to 90^o , this allows increased cooling effect on the crown and exhaust valves necessary with the increase in fuel burnt.

Two stage systems



The purpose of this system is an attempt to utilise the advantages of both systems. Although the inherent disadvantages are also present. The turbochargers are of different sizes because of different flow rates and pressure levels

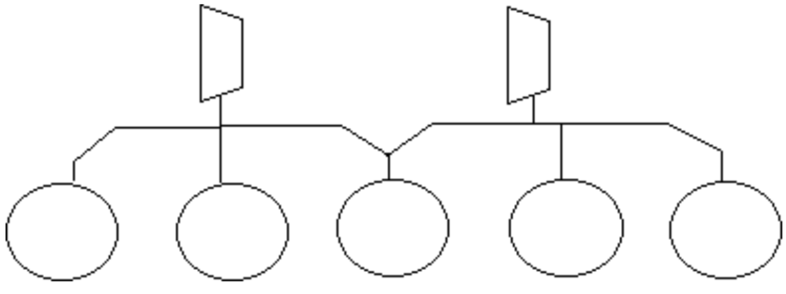
Another purpose for two stage systems is the production of scavenge air at an increased pressure. For a single unit there is a limit to the maximum pressure that can be generated governed by the work that can be recovered from the exhaust gas and the volume of air required for scavenging i.e. for a set volume of air, the required energy to compress increases with final pressure.

Greater scavenge pressures allow for increased mass of air for combustion for the same bore/stroke, hence more fuel can be burnt more efficiently.

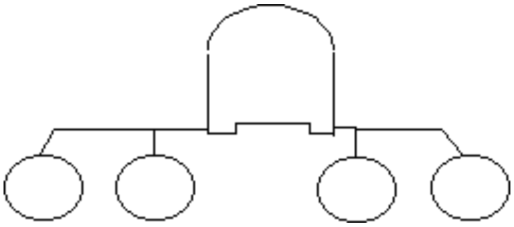
A second method of two stage Turbocharging involves two turbines mounted within the same casing. Both the air and exhaust gas flows through the turbines in series. The second stage turbine has larger blades to cope with the expanded gas. The compressor attached to the second stage turbine acts as the first stage of air compression. An intercooler is fitted between the stages.

Other types

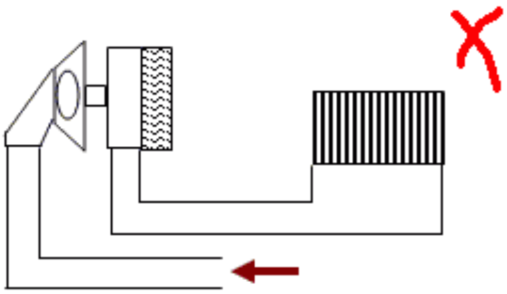
Balanced system-variation on pulse

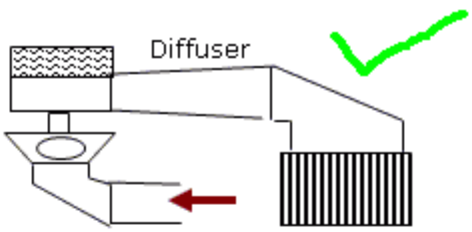


Divided Gas flow-split entry blower(allows more than three exhaust pulses per blower)

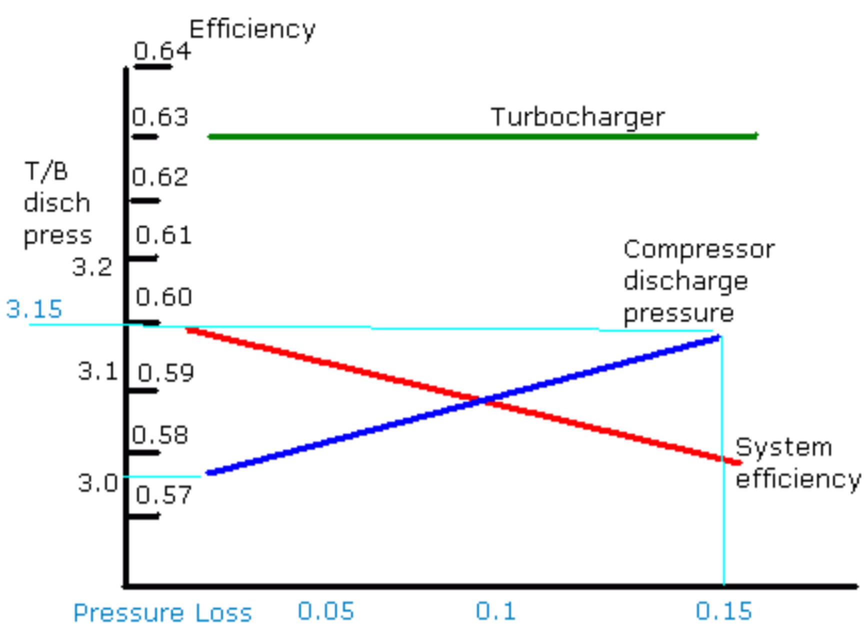


System layout





benefits in improved efficiency can be gained by reducing the number of bends in the pipework associated with the turboblower. A diffuser considerably reduces the pressure loss associated with the two bends. Straight pipes avoid the pressure loss due to bends.



Failure to ensure filters, blower components, piework and downstream items such as exhaust gas boilers clean can lead to compressor surging

Air Coolers

By increasing the pressure of the air the density is also increased. This allows more fuel per cycle stroke to be burnt increasing the power of the engine per unit size.

Associated with the increase in pressure of air passing through the compressor of the turbocharger is an increase in temperature.

From the general gas equation;

p.v = m.R.T

p = pressure
v = volume
m = mass
R = gas constant
T = absolute temperature

m/v = p /R.T

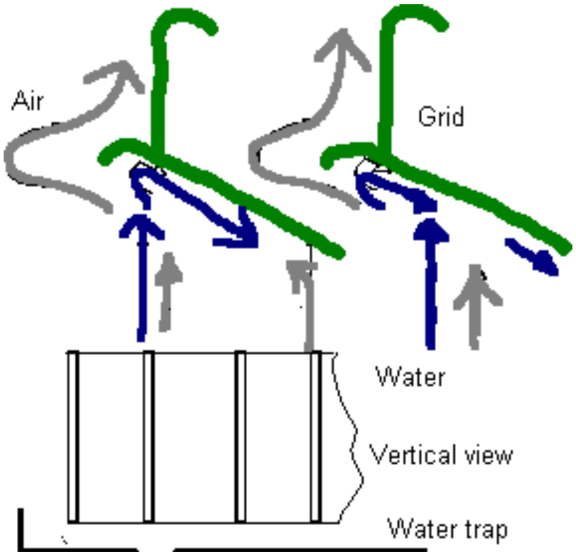
It can be seen that should the should the absolute temperature increase at the same rate as the pressure then the effects of compression is negated. Air coolers are therefore used, these are situated down stream from the compressor, before the air enters the scavenging ports.

The coolant is generally sea water circulated through finned tubes, the cross section of which may be of various shapes including round and oval. The thin fins are normally soldered on to the tubes but if the tubes are round they may be expanded into the fins. Flat sided an oval tubes are soldered into the tube plates whilst round tubes are expanded. An allowance must be made for expansion, in some cases the tubes are formed into a 'U'-shape, in other one end of the tube is fixed, the other end sits in a floating tube plate able to move in the casing and sealed by o-rings.

An ultimate limit is placed on the degree of cooling, this being to prevent thermal shocking especially of the piston crown, prevent excessively increasing cylinder lube oil viscosity and keeping above the dew point.

At the dew point water droplets will form which can scour the cylinder lub oil of the liner walls. Where engines operate close to or below the dew point then water separators are fitted downstream of the cooler. Grid type separators consisting of a pair of angled blades and relying on the higher inertia of the water droplets can remove upto 85% of the water.

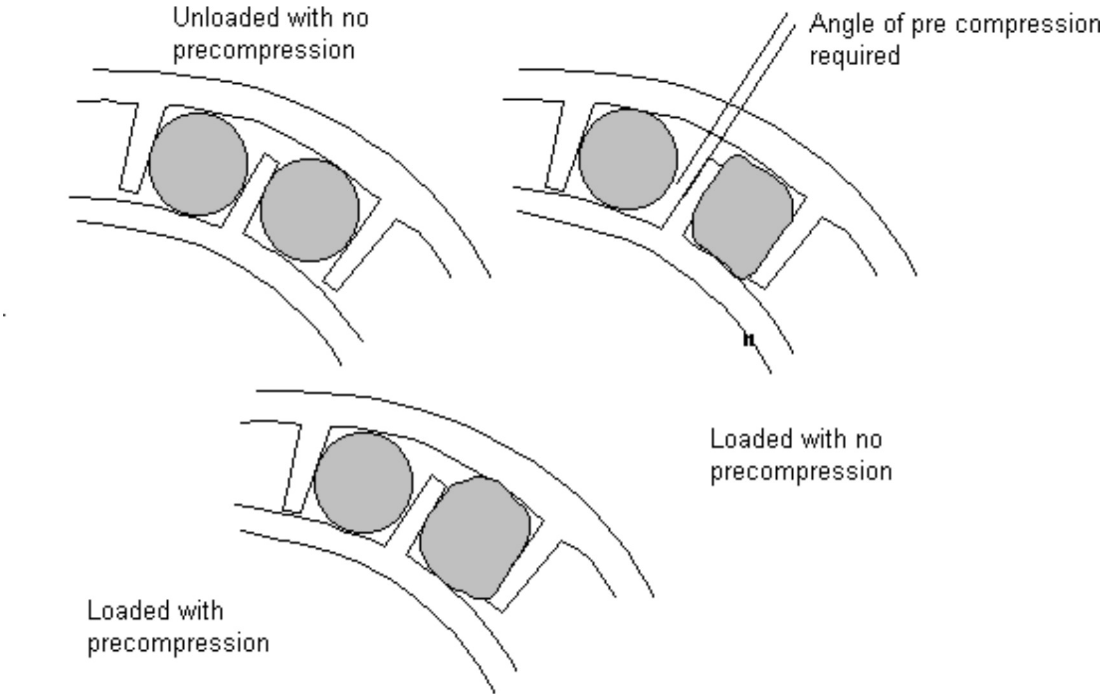
Air cooler grid type water separator


Air
Grid
Water
Vertical view
Water trap

Flexible couplings

With a medium speed system an number of engines and other devices are connected together. Flexible couplings are required to account for the slight misalignment which can exist. The claw type coupling as used with steam turbines allows for this misalignment and provides for a large area of contact which keeps he stress limited.

The diesel engine drive is pulsating and normal face to face contact cannot be allowed. Rubber blocks are therefore fitted between the claws. When the dive takes place the leading blocks are compressed allowing clearance at the trailing blocks which are hammered because of the pulsating drive. This results in wear. Blocks must there fore be pre compressed so that trailing blocks can expand and maintain normal contact with the drive.



Crankcase explosions

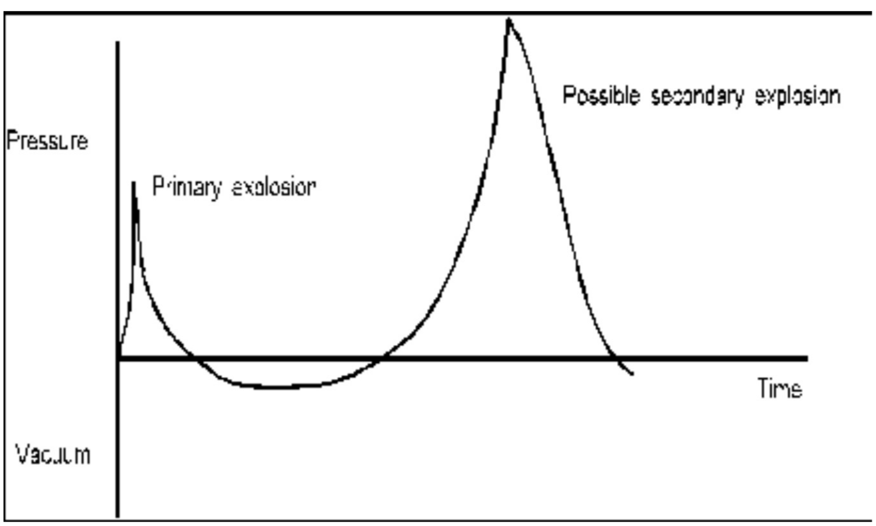
Under normal conditions the atmosphere in the crankcase when the engine is running contains a large amount of relatively large oil droplets (200 micron) in warm air. Because of the droplets small surface area to volume ratio, the possibility of ignition by a heat source is very low.

Should overheating occur in the crankcase, say by failure of a bearing, then a hot spot is formed (typically over 400'C although experiments have shown two seperate temperature ranges, the other between 270 - 300'C>. Here lub oil falling on to the surface is vaporised (in addition some is broken down to flammable gasses such as **Hydrogen** and **acetylene**), the vapour can then travel away from the hotspot where it will condense. The condensed droplets, in the form of a dense white mist, are very much smaller (6 to 10 microns) than the original and so have a high surface area to volume ratio. Ignition by a hot spot (generally of the flammable gasses which in turn ignite the fine droplets in the mist), which may be the same on that cause the original vaporisation, is now a possibility.

Oil mists are formed at temperatures of around 350^{o}C

Ignition occurs at under 500^{o}C

The white mist will increase in size and density until the lower flammability limit is exceeded (about 50mg/l is generally found in real situations), the resultant explosion can vary from relatively mild with explosion speeds of a few inches per second and little heat and pressure rise. To severe with shock wave and detonation velocities of 1.5 to 2 miles per second and pressures of 30 atmospheres produced. This is the extreme case with pressures of 1.5 to 3.0 bar more normal raising to a maximum of 7.0 bar.



It can be seen that following the initial explosion there is a drop in pressure, if the initial explosion is not safely dealt with and damage to the crankcase closure occurs, it is possible that air can be drawn in so creating the environment for a second and possible larger explosion. The limiting factors for an explosion is the supply of fuel and the supply of oxygen, the air as shown can be drawn in by the slight vacuum created by the primary explosion. The supply of fuel may be created by the passage of the shockwave shattering the larger oil droplets into the small size that can readily combust.

By regulation,non returning relief doors must be fitted to the crankcase in order to relief the pressure of the initial wave but prevent a rapid ingress of air

Vapour extraction fans

These generally take the form of a small electrically driven fan. They are fitted with flame traps on the exhaust side.

Although the fans keep the crankcase at a slight negative pressure thereby increasing the risk of air being drawn in, this is seen to be more than compensated by the removal of flammable vapours and the reduction in oil leakage.

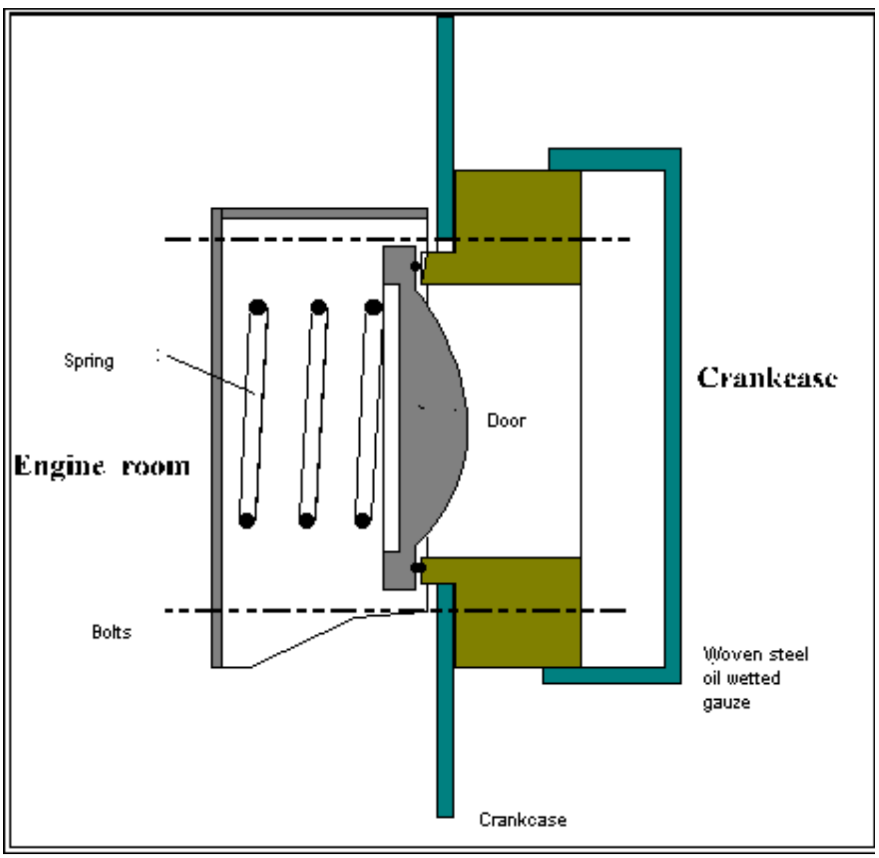
Crankcase doors

These when properly designed are made of about 3mm thick steel with a dished aspect and are capable of withstanding 12 bar pressure. They are securely dogged with a rubber seal arrangement.

Crankcase relief door (setting 1/15bar)

Due to the heavy force of momentum the gas shockwave is not easily deflected. Thus any safety device must allow for a gradual change in direction, and be of the non-return type to prevent air being drawn back into the crankcase

The original design was of cardboard discs which provided no protection against the ingress of air after the initial explosion, in addition it was known for these discs to fail to rupture in the event of an explosion.



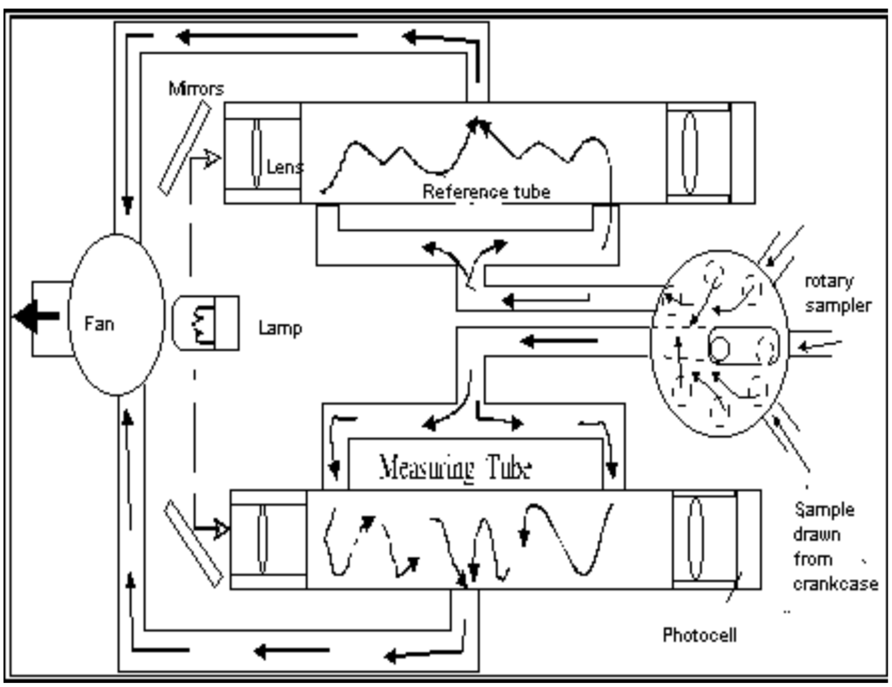
The valve disc is made of aluminium to reduce inertia. The oil wetted gauze provides a very effective flame trap This reduces the flame temperature from 1500'C to 250'C in 0.5 m. The ideal location for this trap is within the crankcase where wetness can be ensured. The gas passing from the trap is not normally ignitable. The gauze is generally 0.3mm with 40% excess clear areas over the valve.

Specifically the regulations are;

1. *Non-return doors must be fitted to engines with a bore greater than 300mm, at each cylinder with a total area of 115sq.cm/m3 of gross crankcase volume. The outlets of these must be guard to protect personnel from flame. For engines between 150 to 300mm relief doors need only be fitted at either end. Below this bore there is no requirement. The total clear area through the relief valve should not normally be less than 9.13cm^2/m^3 of gross crankcase volume*
2. *Lub Oil drain pipes to the sump must extend below the surface and multi engine installations should have no connections between the sumps*
3. *Large engines, of more than 6 cylinders are recommended to have a diaphragm at mid-length and consideration should be given to detection of overheating (say by temperature measuring probes or thermal cameras) and the injection of inert gas.*
4. *Engines with a bore less than 300mm and a crankcase of robust construction may have an explosion door at either end*
5. *Means of detection of oil mist fitted.*

Continuous extraction by exhauster fan may be used but this tends to be costly, flame gauzes must be fitted to all vents. Similarly a continuous supply of air can be used to reduce gas mist levels.

Crankcase oil mist detector (Obscuration)(set point 2.5% L.E.L)



Oil mists can be readily detected at concentrations well below that required for explosions, therefore automated detection of these oil mists can be an effective method of preventing explosions

Shown above is the Graviner oil mist detector. This is in common use in slow speed and high speed engines. The disadvantage of this type if system is that there is a lag due to the time taken for the sample to be drawn from the unit and for the rotory valve to reach that sample point. For this reason this type of oil mist detector is not commonly used on higher speed engines.

Modern detectors often have the detection head mounted in the probe, the probe is able to determine the condition of the crankcase and output an electrical signal accordingly

The assembly consists of;

Extraction fan-draws the sample from the sample points through the reference and measuring tubes via non-return valves.

Rotary valve-This valve is externally accessible and is so marked so as to indicate which sample point is on line. In the event on exceeding the set point , the valve automatically locks onto that point so giving a clear indication of the locality of the fault condition.

Reference tube-measures the average density of the mist within the crankcase, as there will always be some mechanically generated mist.

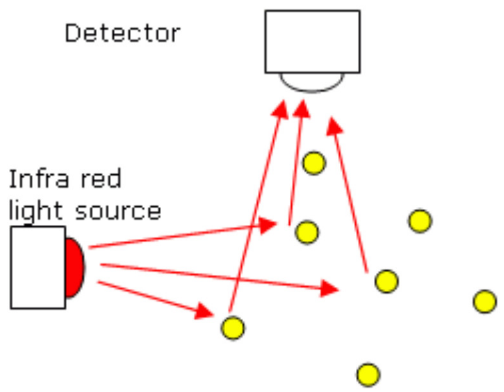
Measuring tube- measures the opacity of the sample by means of a photoelectric cell as with the measuring cell. To exclude variables in lamps a single unit is used with beams directed down the tube by mirrors.

The photoelectric cell gives an output voltage proportional to the light falling on it. In this way the opacity of the sample is measured, the voltages generated in the cell in the measuring and reference tubes are compared in an electronic circuit. The difference is compared to a potentiometer varied setpoint which if exceed initiates an alarm circuit. The alarm circuit, dependant on installation, will generally declutch the drive to the rotary valve, give an output signal to the engineroom alarm monitoring system and an output to the engine protection system causing it to slowdown.

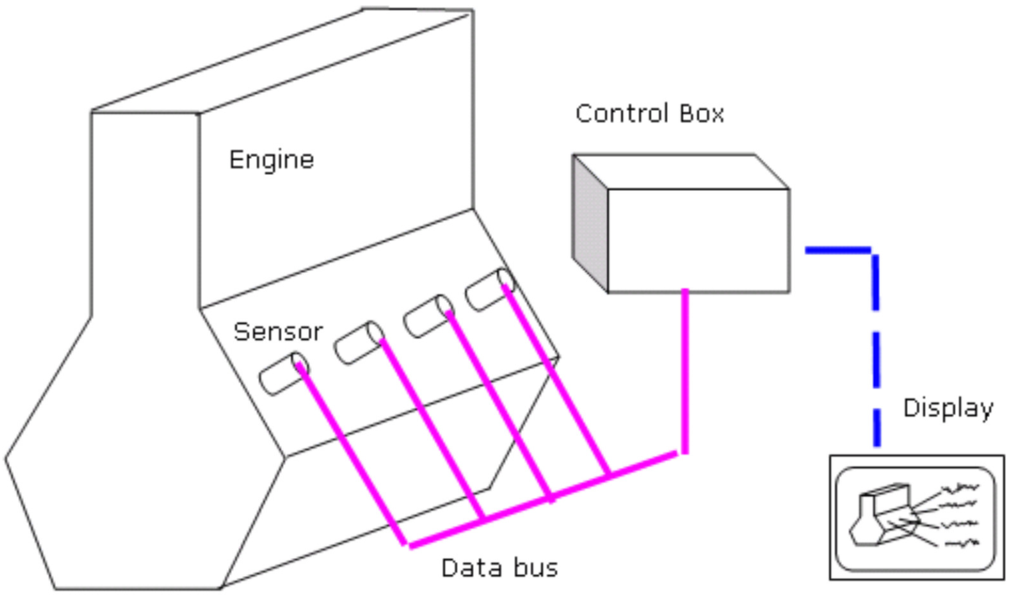
The rotary valve also has a position marked 'O' at which air is supplied to both tubes, and zero automatically (and manually if necessary) adjusted at each cycle. In addition at position 'L' an average sample of the crankcase is compared to air.

Crankcase oil mist detector (light scatter)

The disadvantage of obscuration types is that they are generally slow to operate and suffer from inaccuracies and false alarms caused by such things as a dirty lens.
Light scatter do not suffer from these problems, are faster reacting and do not need to set zero during engine operations.



The relationship between the light landing on the sensor is nearly proportional to the oil mist density therefore the unit can be calibrated in mg/l.
It is possible to have the sensor and a LED emiter in a single unit which may be mounted on the crankcase. Several of these can be placed on the engine each with a unique address poled by a central control unit. The results of which may be displayed on the control room.



having these heads mounted on the engine removes the need for long sample tubes which add to the delay of mist detection.This makes the system much more suitable for use with medium and high speed engines were otherwise detection would be impossible.

Crankcase doors (non relieving)

The older type consisted of doors lightly held by retaining clamps or clips. With doors of this type a pressure of 0.5psi would give a permanent set of about 25mm, the doors would be completely blown off by pressures of 2 to 3 psi Modern large slow speed engines have two types of crankcase door, a large securely held heavy mild steel square door which allows good access for heavy maintenance.

A second smaller round dished aluminium door at around x-head height which allows entry for inspection. Due to the curved design the door is able to withstand pressures well above the setpoint for the relief doors.

Actions in the event of Oil Mist detection

The consequences of a crankcase explosion are extremely serious and the greatest possible caution in the actions taken should be exercised.

Should the oil mist detector activate an alarm condition, then personnel should take steps to ascertain if the fault is real. They should initially assumed that it is, the bridge should be informed and the engines slowed if the oil mist detector has not already done so. Should the bridge require manoeuvrability, and it is essential that the engine be operated then consideration of evacuation of the engineroom should be made. Otherwise the engine should be stopped and turned on gear until cooled.

The Graviner Oil Mist detector indicates via markings on the rotary valve which sample point has the high readings. By inspection of the graviner, and by viewing crankcase (or thrust, gearcase) bearing readings it is possible to ascertain whether a fault condition exists.

Under no circumstances should any aperture be opened until the engine has sufficiently cooled, this is taken as normal operating temperatures as an explosion cannot occur when no part has a temperature above 270'C (Cool flame temperature)

Once cooled the engine can be opened and ventilated (the crankcase is an enclosed space).

An inspection should be made to locate the hotspot, the engine should not be run until the fault has been rectified.

Crankcase safety fitting

For the purpose of this Section, starting air compressors are to be treated as auxiliary engines

Relief valves

- Crankcases are to be provided with lightweight spring-loaded valves or other quick-acting and self-closing devices, of an approved type, to relieve the crankcases of pressure in the event of an internal explosion and to prevent any inrush of air thereafter. The valves are to be designed to open at a pressure not greater than 0,2 bar.
- The valve lids are to be made of ductile material capable of withstanding the shock of contact with stoppers at the full open position.
- The discharge from the valves is to be shielded by flame guard or flame trap to minimize the possibility of danger and damage arising from the emission of flame.

Number of relief valves

- In engines having cylinders not exceeding 200 mm bore and having a crankcase gross volume not exceeding 0,6 m3, relief valves may be omitted.
- In engines having cylinders exceeding 200 mm but not exceeding 250 mm bore, at least two relief valves are to be fitted; each valve is to be located at or near the ends of the crankcase. Where the engine has more than eight crank throws an additional valve is to be fitted near the centre of the engine.
- In engines having cylinders exceeding 250 mm but not exceeding 300 mm bore, at least one relief valve is to be fitted in way of each alternate crank throw with a minimum of two valves. For engines having 3, 5, 7, 9, etc., crank throws, the number of relief valves is not to be less than 2, 3, 4, 5, etc., respectively.
- In engines having cylinders exceeding 300 mm bore at least one valve is to be fitted in way of each main crank throw.
- Additional relief valves are to be fitted for separate spaces on the crankcase, such as gear or chaincases for camshaft or similar drives, when the gross volume of such spaces exceeds 0,6 m3.

Size of relief valves

- The combined free area of the crankcase relief valves fitted on an engine is to be not less than 115 cm2/m3 based on the volume of the crankcase.
- The free area of each relief valve is to be not less than 45 cm2.
- The free area of the relief valve is the minimum flow area at any section through the valve when the valve is fully open.
- In determining the volume of the crankcase for the purpose of calculating the combined free area of the crankcase relief valves, the volume of the stationary parts within the crankcase may be deducted from the total internal volume of the crankcase.

Vent pipes

- Where crankcase vent pipes are fitted, they are to be made as small as practicable to minimize the inrush of air after an explosion. Vents from crankcases of main engines are to be led to a safe position on deck or other approved position.
- If provision is made for the extraction of gases from within the crankcase, e.g. for oil mist detection purposes, the vacuum within the crankcase is not to exceed 25 mm of water.
- Lubricating oil drain pipes from engine sump to drain tank are to be submerged at their outlet ends. Where two or more engines are installed, vent pipes, if fitted, and lubrication oil drain pipes are to be independent to avoid intercommunication between crankcases.

Alarms

- Alarms giving warning of the overheating of engine running parts, indicators of excessive wear of thrusts and other parts, and crankcase oil mist detectors are recommended as means for reducing the explosion hazard. These devices should be arranged to give an indication of failure of the equipment or of the instrument being switched off when the engine is running.

Warning notice

- A warning notice is to be fitted in a prominent position, preferably on a crankcase door on each side of the engine, or alternatively at the engine room control station. This warning notice is to specify that whenever overheating is suspected in the crankcase, the crankcase doors or sight holes are not to be opened until a reasonable time has elapsed after stopping the engine, sufficient to permit adequate cooling within the crankcase.

Crankcase access and lighting

- Where access to crankcase spaces is necessary for inspection purposes, suitably positioned rungs or equivalent arrangements are to be provided as considered appropriate.
- When interior lighting is provided it is to be flameproof in relation to the interior and details are to be submitted for approval. No wiring is to be fitted inside the crankcase.

Fire-extinguishing system for scavenge manifolds

- Crosshead type engine scavenge spaces in open connection with cylinders are to be provided with approved fixed or portable fire-extinguishing arrangements which are to be independent of the fire-extinguishing system of the engine room.

Reversing a slow speed engine

For an engine to be reversed consideration must be given to the functioning of the fuel pump, air distributor and exhaust valves. That is, there commencement and completion of operation in respect to the crankshaft position.

Distributor

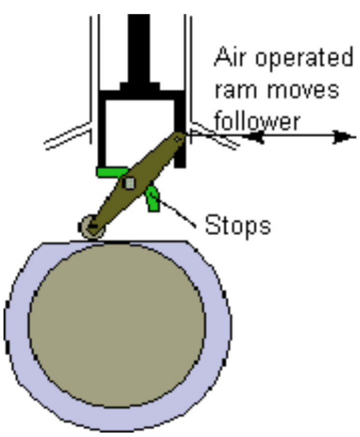
Due to the differing requirements for the change in angle between the distributor and the Fuel and exhaust cams, two camshafts are fitted although this adds to the cost of installation. The small distributor camshafts has seperate ahead and astern cams adjacent to each other. Reversing is by pulling and pushing the camshaft axially.

During normal engine operation the pistons of the distributor are held off the cams, this simplifies the changeover of the camshaft. When starting air is required the pistons are first forced onto the cams. Starting air is emitted during the low points and stop and the majority high points.

Reversing methods

There are five solutions to reversal of the engine timing are

1. *Reversing servos on all camshaft-such as older Sulzers*
2. *separate ahead and astern cams with axial movement to bring cams into align with rollers*
3. *timing of fuel pumps, exhaust valve symmetrical*
4. *fit air distributor as per doxford where reversal is performed internally by air flow*
5. *fit fuel pumps as per B&W new design where the follower is repositioned relative to the camshaft and this retimes pump for new direction.The Exhaust timing is symetrical*



Timed cylinder lubrication

Cylinder lubrication should be injected in carefully metered amounts. The injection points should be spaced around the periphery in such a way as to ensure adequate coverage when the piston passes the feed points. The best timing for injection is suggested as being between the first and second rings. The difficulties in achieving this are great, but injecting at TDC and to a lesser extent BDC assists

Lubrication is of the total loss system i.e. the oil is expected to be completely combusted without residue. The oil is injected through quills which pass through the liner wall.

Cylinder lub oil properties

The type of cyl l.o. required will depend upon the cylinder conditions and the engine design e.g crosshead or trunk piston. However, the property requirements are basically the same but will vary in degree depending upon the fuel and operating conditions.

Normal properties required are;

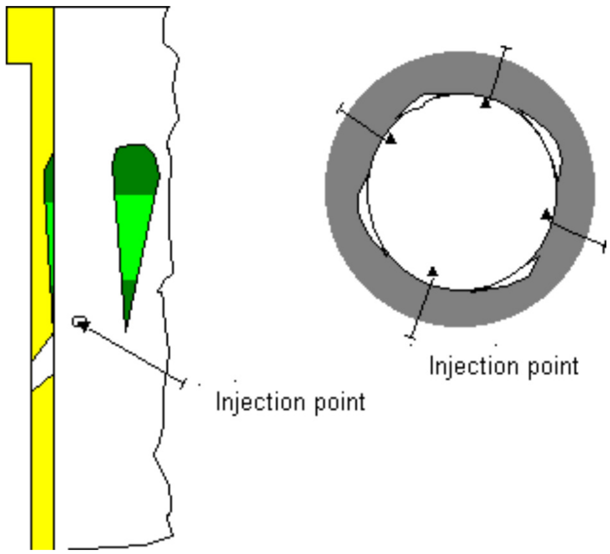
a. adequate viscosity at working temperature so that the oil spreads over the liner surface to provide a tough film which resists the scrapper action of the piston rings
b. the oil must provide an effective seal between the rings and liner
c. only a soft deposit must be formed when the oil burns
d. alkalinity level (total base number or TBN) must match the acidity of the oil being burnt
e. detergent and dispersant properties are required in order to hold deposits in suspension and thus keep surfaces clean

Behaviour depends upon the temperature of the liner, piston crown and piston rings. TBN and detergency are closely linked. This can have an adverse effect when running on lighter fuels with lower sulphur content for any period of time. Coke deposits are can increase.

Consequences of under and over lubricating

Over lubrication will lead to excessive deposit build up generally in the form of carbon deposits. This can lead to sticking of rings causing blowpast and loss of performance, build up in the underpiston spaces leading to scavenge fires, blockage and loss of performance of Turboblowers as well as other plant further up the flue such as waste heat recovery unit and power turbines.

Under lubrication can lead to metal to metal contact between liners causing microseizure or scuffing. Excessive liner and piston wear as well as a form of wear not only associated with under lubrication but also with inadequate lubrication called cloverleafing

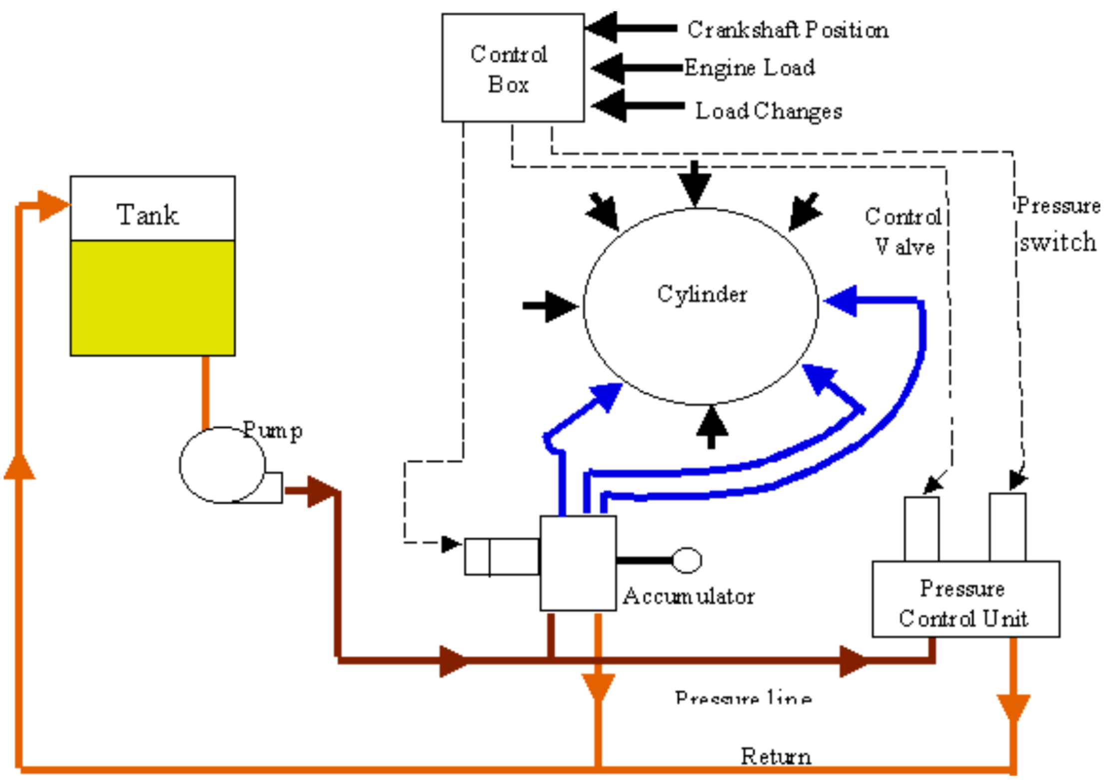


Causes

- Insufficient cyl l.o
- Incorrect cyl l.o.
- Blocked quill
- Incorrect cyl at each stroke.

The fine adjustment operates in such away that by screwing it in the stroke of each pump may be accurately metered. Additionally it may be pushed into give a stroke enabling each p/p to be tested. The eccentric stroke adjuster acts as a coarse adjustment for all the pumps in the block. Additionally it may be rotated to operate all the pumps, as is the case when the engine is pre-lubricated before starting. Correct operation of the injection pumps whilst the engine is running can be carried out by observing the movement of the ball

Electronic cylinder lubrication



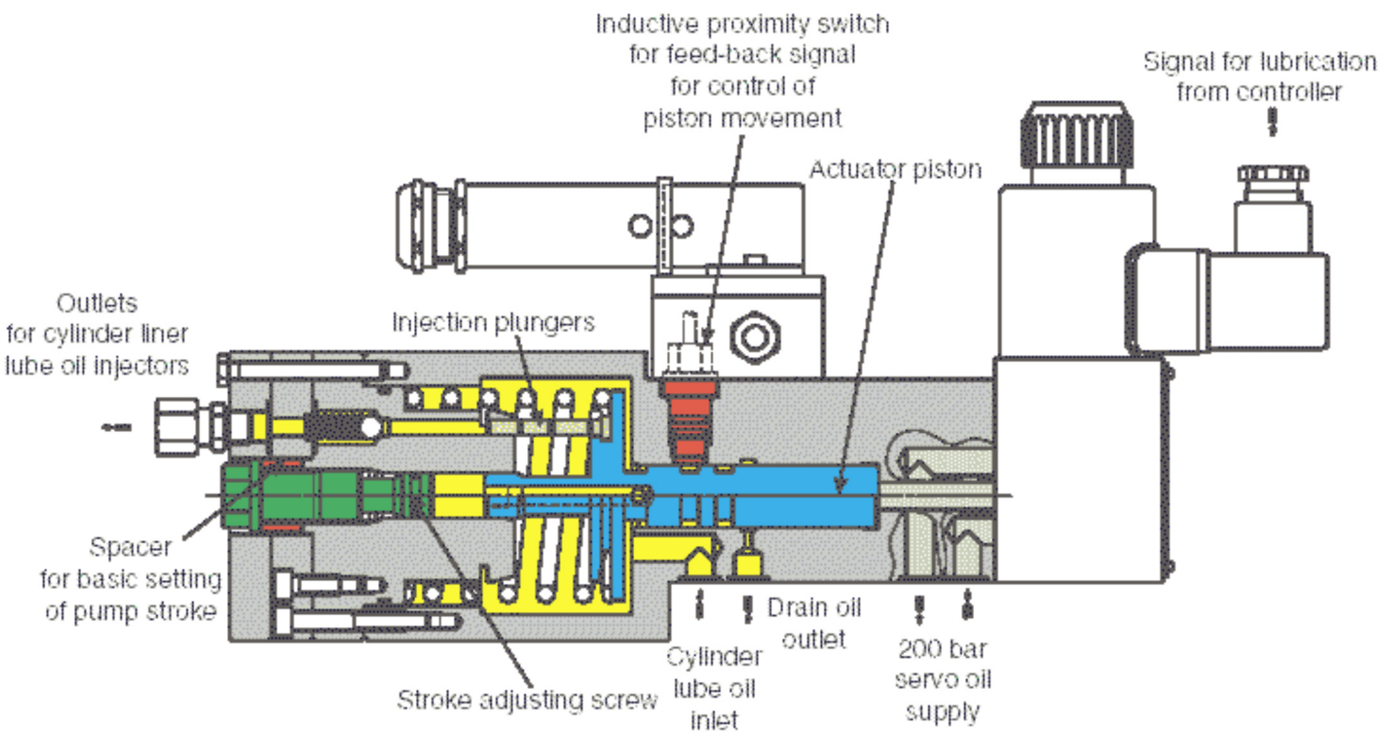
Exact injection timing of cylinder lube oil is essential for efficiency. A move to electronics for the control of this has been made by some large slow speed engine manufacturers.

The system is based on an injector which injects a specific volume of oil into each cylinder on each (though more normally alternate) revolution of the engine. Oil is supplied to the injector via a pump or pumps. A computer, which is synchronised to the engine at TDC each revolution, finitely controls the timing . Generally most efficient period for lubrication is taken at the point when the top rings are adjacent to the injection points.

The injection period is governed by the opening of a return or 'dump' solenoid which relieves system pressure.

Quantity can be adjusted by manually limiting the stroke of the main lubricator piston, by altering the injection period or by the use of multiple mini-injections per revolution.

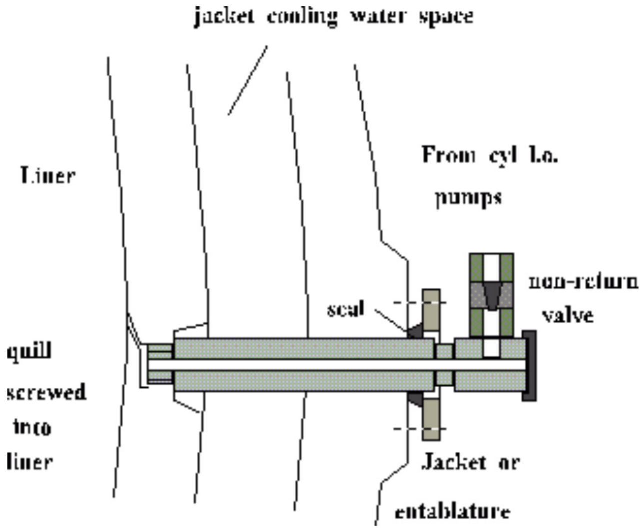
The high degree of accuracy with this system allows for lower oil consumption rates.



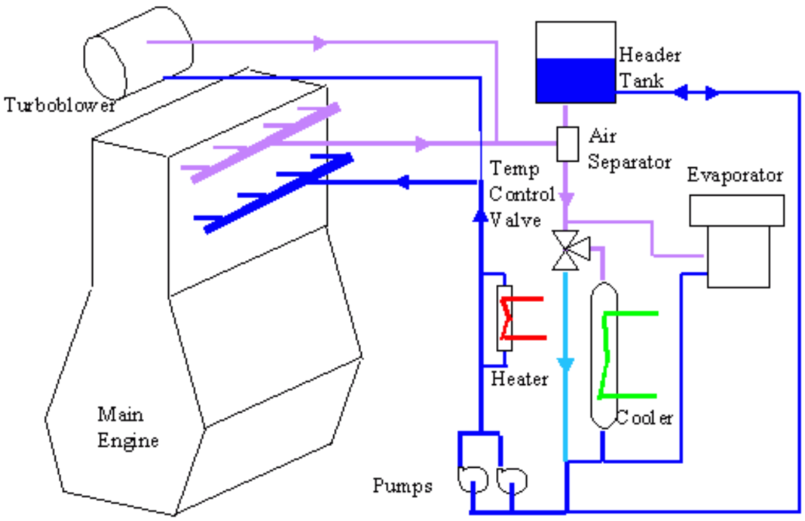
Shown is the injector unit fitted to modern camshaftless slow speed engines. The motive force is via a dedicated or common hydraulic system. The hydraulic piston acts on multiple plungers one for each quill. At the dedicated time the electric solenoid valve energises an allows hydraulic oil to act on the piston commencing oil injection. One or two pumps per unit may be fitted dependent on cylinder diameter and oil flow requirements.

Precise control of the timing of injection allows oil to be delivered into the ring pack, something which has proved impossible with mechanical means. This has reduced oil consumption by as much as 50%.
Pre- lubrication for starting may be built into the bridge remote control system or carried out manually

Cylinder lubricator quill


jacket cooling water space
Liner
From cyl l.o.
pumps
non-return
valve
seal
quill
screwed
into
liner
Jacket or
entablature

Jacket Water System



Shown above is a typical cooling water circuit for a slow speed engine.

Water is pump via one of two centrifugal pumps. One is normally in use with the other stand-by. The water passes through to the distributing manifold on the engine side.

Jacket Water Heater In the line is a steam jacket water heater. When the engine is shut down steam heating maintains the engine in a state of readiness reducing the time needed for starting. Attempting to start the engine without heating can lead to poor combustion, poor lubrication and thermal shocking. A modern variation on this is the "blend" water from the stand-by auxilliary alternator engines into the main engine circuit increaseing plant efficiency

The water enters and leaves the engine via a series of cylinder isolating valves. In this way each cylinder may be individually drained to prevent excessive water and chemical loss. In addition dual level drains may be fitted which allow either full draining or draining of the head only. A portion of the water is diverted for cooling of the turbocharger.

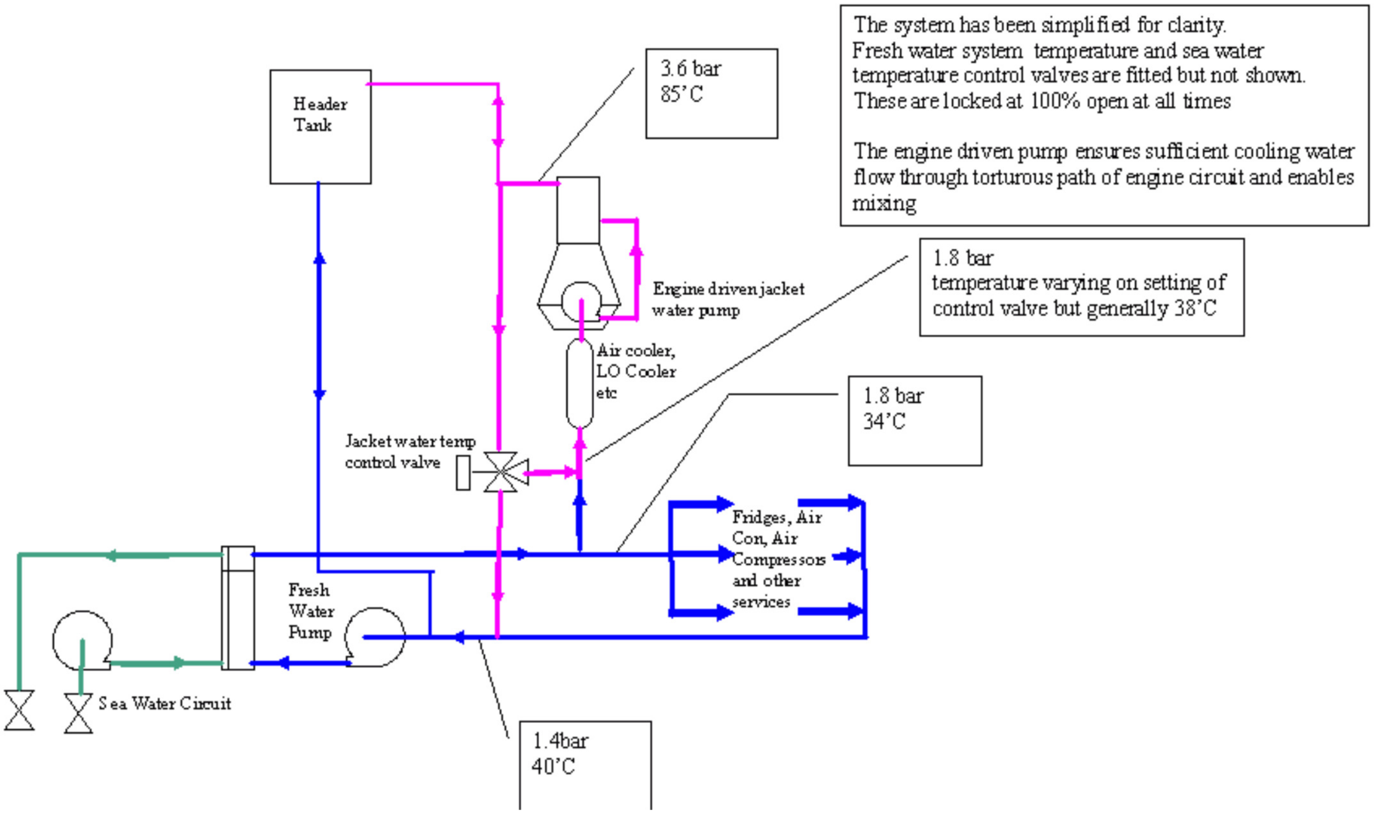
Deaerator Was an essential part of engines incortporating water cooled pistons were air was deliberately introduced in to the system to aid the "cocktail shaker" cooling action. Air or gas entering the system can lead to unstable and even total loss of cooling water pressure as the gas expands in the suction eye of the circulating pumps. In the event of gas leakage via the head or cracked liner rapid loss of jacket water pressure can occur. The deaerator is a method to try to slow this process sufficiently to allow the vessel to be placed in a safe position for maintenance. This system also allows the vessel to operate with minor gas leakage.

Jacket Water Cooler The hot water leaving the engine passes to a temperature controll vlave were a portion is diverted to a cooler. Temperature is controlled using both a feedback signal (temperature measured after the cooler) and a feed forward signal (temperature measured at outlet from the engine). In this way the system reacts more quickly to engine load variations.

EvaporatorIncreases plant efficiency by utilising heat in jacket water to produce fresh water. Modern systems sometimes rely on the evpaorator to supplement a reduced size main cooler.

Expansion or header tankr Maintains a constant head on the circulation pumps reducing cavitation at ellevated temperatures. Allows the volume of water in the system to vary without need for dumping. Acts as a reserve in the event of leakage.

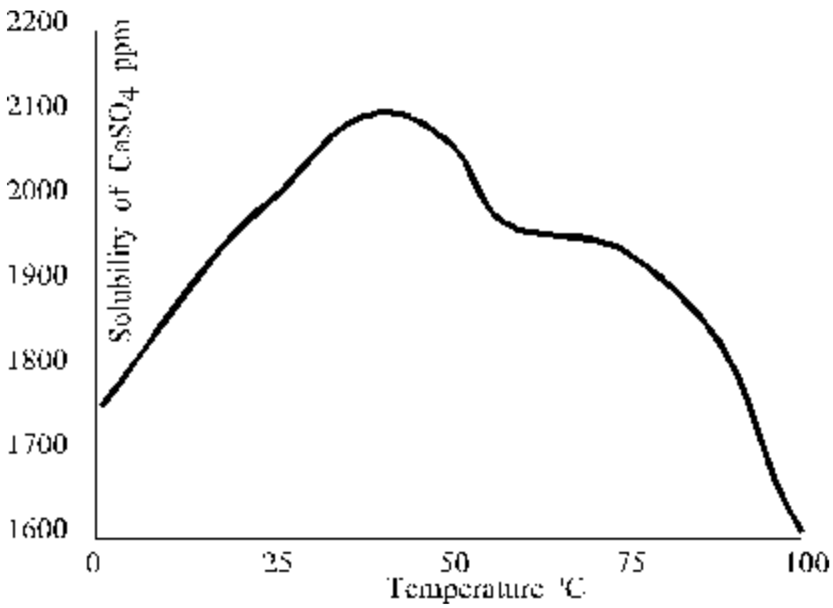
HT/LT systems


The system has been simplified for clarity.
Fresh water system temperature and sea water temperature control valves are fitted but not shown.
These are locked at 100% open at all times
The engine driven pump ensures sufficient cooling water flow through torturous path of engine circuit and enables mixing
3.6 bar
85'C
Header Tank
Engine driven jacket water pump
1.8 bar
temperature varying on setting of control valve but generally 38'C
Air cooler, LO Cooler etc
1.8 bar
34'C
Jacket water temp control valve
Fridges, Air Con, Air Compressors and other services
Fresh Water Pump
Sea Water Circuit
1.4bar
40'C

Scaling of Jacket Water System

Scale and deposit formation

In areas of deposit formation, dissolved solids, specifically Calcium and magnesium hardness constituents can precipitate from cooling water as the temperature increases. Deposits accumulate on the heat transfer surfaces as sulphates and carbonates, the magnitude of which is dependent on the water hardness, the dissolved solid content, local temperatures and local flow characteristics.
Temperature solubility curves for $CaSO_4$



Scales can reduce heat transfer rates and lead to loss of mechanical strength of component parts, this can be exacerbated by the presence of oils and metal oxides.

The degree and type of scaling in a cooling water circuit are dtermined by;

- System temperatures
- Amount of leakage/makeup
- quality of make up
- quality of treatment

Calcium Carbonate

Appears as a pale cream, yellow deposit formed by the thermal decomposition of calcium bi-carbonate

$Ca(HCO_3)_2$ + Heat becomes $CaCO_3 + H_2O + CO_2$

Magnessium Silicate

A rought textured off white deposit found where sufficient amounts of Magnessium are present in conjunction with adequate amounts of silicate ions with a deficiency onh OH alkalinity

$Mg^{2+} + OH^{-}$ becomes $MgOH^{+}$

H_2SiO_3 becomes $H^{+} + HSiO_3^{-}$

$MgOH^{+} + HSiO_3^{-}$ becomes $MgSiO_3 + H_2SO_4$

Silicate deposit is a particular problem for systems which utilise silicate additives for corrosion protection. Thi sis typical of systesm with aluminium metal in teh cooling system. The silicate forms a protective barrier on the metal surface. A high pH (9.5 - 10.5) is required to keep the silicate in solution. In the event of sea water contaimination or some other mechanism that reduces the pH the silicate is rapidly precipitated and gross fouling can occur.

Copper

The prescence of copper within a cooling system is very serious ast it can lead to agressive corrosion through galvanic action. Specific corrosion inhibitors are contained with cooling water system corrosion inhibitors.

Effects of scale deposition

The effects of scale deposition can be both direct or indirect,typically but not specifically

Insulates cooling surfaces leading to;

- increased material temperatures as the temperature gradient must increase to ensure maintain heat flow.
- Loss of efficiency as exhaust gas temperatures form cylinders increases
- Increased wear due to lubrication problems on overheated surfaces

Indirectly;

- Lead to caustic attack be increasing the OH^{-} ion concentration
-

Corrosion inhibitors used in Jacket Water System

Jacket Cooling water system

In order to maintain mechanical strength the components surrounding the combustion zone must be cooled. The most convenient cooling medium is water, the use of which could lead to possible problems of corrosion and scaling if not properly treated.

Within the jacket water system a number of corrosion cells are available but the two most common and most damaging are due to dissimilar metals and differential aeration. In both types of cell there exists an anode and a cathode, the metals which form part of the jacket system, and an electrolyte which is the cooling water. The rate at which corrosion takes place is dependent upon the relative areas of the cathode and the anode and the strength of the electrolyte. It is the anode that wastes away. Corrosion due to temperature differences is avoidable only by the use of suitable treatments. Dissimilar metals-a galvanic cell is set up where two different metals and a suitable liquid are connected together in some way. All metals may be placed in an electro-chemical series with the more noble at the top . Those metals at the top are cathodic to those lower down. The relative positions between two metals in the table determined the direction and strength of electrical current that flows between them and hence, the rate at which the less noble will corrode

Galvanic Action

Corrosion within cooling systems can occur if the coolant, i.e. water, has not been properly treated. The corrosion can take the form of acid attack with resultant loss of metal from a large area of the exposed surface, or by Oxygen attack characterised by pitting. A primary motive force for this corrosion is Galvanic action

The Galvanic Series.

Or Electromotive series for metals

Cathode

Gold and Platinum

Titanium

Silver

Silver solder

Chromium-Nickel-Iron (Passive)

Chromium-Iron (Passive)

Stainless Steel (Passive)

Copper

Monel

70/30 Cupro-Nickel

67-33 Nickel-Copper

Hydrogen

lead

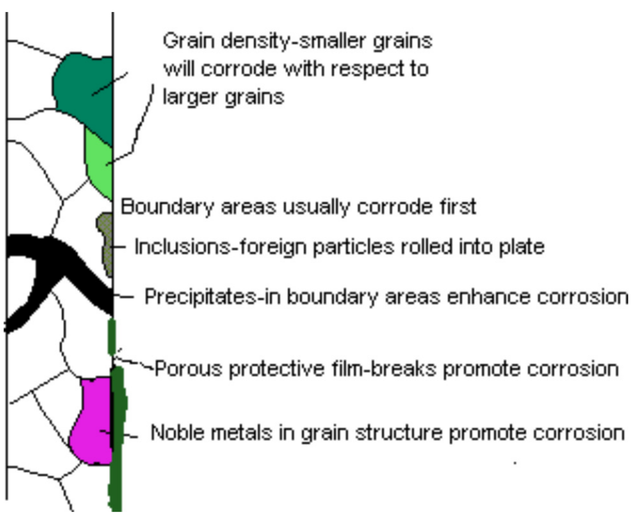
Tin

2-1 Tin lead Solder
Bronzes
Brasses
Nickel
Stainless-Steel 18-8 (Active)
Stainless Steel 18-8-3 (Active)
Chromium Iron (Active)
Chromium-Nickel-Iron (Active)
Cadmium
Iron
Steel
Cast Iron
Chromium
Zinc
Aluminium
Aluminium Alloys
Magnesium
Anode

The metals closer to the anodic end of the list corrode with preference to the metals towards the cathode end.

A galvanic cell can occur within an apparently Homogeneous material due to several processes on of which is differential aeration where one area is exposed to more oxygen than another. The area with less oxygen becomes anodic and will corrode.

Galvanic action within metal



Galvanic action due to temperature gradient

This situation can exist in cooling water systems with complex layout of heat exchangers and passage ways within the diesel engine. Systems containing readily corrodible metals such as zinc, tin and lead alloys can complicate and intensify problems by causing deposit formations.

Differential Aeration

-Where only a single metal exists within a system corrosion can still take place if the oxygen content of the electrolyte is not homogenous. Such a situation can occur readily in a jacket water system as regions of stagnant flow soon have the oxygen level reduced by the oxidation of local metal. The metal adjacent to water with reduced levels of oxygen become anodic to metals with higher oxygen content electrolyte in contact with it.. Generally, the anodic metal is small in comparison the cathode i.e. the area of stagnant flow is small compared to the area of normal flow of electrolyte, and high rates of corrosion can exist. One clear case of this is the generation of deep pits below rust scabs.

Solutions

Water treatment

To remove the risk of corrosion it is necessary to isolate the metal surface form the electrolyte. One method would be by painting, but this is impractical for engine cooling water passages. A better solution would be a system which not only searched out bare metal coating it with a protective barrier, but also repaired any damage to the barrier.

for corrosion to occur four conditions must be met;

- There must be an Anode
- There must be a cathode
- An electrolyte must be present
- An electron pathway should exits

Corrosion Inhibitors

Corosion inhibitors are classified on how they affect the corrosion cell and are placed into three catagories;

- Anodic Inhibitors
- Cathodic Inhibitors
- Combination inhibitors/organic inhibitors

Common Corrosion Inhibitors

Principally Anodic Inhibitors

- Chromate
- Nitrite
- Orthophosphtae
- Bicarbonate
- Silicate
- Molybdate

Principally Cathodic Inhibitors

- Carbonate
- Polyphosphate
- Phosphonates
- Zinc

Both Anodic and Cathodic Inhibitors

- Soluble Oils
- Mercaptobenzothiazole (MBT)
- Benzotriazole (BZT)
- Tolytriazole (TTZ)

Anodic Inhibitors

Nitrite (NO_2^-)- These are the most commonly used form of treatment and operate by oxidising mild steel surfaces with a thin, tenacious layer of corrosion product (magnetite Fe_3O_4). Relatively high volumes of treatment chemical are required so this method is only viable on closed systems

Sodium Nitrite- (sometimes with Borate added)-effective with low dosage, concentration non-critical. It is non toxic, compatible with anti freezes and closed system cooling materials. It does not polymerise or breakdown. However protection for non-ferrous materials is low. An organic inhibitor is thus required. Although will not cause skin disease it will harm eyes and skin. Approved for use with domestic fresh water systems.

Sodium Nitrite is a **Passivator**, a passivator will act chemically to produce an insulating layer on the metal surface. Whenever corrosion takes place the corrosion products including bubbles of gas, are released from the metal surfaces. Passivating chemicals act on the corrosion products preventing release from the metal surface and thus stifling further corrosion. If the insulating layer becomes damaged, corrosion begins a gain and the passivator acts on the new products to repair the layer.

Chromate's-the first passivator product was Sodium Chromate which was an excellent inhibitor. Inexpensive, effective and concentration easily tested. Corrosion may increase by incorrectly dosing, dangerous to handle, poisonous and can cause skin disease. Not allowed where domestic water production is in use (Jacket water heated evaporators). Unfortunately it was also highly toxic, a severe pollutant and staining agent, was imcompatible with antifreeezes, nd will attack zinc and soft solder slightly. Due to its toxicity is sometimes used as a biocide in such places as brine in large Reefer plants.

Silicates- react with dissolved metal ions at the anode. The resultant ion/silicate complex forms a gel that deposits on anodic sites. This gel forms a thin, adherent layer that is relaitvely unaffected by pH in comparsion to other inhibitors. The inhibiting properties increase with temperature and pH, normal pH levels are 9.5 to 10.5.

Care should be taken with the use of silicates, which are often used for the protection of systesm containing alumiinium. In the event of boiling increased concnetrations and lead to aggressive corrosion due to the high pH.

Orthophosphate Forms an insoluble complex with dissolved ferric ions that deposit at the anodic site. It is more adherent and less pH sensitive than other anodic inhibitors. The film forms in pH of 6.5 to 7.0. Dosage is typically 10ppm in neutral water

Cathodic Inhibitors

Polyphosphate- Forms complexes with Calcium, Zinc and other divalent ions, this creates positively charged colloidal particles. These will migrate to the cathodic site and precipitate to form a corrosion inhibiting film. The prescence of calcium is required at a typical minimum concentration of 50ppm.
Extreme variations in pH can upset the film and a reversion to orthophosphate will occur with time and temperature.
Positively charged zinc ions migrate to the cathodic site and react with the free hydroxyl ions to form a zinc hydroxide stable film at pH 7.4 to 8.2. If the water is too acidic the film will dissolve and not reform. If it is too alkaline the zinc hydroxide will precipitate in bulk and not at the cathodic site.

PhosphonatesInitially introduced as scale inhibitors to replace polyphosphates, they exhibit absorbtion at the metal surface especially in alkaline hard water. Generally used with other inhibitor types

Both Anodic and Cathodic Inhibitors

Benzotriazole and Triazole Specific corrosion inhibitor for copper. They break the electrochemical cirsuit by absorbing into the copper surface.
They are generally added to standard treatments.

Sollble and dispersible oils. Petroleum industry recognised that emulsifying cutting oils (erroneously called soluble oils) were able to reduce corrosion on metals by coating the surface. There were disadvantages though, if the coating became too thick then it could retard the heat transfer rate. Adherent deposits form as organic constituents polymerise or form break down products which can accumulate and disrupt flow. MAN-B&W recommend it not to be used.

It is effective in low dosages, safe to handle and safe with domestic water production. Effectiveness is reduced by contamination with carbon, rust, scale etc. Difficult to check concentration, overdosing can lead to overheating of parts
Oils are classed as a **barrier layer** type inhibitor. The surfaces being coated in a thin layer of oil.

Modern treatment

Nitrite-Borate treatment is most effective with a high quality water base. This treatment has no scale prevention properties and its effectiveness is reduced by high quantities of dissolved solids.

A modern treatment will be a Nitrite -Borate base, with a complex blend of organic and inorganic scale and corrosion inhibitors plus surfactants, alkali adjusters, dispersants and foam suppressers. A high quality water supply is still strongly recommended.

The Use of Sacrificial Anodes

-Electrolytic protection for the whole system by the use of sacrificial anodes is impractical. Parameters such as water temperature, relative surface area of anode and cathode, activity of metals in system and relative positions in galvanic series come into play. Anodic protectioon has become out of favour for cooling water systems as it can lead to local attack, causes deposits leading to flow disturbance and it has no scale protection

Preparation for cooling water treatment

-All anodes should be removed and the system inspected. No galvanised piping is to be used (old piping can be assumed to have had the Galvanising removed). High quality water should be used and chemicals measured and added as required. A history log should be kept

Microbiological Fouling

Under certain conditions bacteria found in cooling water systesm can adapt to feed on the nitrite treatment.This can lead to rapid growth, formation of bio-films, fouling and blocakages.
Typical evidence is a loss of nitrite reserve but a stable or rising conductivity level as the nitrate formed still contributes to the conductivity,
Problems of this sort are rare due to the ellevated temerpatures and pH levels. SHould it occur treatment with a suitable biocide is required.

CO-GEN WITH A MARINE PROPULSION ENGINE

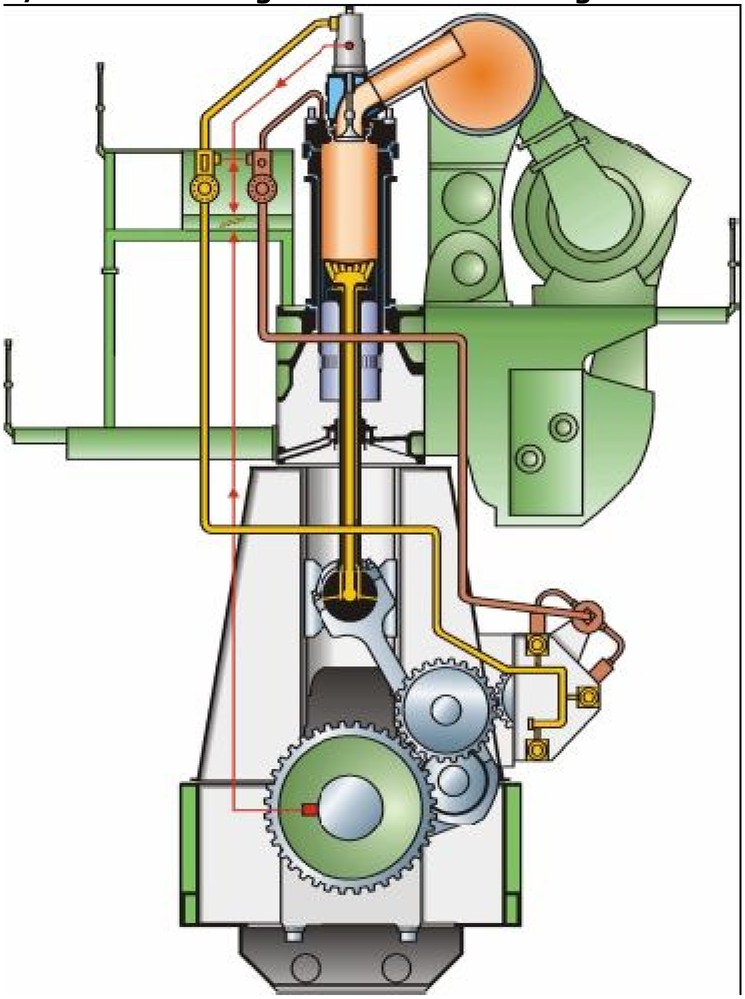
Reproduced from original work by

Vivek Jolly

Introduction:

Large 2-stroke, direct reversible, turbocharged diesel engines are the dominant prime movers for the world's deep sea shipping. Large 4-stroke engines are generally used on smaller vessels or for diesel-electric propulsion in cruise vessels due to space restrictions and power concentration required. Steam turbines remain only in the niche of LNG carriers while gas turbines have made a very marginal entry in cruise vessel propulsion due to their advantages in size, weight, lower NOx emissions and low noise levels.

C/S view of a large 2-stroke Diesel Engine



Current 2-stroke diesel engines are operating with overall thermal efficiency of 50%, with very low exhaust temperatures after T/C & NOx levels at their limiting values (IMO). This temperature is just sufficient to generate the domestic L.P. steam requirement in an E.G.E. The liquid enthalpy of its cooling water is used for fresh water production in a L.P. evaporator.

These engines employ uniflow scavenging with constant pressure turbo charging. Electrically driven auxiliary blowers supplement the scavenge air requirement at low loads (30% &

lower).

Currently 100MW engines are in service driving a single propeller below 100 rpm.

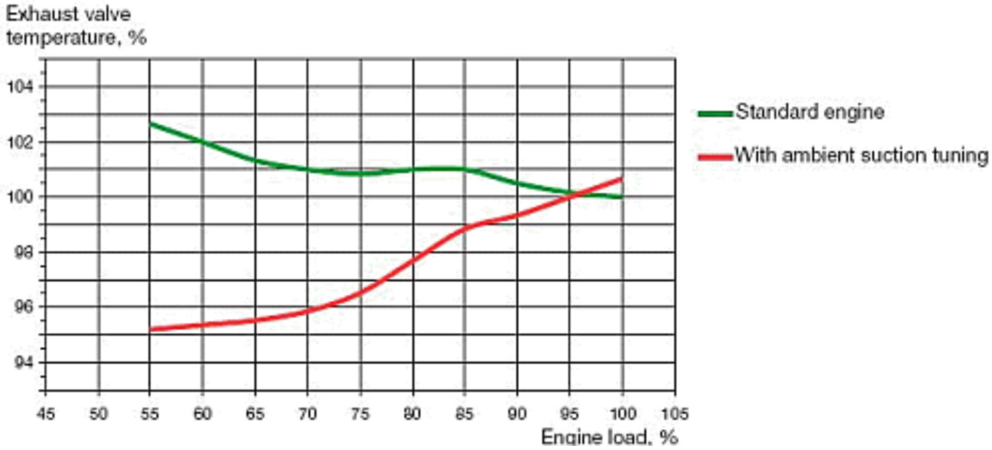
As fuel prices are at a historical high, it is imperative to reduce fuel consumption. However any further reduction in SFOC will involve a natural increase in NOx emissions.

This COGES plant integrated with a marine propulsion diesel engine is a practical path forward towards reduced operating costs & lower CO2 emissions.

PRINCIPLE OF OPERATION:

By adapting the engine for ambient air intake by changing its timings & rematching of its turbochargers, exhaust gas energy level can be increased & also 10% flow can bypass the turbochargers & feed the power turbine of COGES unit without increasing thermal loading of the engine. Infact as shown below the thermal loading of main engine decreases. This is due to the full utilization of the available turbocharger efficiency.

Engine thermal loading v/s SMCR(12RTA96 Wartsila)



This adapted tuning however incurs a penalty of about 1% increase in fuel consumption, but the gain in recovered energy more than compensates for the loss in efficiency from higher fuel consumption.

However the brake mean effective pressure would normally be increased as compared to a standard engine & thereby an increase in specific fuel oil consumption can be avoided.

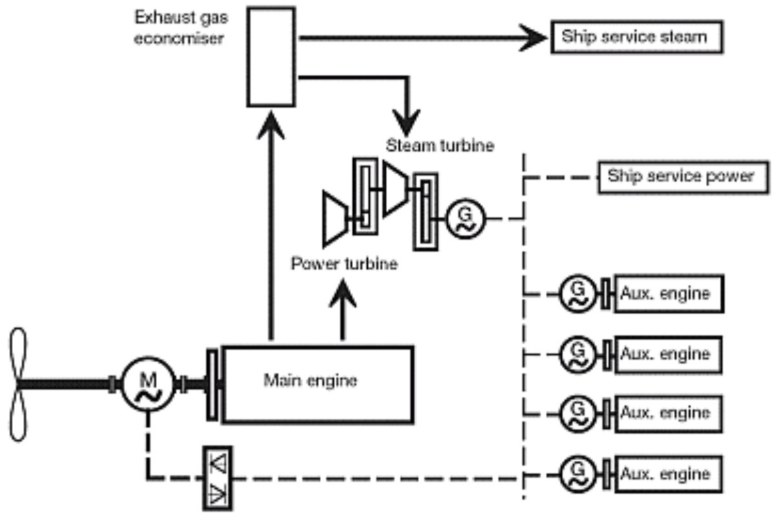
As this engine would be operating at elevated firing pressures either it would be derated for minus ambient temperatures or a waste gate would be incorporated to prevent any excess built up of scavenge pressures from ISO limits.

The higher exhaust gas temperatures are used in a natural draft, closed fin exhaust gas economizer to generate larger mass flow of superheated low pressure steam which operates a turbo generator & low mass flow of saturated low pressure steam for domestic heating services.

The power turbine is able to generate about 40% of COGES output power.

DESCRIPTION OF COGES UNIT:

Schematic view of the COGES unit

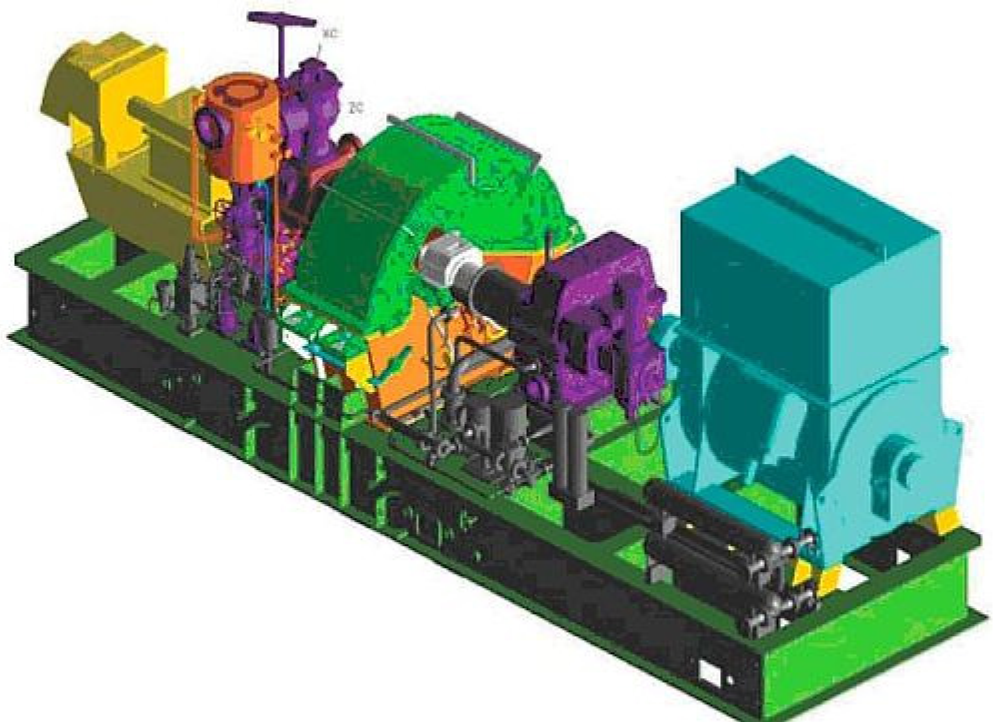


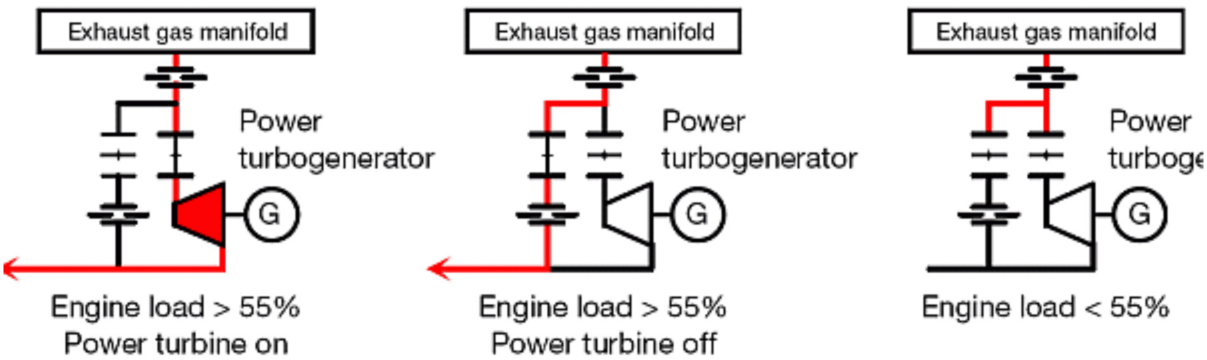
This system consists of an exhaust gas fired boiler, multistage condensing steam turbine (turbo generator), a single stage exhaust gas turbine (power turbine) and a common generator for electric power production. The turbines & generator are placed on a common bedplate.

The power turbine operates between 50 to 100% SMCR of main engine only, as below this load the efficiency of main turbochargers drop significantly. Due to this bypass arrangement the mixed exhaust gas temperatures rise by around 50 degC. Power output from power turbine is fed to turbo generator via a reduction gearing & overspeed clutch which protects the power turbine from over speeding in case the electric generator drops out due to overload.

The steam turbine feeds its generated power to generator via another set of reduction gearing. In general, when producing excess power the surplus steam to turbo generator can be dumped to a vacuum condenser by the speed control governor via a single throttle valve. While operating in parallel with other diesel generators, the governor operates in a regular way to give correct load sharing.

Arrangement of COGES unit as proposed by Peter Brotherhood Ltd.





A more complicated arrangement also incorporates a tail shaft motor/generator set. This unit is able to generate & feed power to the grid while sailing in low load requirements & vice-versa able to motor the main engine in high load/torque requirements.

This Coges unit claims to deliver upto 10% SMCR KWe at full load.

DATA

Main Engine	
Model	12K98ME/MC Mk6
Manufacturer	Man B&W- Denmark
Nominal MCR	68640 KW @ 94 rpm (guaranteed upto tropical conditions)
BMEP	18.2 bar
SFOC	171 g/Kwh (Nox compliant) @ ISO conditions
Bore	980 mm
Stroke	2660 mm
Lube oil	1480 m3/hr, 4.8 bar, 70degC max, 12900 Kgs
Cooling sea wtr	2140 m3/hr, 2.5 bar, 50degC max
Cooling fresh wtr	550 m3/hr, 3 bar, 100 degC max
Exhaust gas flow	179.6 Kgs/s, 245 degC at nominal MCR (tropical)
Air flow	176.4 Kgs/s (98% w/w)
Dry Weight	2190 tone

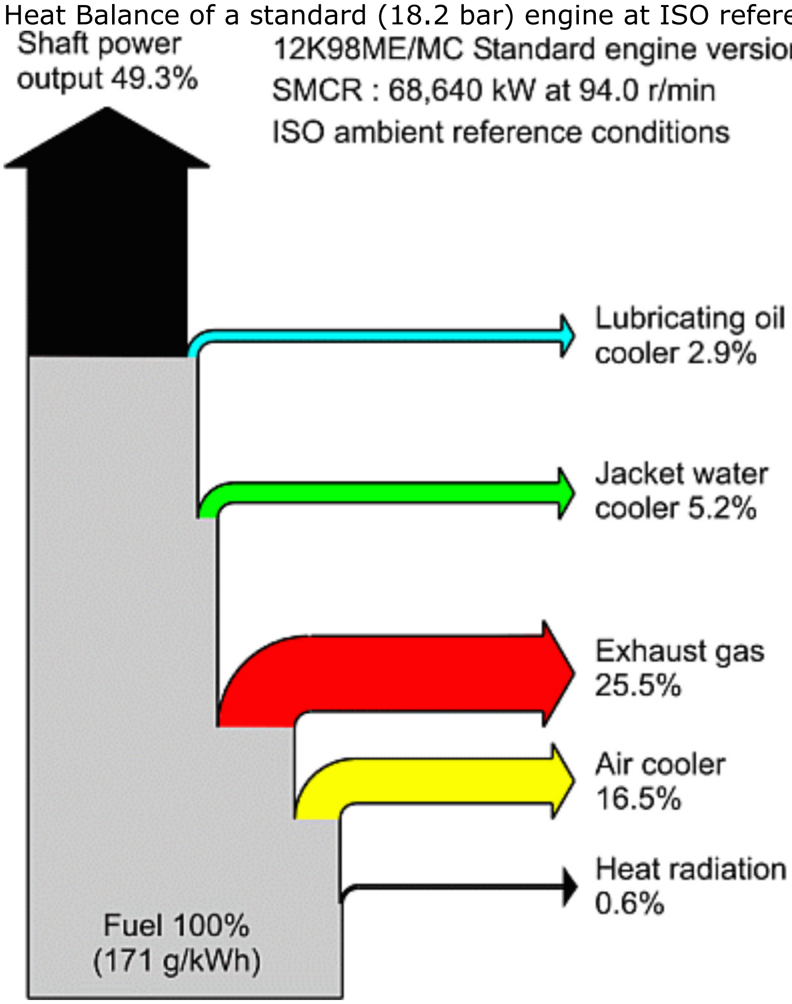
Turbocharger	
Model	TPL 91B x 3 units
Manufacturer	IHI-ABB Japan
Max air flow	55.7 m3/s per unit
overall (max)	74%
turbine (max)	85%
compr (max)	85%
compr (max)	4.0
Shaft power 10,450 KW/unit @ 12000 rpm	
Dry weight	14.5 tones/unit

Coges Unit + Exhaust Gas Economizer

Manufacturer	Peter Brotherhood Ltd - UK
MCR	7000 KWe
Steam	7 Bar, 270 degC
Condenser	0.06 bar
Feed water	135 degC, hf= 570 Kj/Kg
Turbo generator	6750 rpm
Power turbine	12000 rpm
Generator	1800 rpm
gear box	0.97
generator	0.95
effectiveness	0.70 (E.G.E)

Heat Balance for Main Engine

Heat Balance of a standard (18.2 bar) engine at ISO reference conditions & 100% SMCR



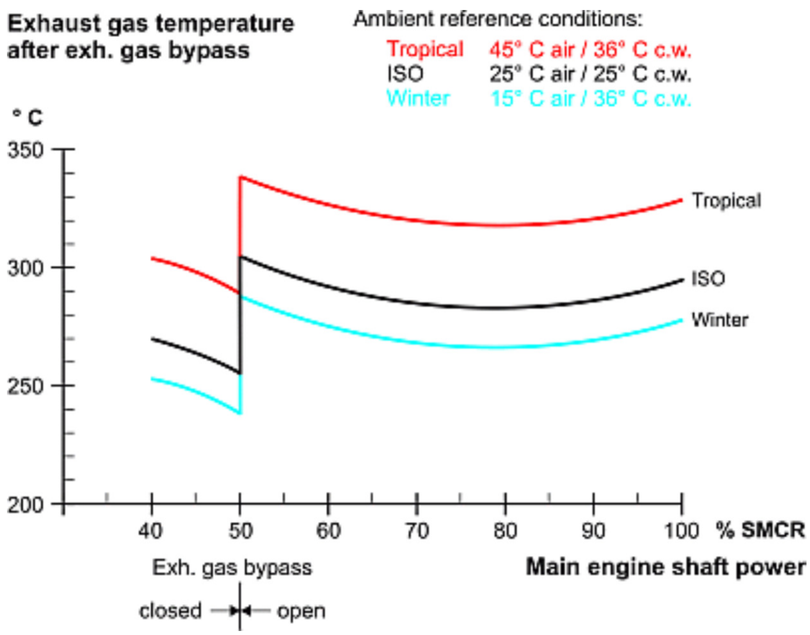
Input
(Fuel power) = = 171 x 42700 x 68640 / 1000 x 3600 = 139,219 KW,

Output
To SMCR = 68640 KW (49.3%)
To Lube oil = = 1480 x 900 x 0.75 x (60-45) / 3600 = 4163KW (2.98%)
To Jkt Wtr = = 550 x 1000 x 4.186 x (80-68) / 3600 = 7674 KW (5.51%)

To Exhaust Gas = = 194 x 1.005 x (215-25) = 37050 KW (26.5%)

(Exhaust gas flow & temperature is corrected for ISO conditions as per project guide instructions)
To Scavenge air = = 194 x 0.98 x 1.005 x (175-45)
= 24840 KW (17.8%)

Power turbine Calculations



After Calculations we have

Work Done = 194 x 0.12 x 1.005 x (706-568)

= 3229 KW **Electrical power** = 3229 x 0.97 x 0.95 = 2975 KWe (4.33%)

Exhaust Gas Economizer

Heat Recoverable = 194 x 1.005 x (295-165) x 0.70 = 17745 KW

Steam Generation

Steam generation is as follows:

For turbo generator = 20500/3600 x (2997-570) = 13820 KW

For feed wtr heating = 4000/3600 x (2764-570) = 2438 KW

For Domestic purposes = 2500/3600 x (2764-570) = 1524 KW

Turbo generator power = 13820 x 0.3 = 4146 KW = 4146 x 0.97 x 0.95 = 3820 KWe (5.56%)

Economical considerations

Assumptions:
a) Increase in SFOC of engine is avoided using a higher BMEP
b) All electric power produced onboard is utilized.
c) SFOC of diesel generators are at same level as main engine.

d) Annual Savings in maintenance/lube oil costs of 2 gensets is $100000

Now total electric production from COGES unit = 5.56 + 4.33 = 9.9% of SMCR

When operating at 100% SMCR for 280 days/year at ISO conditions:

Annual Fuel costs = 280 x 24 x 0.00017 x 68640 x 355($/ton) = $27,837,089

Annual Fuel Savings = 27,837,089 x 0.099 = $2,755,871

Total Annual Savings = 2,755,871 + 100000 = $2,855,871

Cost of COGES = $4,600,000

S.P.P = 4,600,000/2,855,871 = 1.6 years.

Practical Considerations and other ECO

On the face of it CHP with COGES looks very attractive & is being promoted by both wartsila and man b&w.

However if one reads between the lines there are many other considerations involved

- Engines would be operating with much reduced mass purity of gases. With the present fuel specs (ash, carbon residue, sodium and vanadium contents) this would certainly involve much greater fouling in the hot gas circuit resulting in reduced maintenance time between overhauls of all the associated equipments.
- Reduced thermal loading with increased exhaust temperatures would lead to greater hot corrosion of exhaust valves.
- Increased back pressure from E.G.E would decrease the surge margin and affect both the turbocharger and power turbine performance.
- Due to increased firing pressures the engines would have to be derated at sub zero conditions
- Apart from the capital cost the installation cost would be very high as this is a non standard piece of equipment in a merchant vessel.
- As engines are normally optimized for continuous operations below 85% of nominal MCRs, the actual SFOC is reduced by around 9g/KWh. Besides engines normally operate between 50 to 85% of SMCR. This would result in reduced saving potential.
- Diesel gensets would have to be operated in parallel with this COGES unit during narrow passages and rough weather conditions due to their reliability and independent nature. This would reduce the saving potential.
- It is very unlikely to absorb 10% of SMCR on a vessel as such electrical loads do not exist.

One idea which is coming up is a turbocharger with an integral motor/generator drive. At lower loads when the T/C is unable to meet the engine requirement the motor drive would feed the additional energy. At higher loads when T/C does not need all the energy of exhaust gases this extra energy could be abstracted by the integral auxiliary drive working as a generator.

This system would simplify engine design. Auxiliary blowers and scavenge air valves could be omitted. This would result in better combustion at part load operations with resultant lower thermal loads & smoother acceleration. Surplus electric power would also be available at service loads.

References:

1) www.Peterbrotherhood.com

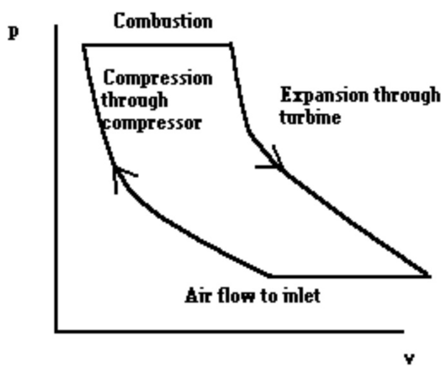
2) www.manbw.com

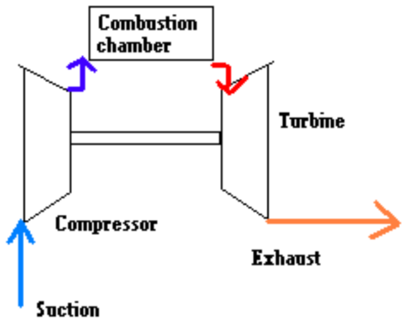
3) www.wartsila.com

4) www.abb.com

Gas Turbines

Joule (Constant Pressure) Cycle





Shown above is a simple gas turbine layout. Filtered air is drawn into the system and compressed to about 6 bar. It passes through to the combustion chamber where fuel is introduced and combustion occurs. The hot gas passes through the turbine through to the exhaust. In passing through the turbine it provides motive force for driving the compressor and external requirements.

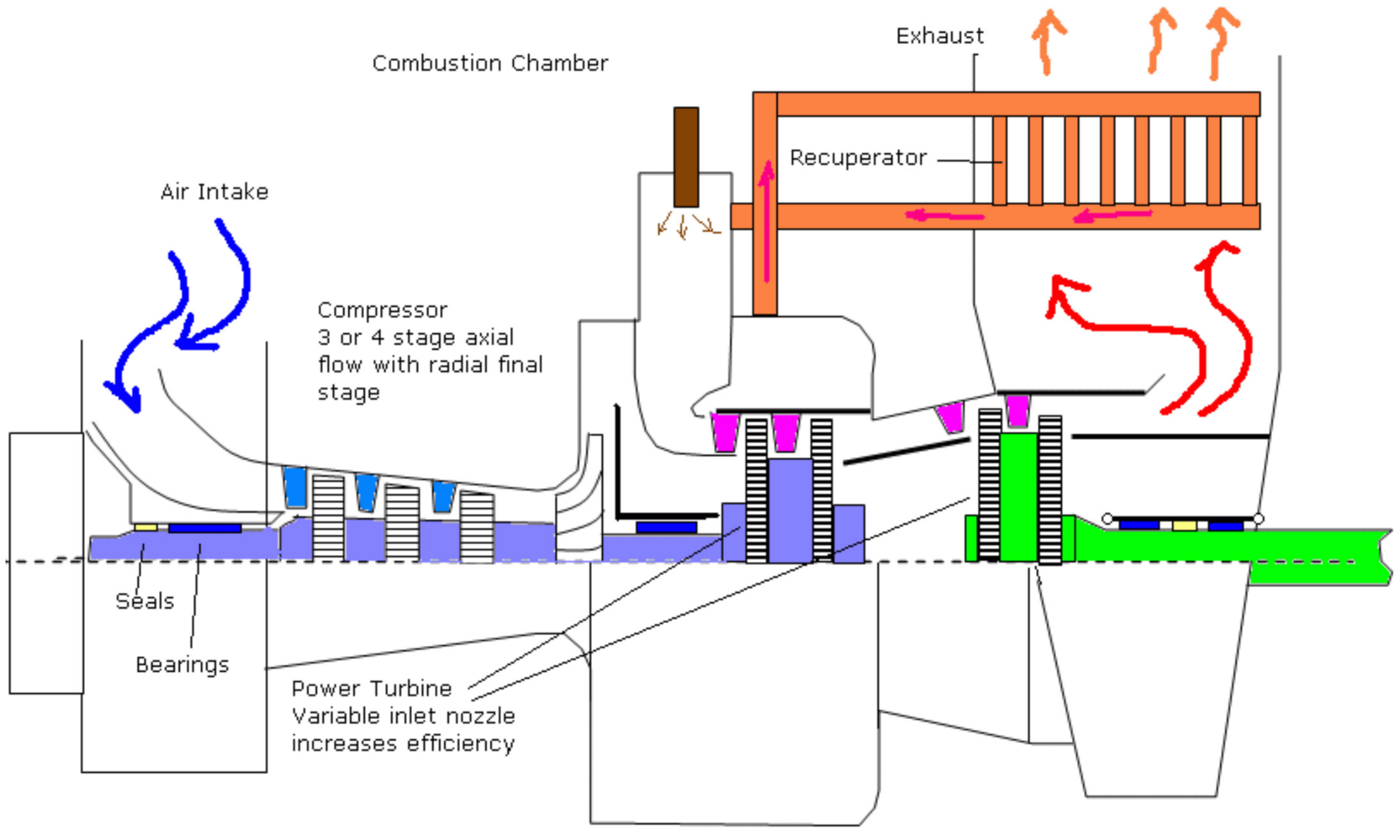
Advantages and disadvantages

Most modern gas turbine installations are based on aero industry design with suitable marinisation. This takes the form substantially of material changes with respect to the poorer quality fuel used and increased sulphur content.

Specific fuel consumptions of 360g/kWh are possible with simple installations. Heat recuperation from the exhaust and gas inlet temperatures of 650'C can improve this to 280g/kWh.

Where inlet temperatures can be increased to 1200'C this falls further to 200g/kW/h. Very special materials are required to make this possible with ceramic and cooled metallic blades being fitted This compares to the 140g/kWh possible in some large slow speed diesel installations. The advantage of the gas turbine falls mainly around its compact size, low weight and reduced maintenance requirements Gas turbine plant was very much out of favour for a long time due to its poor fuel consumption. Emergency generators and fire pumps saw some applications. With improved performance and more flexible plant design- controllable pitch propellers and electrical drives- the much reduced engine size and high power to weight has seen some operators specify this plant especially for high speed ferries

Modern Design



The above shows a typical layout of a marine gas turbine with thermal efficiency of 38-40%. The NOx ouput is about 1/10 that of a marine slow speed diesel. The turbine inlet temperature is up to 1200'C and requires critical blade design and material choice.

Shown is a single comuster, in reality there will be several equally spaced around the assembly.

Specific fuel consumption is about 257 g/kWh

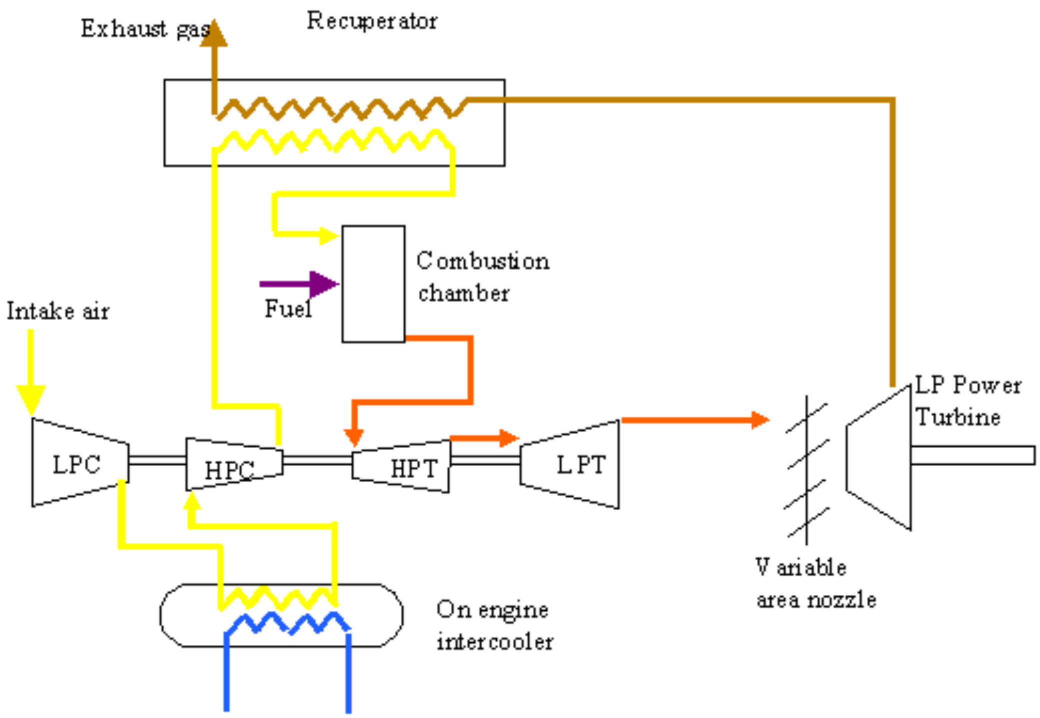
Intercooling and Recuperation

ICR technology promises significantly higher efficiencies , flatter fuel consumption curves and improved power to weight ratios for gas turbine propulsion plants.

The system will initially be fitted to warships.

A 30% fuel saving over current simple cycle marine turbines is claimed. Lower manpower requirement, enhanced reliability, reduced exhaust emissions and low airbourne noise are also pointed out.

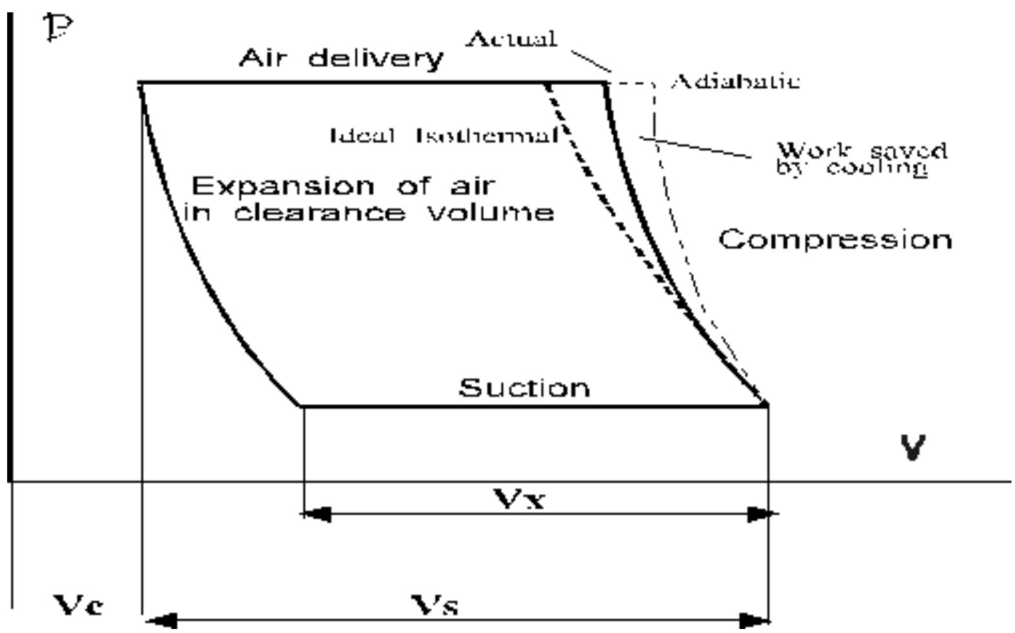
Components of proven reliability are used such as the RR RB211 and Trent turbines.



An ICR cycle features the following process; Intake air compressed in a low pressure compressor is cooled by rejecting heat via an on-engine intercooler before entering the high pressure compressor. This reduces the work required to compress the air, improving HP spool efficiency and raising net output power. Intercooling also serves to reduce the HP compressor discharge temperature which increases the effectiveness of the recuperator. The recuperator preheats the combustion air by recovering waster energy from the exhaust, thus improving the overall cycle efficiency. The result is reduced fuel consumption over the whole power range.

Low power efficiency is further improved by the use of the power turbines variable nozzles. These maintain a constant power turbine entry temperature which, in turn, maintains recuperator gas side entry conditions and improves recuperator effectiveness as power reduced

Air Compressors



Graph of Pressure against volume in a reciprocating compressor

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Volumetric efficiency Vh = Actual suction volume Vx/
                                             Theoretical suction volume Vs
```

For greater efficiency air compression should be isothermal as this requires the minimum work input. In practice Isothermal compression is not possible, an ideal Isothermal cycle requires sufficient time to allow all the required heat to be transferred out of the cylinder, practicality dictates that the piston must have a relatively high speed to give a reasonable output,

Cylinder cooling on a single stage compressor gives better efficiency but there is a limitation in the surface area to cylinder volume that can be used for cooling effect, but multistage compressors with an efficient extended surface interstage cooler gives cycle improved compression efficiency better approaching that of the isothermal. In theory the greater the number of stages the closer the curve will approach the ideal isothermal compression curve, however there is an increase in cost, complexity, and the law of diminishing returns limit the number.

Compression in stages has the following advantages;

1. The compression ratio at each stage is lower and so the final temperature is lower. This reduces problems with lubrication
2. . The machine is smaller and better balanced
3. water can be drained off at each stage
4. Compression better approaches the ideal isothermal

It is important that the compressor clearance volume is kept small as possible in order to improve overall volumetric efficiency as the air trapped in this space must expand to below suction pressure before new air can enter, this is an effective loss of stroke.

A clearance is required in order to prevent the piston striking the cylinder cover when starting or stopping off load. The clearance volume is sometimes referred to as the 'Bump Clearance'.

Crankcase lubrication

Lubrication of the crankcase in a compressor does not pose any specific problems and normally consist of splash lubrication with pressurised oil being fed to shell bearings. Where drip cylinder lubrication is used, this should be kept to a minimum conducive with liner wear. A standard mineral oil similar to that used in the main engine may be used, although due to carbon deposits, higher quality oils are generally used with the most effective being specifically designed synthetics which have allow a considerable reduction in maintenance but are costly.

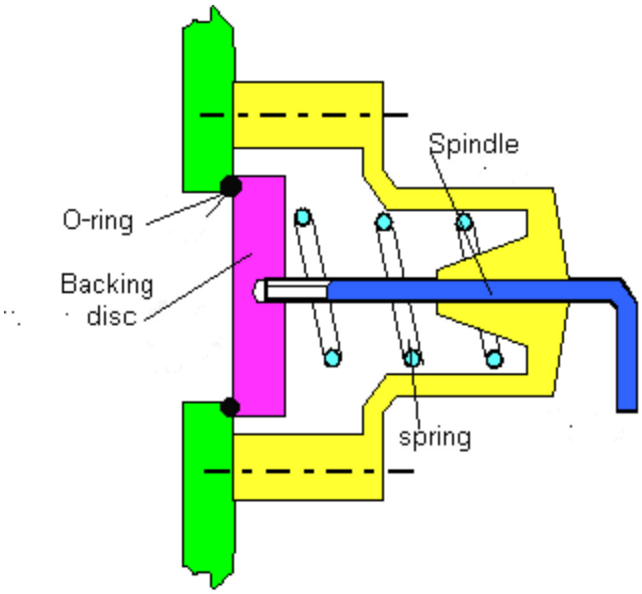
Mineral oils contain a blend of lighter elements such as paraffin's, and heavier elements such as asphaltenes. During compression the lighter elements are vaporised leaving the heavy ends, these coat the piston rings and discharge valves in combination with oxidised oil deposits. These deposits also coat passage ways and coolers resulting in higher interstage air temperatures. Deposits on discharge valves cause them to become sticky and leak resulting in hot air being drawn back into the cylinder for recompression. This increases the temperature and hence causes greater oxidation and deposits, and so the condition deteriorates with increasing rapidity.

Temperature can become very high, this may result in oily deposits at the discharge valves carbonising. Eventually this carbon could glow red and cause detonation. It is more likely, however, that oily deposits will be carried over to the air receiver and air start manifold to be ignited by blowpast at the cylinder air start valve.

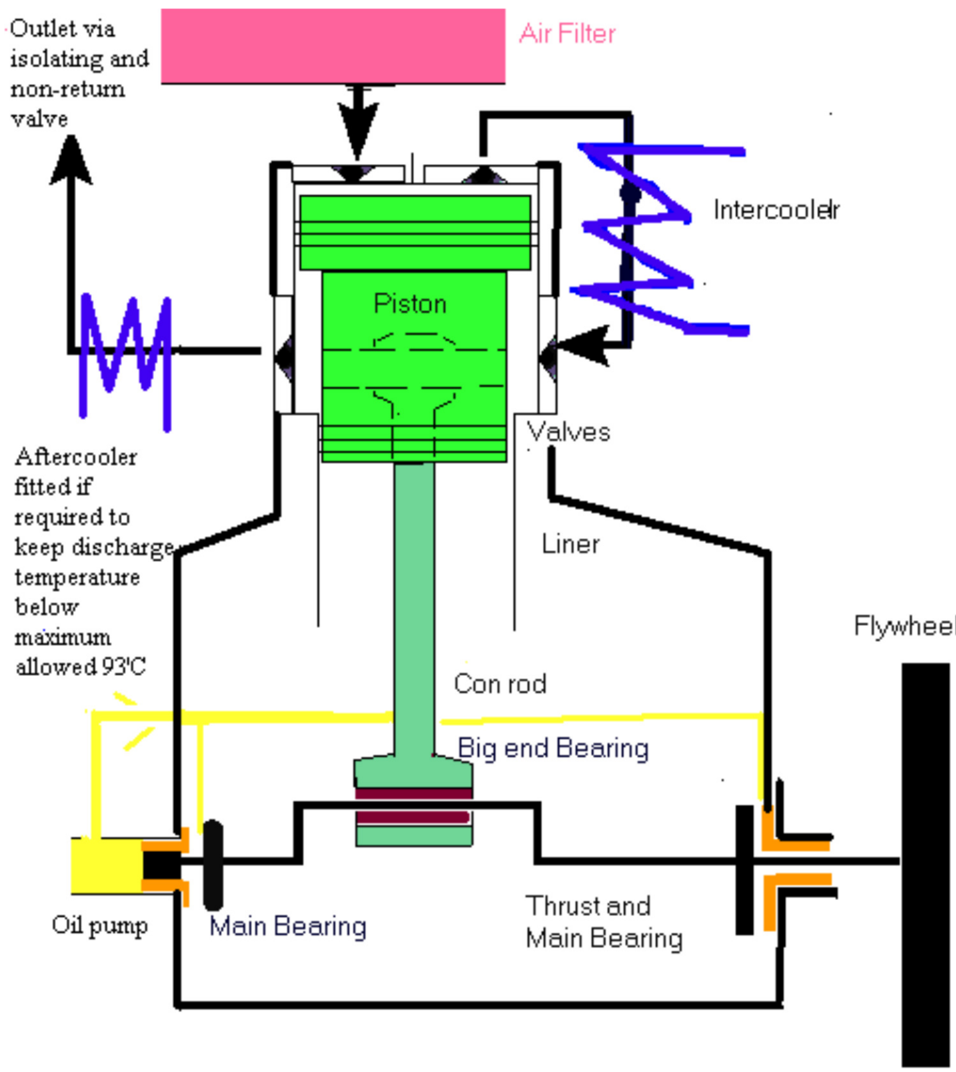
Deposits at piston rings cause leakage allowing oil to enter the cylinder from the crankcase thus increasing the danger it is essential that crankcase lubrication be kept to a minimum compatible with an acceptable wear rate. Regular maintenance will minimise oily deposits build up and hence the risk of explosion

Materials and design of a reciprocating compressor

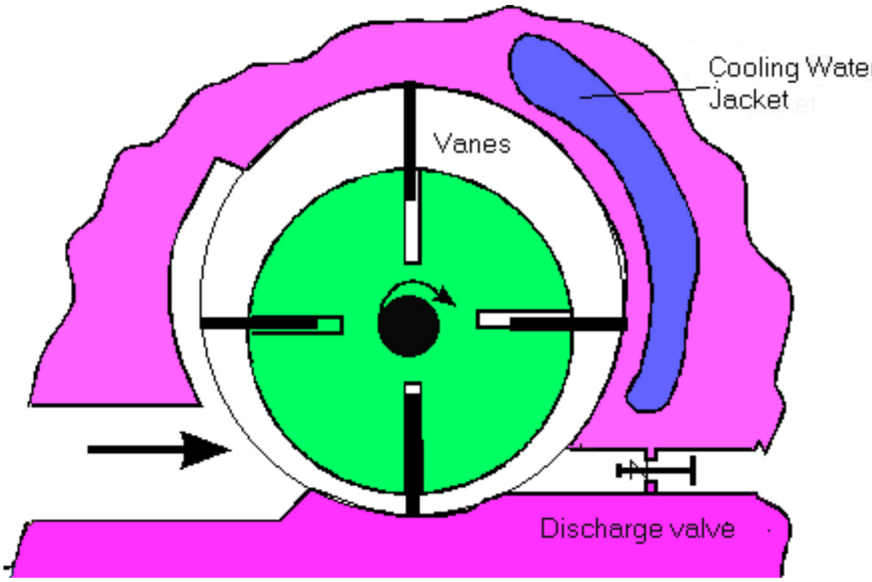
The compressor casing, cylinder covers and piston rings are generally of cast iron. Pistons may be of cast iron, steel of aluminium. Aluminium being the preferred material for use on the LP piston due to its larger diameter. Valves are usually made so that parts can be interchanged between the suction and discharge valves. Seats are of mild steel with small diameter air passages to prevent the fragments of broken valve plate from entering the cylinder. Valve plates are of vanadium steel heat treated and ground to provided the required hardness and surface finish. Springs should be arranged such that they lift and seat squarely. Uneven spring force or deposits on the seat cause valves to bend resulting in fatigue cracking.



For compressors designed for starting air requirements a water jacket relief valve is fitted.



Rotary Compressor



The rotary compressor may be of the impeller type similar to that used in the turbocharger , scroll, twin rotating lobes or of the sliding vane type similar to the one shown above. In practice there would be several more vanes than shown.

Rotary compressors are capable of handling large quantities of low pressure air much more efficiently than a reciprocating compressor. In order to produce increased pressures it is possible to stage rotary compressors but leakage problems increase at higher pressures as well as stress on the vanes.

The sliding vane compressor consists of a slotted rotor with its axis offset from that of the cylindrical casing. Vanes fit in the slots and have contact with the casing

On the suction side the space contained between the casing, the rotor and an adjacent pair of vanes is gradually increasing allowing air to be drawn in.

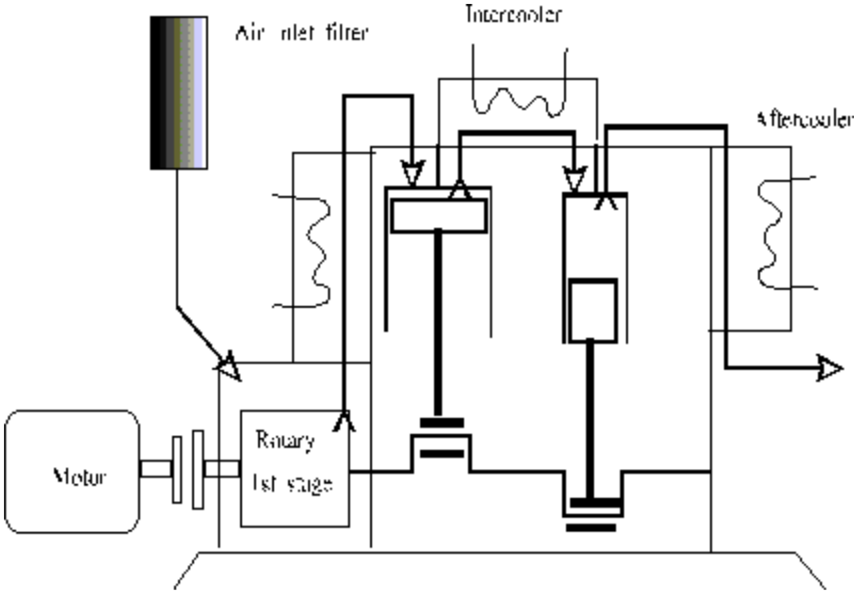
On the compression side this same space is gradually reduced causing the pressure increase. When the leading vane uncovers the discharge port air will flow to outlet. Larger compressors of this type are water-cooled, smaller compressors tend to be air cooled.

The main problems related with sliding vane compressors concern wear at the vane tips and sealing of the ends

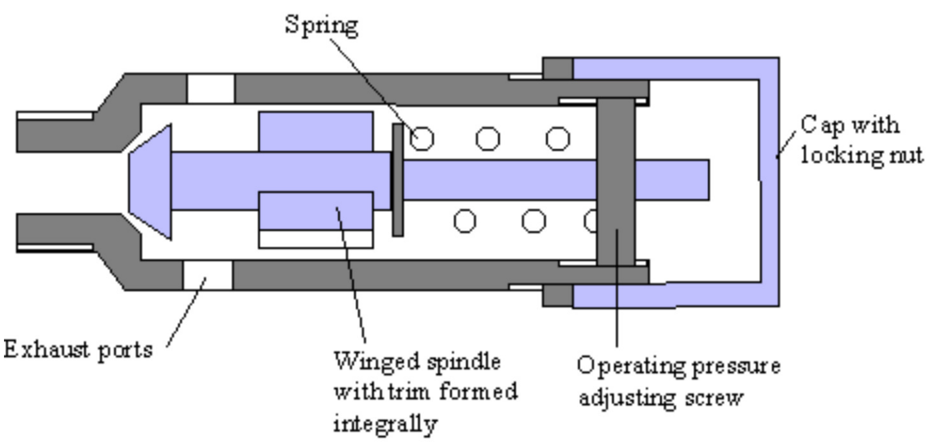
Rotary/reciprocating Compressor

Rotary compressors in general do not require internal lubrication but they are not suitable alone for providing air at a pressure for starting duties. They can, however, be linked to reciprocating stages to produce a hybrid compressor.

The compressor is lighter, more compact and better balanced than an equivalent all reciprocating unit. In basic terms the rotary first stage supplies air to the reciprocating second and subsequent stages. All stages being driven by the same shaft



Safety Valve



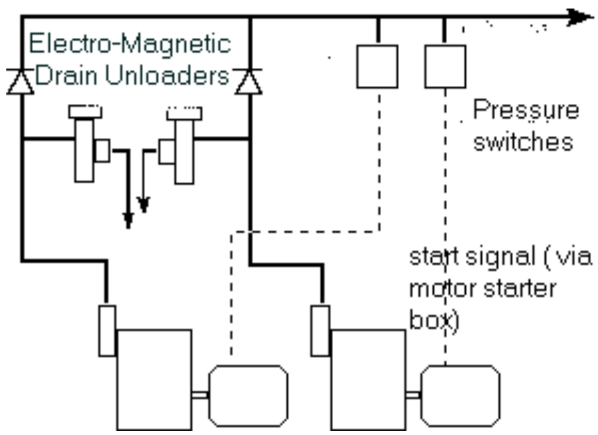
Materials

Cast iron-Casing, Liners, Pistons(the LP piston is sometimes made from an aluminium alloy, Cylinder covers **Steel**- Crankshaft, Conrods, Pistons, Valve seats **Vanadium Steel**- Valve plates

Starting air compressor circuit

Starting and stopping sequence is adjustable, the magnetic valves are open when the compressor is stopped so any residual pressure is blown off. On starting the magnetic valve are sometimes delayed to close so as to allow the compressor motor to reach full speed before the compressor is loaded up.

The non-return valves prevent HP air leaking back from the receiver on which the filling is also of the non return type.



Calculation of required cylinder compression for a multistage reciprocating compressor

r = stage pressure ratio
R = compression pressure ratio
for a two stage
r = R1/2

for a three stage
r = R1/3

for example, a 3 stage compressor requiring a final pressure of 64bar would have the following interstage pressures 1st stage 1bar compressed to 4bar
2nd stage 4bar compressed to 16bar
3rd stage 16bar compressed to 64bar

It would appear that most of the work is being carried out in the final stage, this is untrue as with the increase in pressure is a complimentary reduction in volume, if the temperature conditions remain the same then work will be equally divided between the stages.

By reducing the suction pressure, the cylinder is required to do more work on the air before the discharge valve opens. This means that the air will be delivered at a higher pressure. The higher temperature can lead to problems with the cylinder lubrication as well as a drop in efficiency as well as carbonising of the oil and increased deposits on the valves and piston rings and interstage passages. In the extreme it can lead to seizure and possible diesel detonation of the oil laden air.

The reduction in pressure at the suction can be due to a partially blocked suction filter or partially choked suction valve. The lower pressure conditions in the cylinder at the start of compression can cause oil laden air to be drawn from the crankcase up the liner. This oil can lead to increased deposits in the compressor as well as further downstream in the distribution system

(P1.V1)/ T1 = (P2. V2)/T2

and

(P1/P2).(T2/T1) = (V2/V1)

$P1.V1^g = P2.V2^g$

and

$P1/P2 = V2^g/V1^g$ From these we get;

$T2 = T1. (P2/P1)^{(g -1)/g}$
g = 1.4
and if we take for and example
P1 = 0.4 bar
P2 = 1 bar
Pf = 5 bar
Tinitial = 300 K we end with final temperatures for the two compression's of
T1= 617 K and T2 = 475 K
from the graph it can be clearly seen that losses due to the bump clearance has increased and the period of constant pressure delivery has been reduced.

Coolers

Plain Tube-

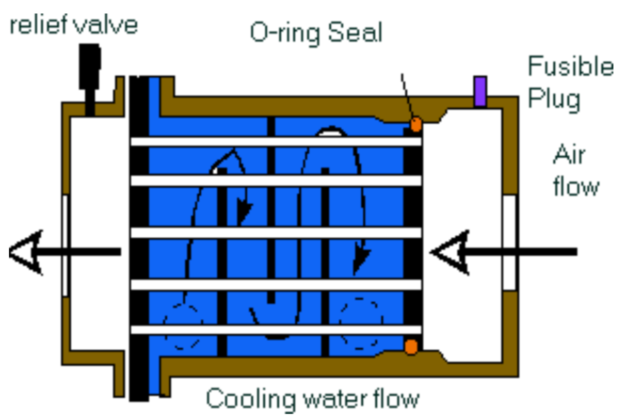
- **-easy to clean**
- **-very effective due to large surface area of large number small diameter tubes**
- **-plugging of failed tube allos cooler to continue in service with little loss in efficiency**
- **-must allow for thermal expansion by having one tube plate floating**

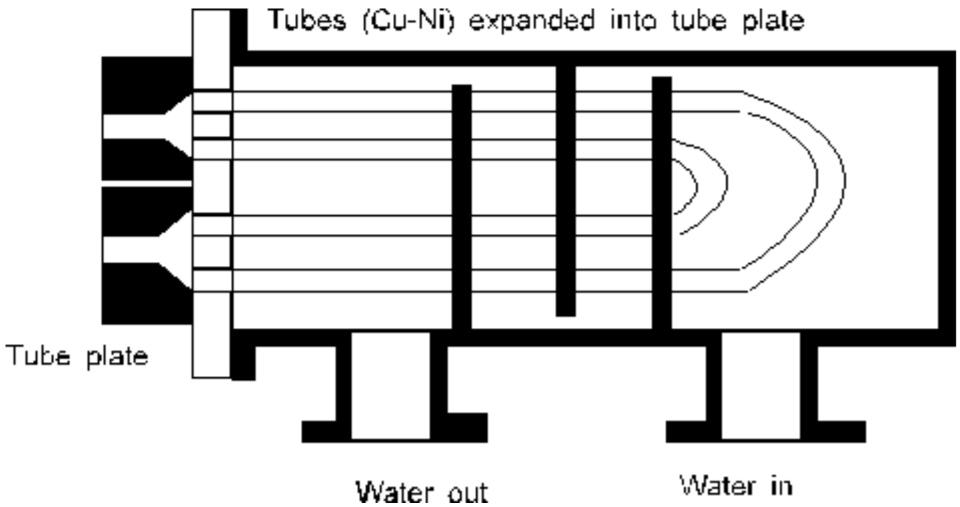
'U' tube-

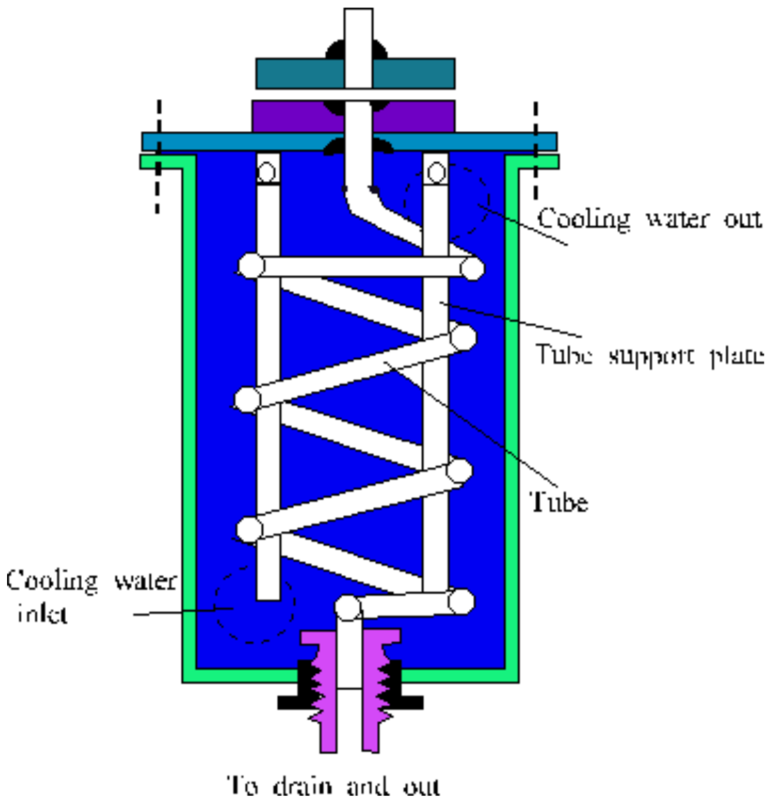
- **-suitable for higher pressures than plain tube**
- **-self compensating for thermal expansion**
- **-efficent due to large nomber small diameter tubes**
- **-failed tubes may be plugged**
- **-more expensive than plain tube and diificult to clean**

Coil tube

- **-self compensating for expansion**
- **-suitable for high pressures**
- **-difficult to clean**
- **-inefficicent due to large tube diameter**
- **- not easy to plug**
- **-expensive**




Tubes (Cu-Ni) expanded into tube plate
Tube plate
Water out
Water in


Cooling water out
Tube support plate
Tube
Cooling water inlet
To drain and out

Air Start Systems

Regulations

1. *There must be at least two starting air receivers, the total capacity of which will give 12 starts for a reversing engine or 6 starts fo a non-reversing engine with CPP.*
2. *There must be at least two compressors*
3. *In addition to these there must be a compressor which can be started by hand i.e. with a dead ship. Note: this is not necessary if one of the compressors is run off the emergency switchboard*
4.
   i. *A relief valve must be fitted to the HP discharge and be sufficient size to ensure that the pressure rise does not exceed 10% of the w.p. when the compressor is running and the outlet valves on the bottle are shut.*
   ii. *A relief valve or bursting disc on the hp cooler casing in order to protect the casing from overpressure in the event of cooler tube failure Note: Bursting discs are generally preferred because they fail and stay failed giving complete protection. A relief valve will reseat when the compressor is stopped allowing water to enter the air side.*
   iii. *A drain must be fitted at each stage*

Diesel start air system

The components of the air start system are taken to include compressors and storage bottles in addition to the engine air start arrangement. The minimum of tow compressors should be matched to the starting air requirements of the engine. The compressor after coolers should be protected by a bursting disc. All high pressure lines in the system to be of solid drawn pipe.

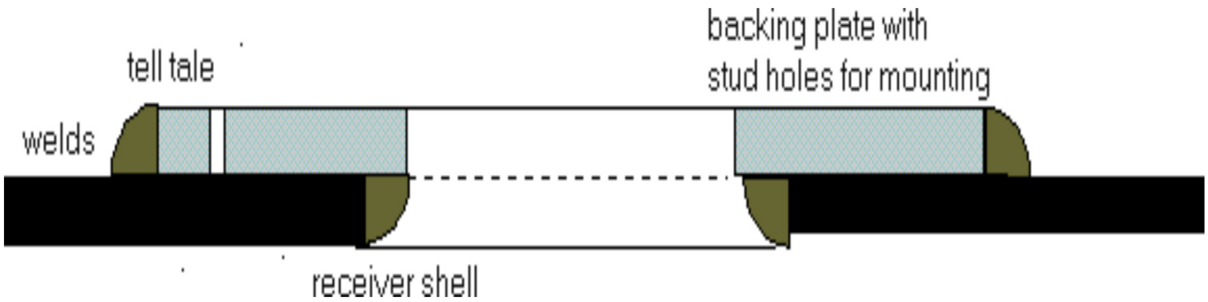
Air Receivers

There must be a means of access to allow cleaning and inspection of internals. The internal surface should be protected by a coating which is flexible enough to move when the metal distorts. Copal varnish is generally used because it has these properties and willnot easily oxidise. Usually precautions are taken the same as for an enclosed space when entering. Ventilation is required to the solvent fumes in the varnish

Drains must be fitted in the lowest part of the receiver

Receivers must be protected by means of a relief valve, if the relief valve can be isolated from the reciever than a fusible plug or plugs must be fited. These are usually fitted because in the event of a fire near to the bottle they will fail and release the entire contents of the bottle rapidly. A relief valve however will only release air down to its closing pressure which is set point less blowdown. If the structure of the bottle becomes weakened by the heat then its ability to withstand even the reduced pressure is weakened an possible rupture could occur.

The inlet and outlet valves are to be arranged to prevent direct flow through the bottle with insufficient residence time for moisture to rpecipitate. Valves to be of the slow opening type to prevent excessive pressure rises. All attachments should be via a support plate

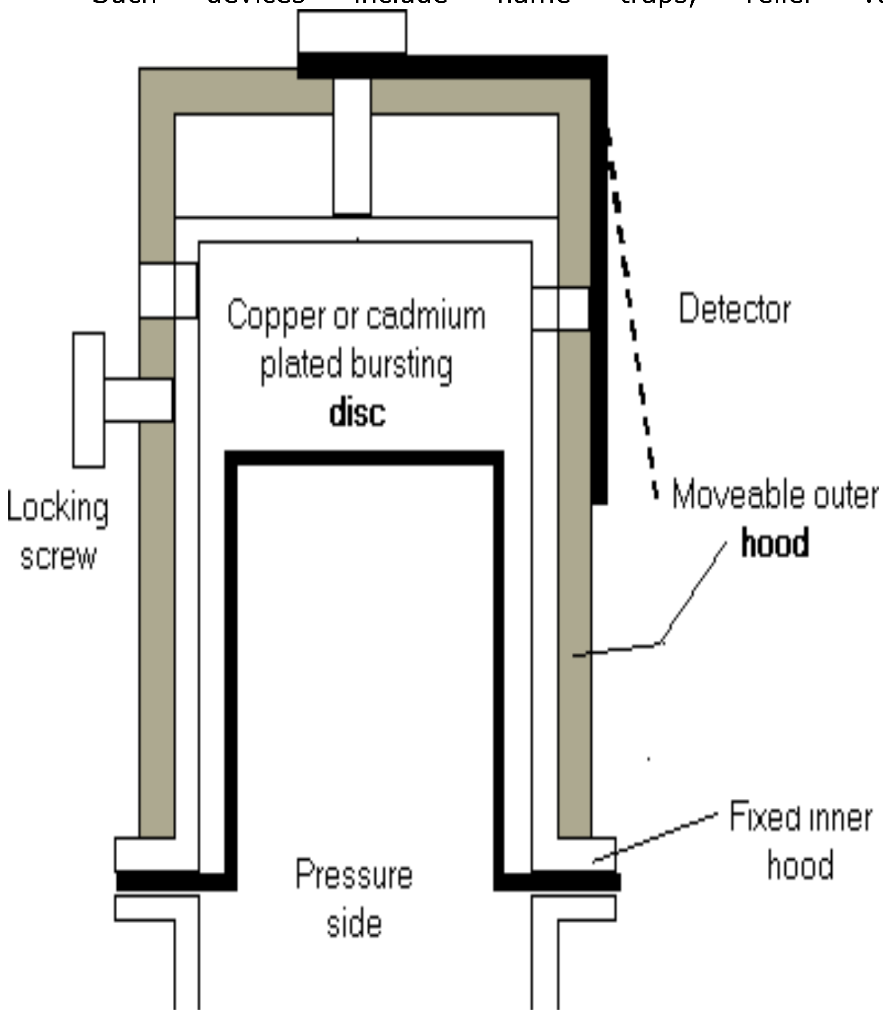


Safety devices

The automatic valve (Main air start block valve) prevents connection between the air receiver and air start manifold unless actually in the process of starting.

This minimises the risk of an explosion in the air manifold actually propagating back to the air receiver where a much more severe explosion is possible. Safety devices are encorporated in the air start manifold in order to dissapate the energy of an explosion thus keeping its effects local.

Such devices include flame traps, relief valves and bursting discs



Loss of air can be kept to a minimum by rotating moveable outer hood to blank off relief ports. The failed cap should be replaced as soon as possible.

Starting air explosions

Causes-continuous leaking of start valve followed by it sticking open on start.

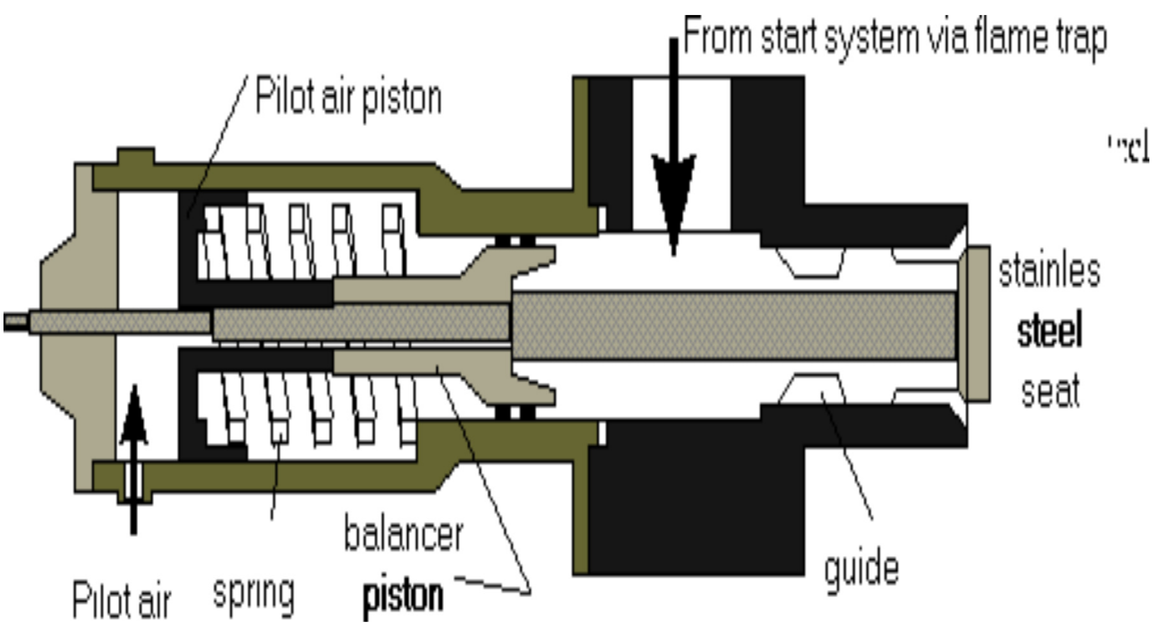
An oil film may build up on the start air pipe due to oil dscharge from the compressor. This oil may come from general lubrication or sticky scraper ring or from the engine room air,

With a continuous leaking valve hot gasses with unburnt fuel will enter the pipe and turn the oil film into a hot incandescent carbon. When high pressure air is put on the pipe line an explosion can occur with resultant high speed high pressure shock wave.

Alternately, air discharged into cylinder during starting may have an oil mist which can ignite in a hot cylinder. The hot gasses can return through the start valve. To prevent this the non return valve should be properly maintained, oil discharge from the compresors should be kept to a minmum and pipelines inspected nad cleaned when necessary.

To minimise effects a flame gauze should be fitted to the start valve and ample relief valves, bursting discs or caps fitted. An isolated valve on the discharge side of the manouervring control valve.

Starting air valve.



Starting Air Regulations

First start requirements

Equipment for starting the main and auxiliary engines is to be provided so that the necessary initial charge of starting air or initial electric power can be developed on board ship without external aid. If for this purpose an emergency air compressor or electric generator is required, these units are to be power driven by hand starting oil engine or steam engine, except in the case of small installations where a hand operated compressor of approved capacity may be accepted. Alternatively, other devices of approved type may be accepted as a means of providing the initial start

Air Compressor requirements

Air Compressor number and capacities

Two or more air compressors are to be fitted having a total capacity, together with a topping-up compressor where fitted, capable of charging the air receivers within 1 hour from atmospheric pressure, to the pressure sufficient for the number of starts require At least one of the air compressors is to be independent of the main propulsion unit and the capacity of the main air compressors is to be approximately equally divided between them. The capacity of an emergency compressor which may be installed to satisfy the requirements of first start is to be ignored.

Maximum discharge air temperature

The compressors are to be so designed that the temperature of the air discharged to the starting air receivers will not substantially exceed 93'C in service. A small fusible plug or an alarm device operating at 121AC is to be provided on each compressor to give warning of excessive air temperature. The emergency air compressor is excepted from these requirements.

Safety Valves

Each compressor is to be fitted with a safety valve so proportioned and adjusted that the accumulation with the outlet valve closed will not exceed 10 per cent of the maximum working pressure. The casings of the cooling water spaces are to be fitted with a safety valve or bursting disc so that ample relief will be provided in the event of the bursting of an air cooler tube. It is recommended that compressors be cooled by fresh water.

Air Receiver requirements

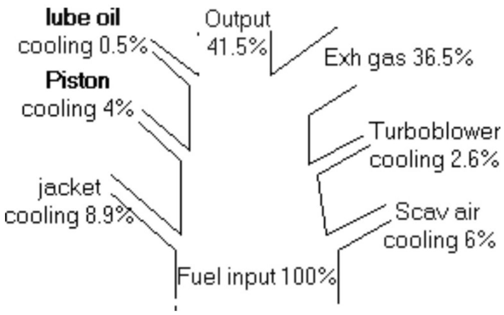
Air Receiver capacity

Where the main engine is arranged for air starting the total air receiver capacity is to be sufficient to provide without replenishment, not less than 12 consecutive starts of the main engine, alternating between ahead and astern if of the reversible type and not less than six consecutive starts if of the non-reversible type. At least two air receivers of approximately equal capacity are to be provided. For scantlings and fittings of air receivers

For multi-engine installations, the number of starts required for each engine will be specially considered.

Evaporators

Waste heat recovery



Even with a very efficient engine, only about 50% of the heat in the fuel is converted into useful work at the crankshaft. The remainder I potentially wasted. Heat energy is lost in the cooling systems and exhaust gas but some can be recovered whether it is worth recovering depends upon a number of factors including the amount of energy available, the time for which it is available, capitol costs of recovery plant. Modern highly pressure charged engines have a large amount of energy in scavenge air cooling water and this can provide a primary heating source for bunker fuel tanks.

Jacket cooling water also contains a considerable quantity of heat this may be recovered in fresh water evaporators provided operates at a pressure giving a corresponding saturation temperature for water lower than the jacket water entering the heating element. By heating the water to its saturation temperature gasses dissolved in it are liberated. Thus there is the requirement for air ejection to maintain a low pressure.

Any low temperature evaporator will operate over prolonged periods because scale does not form to any great extent. Joints and seals do not deteriorate.

Types of plant

There are two methods for generating fresh water, Reverse Osmosis (RO) and distillation. Reverse osmosis is generally used were large quantities of relatively low quality water is required. Typical examples of water produced are;

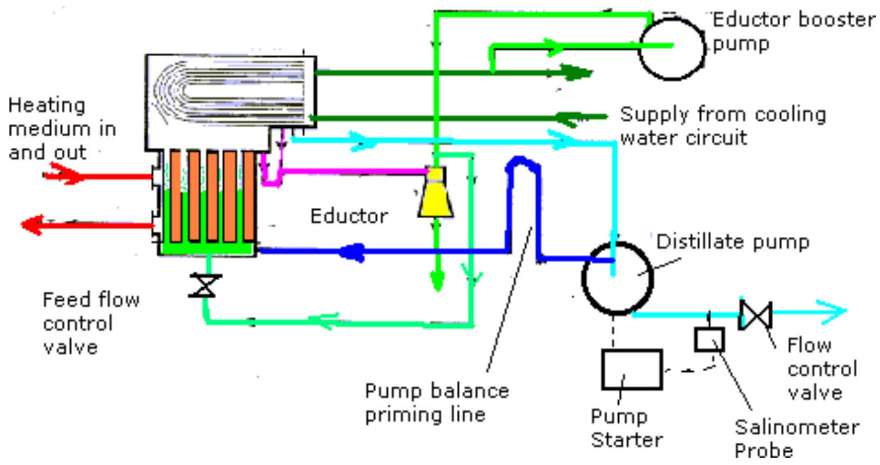
Treatment	Total Hardness	Calcium Hardness	Silica	Sodium Chloride	TDS
Sea Water	250	200	14	15000	15000
Evaporator	<0.2	<0.2	<0.2	<20	<20
Reverse Osmosis	20	5	<1	<750	<750
After Demineraliser	0	<1	Trace	<2	<3

Distillation

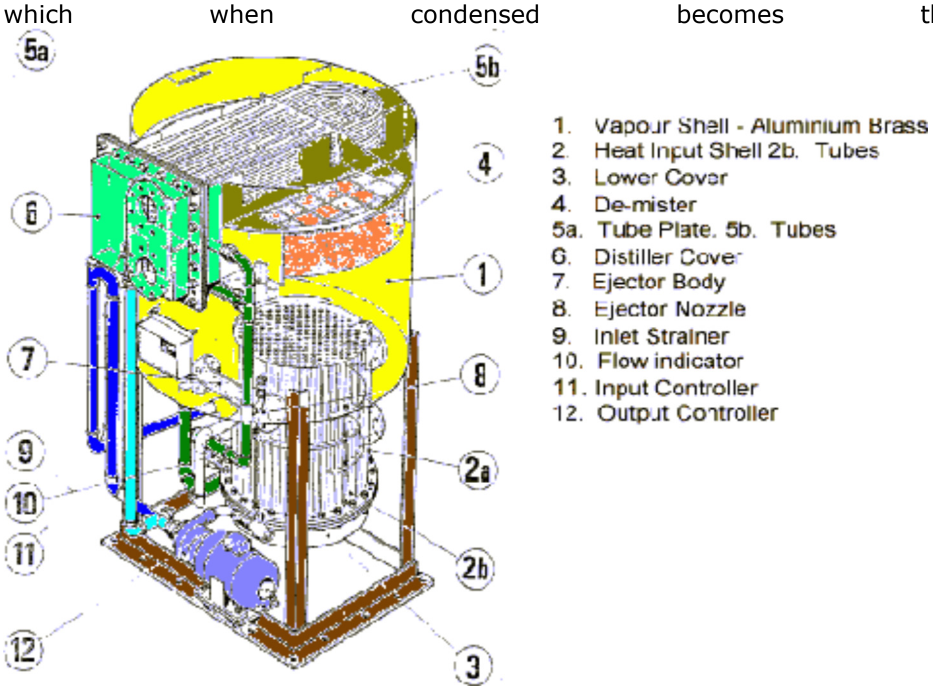
The most commonly used form of shipboard freshwater generation is evaporative distillation, which uses engine jacket cooling water or steam heat from exhaust or gas fired boilers to evaporate sea water, which is then condensed into fresh water.

Evaporation distillers comes in two main forms, multistage flash (MSF) and multi effect (ME) evaporators.

Simple single effect evaporator



Single (and Multi-effect) submerged tube distillation was one of the early types of fresh water generation. It uses heat passing through submerged coils or tube bundles immersed in sea water to produce the distillate, which when condensed becomes the fresh water.



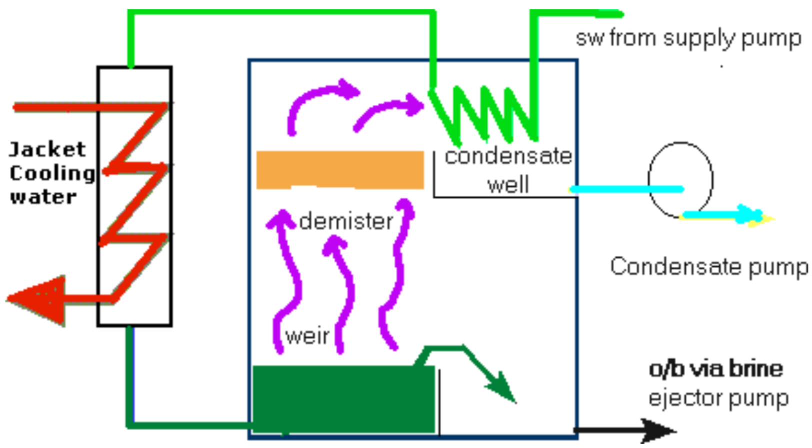
The system above shows an evaporator typically heated by Main Engine Jacket water with means to supply steam when the engine is shut down.

To start this evaporator

- Open sea water cooling to the coiling coils
- a take off line from the outlet of the cooler goes to the ejector booster pump. After shutting any vents the booster pump is started. The vacuum in the shell should begin to drop.
- A take off from the eductor booster pump is led to the shell via a flow control valve. This should be cracked to fill the unit increasing to a design level gradually as the vacuum increases.It should be noted that it is possible on some systems to increase feed to a point where the eductor can no longer cope and the shell is overfilled. This should be avoided as the possibility exists of getting saltwater on the demister -this is a mesh arrangement designed to remove wetness from the steam. Should this happen then it can take considerably longer before the salinity of the distillate falls to an acceptable level.
- Treatment chemical in the feed should now be added
- When the water reaches working level in the shell the heating coils may be warmed through. It should be noted that it is rarely the case the eductor is able to provide all the vacuum required, instead as the unit begins to steam, the condensing of this steam assists to pull the down the shell pressure.
- The heating should be increase as the shell pressure reduced. The maximum temperature in the shell is governed by design and to a maximum of 85'C to reduce scaling
- the salinometer may be switched on once condensate is detected in the distillate pump suction.
- the distillate pump control may be switched to auto. On some installations a recirc is fitted which dumps the outlet

from the distillate pump back to the evaporator. This may take the form of an automatic three way valve operated by the salinometer. In addition a manual dump to bilge may be fitted to dump the initial charge of distillate out of the unit reducing the time to on-line

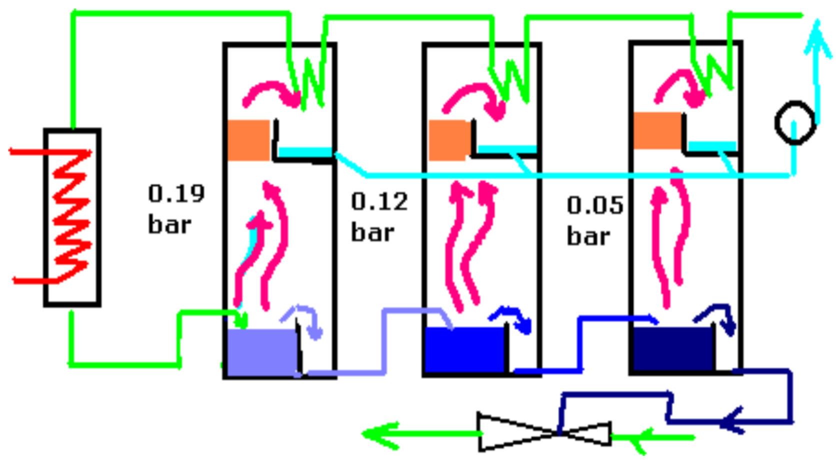
Single Stage Flash Evaporator



An alternative arrangement to the shell evaporator is the flash evaporator were heating takes place externally, the hot brine enters the low pressure chamber into a weir where some of the water flashes off. Water overflowing the weir is either educted out or passed on to a second stage.

Multi stage units with each stage maintained at a lower pressure allow improved efficiency and high outputs.

Multi Stage Flash Evaporator

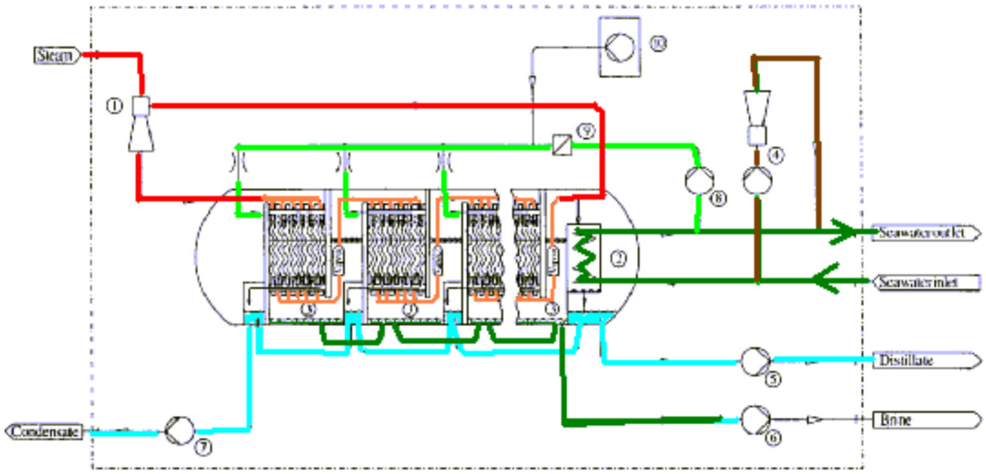


A typical multi stage flash system is based upon preheating of a pressurised sea water stream, or more typically a recycle brine stream to which the feed sea water is added; the stream is heated in the heat input section brine heater. From here the recycle stream is passed into the first stage of a series of flash chambers. Here the pressure is released, permitting a portion of the brine stream to flash to form salt-free vapour which is condensed to give the fresh water. In condensing the vapour gives off its latent heat to the recycle brine stream. From the first stage the flashing brine stream is passed to the second stage which is kept at a slightly lower pressure; more vapour flashes off. In the same way the flashing brine stream passes to the next stage and so on through the plant with a portion of the vapour flashing off at each stage. A heat balance shows that the heat supplied in the brine heater has to be rejected. This is done in the last two stages of the plant which are cooled by a sea water stream which subsequently passes to waste.

Modern Developments

Since the introduction of MSF, more efficient types of ME evaporators have been introduced.

Large Multi-effect Alfa laval evaporator



1 Thermo-compressor
2 Condenser
3 Evaporator effects
4 Ejector pump/ejector
5 Distillate discharge pump
6 Brine discharge pump
7 Condensate discharge pump
8 Feed water pump
9 Make-up filter
10 Anti-scalant dosing unit

In 1990 Alfa-Laval Desalt introduced its D-TU concept-a ME desalination system based on tube type distillers, using evaporation under vacuum with the rising film principle. This means that the inner surfaces of the tube are always covered with a then film of feed water, preventing formation of scale.

The heating medium (hot water/steam) circulates on the outside of the tubes in the heat exchanger. The vacuum is created by water ejectors connected to each effect.

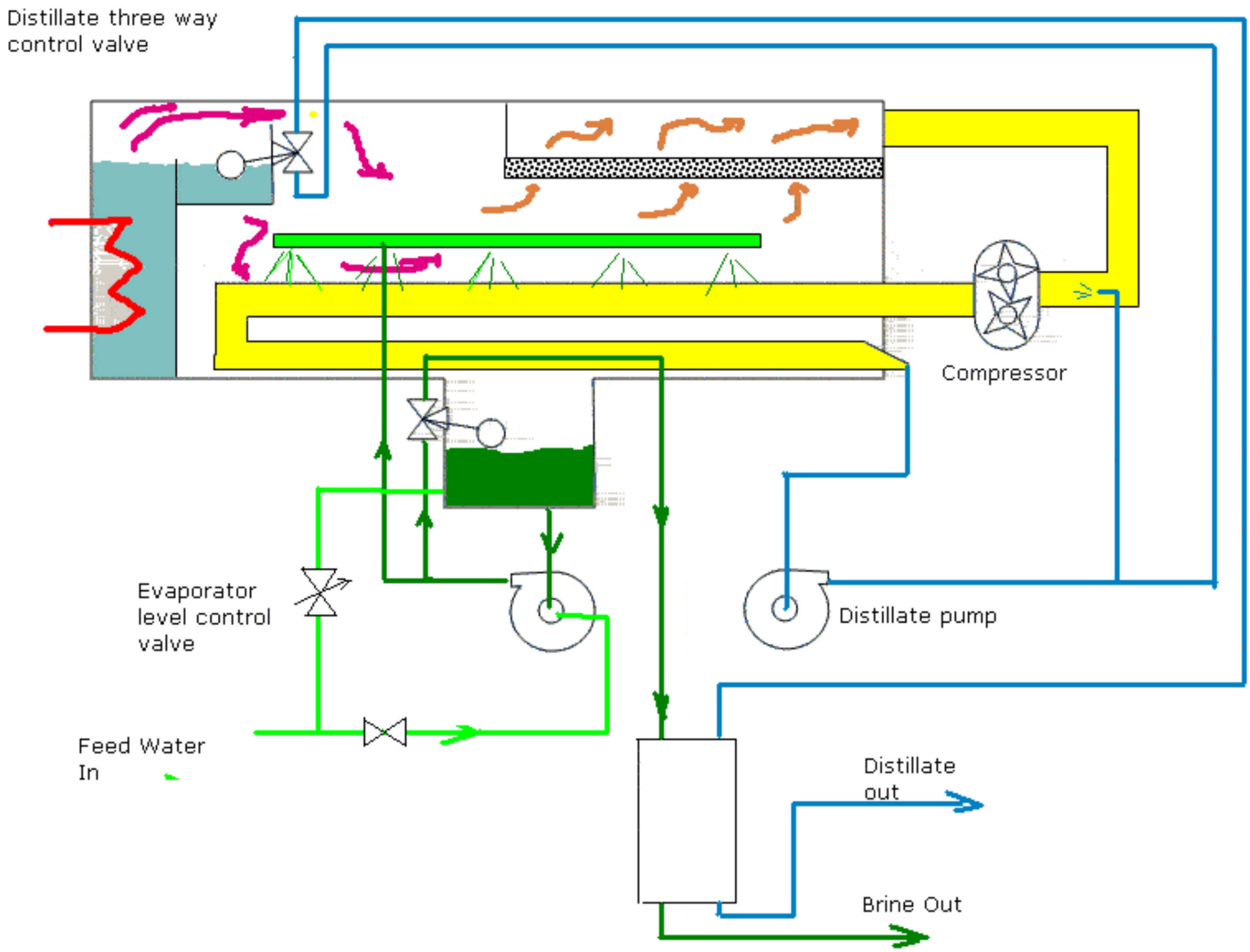
A controlled amount of sea feed water is led to the bottom of each effect, where it is mixes with the brine from the previous effect and into the tubes in the heat exchanger, where it is heated.

The generated vapours enter a separator where the brine droplets from the wet vapour are separated. The dry vapour pass through the separator to the following effect where they condense. Th remaining sea water which has been converted to brine, flows to the next effect as feed water. The brine is taken out and discharged overboard.

The latent heat in the vapours from the previous effect is used as a heating medium in the following effects. The process continues until the last effect where the generated vapours condense cooled by sea water. The condensate vapours flow from one effect to the next, and are retained in a collecting tank as distilled water.

If a low temperature evaporator is to be used for domestic purposes certain restrictions apply. Operation is not allowed within 25 miles of the coast or 50 miles of an estuary. Chromate jacket water treatment must never be used. The condensate must be treated in order to destroy bacteria. Care must be taken if chemicals are used to inhibit marine growth in pipework.

Vapor Compression



The boiler section is initially filled with fresh water. When the system is operating feed water is supplied via the level control valve. Hot steam is created in the boiler which passes over into the main section. Here the steam is mixed with a brine spray. Some of the steam is condensed and some of the brine spray is flashed off. The combined steam passes over to the vapour section via a scrubber. Flow of vapour occurs due to the action of the compressor which increases the vapour pressure increaseing its saturation temperature. The compressed vapour has a tendency to condense out and latent heat is given up to the brien spray in the evaporator main section.

The produced condensate is pumped via the distillate pump, a proportion is fed to a desuperheater at the compressor inlet, a further proportion passes to the boiler section maintaining water level. Any excess is then delivered to distillate system via a heat exchanger were it is cooled by the exhausted brine.

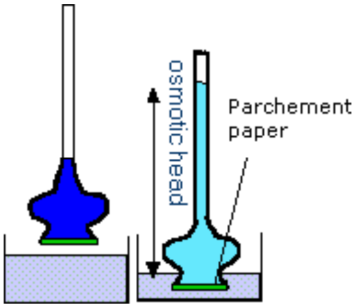
A recirculation pump draws brine from the brine well, a proportion of this is fed back to the well to maintin a level, anouther proportion passes to the brine spray. Excess is passed out of the brine blowdown overboard.

The above description has been formed from interpretation of a not to great drawing. If anybody has actually sailed with this system I would be grateful for a more accurate description.

Reverse Osmosis

Osmosis describes the process whereby a fluid will pass from a more dense to a less dense solution through a semi-permeable membrane. It is very important to the water absorbtion processes of plants. RO is a process which uses a semipermeable membrane which retains both salt and impurities from sea water while allowing water molecules to pass. Filtration of up to 90% is possible thus making the produced water unsuitable for boiler feed without further conditioning. Improved quality is possible using a two or more pass system.

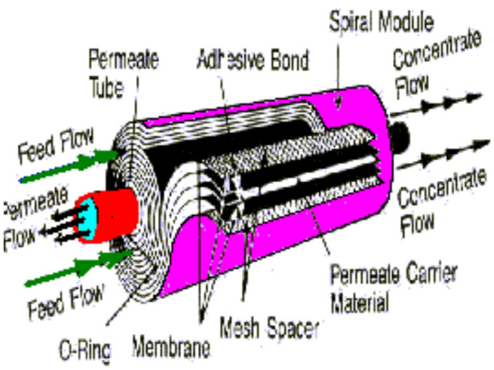
An experiment to determine this osmotic head is shown.



The parchment paper acts as the semi-permeable membrane and allows the water molecules to pass but not the larger salt molecules.

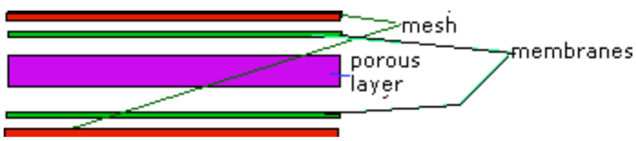
Reverse osmosis is the process whereby a pressure greater than the osmotic head pressure is applied to a solution of high density. Fluid is forced from the high density side to the less dense side. For desalination plants the pressure is applied to sea water and the water is forced through the semi-permeable membrane.

The semi permeable membrane which is typically made of polyamide membrane sheets wrapped in a spiral form around a perforated tube resembling a loosely wound toilet roll.

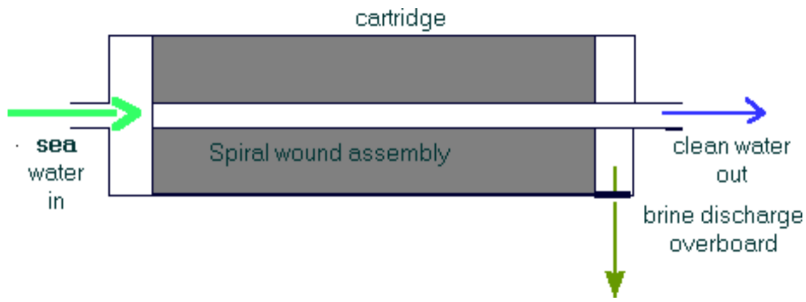


Membrane Module

Design of the cartridges is therefore such that the sea water feed passes over the membrane sheets so that the washing action keeps the surfaces clear of deposits. A dosing chemical is also injected to assist the action.



The two membranes sealed on the outer three edges, enclose porous under-layer through which the permeate spirals to central collecting tube



Pressurised feedwater passes lengthways through the tubular spiral wound membrane element. Freshwater permeate travels through the membrane layers as directed along a spiral bath inot a central perforated tube, while brine is discharged out the end of the membrane element..

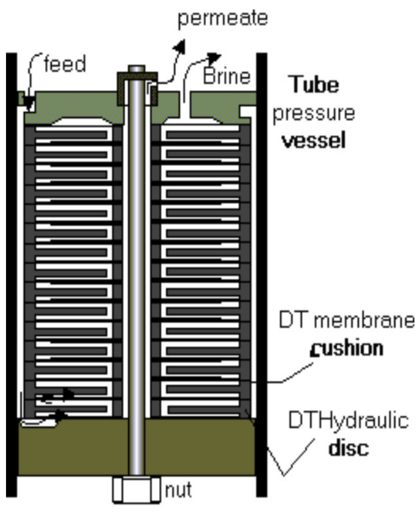
The fluid could be water and the solutions sea water. Under normal conditions the water would pass from the less saline soultion to the more saline solution until the salinity was the same. This process will cease however if the level in the more saline side raises to give a difference greater than the Osmotic height.

For practical use to allow the generation of large quantities of water. It is necessary to have a large surface area of membrane which has sufficient mechanical strength to resist the pressurised sea water.. The material used for sea water purification is spirally wound polyamide or polysulphonate sheets. One problem with any filtration system is that deposits accumulate and gradually blocks the filter. The sea water is supplied at a pressure of 60bar, a relief valve is fitted to the system. The Osmosis production plant is best suited to the production of large quantities of water rather than smaller quantities of steam plant feed quality.

Pretreatment and post treatment.

Sea water feed for reverse osmosis plant is pretreated before being passed through. The chemical sodium hexa phosphate is added to assist wash through of salt deposits on the surface of the elements and the sea water is steriliased to remove bacteria which could otherwise become resident in the filter. Chlorine is reduced by compressed carbon filter while solids are removed by other filters. Treatment is also necessary to make the water drinkable.

Rochem disc tube reverse osmosis plant

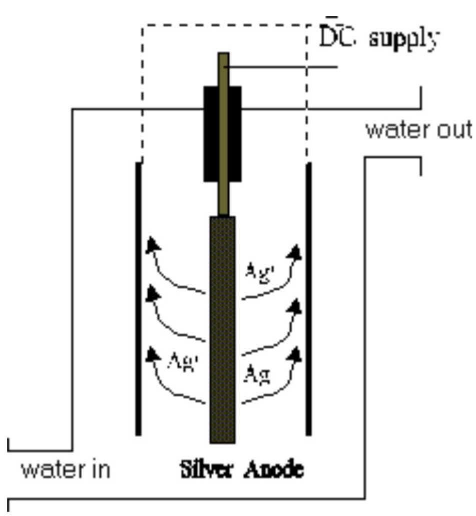


The disc tube module is supposed to have the main advantage over the spiral wound type in that it avoids the need for the difficult cleaning processes required. With long lasting membranes, typically 5 years and in built cleaning system the unit will recover 30% as pure water from sea water passing through it

Silver ion sterilisers

The use of silver ion sterilised is recognised as a method of water sterilisation, the following are the requirements for its usage;

1. A set of manufacturers instructions is to be located with the set.
2. The system is designed to cope with the maximum flow of the production plant and is not to be bypassed and indeed no facility for by passing should be fitted.
3. It should be readily accessible for maintenance, and be as close to the production equipment as practicable
4. The system is to be fail safe in that it should prevent the passage of water by closing a fail-closed solenoid valve. An audible, independently supplied failure alarm should be fitted
5. The set should be capable of maintaining the minimum concentration of 0.1 ppm silver ion concentration at maximum flow rate.
6. The fresh water storage system should be so set up that a four hour period be allowed for contact with the silver ions. This should allow a maximum level of 0.08 ppm concentration of silver ions in the system, which should be checked regularly by a competent laboratory.
7. Water conditioning should be installed after disinfecting unit.
8. Spares of not less than the manufacturers recommendations should be carried.



A D.C. voltage driven silver coated anode releases silver ions into the water. Silver is toxic to many organisms. In addition the silver ions do not evaporate as in the case of chlorinating. The rate of ion release, and thus anode wastage is governed by the current flowing. This is adjustable on the controller.

Evaporator scale

There are numerous types of evaporators all working to produce pure water with concentrated sea-water as waste. This concentration effect can lead to the formation of damaging scales within the evaporator. Over concentration is usually prevented by having a continuous stream of sea-water passing through the unit thus maintaining a satisfactory dilution of the sea-water side of the evaporator. However, because of the high salt content, when sea-water is elevated to temperatures above 30 C scales can begin to form on heat transfer surfaces. Additionally as the majority of evaporators operate under vacuum there is a tendency for the make-up water side to foam, which can give rise to carry-over and contamination of the pure water stream.

Four scales which are principally found in evaporators are;
Calcium Sulphate ($CaSO_4$)-1200ppm, scale formation is principally on density, remains in solution below 140^oC and/or 96000ppm.The worst scale forming salt forming a thin hard grey scale

Magnessium Hydroxide $Mg(OH)_2$

remains in solution below 90^oC

Magnessium Bi-Carbonate 150ppm
soluble below 90^oC, forms a soft scale, prevention by keeping operating temperature of evaporator below 90^oC
Above 90^oC
breaks down to form $MgCO_3$ and CO_2 and then $Mg(OH)_2$ and CO_2

Calcium bicarbonate $Ca(HCO_3)_2$ 180ppm

Slightly solube, above 65^oC breaks down to form insuluble calcium carbonate forming a soft white scale. scale formation prevented by chemical treatment $Ca(HCO_3)_2 = Ca + 2HCO_3$
$2HCO_3 = CO_3 + H_20 + CO_2$

If heated up to approximately 80^oC

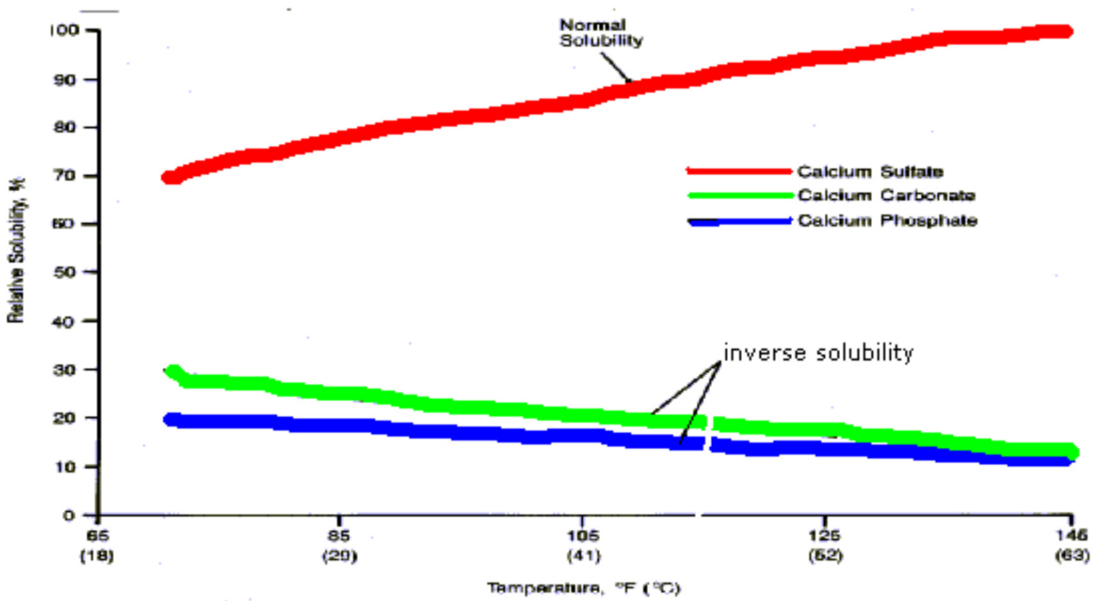
$CO_3 + Ca = CaCO_3$

If heated above 80^0C

$CO_3 + H_20 = HCO_3 + OH$
$Mg + 2OH = Mg(OH)_2$

Hence if sea water in the evaporator is heated to a temperature below 80^oC calcium carbonate predominates. If it is heated above 80^oC then magnesium hydroxide scale is deposited.

Sodium Chloride 32230 to 25600ppm -generally ignored
Soluble below 225000ppm forms a soft encrustation, free ions promote galvanic action. It is unlikely to precipitate and is easily removed



Supersaturation
This is where the concentration of dissolved salts exceed their solubility at the particular temperature encountered and precipitation begins to occur. When deposition occurs under these conditions heavy scale deposits can rapidly build up and lead to a loss of heat transfer efficiency. Scale deposition due to supersaturation is often localised in areas of elevated temperature such as heat transfer surfaces in heat-exchangers. This is because of localised over concentration of salts with respect to the temperature of the thin water layer at the surface of the metal. Scale deposition can therefore occur on heat-exchange surfaces even when the conditions in the bulk of the water are not scale forming.

Methods of controlling and minimising scale (evaporators)

1. *Use low pressure evaporation plant-Operating at temperature below 80oC so that calcium carbonate scale predominates. That is a soft scale easily removed and not such a poor conductor of heat.*
2. *Use magnetic treatment-A unit consisting of permanent magnets, preceded by a filter., is installed in the evaporator feed line. The water passes through a strong magnetic field which alters the charge on the salts so that amalgamation of the salt crystals, formed during precipitation in the evaporator , is prevented and the salt then goes out with the brine.*
3. *Use flexing elements-a heating element made of thin gauge monel metal built like a concertina may be used. The advantage of such an element is that when pressure, and hence temperature , vary slightly the element flexes considerably thereby cracking off scale effectively and permitting longer running periods of the evaporator between shut downs. Care should be made not to submit the element to over pressurisation.*
4. *. Use continuous chemical treatment*

Treatments

Ferrous chloride-$FeCl_2$- Keeps pH too low for $Mg(OH)_2$ and $CaCO_3$ to decompose to form scale.

- **sodium sulphate**-$Na(SO_4)_2$ or HCl and corrosion inhibitor alternative;Rubber lining necessary to protect shell from acidic water.
- **Sodium polyphosphate**
  i. *-Prevents scale formation below 80^{o}C*
  ii. *- Mixture of different phosphates*
  iii. *-sludge (coagulent and antifoam) conditioners*

iv. *-can be used with potable water.*

- **Polyelctrolytes**
  i. *-Prevent scale above 80^{o}C*
  ii. *-safe with potable water.*

Recommendations to prevent contamination of ships freshwater storage and distribution systems

With recent research it is required that more close attention is paid to the quality of fresh water storage and disinfection due to the potential dangers of bacteria such as legionella or to the prescience of toxic chemicals.

Freshwater loading and supply arrangements

Fresh water loaded from shore mains or water barge- should be done so via dedicated hoses. Every effort should be made to avoid possible contamination of the loading line and manifold

Treatment of freshwater- All fresh water loaded from shore or barge should be tested and treated to ensure a residual chloride reading of 0.2ppm

Fresh water from low pressure evaporator or reverse osmosis- Should only be made when outside 25 miles from shore or 50 miles from an estuary. The suctions should be separate to other suctions and forward of effluent outlets. Antifouling equipment used should be of an approved type suitable for use with potable water production.

New ships fitted with an ultra-violet steriliser must in addition be fitted with an automatic chlorinator system. As an alternative full flow silver ion systems may be used

Alternative means for sterilisation may be submitted to the classification society for approval.

Storage tank arrangements

Storage tanks and delivery systems intended for drinking or washing water-It is preferable that systems used for drinking and washing are kept isolated from the system supplying such circuits as jacket water and oil purifier seal water. Where this is impractical then effort must be made, say by the fitting of efficient non-return valves or an air break in the pipe work to prevent back contamination.

Sitting of tanks-Tanks designed for drinking water should be sited to allow easy inspection and maintenance. Fore peaks which are susceptible to damage should not be used or aft peaks which are too difficult to clean. No freshwater tank should be sited to an oil tank.

Construction-The internal structure should allow easy drainage and cleaning. The tank should be pressure tested every 10 years to ensure no seepage in or out, particularly where the tank is adjacent to the ships side. Manholes should be of an adequate size and raised above deck level. Only pipework containing the same quality of water in the tanks should be allowed to pass through the tank. Goose necks should be suitably designed to prevent the ingress of sea water

Coatings-Coatings should be applied and allowed to cure strictly with adherence of the manufacturers instructions.

Distribution systems

Water treatment, filters, mineralises, softeners etc.-Water supplied to evaporators and reverse osmosis plant should pass through a suitable filtration system. A form of sterilisation must be applied to fresh water. Neutralisers and mineralises may be optionally fitted to make the water more palatable.

Pumps-must be dedicated for freshwater only with no cross connections.

Calorifiers, hydrophore tanks etc.-Should be designed to allow proper cleaning and prevent sludge and scale build up

Design of fw systems-Dead legs are to be avoided, with temperatures between 15-50^{o}C these can promote bacterial growth. Hot water line should be suitably insulated especially where they run adjacent to the cold water line. Special attention to the toxicity of material used in jointing and mechanical of the pump should be made at the design stage.

Maintenance

Freshwater storage tanks-These to be inspected every 12mths an refilled with sterilised water following cleaning with a 50ppm chlorine solution

Distribution system-Including sterilisation plant, should come under the planned maintenance system and regularly inspected. Chlorinators should be raised to 70^{o}C before opening for inspection to kill of any bacteria colonies.
Opportunity should be taken at refits to flush the system with 50ppm chlorine solution.
Shower heads and taps should be cleaned in a similar solution every 3 months.

Where water production systems utilise treated water for cooling (Condensate cooled evap on steam ship) or heating (jacket water evap on motor ship) only approved treatment chemicals should be used.

Operation of a Centrifugal oil purifers

Preamble

The following description relies on the reader having an understanding of the function and internal design of a modern self cleaning centrifugal purifer.

The method describes the operation of a manually controlled system. It is accepted that the vast majority of units are automated, it is intended allow better understanding of the automated process by doing this. The " **Automation** " section will clarify this.

The unit described is a sliding bowl type, does not have on line sludging capability with light phase requiring heating. Operating water is required for both opening, and closing the bowl. It is accepted that in common designs only opening water is supplied, once supplied this water leaks out until it reaches a level determined by a weir arrangement. The water remaining beyond this weir acts to close the bowl

Operating, displacement, seal and sludging water are delivered in finite quantities governed by the type and size of bowl, and the supply water pressure. Although not mentioned it should be taken for granted that water introduced is of a set quantity

Starting and stopping

Before starting the purifier the correct sized gravity ring must be in place for the light phase specific gravity at required delivery temperature.

Most units have a brake arrangement fitted acting on the bowl to slow during stopping. This should be check to be disengaged.

The use of this brake is determined by manufacturers recommendations. The brake should be seen as an emergency device to slow the bowl in the event of some problem, typically an out of balance of the bowl caused by sludge not being evenly removed from the bowl.

Where no preference is given it is the authors recommendation that the brake be used. The reason for this is to allow the bowl to pass as quickly as possible through any critical vibration harmonics.

Correct operating and sludging water supply pressure should be checked

The light phase (oil) supply, discharge valves may be opened, the flow control valve and back pressure valve may be set at approximate initial settings. The three way valve is set to recirc (dump)

Remember that when the oil is introduced to the bowl the bowl is cool and so the oil will be cooled and will tend to pass over with the heavy phase. This action may be reduced by having the back pressure discharge valve slightly more open than required closing as the bowl warms.

The bowl may be started. Drive to the bowl is via a centrifugal clutch arrangement reducing the starting current on the motor. The start up time is determined by the slippage of this clutch which is in turn determined by the number of pads. The oil is now being circulated though the heater. The heating medium may be introduced to bring the oil to purifying temperature

It should be noted that for some designs the motor is non-standard being able to carry high starting currents over a longer period. When requesting replacements this should be noted.

Too few pads causes an overly long start up time. In addition, the drag of the liquid as it leaves the bowl during a sludge cycle causes a reduction in speed. For automated systems, this speed must be regained before the oil is reintroduced otherwise carryover can occur. With some designs correct sludging is determined by an expected rise in drive current caused by the motor trying to bring the bowl back to speed. Too few pads may cause problems in both these cases.

Too many pads leads to excessive force on the drive gear leading to premature failure especially of the wheel and the electric motor.

When the bowl has reached it operating speed the bowl may be closed by introducing closing operating water.

this may be checked by viewing the external speed indicator or by observation of a reduction in amps as the bowl reaches its operating speed. The best method is a combination of the two. Observe the amp reduction and visually check the speed indicator to confirm that a fault has not occurred in the clutch.

Once correct oil temperature is observed the purification process may begin. Seal water is introduced to the bowl. The three way valve is operated to supply oil to the bowl. Correct flow and back pressure should be set once full flow is achieved. The amount of heating medium to the heater should be increased as required

The sludge port should be viewed to ensure no leakage from bowl- remember to close port before sludging. Check heavy phase (water) shute to ensure no oil overflow. Check operating water shute to ensure valves have isolated

It is unlikely that the bowl will immediately come " on-line ", this is generally due to the bowl being cold, cooling the oil, increasing its specific gravity and causing it to pass over the heavy phase (water) shute.

The amount of carryover may be reduced by opening the back pressure valve. The best solution is to removed the cool oil that is in the bowl by sludging. This may be repeated couple of times before the bowl has reached operating temperature.

The correct function of the desludging mechanism should be checked.

Sludging

- Change three way valve to recirculation (dump). Reduce heating medium to heater if required
- Introduce displacement water. This removes the oil from the bowl preventing wastage
- Open bowl open operating water
- Observe amps (increase), check sludge port (see discharge). Close sludge port. There is normally an audible indication that the bowl has opened
- Operate bowl closing water
- Once amps has returned to normal running the bowl can be assumed closed, again there is generally an audible indication of this
- Bring unit back on line

Once the unit has been proved on line and operating correctly the alarms and shutdowns should be tested. Where the units overflow to a sludge tank the correct operation of the alarm should be checked.

The testing of the alarms and shut downs is paramount. Once completed, especially for main engine lube oil purifiers, a note should be made in the engineroom log book

It is common to find dedicated sludge tanks for the purifiers. The level in which is kept artificially high and just off the high level alarm. In this way the tank acts as a back up alarm for the purifier.

Automation

The vast majority of units will be fully automated for UMS enginerooms. Sludging will involve pressing a single button. A controller will then cycle through the operating, displacement and seal water valves as well as operate the three way valve. The heater will have an independent controller although a zero output signal may be generated by the purifier controller during the sludge period.

Detection of correct desludging may be by drive motor current, as discussed, flap arrangement which is struck by the discharge from the open bowl or by measuring the discharge pressure which falls to or below zero pressure during the sludge cycle.

Centrifugal Purifiers/Clarifiers

Purifiers and Clarifiers differ only in that clarifiers are not set up to remove water. Their design are similar to the point that most purifiers found on board can be converted to use as a clarifier with simple alteration of the gravity disc

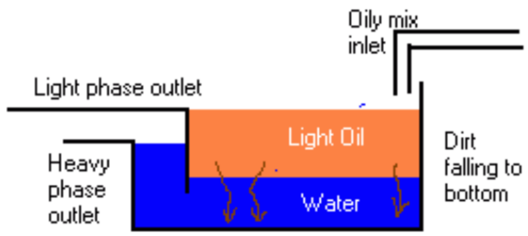
If an oily water mix is placed into a tank then speration of the two parts will begin with the lighter element rising to the top. The rate the seperation occurs is governed by several factors including the difference in specific gravities and the force of gravity acting upon it.
For mixes placed into a settling tank there is little that can be done about the gravity but the difference in the specific gravities can be increased by heating. This because water density changes at a much reduced rate when compared to oil. The limiting factor to this is that the water cannot be heated above 100'C for obvious reasons.

A wide shallow tank will increase the rate of clarification over a tall thin tank

Principles of operation

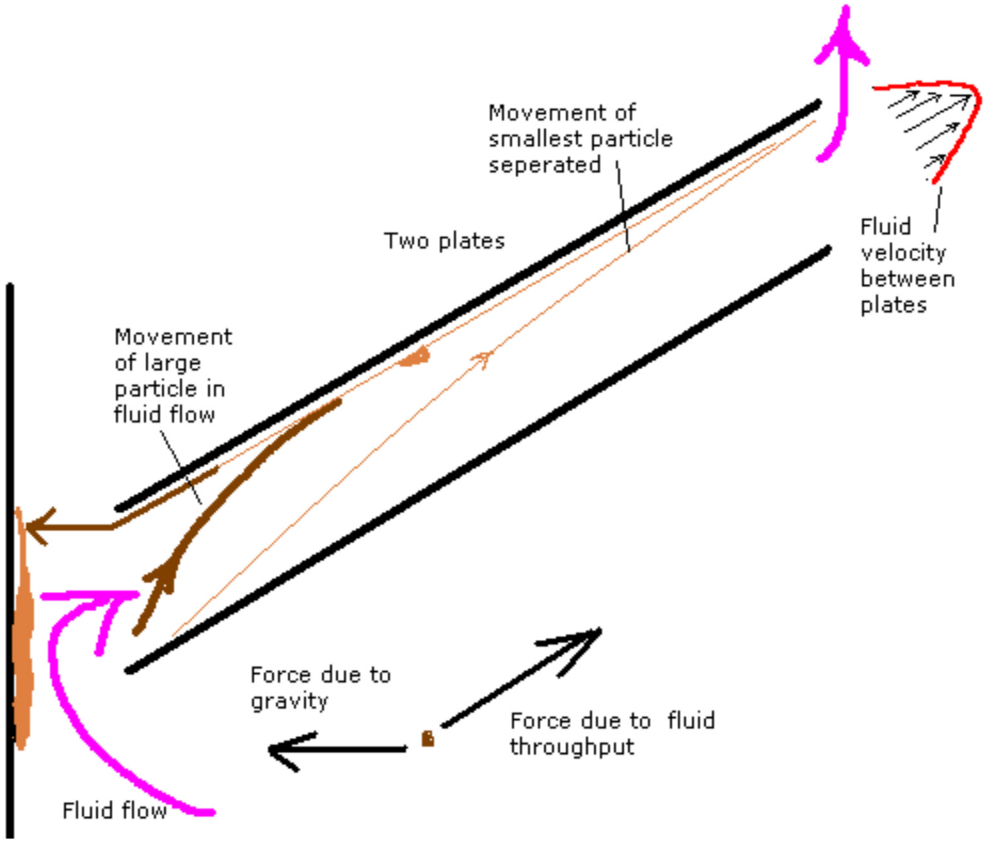
When a volume of light oil is placed into a tank contain a weir and a quantity of water the fluids will tend to arrange themselves as shown above. The height of the water in the weir rises to a point governed by the volume (and thereby relative height) and specific gravity of the light oil.

Knowing this it is possible to form a rudimentary purification system.



As a oil/water mix is fed into the tank seperation begins with heavy particulates falling to the base of the tank along with water which joins the other water excess overflowing the heavy phase weir. Hopefully clear oil passes over the light phase weir. The problem arises that to ensure their is suffcient time to allow for full(seperation of the oily mix the flow would have to be very small relative to the size of the tank.

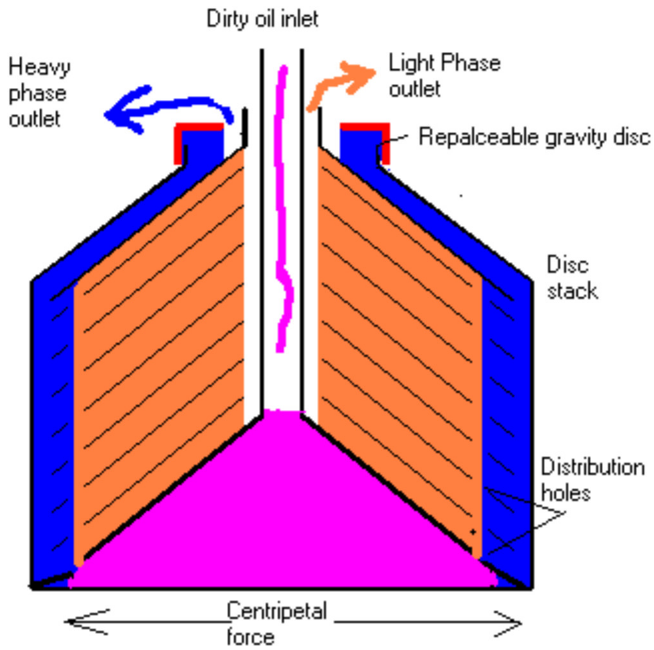
Principle of seperation in centrifuge containing angled plate stack



Fluid moving between two plates has a velocity greatest at mid point and minimum approaching the plates.

a particle entering into the plates will tend to be pushed upwards by the fluid flow. All the time centrifugal foce tends to retard the horizontal component of the movement causing the partical to approach the underside of the top disc. As it approaches the fluid flow velocity reduces. The centrifugal force eventually overcomes the force acting on the partical due to fluid movement and th epartical starts to move towards the oute rim. The centrifugal force acting on a particle is proportional to its mass therefore a small particle will tend to move further under the influence of fluid flow. Indeed a particle small enough will be carried through the plates and out with the discharge. In this way it can be seen that reducing the flow rate to a purifier will tend to increase the quality of the output.

Basic centrifuge

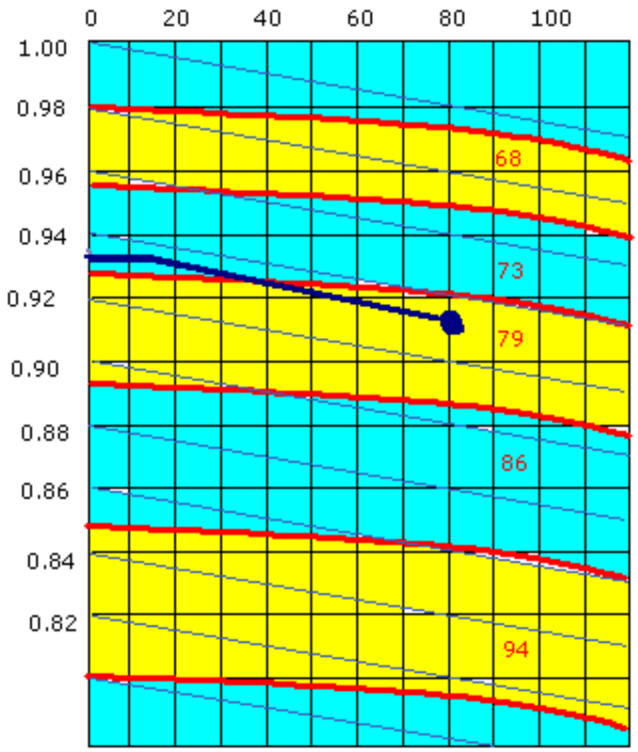


The basic centrifuge differs than that described above most obviously by sitting on its side. In reality it takes the form of a round bowl a cross section of which will show something like that seen above. Gravity is replaced by centripetal force as the bowl is spun at high revolutions thereby creating very high g-forces.
A disc stack is incorporated to encourage a laminar flow increaseing improving the seperation effect. Dirty oil is introduced via a centreline oil feed dip tube. The oil is led to distribution holes which are refected in the disc stack but not the dam

The following factors are of importance when understanding the function of the purifier

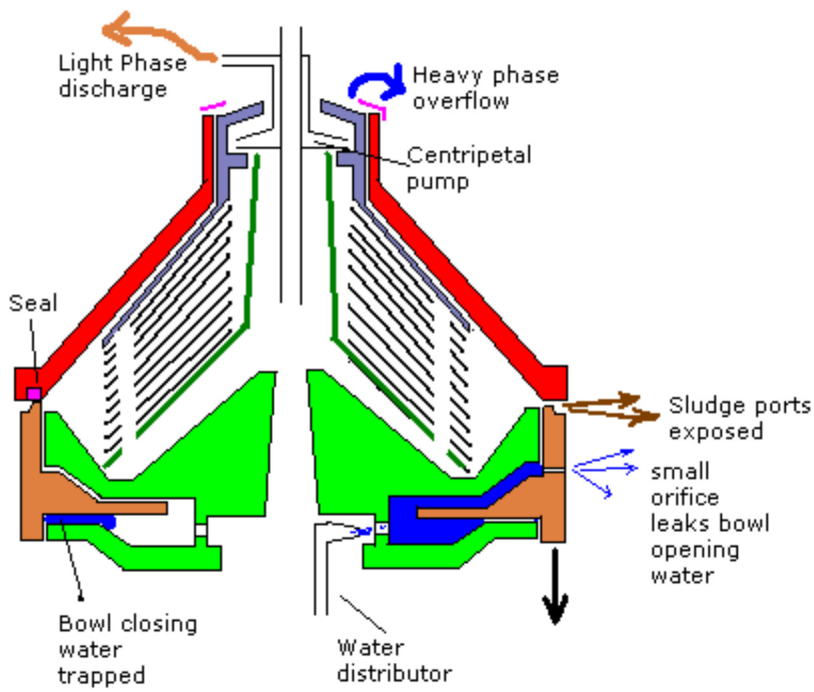
- Increasing the sg of the oil will tend to push the interface outlet and cause overflow from the heavy phase outlet untill the equilibrium is restored. Should the interface be moved so far as to breach the dam oil will be issued from the heavy phase outlet and an alarm will sound.The ideal position for the interface is to lie over the distribution holes
- Reducing the sg of the oil will tend to bring the interface towards the axis, this reduces the force of speration on the oil mix and reduces the efficacy of the unit possibly leading to contaminants and water carryover with the light phase outlet
- the "gravity" disc are changeable on virtually all purifers. Their centre bore is governed by the sg of the oil being centrifuged. The largest bore should be used without risking overflow
- The flow rate of a purifer should be set to optimise removal of whole system impurities. The lower the oil feed the greater the time for impurity removal and the more efficient the purification. The higher the rate the greater the amount of system oil is treated per unit of time. For a system such as main engine oil where contaminants are continuously being added to the system. As a rule of thumb the total volume of the system should pass through the purifer three times every 24 hours, this rate may be vary depending on operational parameters. A similar calculation has to be made with fuel oil to ensure removal of water and sludges which may accummulate over time.

Choosing Gravity Disc



The graph shown above is one typical of one found in a purifer instruction book for selecting appropriate gravity disc size. Shown on the diagram is an example of an oil of sg 0.93 at 0'C. The sg at 15'C for use with this graph is found by projecting along a horizontal line to 15'C. This step would be omitted if the sg at 15'C was already known. A line is then drawn parallel to the pre-drawn sloping lines. Where the drawn sloping line cuts the appropriate oil supply temperature isothermal then This becomes the selection point for the disc. This is found simply by ascertaining which size band the point lies in.

Self cleaning centrifuge



The majority of purifers found on board are of the self cleaning type intat they are able to open the bowl to discharge any accummulated sludge. Apart from the sliding bowl the main difference is the centripetal pump over the simple design. In this a fixed centrigual style impeller is mounted in the light phase outlet drawing the oil and discharging it at pressure sufficient to deliver it to the receiving tank. A discharge valve is fitted which is adjusted to give a constant back pressure in the bowl. The adjustment of this back pressure tends to move the position of the interface but more importantly increases the oil in the light phase delivery chamber increaseing the immersion depth of the lip of the pump. This reduces possiblility of air being entrained and removes foaming.. In the event of bowl failure back pressure will fall, this may be detected by a pressure switch initiaing a shut down

Desludge event

For the bowl shown above a typical sequence of events would be< p class = "noindent">

1. *Bowl online*
2. *sludge cycle timer activates and bowl comes off line (heater may be disconnected at this time*
3. *Oil feed stopped*
4. *Oil still in bowl displaced by addition of a quantity of displacement water*
5. *Bowl open control water passed to bowl via distributor, bowl opens*
6. *Bowl open water discharged via a small orifice*
7. *Bowl closes*
8. *Seal water added*
9. *Oil feed commenced, timer started to give set time for back pressure to build up for oil disharge*
10. *heater reconnected*

Typical alarms and shut downs

The following gives a general list of alarms only some of which may be fitted.

- Back Pressure shutdown- this measures the discharge oil pressure and alarms and initiates a shut down when below a set value
- Heavy phase overflow. Oil has a much higher visccosity than water. The heavy phase outlet is led to asmall catchment tank containg a float. The outlet from the tank is restricted in such a way that water flows freely but oil tends to back up. This initiates an alarm and shut down
- Bowl not open- This may be dome in several ways, typically by a lever switch operated by the discharged sludge hitting a striker plate. A nouther method is by measuring the motor current, when the bowl opens the bowl speed is dragged down due to friction effects of the dischargeing sludge and water. The motor current rises until full speed is reestablished. This is detected by a current sensing relay
- Water in oil- This found on modern designs which have a detection probe mounted in the oil discharge
- High temperature alarm and shut down
- Low control/seal water pressure. Where control water is supplied via a fixed small header tanks a float switch may be fitted.

Other Designs

Sharples constant sludging

Heres one to send a shiver down the spine of anybody of my age.
This consisted essentially of a standard non desludging bowl into which were drilled small holes on the circumference fitted with nozzles. Seal water was pumped continuously from a small catchment tank mounted adjacent to the purifer into the bowl where it passed though to be ejected through the jets. It then drained to the catchment tank. Dirty oil would float to the surface where it would overflow though a surface mounted skimmer to the sludge tank. Theoretically the bowl could run for

considerable periods without cleaning. The reality was one to two weeks, bowl cleaning included patiently trying to clear the small bore nozzles. I remember loading bunkers which were brick red, it contained lots of sand. The purifer was permenantly overflowing to an extent we had to use the second purifier to run on the sludge tank. Bowl cleans were every day with the other engineers playing the 'it best if one person concentrates on them' card. The worst aspect was the Chief Engineer who used to lie in wait for me when I was called out during the night. On sneaking back to for some sleep he would drag me into to his cabin (which was next to mine) for a thank you drink- this inevitably lasted untill 8 am

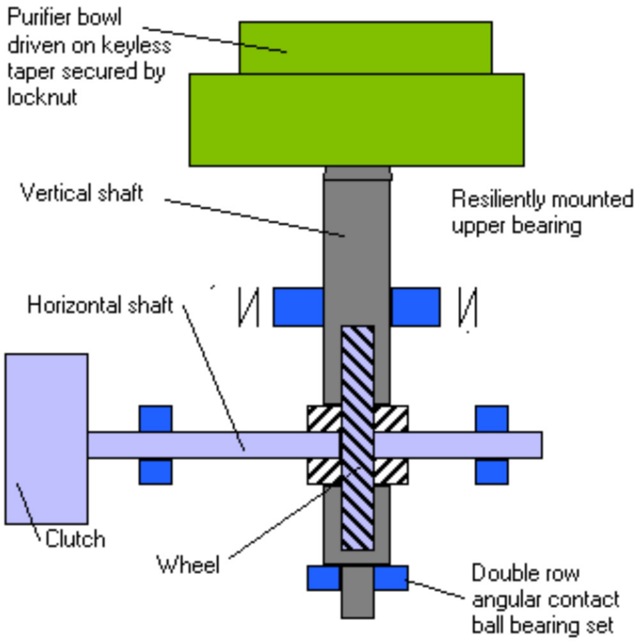
Modern trends

The most obvious trend is that towars online sludging. In this during normal operation a small quanity of extra seal water is added and the bowl opened for an extremently short period of time thus removing the need to interupt the process.

Control and Operating water

Water must be supplied at a fixed pressure to ensure that the quantity supplied to the purifer is constant for the set parameters. The water normally comes from the vessels hot water system or is independently heated to reduce thermal shocking and to prevent cooling of the hot oil

Drive



Considerable torque would be required to direct drive the bowl upto speed using an appropriately sized electric motor. In addition very high loading would occur on the gear train, to prevent scuffing due to oil film breakdown would require large mating areas therby large gear trains which would again increase the starting load.
A centrifugal clutch arrangement is fitted which has between 2 and 6 ferrodo lined brake pads. These are designed to slip during the start up period and also to a much lesser extent during the speed up period after de-sludge. Purifer manufacturers will usually quote a maximum and MINIMUM start up time. As the pads wear it may be necessary to remove and restore the mating surface to keep the start up time correct. As a last measure the number of pads should be altered
The electric motor may be of special design allowing for a long period of slight overload during the start up period.

The gear train is generally a single stage worm and wheel arrangement with the wheel being made of a softer material. Lubrication is normally splash only, the viscosity of the oil is essential to prevent wear as the form of lubrication is mainly boundary therefore the wear is governed by the viscosity and additives contained within the oil.
When wear occurs it will be scuffing and relative movement between the mating faces polishes out any pitting. As wear worsens galling occurs destroying the running surface. This damage is reflected in both elements therefore both should be changed.

As well as overload other causes of premature failure are poor design (step forward westfalia), poor material choice, poor lube oil choice, too long a de-sludge period relative to supplied oil quality, out of balance bowl, failing bearing set in particular the vertical shaft upper resilient bearing arrangement
The use of planned maintenance is essential particularly with respect to bearing changes. It is strongly recommended to monitor condition using vibration analysis

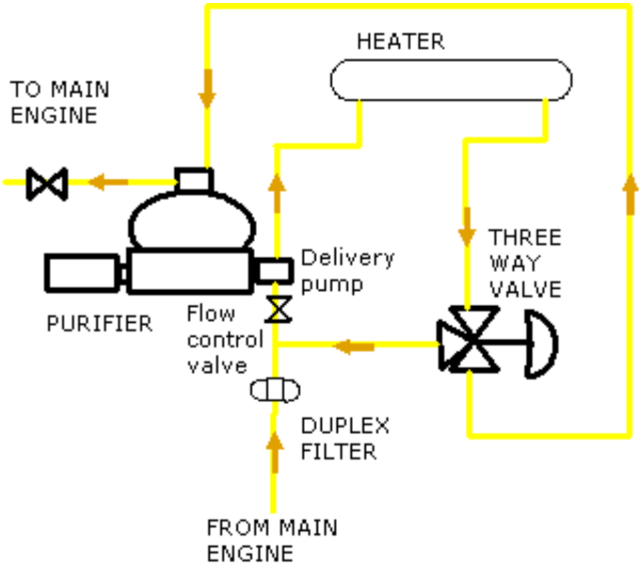
Bowl Cleaning

Should be carried out at regular intervals not exceeding manufacturers recommendations. Every care should be taken not to score the surfaces of the bowl especially the sliding surfaces for de-sludging types. The disc stack is generally numbered and should be built up as per this system as the stack is a balanced unit.

Water washing

This was a techniques employed some time ago to improve purification of lube oil and to remove acids. It involved continuously adding a small quantity of water at oil temperature to the oil inlet which would pass through and overflow. This is much out of favour as it tends to remove the essential oil additives in particualr detergents. An alternative is to inject steam which improves the removal of colloidal carbon by causing it to coagulate

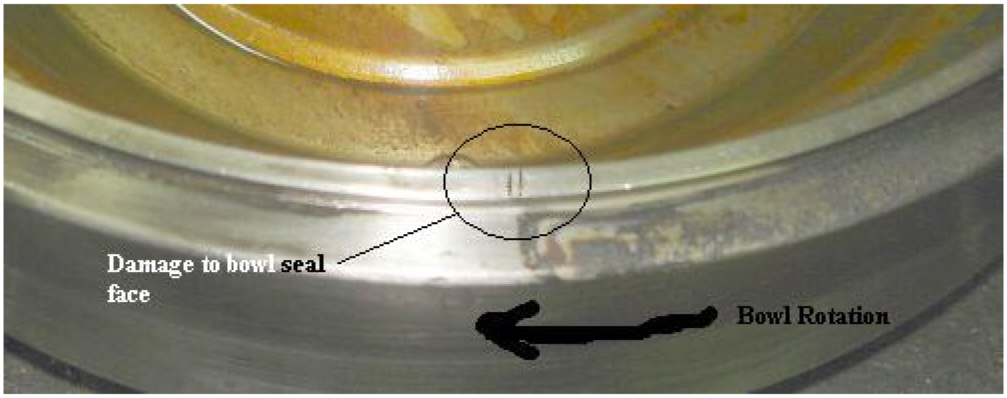
Typical Circuit



Shown is a typical circuit for a lube oil system although it can equally be applied to a fuel system. Control is achieved by the three way valve which eitherdiverst oil to recirculate or sends it to the purifer.

Oil flow rate is controlled by the oil control valve situated before the positive displacement delivery pump which is driven off the purifier horizontal shaft via a weak link arrangement
Back pressure from the purifer is controlled at oultet via the back pressure control valve

Damage

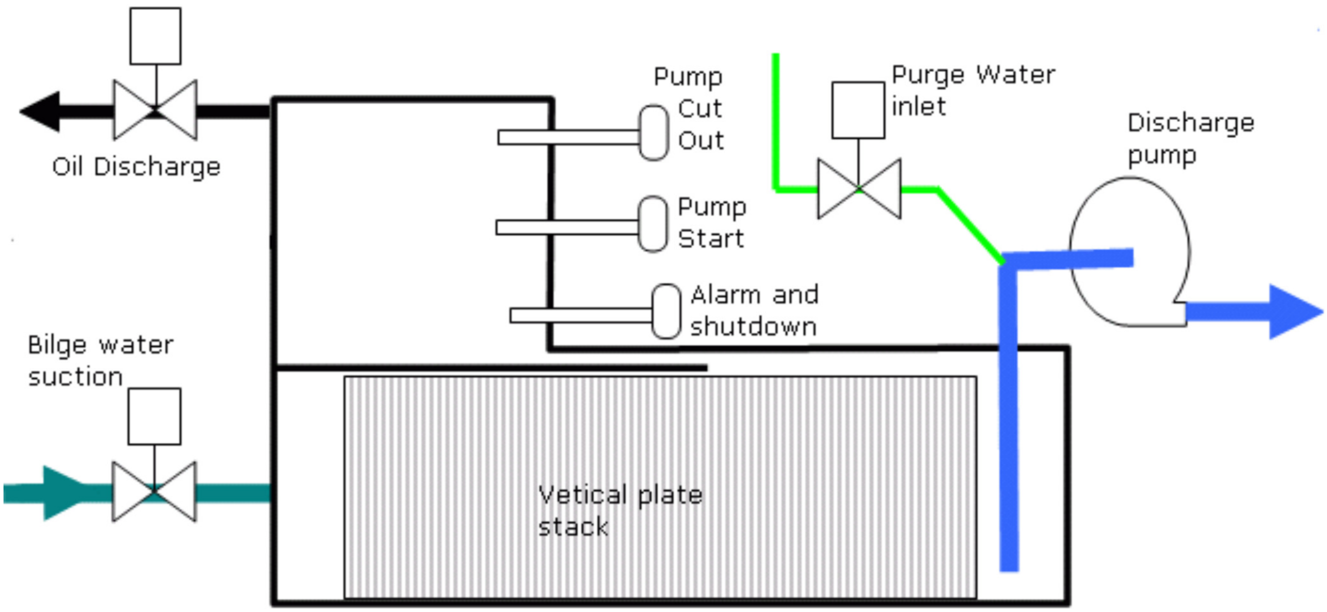


Shown is typical damage to the sealing face of a sliding bowl. This has been caused by either poor assembly or by hard material being trapped aft the bowl closes. Unfortuately it is more likely to be the former.
Failure is detected by loss of sealing water as seen down the sludge shute. In addition there will be carryover to the heavy phase and loss of discharge pressure as the seal is exhausted.

Oily Water seperators

Gravitational

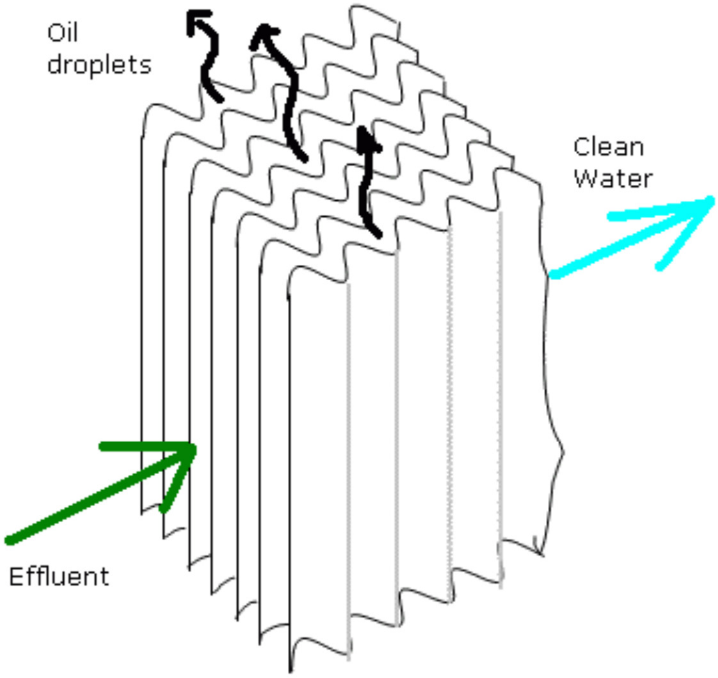
The most common type of oily water seperators found on ships are of the gravitational type. these rely on the difference in SG of the mix to seperate out the oil from the water



Shown above is a gravitational type seperator capable of very good quality effluent discharge. A safety valve (not shown) is mounted on the unit as are test cocks and a drain valve.

Operation

The unit is initially filled with purge water. The discharge from the pump has a sample line take of to a 15ppm monitor. This is lined up and in used with flushing water used until the pump is running. The unit activation button is pressed, the oil outlet valve is closed, the suction valve is opened and the discharge pump is started. Bilge water is drawn through the unit over a vertical arranged plate stack. The 15pp monitor is lined up to the pump discharge sample line



As oil coalescers it is led to the oil discharge chamber. As the oil here builds up the interface drops until the pump cut in probe is activated, the pump is stopped, the suction valve is closed, the oil discharge is opened and the purge water is opened. Oil is forced out of the oil outlet by the purge water.

When the oil water interface reaches the cut out the oil discharge valve and the purge water valve is closed. The suction valve is closed and the pump started.

Alarms and shutdowns

Should the 15ppm equipment detect discharge with oil content over 15ppm it shuts the unit down and activates and alarm
When the pump cut out probe is activated a timer starts, should the oil interface not reach the pump cut in probe within a set time a alrm is sounded and the unit shutdown.
Should the oil interface reach the alarm and shut down probe and alarm is activated and the unit shut down

Centrifugal seperators

Centrifugal seperators have been propsed for the use as oily water seperators. The quality of the output is determined by the throughput rate. The slower the flow of oil through the seperator the better quality output. A question mark exists over their ability to cope with fine emulsions and chemical pre-treatment is recommended.

Seperators capable of emulsion treatment

Gravitational seperators are not capable of operation with oil emulsions , or mixtures containing oil of high sg. Approaching 1 or above. The latter may be improved by the preheating of the mixture before or during the gravitatinal process. The former is more difficult, current regualtion requires the careful control of detergents capable of effecting the operation of the fitted seperator.

This means that modern efficient detergents containing surfactants may be only used in restricted quantities or not at all.

Alternatives to gravitational seperation are now becoming available capable of dealing with these mixtures. The most common at the moment involves the use of Polyaluminium Chloride. This causes the emulsified oil to join to gether (flock). The emulsion is thus broken and the water and oil seperated. Using this process very high quality effluent can be produced with little of no oil or chemical content. The cost is higher than for more conventional gravtiational seperators.

An alternative method is the useof Electrocoagulation. This relies on the three factors of a stable emulsion
-Ionic Charge
-Droplet or Particle Size
-Droplet or particle density

An electrical charge is passed through a scarificial anode made of aluminium. The released ions are attracted to the negatively charge fine droplets of contaminants. The overal effect is one of agglomeration with larger and larger droplet sizes being produced. In addition gas bubbles produced by hydrolysis attach to these droplets increasing there bouyancy. The seperated droplets rising to the surface may be removed. This is a very efficient process and large volumes can be coped with.

Discharge of Oily Water Regulations

Control of discharge of oil

1. *Subject to regualtions regarding discharge of oil mixtures in special areas or in exceptional circumstances listed below, any discharge into the sea of oil or oily mixtures from ships shall be prohibited except when all the following conditions are satisfied:*
    a. for an oil tanker, except as provided for in subparagraph (b) of this paragraph:
        i. *the tanker is not within a special area;*
        ii. *the tanker is more than 50 nautical miles from the nearest land;*
        iii. *the tanker is proceeding en route;*
        iv. *the instantaneous rate of discharge of oil content does not exceed 30 litres per nautical mile;*
        v. *the total quantity of oil discharged into the sea does not exceed for existing tankers 1/15,000 of the total quantity of the particular cargo of which the residue formed a part, and for new tankers 1/30,000 of the total quantity of the particular cargo of which the residue formed a part; and*
        vi. *the tanker has in operation an oil discharge monitoring and control system and a slop tank arrangement as required under regulation 15 of Annex 1 of MARPOL 73/78. (this sets out requirements for approved installations for the handling of tank washings and dirty ballast)*
    b. from a ship of 400 tons gross tonnage and above other than an oil tanker and from machinery space bilges excluding cargo pump-room bilges of an oil tanker unless mixed with oil cargo residue:
        i. *the ship is not within a special area;*
        ii. *the ship is proceeding en route;*
        iii. *the oil content of the effluent withoput dilution does not exceed 15 parts per million; and*
        iv. *the ship has in operation equipment as required under regulation 16 16 of Annex 1 of MARPOL 73/78.(Oil discharge monitoring and control system and oil filtering equipment)*
2. *In the case of a ship of less than 400 tons gross tonnage other than an oil tanker whilst outside the special area, the Administration shall ensure that it is equipped as far as practicable and reasonable with installations to ensure the storage of oil residues on board and their discharge to reception facilities or into the sea in compliance with the requirements of paragraph (1)(b) of this regulation.*
3. *Whenever visible traces of oil are observed on or below the surface of the water in the immediate vicinity of a ship or its wake, Governments of Parties to the Convention should, to the extent they are reasonably able to do so, promptly investigate the facts bearing on the issue of whether there has been a violation of the provisions of this regulation or regulation 10 (discharge in special areas) of this Annex. The investigation should include, in particular, the wind and sea conditions, the track and speed of the ship, other possible sources of the visible traces in the vicinity, and any relevant oil discharge records.*
4. *The provisions of paragraph (1) of this regulation shall not apply to the discharge of clean or segregated ballast or unprocessed oily mixtures which without dilution have an oil content not exceeding 15 parts per million and which do not originate from cargo pump-room bilges and are not mixed with oil cargo residues.*
5. *No discharge into the sea shall contain chemicals or other substances in quantities or concentrations which are hazardous to the marine environment or chemicals or other substances introduced for the purpose of circumventing the conditions of discharge specified in this regulation.*
6. *The oil residues which cannot be discharged into the sea in compliance with this regulation shall be retained on board or discharged to reception facilities.*
7. *In the case of a ship, referred to in regulation 16(6) of this Annex, not fitted with equipment as required by regulation 16(1) or 16(2) of this Annex, the provisions of paragraph (1)(b) of this regulation will not apply until 6 July 1998 or the date on which the ship is fitted with such equipment, whichever is the earlier. Until this date any discharge from machinery space bilges into the sea of oil or oily mixtures from such a ship shall be prohibited except when all the following conditions are*

satisfied:

a. the oily mixture does not originate from the cargo pump-room bilges;
b. the oily mixture is not mixed with oil cargo residues;
c. the ship is not within a special area;
d. the ship is more than 12 nautical miles from the nearest land;
e. the ship is proceeding en route;
f. the oil content of the effluent is less than 100 parts per million; and
g. the ship has in operation oily-water separating equipment of a design approved by the Administration, taking into account the specification recommended by the Organization.

Special Areas

1.
   a. Any discharge into the sea of oil or oily mixture from any oil tanker and any ship of 400 tons gross tonnage and above other than an oil tanker shall be prohibited while in a special area. In respect of the Antarctic area, any discharge into the sea of oil or oily mixture from any ship shall be prohibited.
   b. Except as provided for in respect of the Antarctic area under subparagraph 1(a) of this regulation, any discharge into the sea of oil or oily mixture from a ship of less than 400 tons gross tonnage, other than an oil tanker, shall be prohibited while in a special area, except when the oil content of the effluent without dilution does not exceed 15 parts per million.

2.
   a. The provisions of paragraph (1) of this regulation shall not apply to the discharge of clean or segregated ballast.
   b. The provisions of subparagraph (1)(a) of this regulation shall not apply to the discharge of processed bilge water from machinery spaces, provided that all of the following conditions are satisfied:
      i. *the bilge water does not originate from cargo pump-room bilges;*
      ii. *the bilge water is not mixed with oil cargo residues;*
      iii. *the ship is proceeding en route;*
      iv. *the oil content of the effluent without dilution does not exceed 15 parts per million;*
      v. *the ship has in operation 15ppm oil filtering equipment of approved design*
      vi. *the filtering system is equipped with a stopping device which will ensure that the discharge is automatically stopped when the oil content of the effluent exceeds 15 parts per million.*

Exceptions

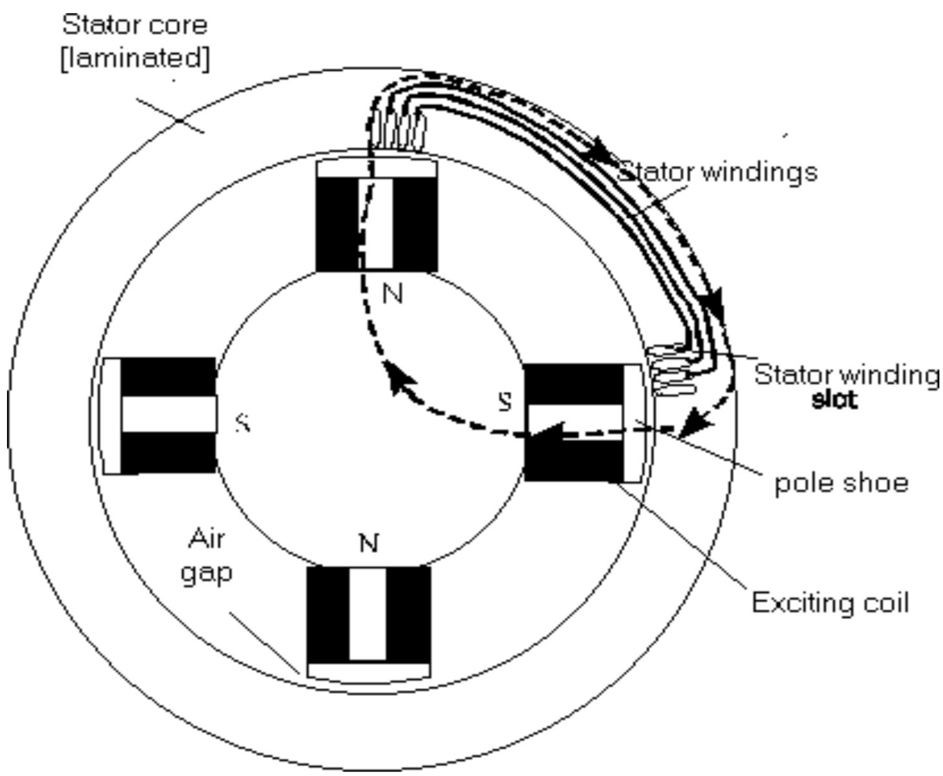
a. the discharge into the sea of oil or oily mixture necessary for the purpose of securing the safety of a ship or saving life at sea; or
b. the discharge into the sea of oil or oily mixture resulting from damage to a ship or its equipment:
   i. *provided that all reasonable precautions have been taken after the occurrence of the damage or discovery of the discharge for the purpose of preventing or minimizing the discharge; and*
   ii. *except if the owner or the master acted either with intent to cause damage, or recklessly and with knowledge that damage would probably result; or*
c. the discharge into the sea of substances containing oil, approved by the Administration, when being used for the purpose of combating specific pollution incidents in order to minimize the damage from pollution. Any such discharge shall be subject to the approval of any Government in whose jurisdiction it is contemplated the discharge will occur.

Generators

The Alternator

The synchronous machine consists essentially of (a) a field system excited by direct current and (b) an armature. Almost invariably the armature is the stationary member and the field system the rotating member. The induced e.m.f. in the armature winding is a motionally induced e.m.f. and its mode of production identical with that of the D.C. machine. The only difference is that it is the magnetic field which moves whereas the armature conductor is stationary.

As with a D.C. machine the e.m.f. induced in an individual armature coil ia an alternating e.m.f. and consequently by bringing the winding out to fixed terminals, the e.m.f. between these will be alternating also. The complete fixed armature, that is magnetic core and windings, is called the stator, and the rotating field system the rotor. The general constructional features of a salient pole alternator are shown below



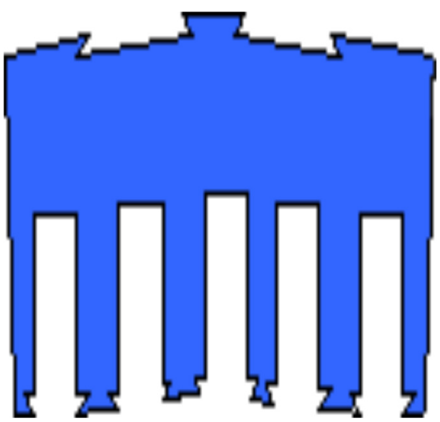
As the field system rotates and carries its flux with it, each portion of the stator core will experience reversals of magnetisation, and therefore, as in a direct current machine, the core has to be laminated. For ventilation purposes, a series of radial ventilating ducts are provided. Since the field system rotates, its exciting winding has to be fed by means of two slip rings, but as the excitation voltage is low and the power taken by the field winding small, these present no difficulties

A salient pole has one field coil per pole, very like a D.C. machine. For the very high speeds of turbine driven alternators it is necessary to adopt a cylindrical construction for the rotor and in such a case the field winding has to be housed in a number of slots. A simplified form shows the cross section of a four pole turbo alternator , the dispostion of the rotor field of a turbo alternator rotor may be as high as 40,000 ft per min or 200 metres per sec. The stresses due to centrifugal force are exceedingly high. The rotors are thus made from steel forging, or in some cases from thick steel discs bolted together.

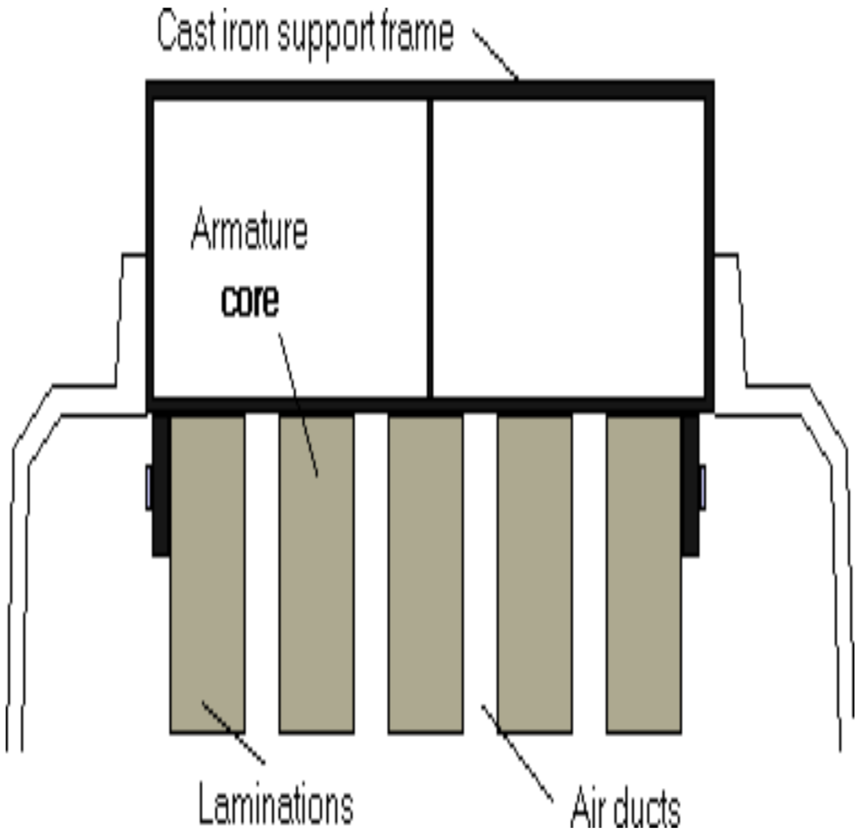
high speed rotor

The axial length is normally considerably greater than the diameter. Has the advantage of great strength and stiffness. The exciting current is carried by bar type conductors in the groups of slots shown below. All currents in one group are in the same direction , those on the next group on the opposite direction. Flux produced is distributed over surface approximately according to sine law.

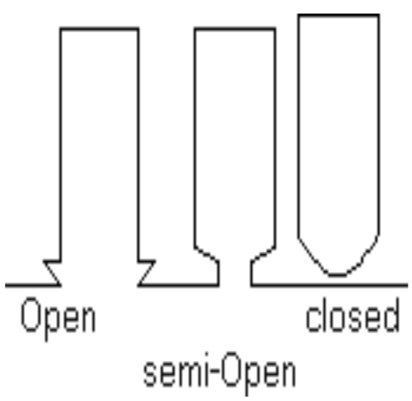
Details of stationary armature alternators.



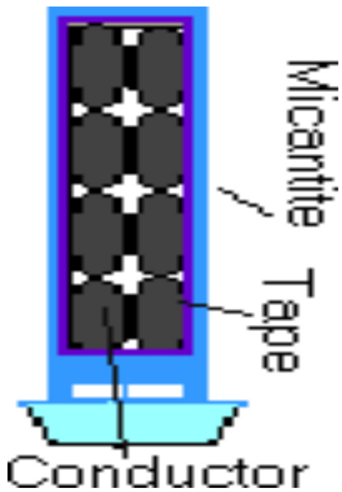
Armature stampings pressed out of sheets of special magnetic iron or steel alloy. In the smaller sizes the stampings are pressed out in compete rings



Section through top stator of salient pole machine. The armature core is built up of laminations which are held tightly together by end clamping rings. Spacing strips inserted at intervals leave ducts for cooling air to pass through. The air is driven through by the fan action of the rotor and escapes via the apertures in the cast iron supporting frame.

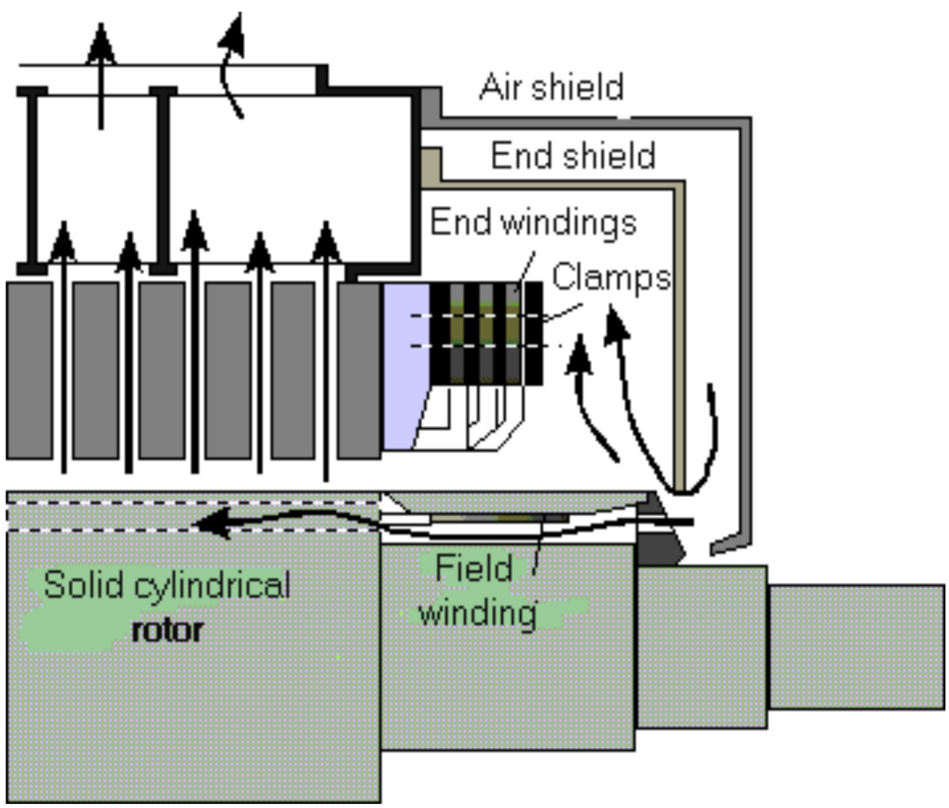


Types of armature slot. The filled slot has round wires but it is common to have rectangular conductors to economise slot space.



Sectional simplified diagram of a turbo alternator

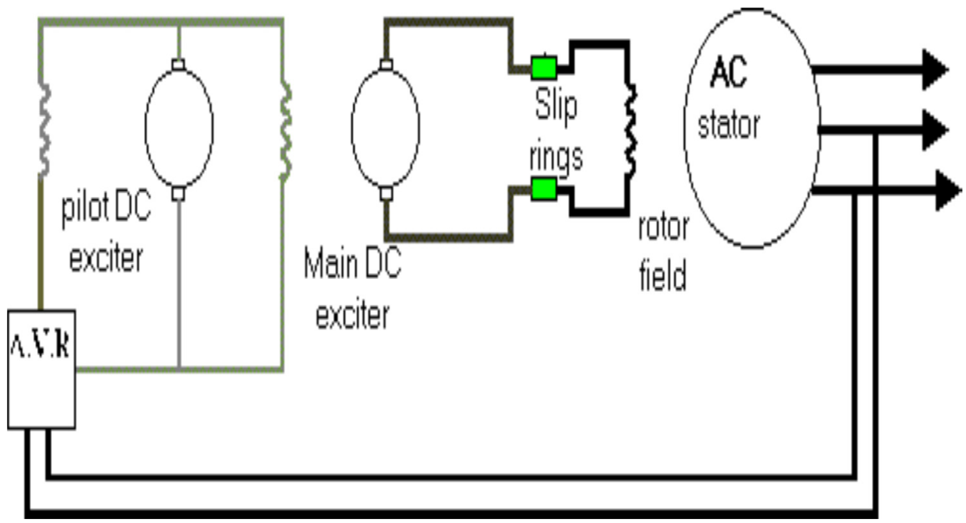
The rotor is turned from a steel forging ans slotted to carry the exciting windings the slots being arranged as shown above. Because of the high running speed, alternators for large outputs have a considerable axial length compared with rotor diameter.



Layouts of A.C. generators

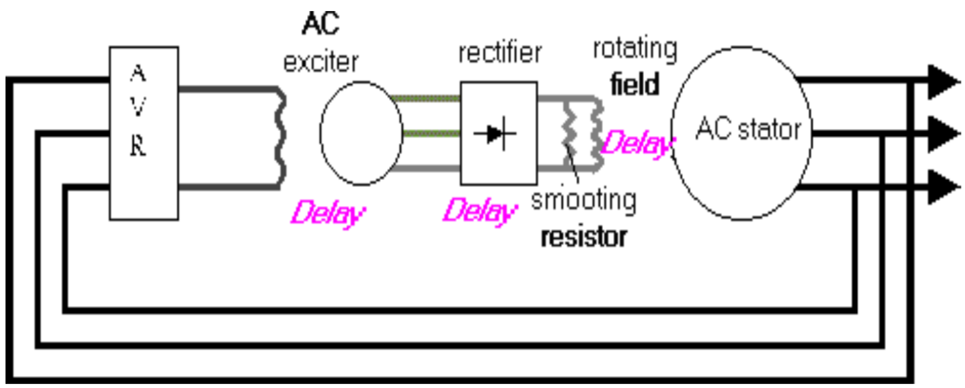
Conventional excitation scheme (Rotary)

Separately excited D.C. exciter (Out dated)



Brushless excitation scheme using shaft mounted diodes (Rotary)

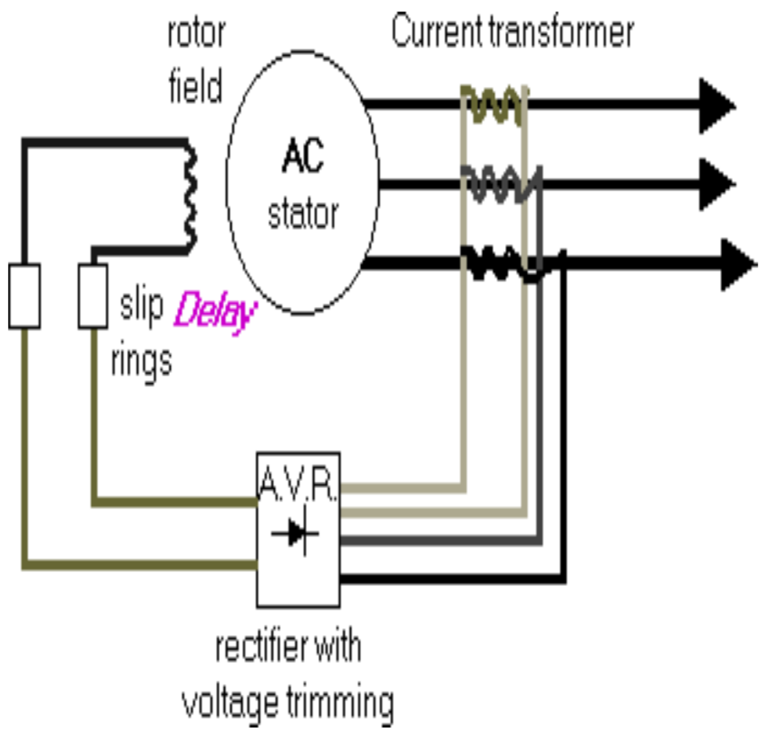
Indirect self excitation (Error)



Comparison of the value required to control with a fixed value. When the variable differs from a fixed reference value an 'error' exists and the function of the controlling medium is to restore equilibrium e.g. if the voltage output falls on the brushless rotary excited alternator the a.v.r. controls the exciter field to restore equilibrium.

Modern compound scheme (static)

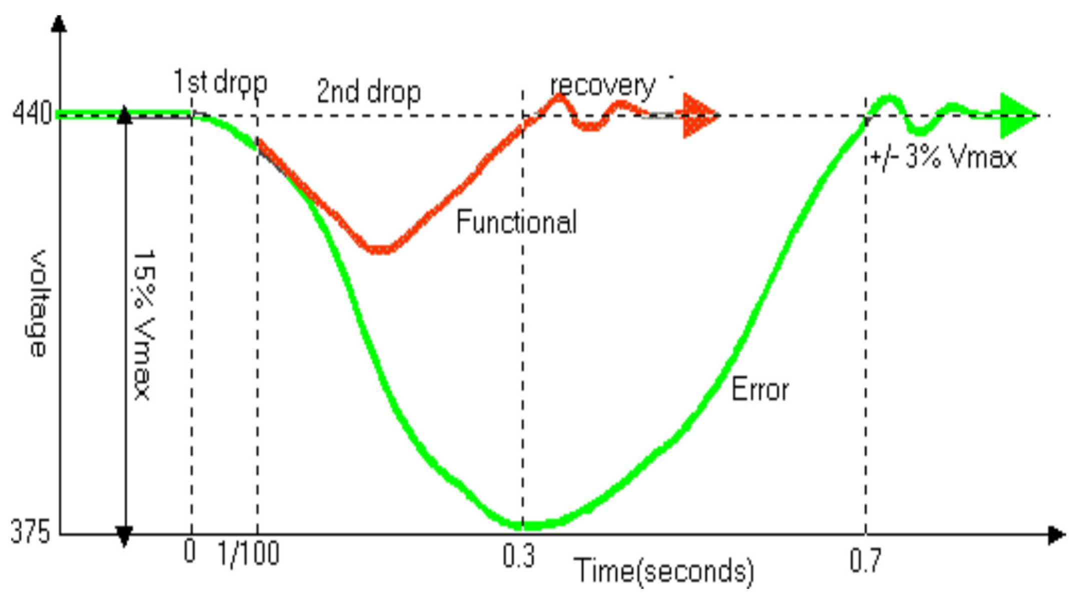
Direct self excited (Functional)



Control of the voltage to a set value is achieved by the inherent characteristics of the machine.

A compound wound d.c. generator with a level compound characteristic has additional current in the series field under load conditions. In the self excited compound alternator there is a constant amount of excitation required for no load condition. Additional excitation due to more current form the current transformers is obtained in response to extra external demands

Recovery graphs for 'functional' and 'error' layouts



Shaft driven generating system

Methods of drive

1. Belt or chain driven
2. Direct coupling engaging the propeller shaft
3. Power taken from the main gearbox.
4. Power taken from the free end of the engine

With D.C. auxiliaries power can be taken by either a chain or belt drive from the propulsion system with an A.V.R. maintaining constant voltage.

For A.C. systems methods used include the use of a D.C. generator with an D.C./A.C. converter, or direct A.C. generation. With the latter either a constant speed drive is required or a frequency converter. With either method the revolutions at which the shaft alternator can be used is limited. In this way direct drive systems will generally be fitted in conjunction with a C.P. system which maintains constant engine speed under full away conditions.

Advantages

i. *Saving on fuel costs, allows efficient use of heavy rather than gas oil*
ii. *reduced maintenance costs*
iii. *Capital saving on reduced number of auxiliary sets*
iv. *Reduced space and weight*
v. *Reduction in noise*

Disadvantages

i. *Power available for propulsion reduced*
ii. *Capitol cost of plant*
iii. *Auxiliaries required for manoeuvring, although some medium speed plants are capable of manoeuvring with shaft alternators and C.P. system*
iv. *Complicated constant speed or frequency gear required with slow speed engines*

Air Gap

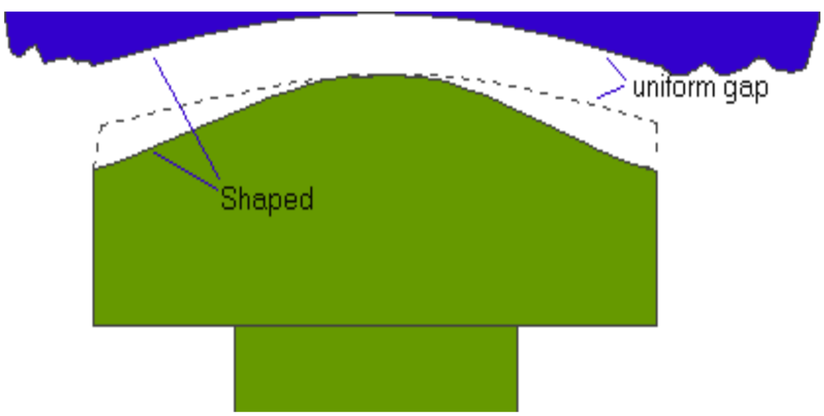
If the air gap around a rotor is not uniform the motor may not start in certain positions. Because the rotor is not centred, probably due to worn bearings, there is an out of balance magnetic pull.

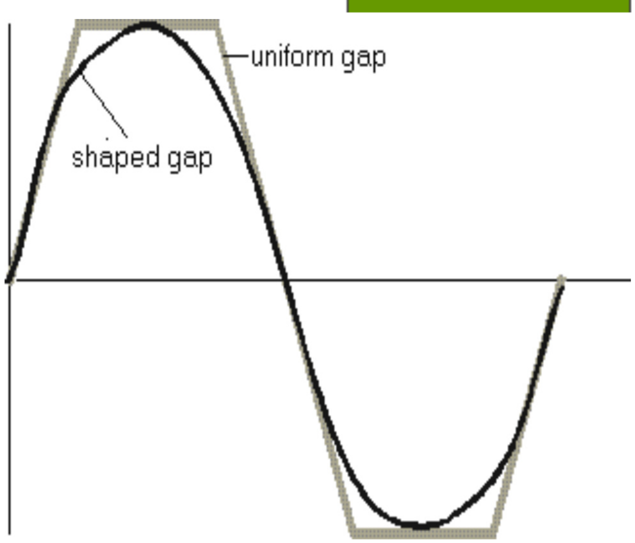
Radial play in between the shaft and the housing should be detected by hand and bearing wear detected by feeler gauge between the rotor and the stator, or armature and field poles may be measured at three or four fairly equidistant points around the machine. If possible one measurement should be made at the bottom of the machine and another in line with the drive. Compare with previous records to check wear. At minimum air gap. Clearance of the bearings should be renewed to avoid the possibility of the rotor rubbing on the stator.

On small machines two feelers on opposite sides of the rotor should be used to avoid error caused by rotor movement from normal position when only one feeler gauge is used.

In synchronous motors and D.C. motors sparking may occur if the radial air gaps between the armature and the field poles are unequal. If necessary renew bearings or add or remove soft iron shims from under the pole shoes. Unequal field strength has a similar effect of sparking at the brushes. This might be due to short circuit or earth fault on the field coils, or a short circuit on the shunt and field coils.

An increase of air gap gives an increase in 'reluctance'.
In a salient pole A.C. generator this fact may be used to produce a sinusoidal flux density curve by gradually increasing the length if the air gap towards the pole tips.





In the induction motor the air gap should be as small as possible if the motor is to act with a high power factor. An increase in air gap increases the reactance of the motor and lowers its power factor. Small motors are accurately machined and centring of the rotor is very important so ball or roller bearings are fitted.

Air gap	Motor size
0.25mm	1kW
0.75mm	10kW
2.0mm	100kW

Parallel operation of generators

D.C. generators

For compound wound D.C. generators it is usually sufficient to ensure that the voltages of the incoming generator is the same as the bus bar voltage. The equalising connection joining the junctions between the armatures and their series fields is incorporated in the circuit breaker in such a way that the equalising connection is automatically closed before and opens after, the main contacts. By adjustment of the shunt field regulator the load sharing may be controlled

A.C. alternators

To parallel alternators the following conditions are required;

1. Same voltage-checked with the voltmeter
2. Same frequency-checked with the frequency meter and synchroscope
3. Same phase angle-checked with synchroscope
4. Same phase rotation-checked with rotation meter. Only important when connecting shore supply, or after maintenance on switchgear or alternator.

Load Sharing Of Alternators In Parallel

Alternators in parallel must always run at the same speed. After a machine has been paralleled and is required to take up its share of the load, this will not be achieved by adjusting the field excitation current. Although the increase in e.m.f. will cause a current to flow in the busbars, and this will show on the machines ammeters, this is a reactive current that lags the e.m.f. by 90o and produces a reactive (kVAr) but not kW. Its only effect is to alter the operating power factor of the alternator.

More power may be obtained at the bus bars from the incoming alternator only by supplying more power to its prime mover. This increase of steam or fuel supply is achieved by altering the governor setting either electrically or manually.

After adjusting the governor the incoming machine takes up its desired amount of the kW loading and this is recorded on the machines watt meter. However, if the kW loading is shared equally between two machines it may be found that the Load Current of the incoming machine is more or less than the other machine. This is fue to the incoming machine having a different power factor. This may be corrected by adjusting the excitation of the incoming alternator.

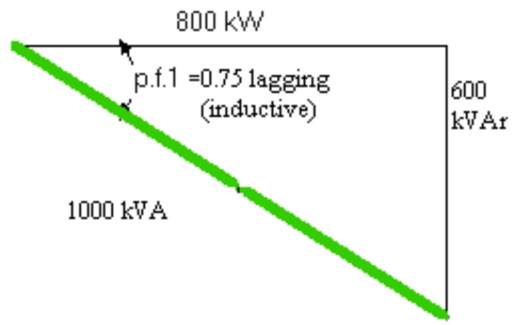
Thus after paralleling an alternator;

i. *Adjust prime mover governor until kW loading is correct*
ii. *Adjust field excitation current until current sharing is correct.*

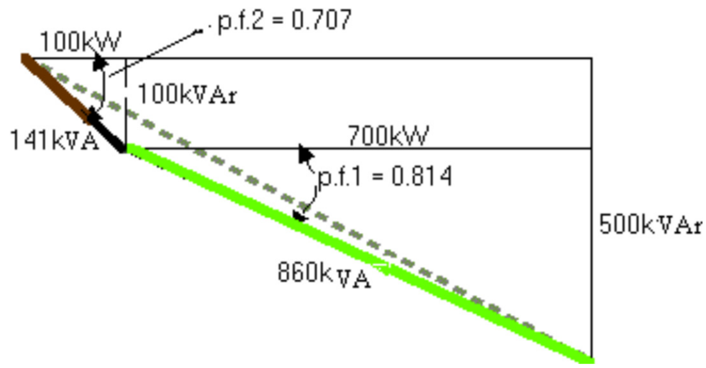
If the alternators have similar load characteristics, once adjusted, the load will continue to be shared. If the load characteristics of alternators vary, the kW loading and load current sharing may require readjusting under different load conditions.

Load sharing of alternators

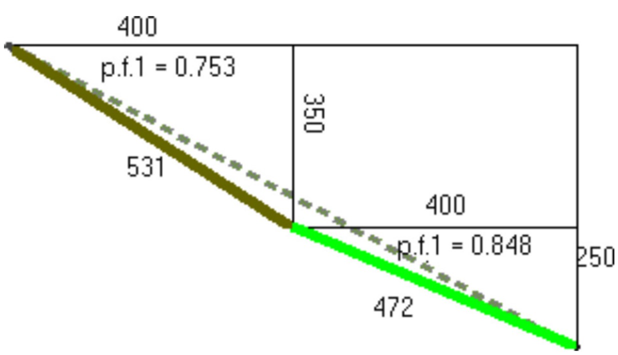
No1 on load



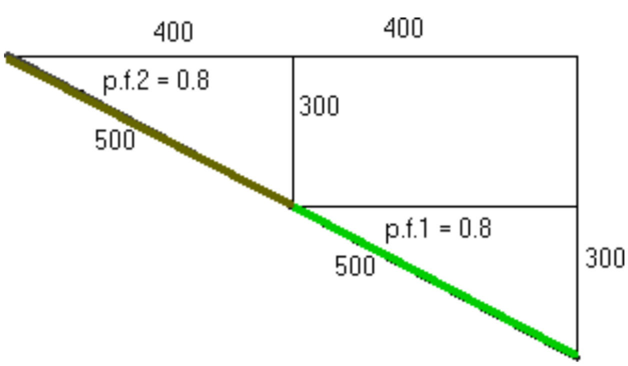
No1 on load, No2 synchronised and taking 100kW



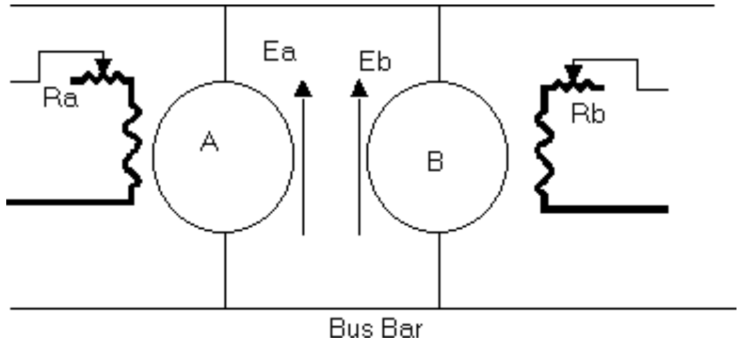
No1 and No2 sharing load after adjusting governor settings, excitation adjusted to prevent excessive volt drop in No2



No1 and No2 sharing load with balanced power factors by adjusting excitation



The effects of altering Torque and Excitation on single phase alternator plant-and by extrapolation a 3-phase circuit

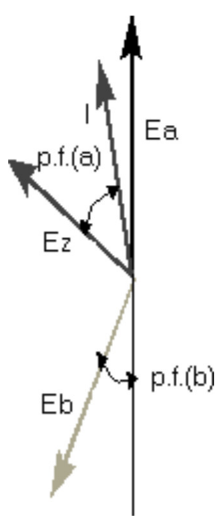


Before paralleling, by varying Rb, adjust the excitation current in the rotor field of 'B' until Va=Vb. When in phase and at the same frequency synchronising may take place.

If there was no external load on the bus bars the torque on the prime movers of A and B is only that required by its own alternator and Ra and Rb are adjusted so that Ea and Eb are equal.

Relative to the bus bars Ea and Eb are acting in the same direction with each other making the top bar positive with respect to the bottom bar.

Varying the driving torque



If the driving torque of 'B' is reduced (less fuel supplied) the rotor falls back by an angle say p.f.(b) giving a resultant e.m.f. of Ez in the closed circuit.

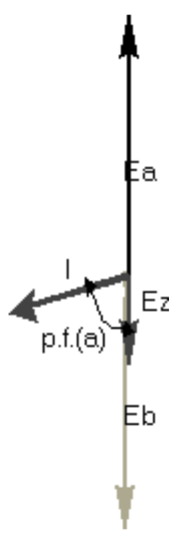
The e.m.f. Ez circulates a current I which lags behind Ez by angle p.f.(a).
This circulating current Iis more or less in phase with Ea and in opposition to Eb.
This means that A is generating power to motor B and this will compensate for any loss of power in the prime mover of B.
Once the power increase in A equals the power loss of B balance is restored and A and B continue to run in synchronism.

Therefore the power is shared by adjusting the torque (fuel input.)

Slight loss of power in B-is taken up by an increase in power from A. The terminal voltage will not vary and the speed and frequency will stay the same or drop only very slightly.

Large loss of power in B-with a large circulating current from A to B the alternator A will try to drive B as a synchronous motor. The amount of full load power required to drive an alternator as a motor is only 2 to 3% for a turbine and 10 to 12% for diesel engine.
As the circulating current flows from A to B the reverse power trip on B will operate after about 3 to 5 seconds.
All the load now falls on A which will probably cause the overload trip to operate and 'black out' .

Varying excitation



Consider A and B are exerting the torque required by its alternator and the generated e.m.f. Ea and Eb are equal. There is no circulating current.
By reducing Rb the excitation current in the field of B can be increased and Eb will increase. Ez is the resultant difference (Eb - Ea) which will give a circulating current I through the synchronous impedances of the two alternators. As the machines are similar the impedance drop in each will be 1/2Ez so the terminal voltage

V1 = Eb - H Ez = Ea + H Ez

Therefore increasing the excitation current will increase the terminal voltage

As p.f.(a) is almost 90^o the Power circulating from B to A is very small

Ez I Cos [p.f.(a)] approx equals Zero (Cos 90^o = Zero)

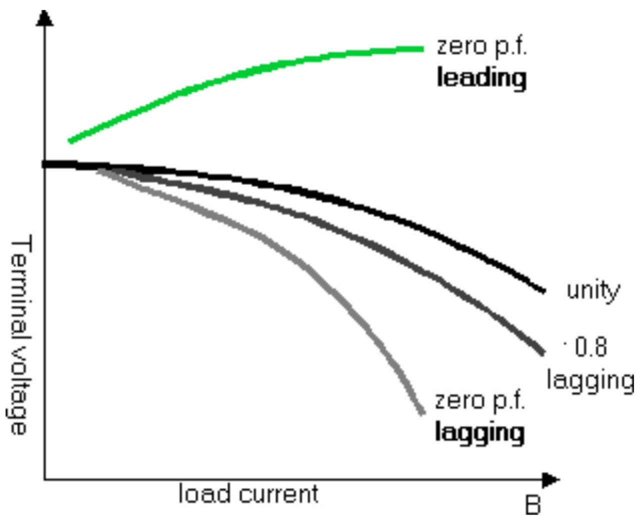
Effect of reducing Excitation

By increasing Rb the reduction of the field excitation current of B will reduce the terminal voltage

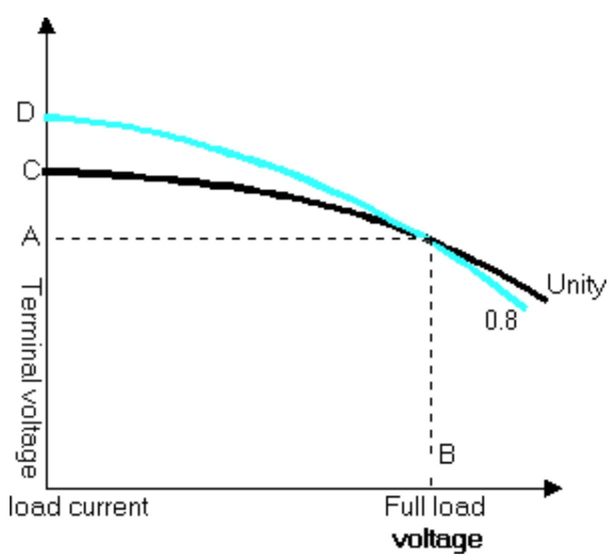
Ea>Eb terminal Voltage V = Ea - H Ez = Eb + H Ez

The circulating current I from A to B will have a large 'Wattless' component. Machine A now has more of the lagging reactive current and its power factor is reduced. Too large a reduction in excitation current in B with subsequent increase in load current in A could cause the current overload trip of A to operate. This could be followed by the low voltage or the overload trip of B operating causing a black out.

Voltage regulation



The graph demonstrates that excitation must be increased (generally) with increasing load to maintain terminal voltage



The worse the power factor the worse the terminal voltage change during load change.

Voltage regulation = DV when load removed/ Full load terminal voltage

At 1.0 p.f. = AC/ OA

At 0.8 p.f = AD/ OA

Therefore lower p.f. = greater voltage regualtion

Limiting voltage dip and response time under impact loading

The effect of a large load suddenly switched on to a small power installation such as a ships plant will be an instantaneous dip in the generator voltage.

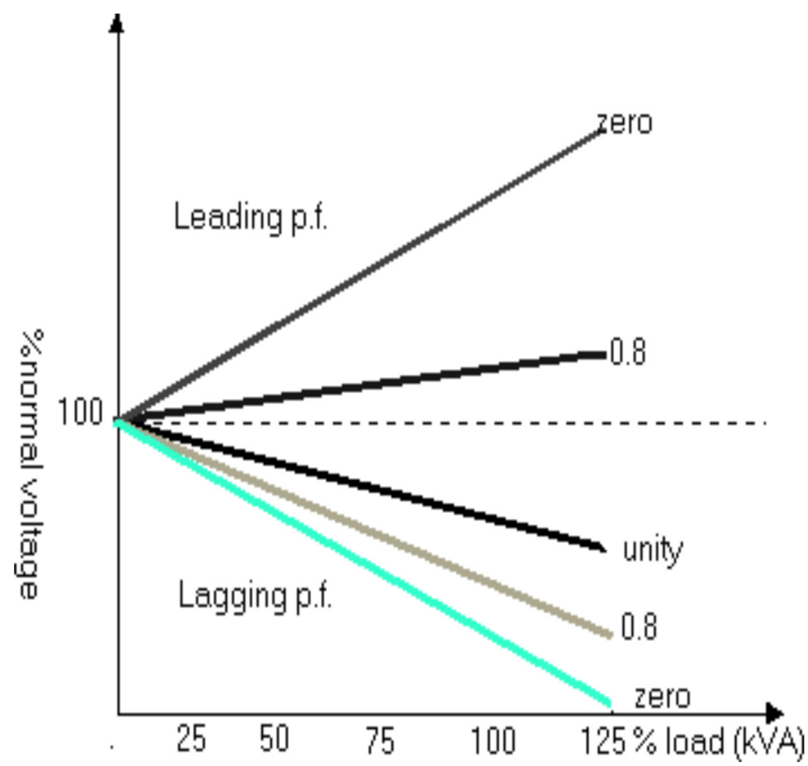
This effect, due to the transient reactance on starting, cannot be obviated either in a self regulated machine, or in a conventional generator with A.V.R.

The sluggish response of the excitation systems limits the speed of voltage recovery.

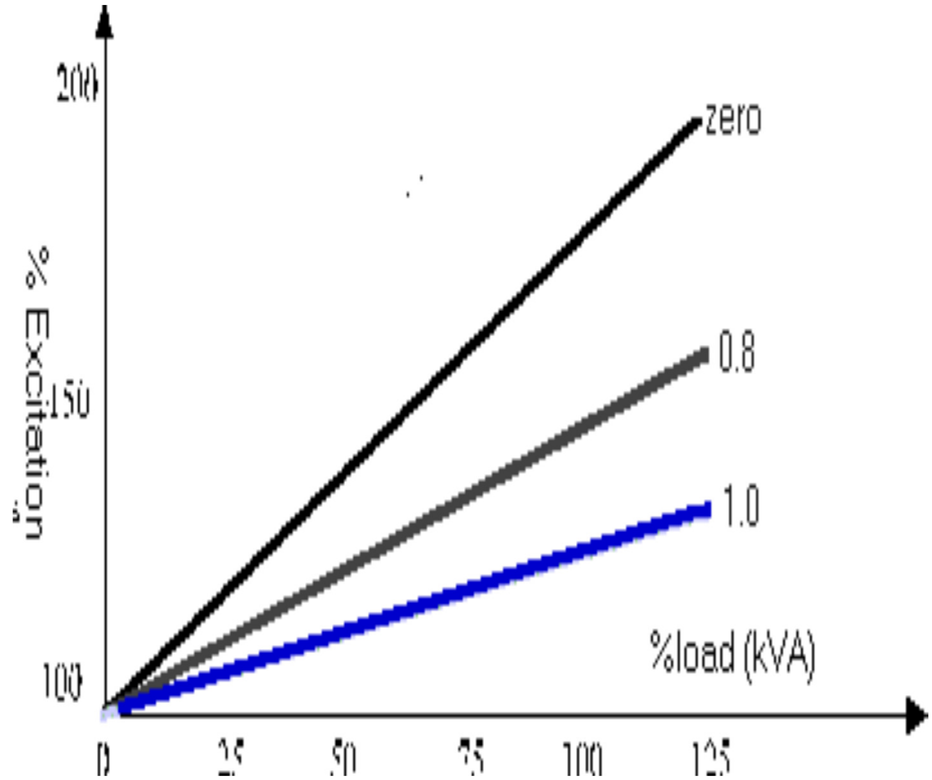
In a self excited generator the dip is less and the recovery time greatly improved. (say 0.3s against 0.7s)

In order to maintain constant voltage, under varying conditions, excitation must be varied.

Variation of voltage at constant excitation



Variation of excitation at constant voltage


200
150
100
% Excitation
zero
0.8
1.0
%load (kVA)
0
25
50
75
100
125

AC switchboards

If voltages exceed 250 volts d.c. or 55 volts A.C. then the switchboard must be dead front (no exposed live parts at the front) of the metal clad type.

Bus bars

High conductivity copper rated to withstand the thermal and electromagnetic forces which would arise in the event of a short circuit at the bus bars with all the generators in parallel. The bus bars will withstand these conditions for the length of time it takes for the alternator circuit breakers to trip or back up fuse to blow.

Certain instruments and controls require a feed direct from the bus bars. Any connection between the bus bars and protecting fuses must be capable of withstanding maximum fault level. Standard practice is to provide a three phase set of fuses, known as 'Back Up' fuses, as near to the bus bars as possible. Connections are then led to the racks of the many instruments fuses fitted.

Circuit breakers

Must be capable of making and breaking under normal conditions and also abnormal conditions such as a short circuit. As the circuit breaker must be able to withstand closing onto a fault conditions without sustaining damage, it is of heavy construction. Fitted with an over current release and overloads with time lags, a circuit breaker can be used as follows;

a. To control the output of a generator
b. As a direct on line starter
c. Control outgoing feeder circuits

On modern switchboards 'draw out' circuit breakers may be fitted. In the open position the whole circuit breaker can be wound clear of the bus bars, thus full inspection and maintenance can be achieved without the necessity of de-energising the bus bars so providing a separate isolating switch.

The 'plug in' contacts joining the circuit breaker to the bus bars are not capable of taking the breaking load and it is essential that the circuit breaker is in the open position before any attempt is made to withdraw it. A mechanical interlock is fitted arranged to trip the circuit breaker before the winding handle can be inserted,

The breaker also has a mid position, in this position the control circuits are still connected with the bus bar connection isolated. The electrical operation of the breaker can then be tested.

Circuit breakers are normally fitted with under voltage protection and tripping is accomplished by shorting or open circuiting the no-volt coil which releases the latching in mechanism. The no-volt coil may also be open circuited by a reverse power relay and an overload trip fitted with a time delay

Instruments

The following instruments are the minimum that must be fitted;

- Bus bar voltmeter and frequency meter
- Volt meter and frequency meter, with selector switch to measure incoming machine conditions
- Ammeter with phase selector switch for each alternator

- Watt meter for each alternator
- Synchroscope and if check synchroscope not fitted lamps
- Earth leakage indicator

Additional instruments that may be fitted

- Watt hour meter
- Power factor meter
- Alternator excitation ammeter
- Alternator excitation volt meter
- kVAr meter
- Share connection supply meter
- Emergency batteries on discharge meter

When a check synchroniser is fitted it is there to prevent connecting an incoming machine to the bus bars whilst out of phase, it is not there as aid to synchronising. In an emergency the 'in synch' light may be used to indicate when the breaker may be closed.

When an incoming machine is selected, its no-volt coil and circuit breaker contactor relay coil are connected in series with contacts on the check synchroniser. These contacts must be closed, that is the machine in phase with the bus bars, before the breaker contactor relay may be energised. If starting from a dead ship the check synchroniser must be switched to off before the first generator is put on the board.

Protection

a. Overload protection-fitted to circuit breakers
b. Reverse power-When motive power is removed an alternator will try to become a synchronous motor and draw current from the circuit. A reverse power relay will operate after about 2 seconds and about 2-3% reverse power for turbines, 10-12% reverse power for diesels. The time delay prevents tripping during paralleling and taking the alternator off the board.
c. Preference trip-automatically , and sometimes sequentially, sheds load from board to maintain supply to essential services during periods of overload.
d. Fuses-Usually of the HRC type
e. Discrimination-The protective device closest to the fault should operate and protect other services
f. Group starter board-Large demand sections may be separated from the main switchboard by fuses and circuit breakers.

Automatic voltage regulators

Shall be supplied separately from all other instrument circuits. Protection should be by fuses mounted as close to the supply connections as possible.

Shore supply connections

a. Where arrangements are made for the supply of electricity from a source on shore or other location a suitable connection box has to be installed in a position in the ship suitable for the convenient reception of flexible cables, it should contain a circuit breaker or isolating switch, fuses, and terminals of adequate size to receive the cable ends.
b. For three phase shore supplies with earthed neutral terminals are to be provided for connecting hull to shore earth
c. An indicator for shore side connection energised is to be provided.
d. A means for checking polarity or phase rotation is to be provided
e. At the connection box a notice indicating ships requirements with respect to supply as well as connection procedure.
f. Alternative arrangements may be submitted for consideration.

Circuit breakers

When selecting a circuit breaker for a particular application the principal factors to consider are; system voltage, rated load current, and fault level at the point of installation

Voltage rating

At medium voltages the phase to neutral voltage may be 250v but the potential difference between two phases with the neutral insulated would be 440v. At these voltages no difficulties should arise in selecting the circuit breaker equipment. However, on a 3.3kV insulated neutral system the phase to neutral voltage is 3.3kV/ж 3 = 1.9kV. If an earth fault develops on one phase the potential of the other two phases to earth is 3.3kV. To ensure the insulation is not subject to excessive stress a circuit breaker designed for a normal system voltage of 6.6kV may be fitted. Also on insulated neutral systems high over voltages may be caused by arcing faults. Medium voltage systems switch gear insulation should be able to withstand such voltages, but 3.3kV and above, the margin of safety is reduced. When a high voltage system is installed both the voltage rating of the circuit breaker and the method of earthing must be considered.

Current rating

Consider three factors;

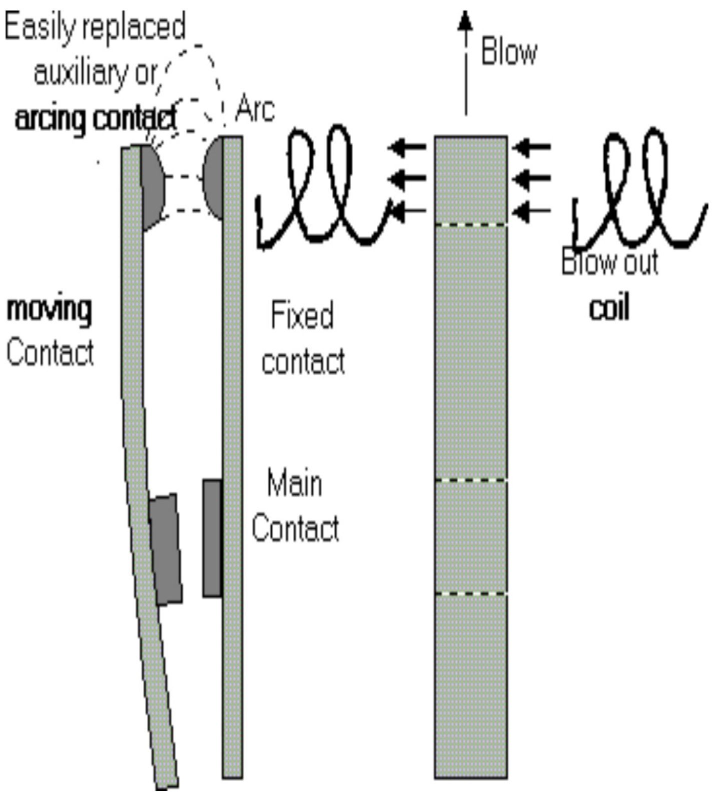
a. Maximum permissible temperature of circuit breaker copperwork and contacts
b. temperature due to LOAD CURRENT
c. Ambient temperature

In industrial use the ambient temperature considered is usually 35^{o}C. If uses in a marine environment temperature of 40^{o}C (Restricted areas) and 45^{o}C (unrestricted areas) are used, therefore the circuit breaker rating may be 'free air' value and this does not consider the degree of ventillation, the number and position of the circuit breakers or the layout of the bus bars. The final switchboard arrangement could be only 80 to 90% of the free air rating

Fault rating

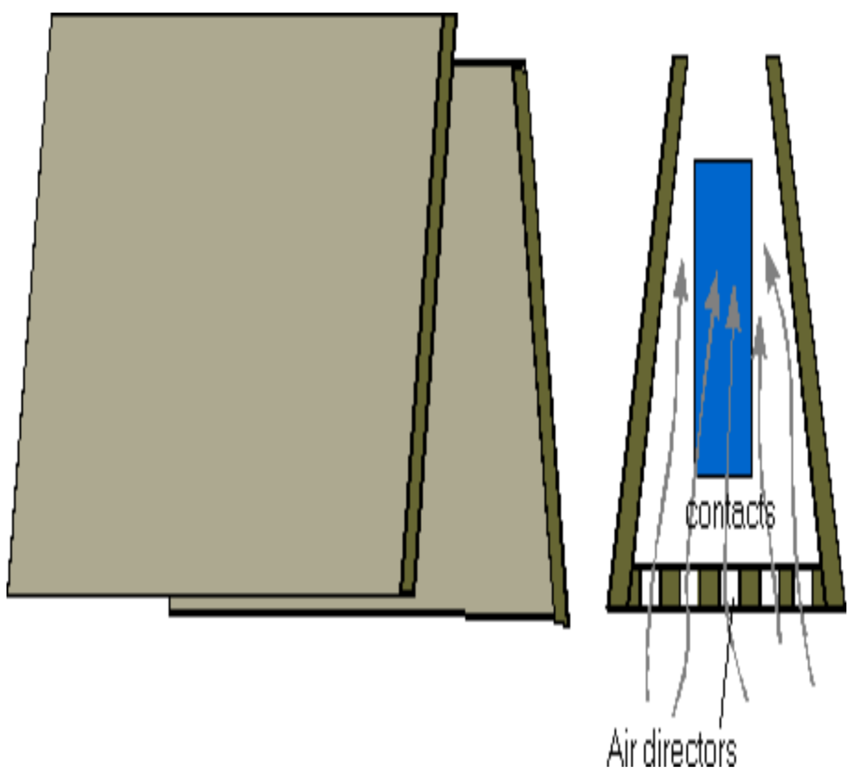
Breakers should be rated to accept a breaking current of about 10 times the full load current. The breaker should also be able to make against a fault condition where the making current may be 25 times the full load current when the contact first make. Circuit breakers must remain closed for a short time when a fault occurs in order to allow other devices which are nearer to the fault to trip first. The breaker should be capable of carrying its breaking current for a specified time of usually about one second.

Arc suppression



Blow force at right angles to arc and field.

The blow out coils, which are connected in series with the circuit breaker contacts, form an electro-magnetic field which reacts with the arc to give a deflecting force which tends to bloe the arc outwards. The increase in effective length of the arc causes it to extinguish more quickly. The blow out coils are protected form the arc by arc resistant material which may be in the form of an air shute.



Hot ionised gases around the arc and contacts are displaced by cold air forming eddy current air flow. This helps to increase resistance between contacts.

Contacts

Attention should be paid to all contacts likely to deteriorate due to wear, burning, inadequate pressure, the formation of a high resistance film or becoming welded together. Faulty contacts are often indicated by overheating when loaded. Different contact materials may need different treatment.

Copper is widely used but is liable to develop a high resistance film, and copper contacts may become welded together if the contact pressure is low and the contents have to carry a high current. Copper is commonly used for contacts which have a wiping action when closing and opening., this action removing the film. Copper contacts are used on knife switches, laminated (brush) contacts of regulators and other controllers, drum contacts, etc.

Carbon and metallized carbon contacts are unsuitable for carrying high currents for long periods but, as they do not weld together, they are used for arcing contacts on some control gear. Pure silver and silver ally contacts tends to blacken in service but the oxide film has a low resistance. Copper- tungsten (sintered compound), grey I colour, is used in contact facing. This material has a high surface resistance which resists heavy arcing and does not weld. Silver tungsten (sintered) has similar properties to copper tungsten but has a lower contact resistance and is less liable to overheat on continuous load..

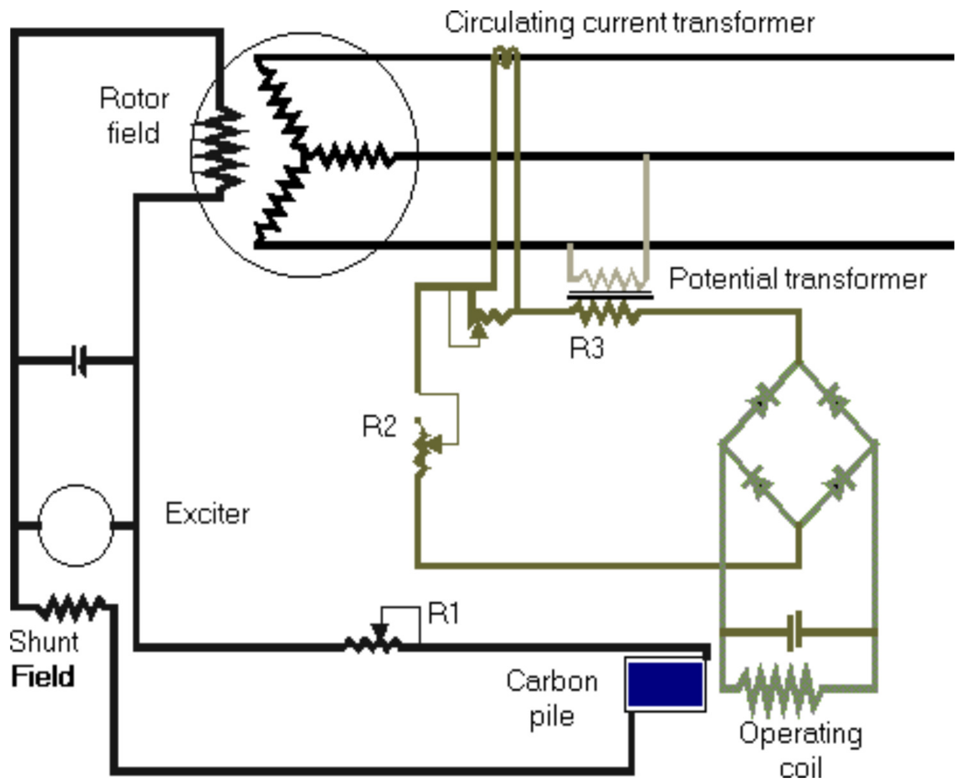
Servicing contacts

Copper contacts should be filed up if necessary to restore the profile required to ensure correct wiping action. Copper contacts which have become burnt or pitted or otherwise damaged, may be carefully dressed with a file. Emery cloth should not be used. Some contacts are provided with pressure adjustment, so if the contact pressure is reduced by dressing it should be readjusted. Using a spring balance pulled in a direction normal to the contact surface a reading should be taken when a piece of paper placed between the contacts is released. Inadequate spring pressure may also be due to the pressure springs becoming weak due to fatigue or overheating.

Carbon contacts should receive the same attention as copper contacts except that they should not need lubrication. Silver, Silver alloy and copper tungsten contacts do not require cleaning. As there is no need to remove surface film from pure silver contacts they may be used for light butt contacts.

Where some contacts have the appearance of pitting on both faces this is sometimes referred to as being 'burnt in'. Some manufacturers recommend that the contacts, unless there is loss of material, are not dressed as this may destroy the contact area.

AVR's



R1-Sets volts value
R2-Trimming resistor (Power factor correction)
R3-Trimmer
Carbon pile-Control resistance for AVR
Operating coil-Along with carbon pile form the controlling elements
CCT and PT-Are the detecting elements, the CCT acts as a feed forward device indicating future voltage changes by detecting variation in current flow
Stabilising element-Is the capacitor across the Exciter (may be replaced by a resistor)

The A.C. voltage is applied to the operating coil through a full wave rectifier. This A.C. voltage supply induced in the potential transformer and the circulating current transformer may vary under varying load conditions such as direct on line starting of relatively large motors. The capacitor connected across the coil smoothes the D.C. output from the rectifier.

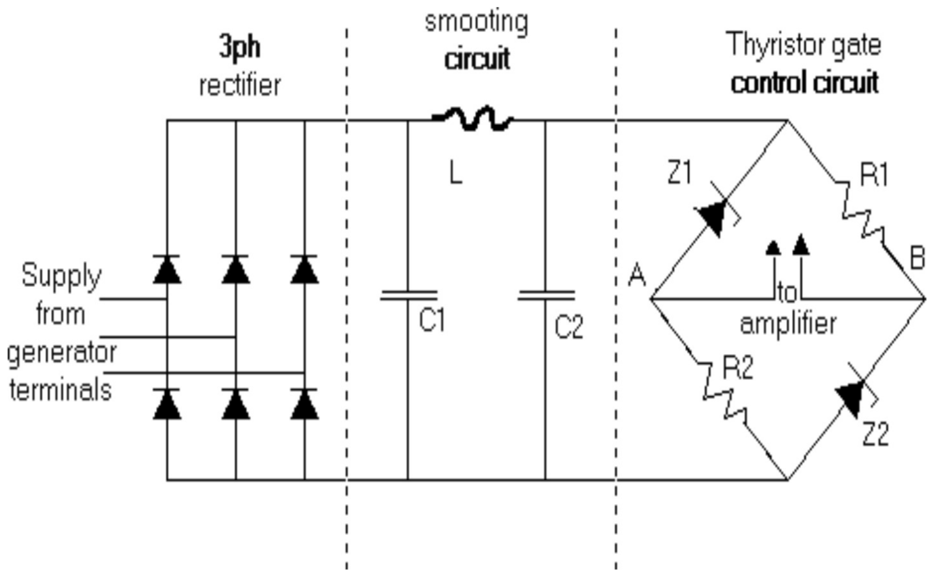
If the A.C. applied voltage falls, the field of the solenoid weakens, and the resistance of the carbon pile decreases. With less exciter circuit resistance the current in the exciter field increases thus increasing the output voltage of the A.C. generator.

The automatic voltage regulator voltage output may be adjusted with the hand regulator R1 in the exciter field. Before synchronising the alternator the open circuit voltage is adjusted with the hand regulator R1.

After synchronising, and after the kW loading has been adjusted on the prime mover governor, the field excitation under steady load conditions may be adjusted using the Trimming resistor R2. Using the trimming resistor the power factor of the incoming machine will be equalised with the machines already in use.

If the load power factor now changes then the terminal voltage will regulate badly, e.g. a rise from 0.8 to Unity Power factor will cause a rise in terminal voltage of about 20 %. So a small Voltage Trimmer R3 is provided across each current transformer to adjust terminal voltage when there is a change in overall power factor

Modern A.V.R. (Zener Bridge)



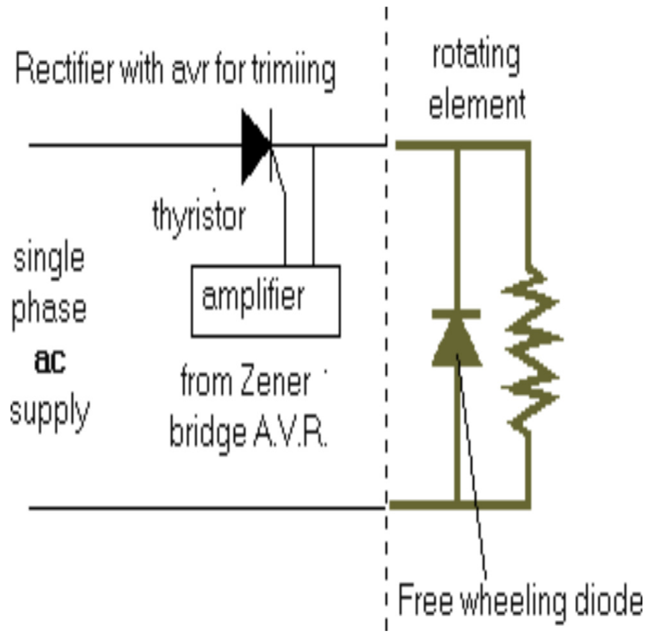
Voltage across the Zener diodes remains almost constant independent of current variations. Smoothed D.C. output is applied to the voltage reference bridge. This bridge is balanced at the correct generator voltage output with no potential difference between 'A' and 'B'.

If the generator voltage fails, current through the bridge arms falls and current flows from 'A' to 'B' through the amplifier.

If the generator voltage falls, current through the bridge arms falls and current flows from 'B' to 'A' through the amplifier.

If the generator voltage rises, Current through the bridge arms rises with current flow from 'A' to 'B' through the amplifier.

The signal from the amplifier will automatically vary the field excitation current, usually through a silicon controlled rectifier (Thyristor) control element.



The Silicon Controlled Rectifier (Thyristor) is a four layer, three terminal, solid state device with the ability to block the flow of current, even when forward biased, until the gate signal is applied. This gate signal could come from a Zener diode Voltage reference bridge. The gate signal will switch on the forward biased S.C.R. and current flows through the exciter field. When reverse biased the S.C.R. will again block current flow. Due to inductance of the field winding the S.C.R. would continue to pass current for a part of the negative cycle. By fitting a 'free wheeling' diode the current though the Thyristor falls quickly at the end of the positive cycle. In some circuits the excitation current is designed to be excess of requirements, so that the gate signal reduces flow.

Insulated neutral system

Advantages

i. *This system avoids the risk of loss of essential services e.g. steering gear*
ii. *If the neutral was earthed and a short circuit on one phase causes the fuse in that phase to blow the system would now be singled phasing and may burn out motors*
iii. *In an insulated neutral, one earth fault does not interrupt the supply but an earth leakage detection system will give warning.*
iv. *Low earth fault currents in insulated systems gives a much less fire risk.*

Disadvantages

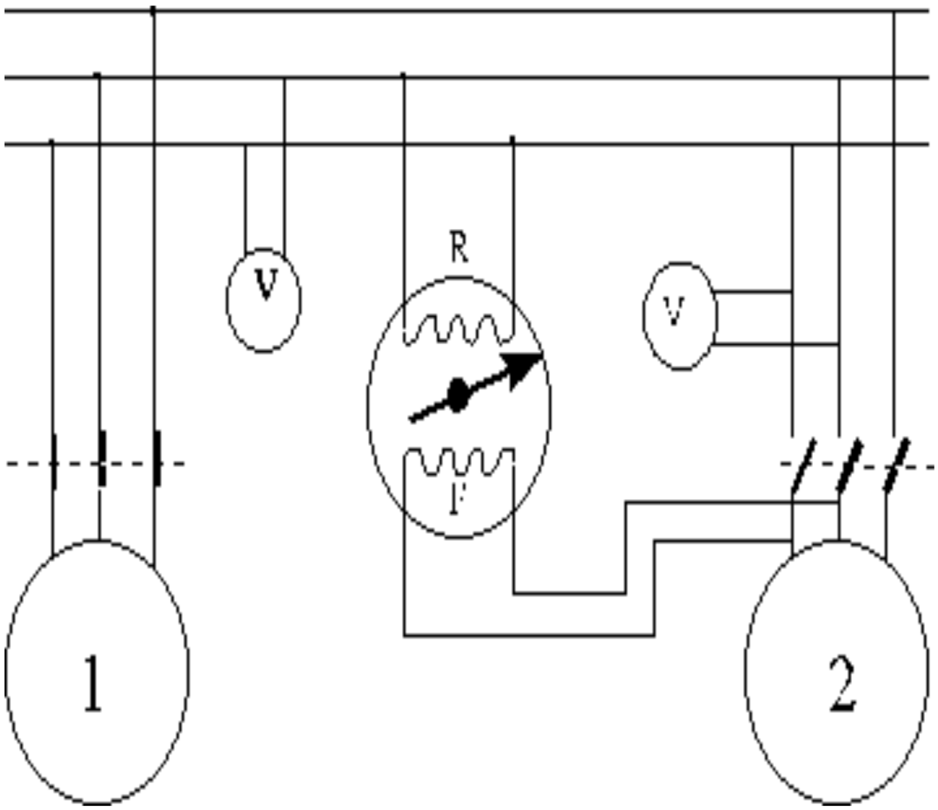
i. *On the insulated system the voltage to earth is 1.73 Vph e.g. 440v vs 250v*
ii. *Tracing an earth fault is more difficult because although selective tripping may trace the earthed circuit, the actual position on the circuits may still be difficult to locate. Resonant or intermittent faults in say a contactor solenoid or a transformer with an insulated neutral can cause voltages to be magnified to say 4 times the normal voltage to earth (250v x 4 = 1000v)*

Note: electrical shock is not reduced by using a non-earthed neutral as large voltages are involved. Both systems are equally dangerous

Earthed neutral system

When an earthed neutral system of generation is used earthing is to be through a resistor. The resistor is to be such that it limits the earth fault current to a value not greater than the full load current of the largest generator on the switchboard section and not less than three times the minimum current required to operate any device against

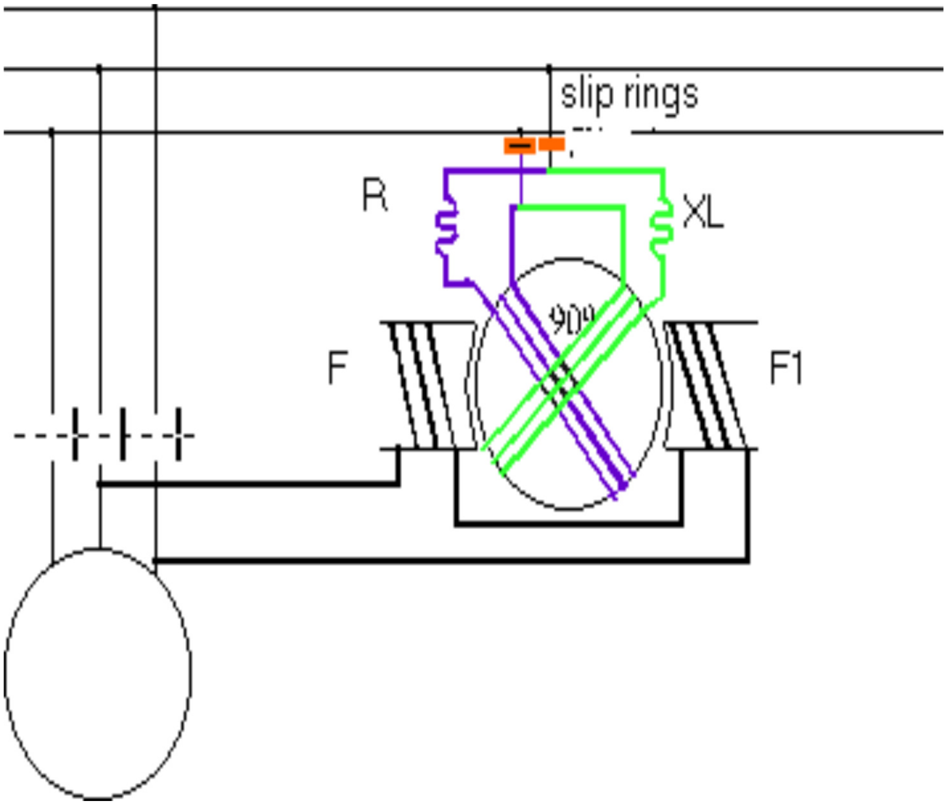
Synchroscopes



The armature of the synchroscope carries two windings at right angles to each other and is capable of rotation between field poles F F1

R is a non inductive resistance and XL is a highly inductive resistance both connected to one phase of the bus bars. This produces a field which rotates relative to the armature at the bus bar frequency. When the incoming machine is connected to the coils of the field poles a pulsating field is produced at the same frequency as the incoming machine.

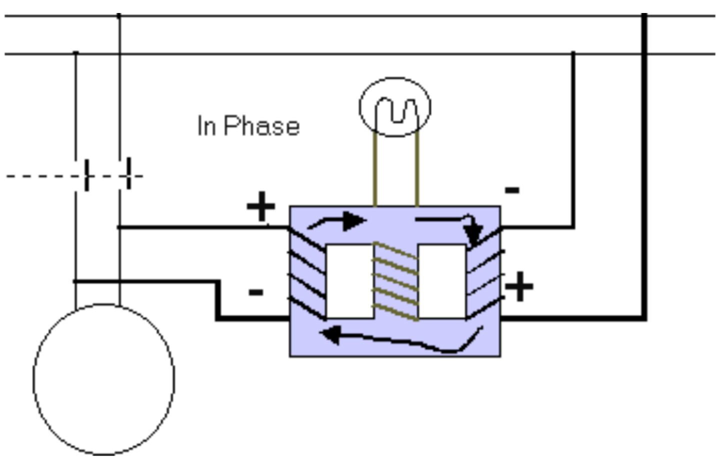
If the two fields are not at the same frequency then the armature will rotate at a speed equal to the difference.



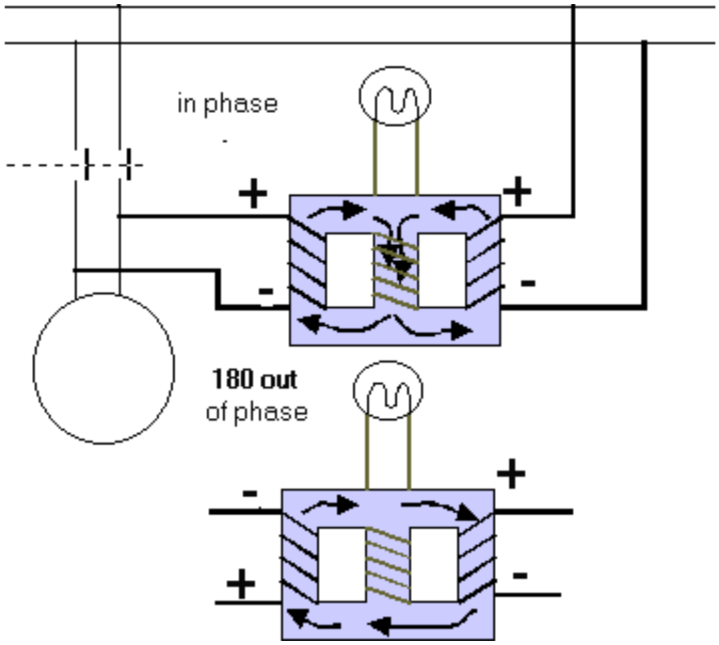
In the modern rotary synchroscope there are no slip rings. The rotor has two soft iron pole pieces and with its shaft carrying the pointer it is magnetised by coil R from the bus bars. With this coil is fixed adjacent to the shaft, therefore, there are no moving coils, contacts or control springs.

Single Phase

Single phase synchronising with lamps Lamps Dark



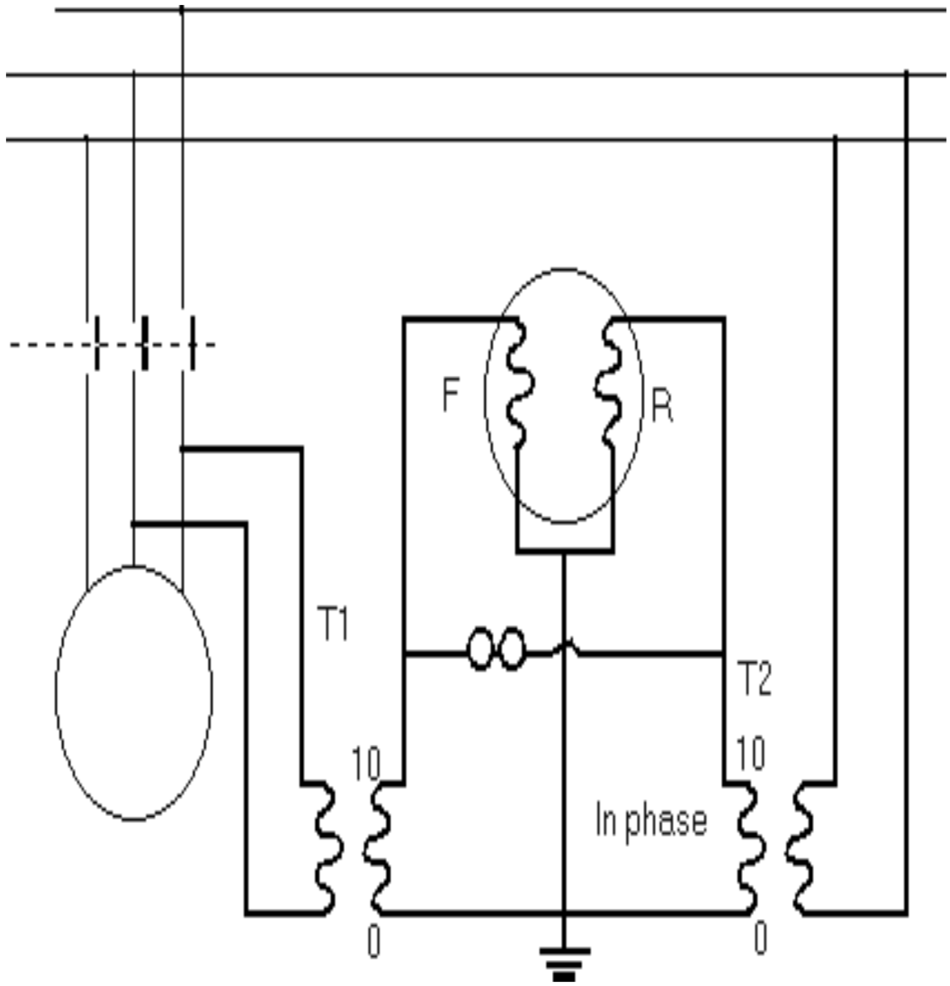
Lamps bright



If using single phase synchronising it is considered better to use the lamp bright method as it is easier to judge the middle of the bright sequence rather than the middle of the dark sequence

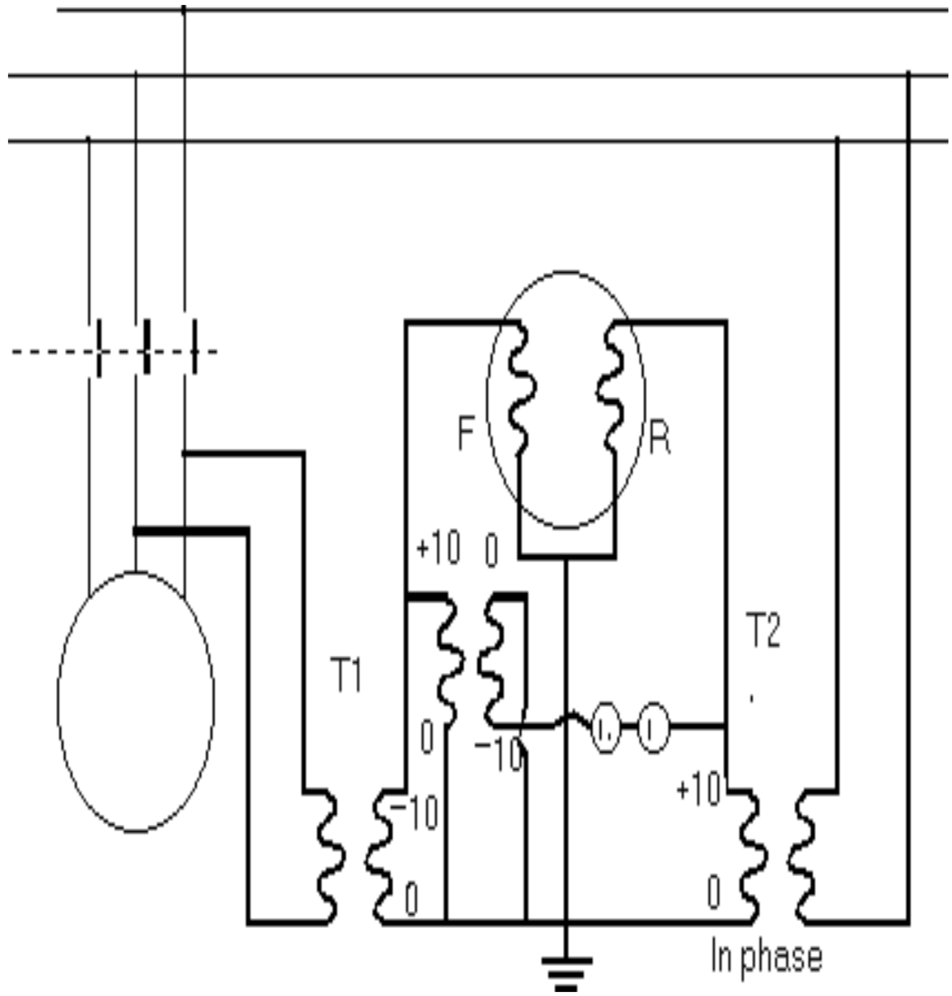
Three phase synchronising

Synchroscope with two lamps (lamps dark)

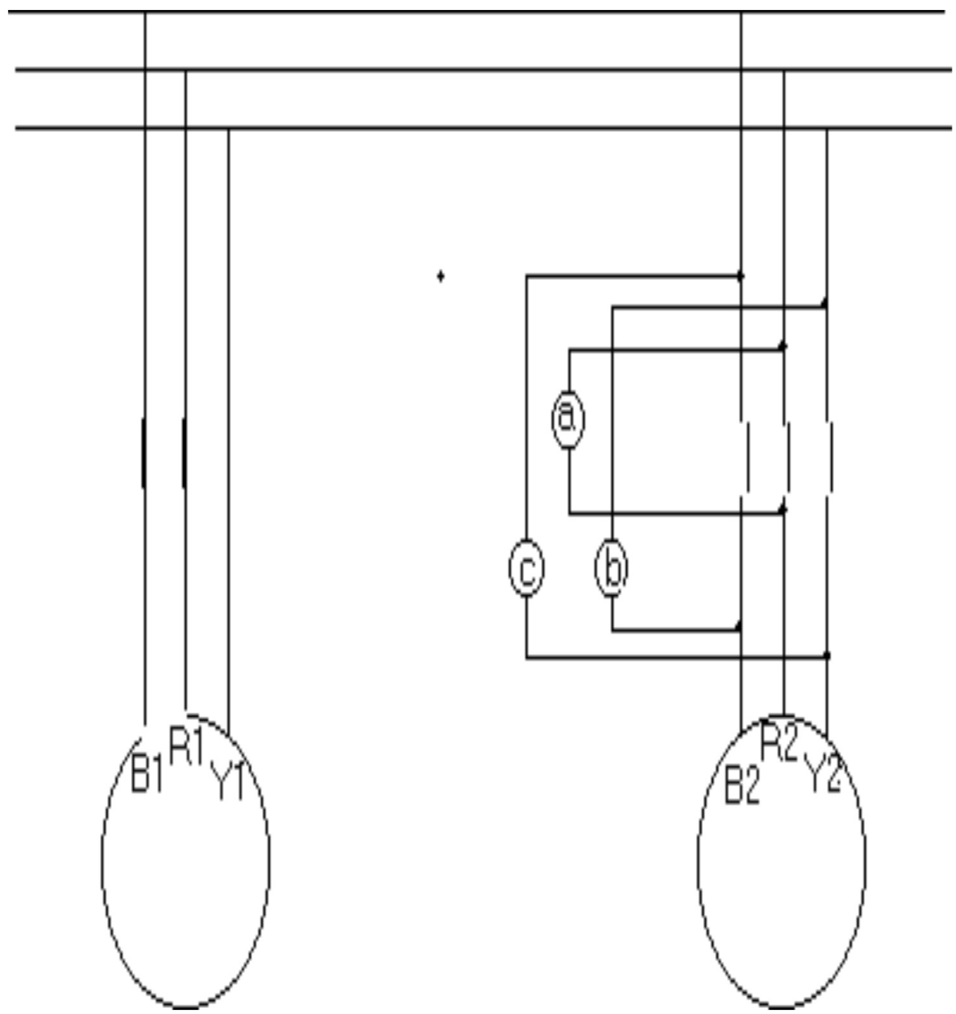


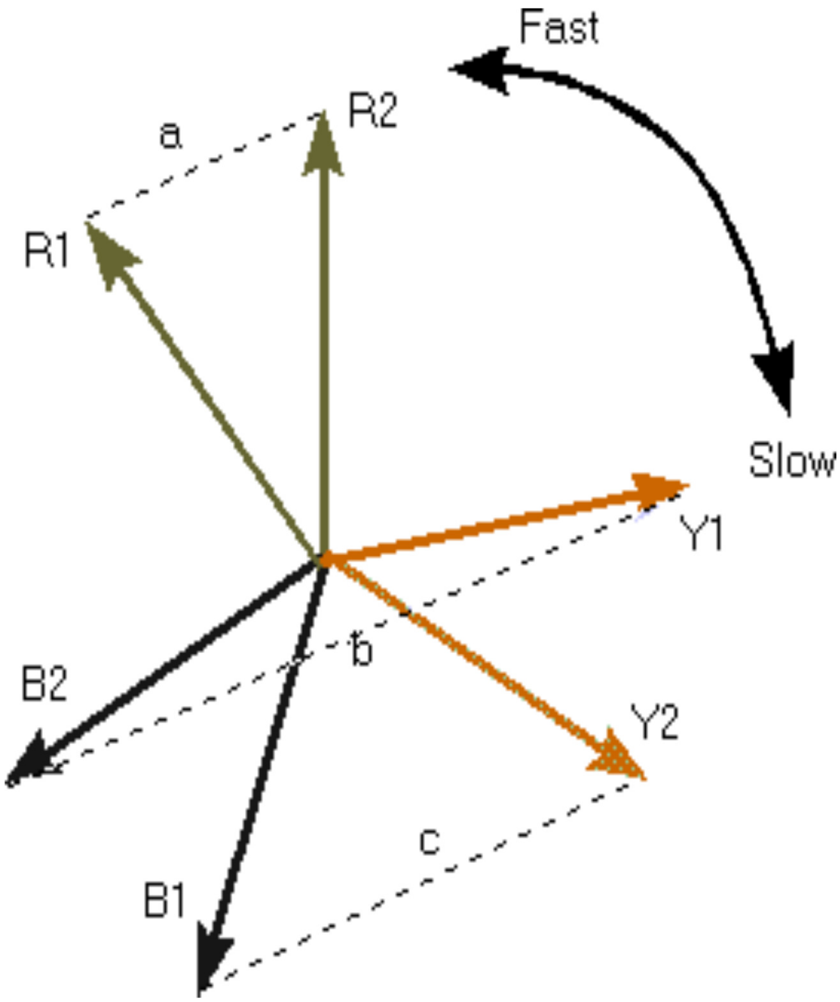
The secondary windings of transformer T1 supplies field coil F of the synchroscope. The secondary windings of T2 supplies the rotating coils R of the synchroscope.
If the incoming machine is in antiphase with the bus bar the voltage difference between the output of the secondary of T1 and T2 is double the normal voltage giving normal volt drop across each lamp. When in phase there is no voltage difference between the outputs of T1 and T2 and therefore lamps are dark when synchronised.

Synchroscope with two lamps (Lamps bright)



Three phase synchronising with lamps (Lamps dark)


a
b
c
B1
R1
Y1
B2
R2
Y2

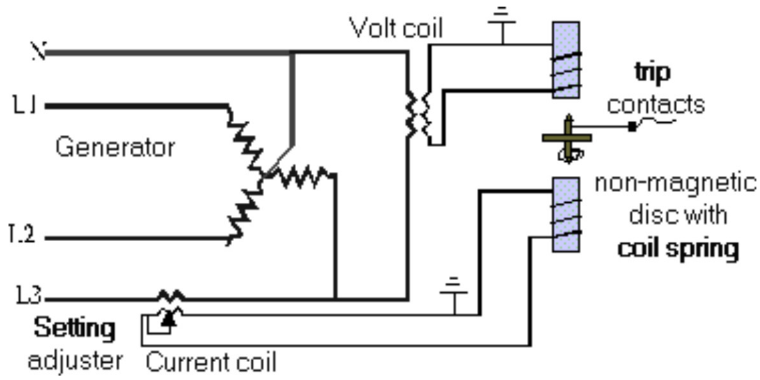


No1 Vector is stationary, if the incoming machine is running two slow then the No2 vector moves away from No1 vector in an anti clockwise direction. In the position shown as the No2 vector moves progressively anti clockwise then 'a' will brighten, 'b' will brighten shortly reaching maximum luminosity then darken, 'c' will darken .

When the machines are in phase, then 'R1' and 'R2' will be in align therefore 'a' will be dark, 'Y1' and 'B2' will be 120^{o} apart and therefore 'b' will be approaching maximum luminosity, and the same will be for 'c' with 'Y2' and 'B1' 120^{o} apart.

Reverse power tripping

A.C.

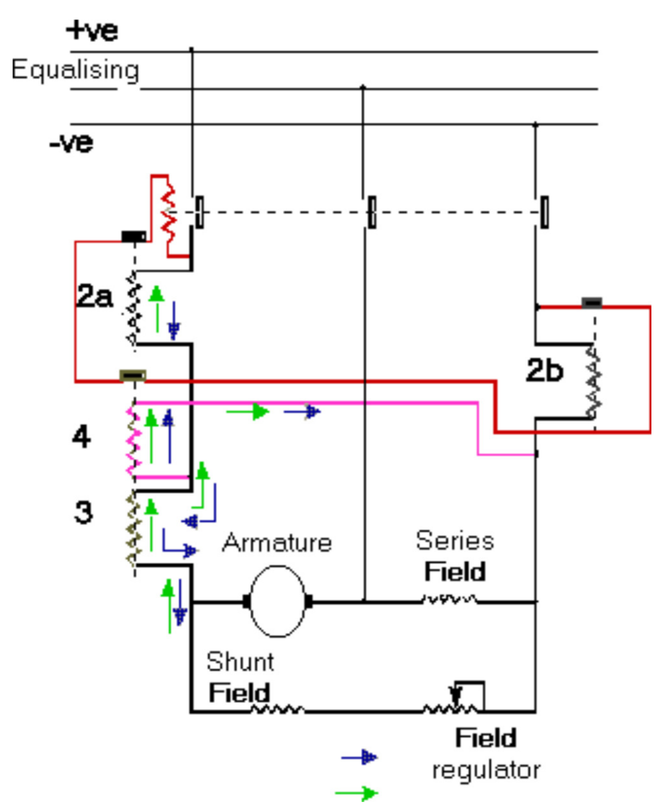


A non magnetic metal disc can rotate in a magnetic field between two electro magnets. The disc is restrained by a coil spring. The flux produces a torque on the side which rotates the trip lever away from the trip contacts.

In reverse power conditions the flux from the voltage coil and current coil interact to rotate the disc in the reverse direction. The amount of torque/current (and hence power) is set on the current coil tapping.

A permanent magnet is provided on the disc to provide damping. A 3 to 5second delay is incorporated into the trip circuit to allow for transients when paralleling.

D.C.



1. **Low voltage coil**
2. **Overcurrent trip**
3. **Reverse current trip**
4. **Reverse current trip**

2a and 2b are fitted in case of circulating current via the equalising connection.

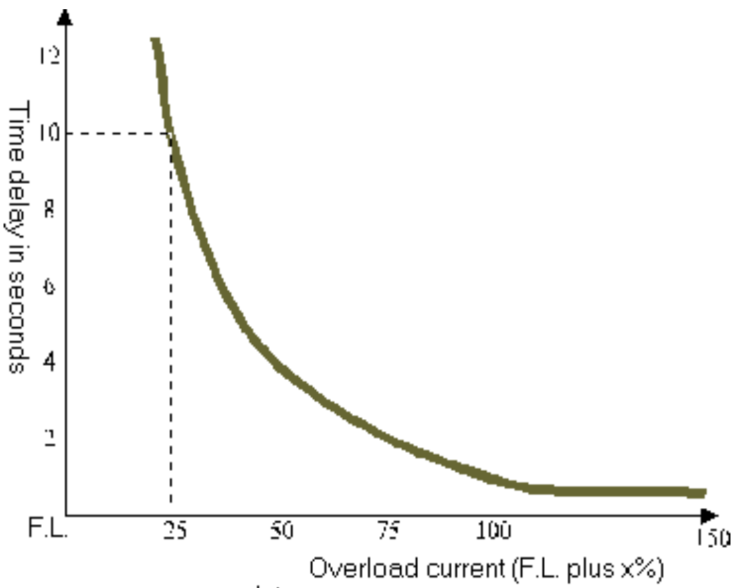
Under normal running , fields of '3' and '4' act together to hold the trip contact down. With reverse current fields are in opposition and a spring pushes the plunger against a trip bar to open the reverse current trip relay.

Time delay devices associated with safety circuits

Dash pots-(magnetic time lag)

The usual form of time/delay is an oil dash pot having an inverse time/current characteristic, relies for its operation upon the retarding action of a plunger immersed in a reservoir of oil, together with the magnetic force generated by a flow of current through a solenoid. The plunger is attached to an iron core which is partially enclose in the solenoid. When the solenoid is sufficiently energised the iron core will attract it, but the action is retarded due to the oil, in this way a time lag is introduced

Characteristic of Oil Dash pot with Inverse Time Delay



It is important to note that as the viscosity of the oil varies with temperature, so will the operating times of oil dash pots vary. Makers will supply dash pot oil suitable for the circuit breakers and relays. The recommended oils are selected on the basis of least variation in viscosity over the working range coupled with viscosity's which will give the time delay marked on the calibration plate. These special oils should invariably be used, the time delays are usually calibrated at 15oC, unless otherwise stated and are only correct at this temperature .

Over current devices fitted with oil dash pot time lags do not operate at the current marked on the calibration scale but at a current 25% greater with the appropriate time delay. The current marked on the scale is the value at which they would operate without time delay. Some makers supply an instruction plate indicating the exact current at which the relay will operate with a given setting.

Thermal device

Depends for its action upon the heating effect of an electric current flowing through, either a bi-metallic strip, or a heating coil placed near a strip. The thermal characteristics of the two dissimilar metals is such that when sufficient heat is generated there is a movement of the strip in one direction until the relay contacts are opened.

Induction relay

Similar to the action of the watt-hour meter, consisting of a metal disc pivoted so that it is free to rotate between two poles of two electro-magnets. The disc spindle carries a contact which is arranged to bridge two contacts when the disc has rotated through an adjustable angle. A spring returns the disc to the reset position, and as, during the deflecting period, the torque exerted by the spring increases, this is compensated for by the provision of graduated slots in the discs periphery. The necessary damping of the movement is provided for by incorporating a permanent magnet through which the disc has to rotate. The upper electro-magnet contains two windings, one, the primary normally is connected to a current transformer to a winding on the lower electro-magnet. Because of the graduated slots, the inertia of the moving system prevents the disc form rotating under normal running conditions, but when overcurrent commence to flow through the external circuit, the torque generated by the interaction of the upper and lower electro magnets is sufficient to cause the disc to rotate, until either the current falls to a safe level, or the relay is operated

Thermal Inspection of Switchboards

In service inspection of switchboard, individual starter and distribution panels can be carried out with the use of infra red temperature measurement or Thermal imaging systems. They require no direct contact with the electrical components being measured

This form of inspection is used to locate areas of increased temperature either associated with local overload or with increased resistance.

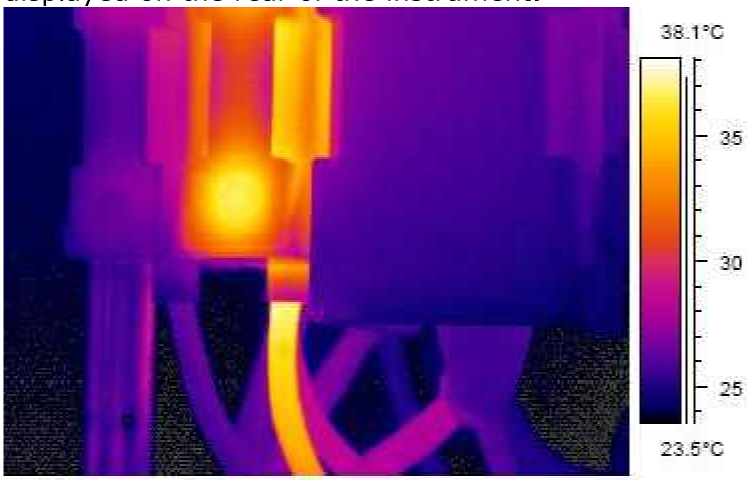
Infrared Temperature measurements

This takes the form of a relatively inexpensive, readily available temperature reading instrument often with laser guidance. The taking of readings is very simple although care must be taken in the interpretation of results. Due to their low cost these are normally found on most vessels as standard item

Thermal imaging

These tend to be expensive specialist instruments although they may be used by untrained personnel and results are generally simple to interpret. Due to their high cost it is normal to have a single unit available for several vessels delivered as required.

The unit is used rather like a video camera and the results viewed in realtime as an image displayed on the rear of the instrument.

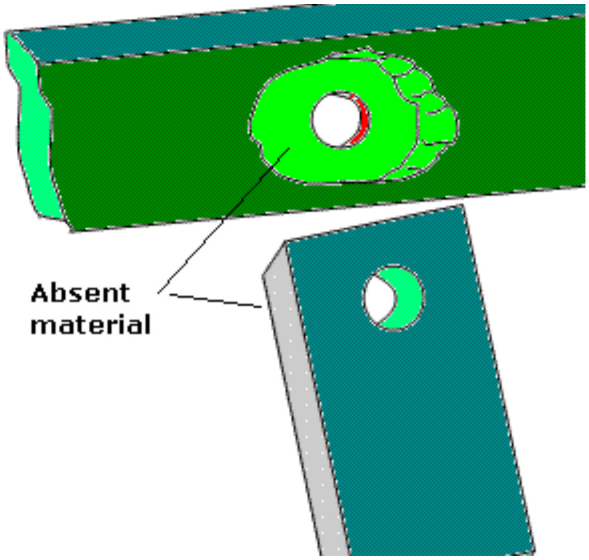


A typical unit is that seen in common use with fire brigades who use it in search and rescues

Author Note

When carrying out a thermal imaging inspection on a cargo pump switchboard on a large LNG carrier it was noticed that the areas around the connection of two busbar sections was unusually hot

The power was isolated on the switchboard and the tightness of the joining bolt checked. It was found tight. The decision was made to investigated further and the busbar section was disassembled



It was found that a large portion of the copper material at the contact face had disintegrated and was found absent from both joining bars. The reduced area of contact led to increased resistance and thus the increase in temperature.

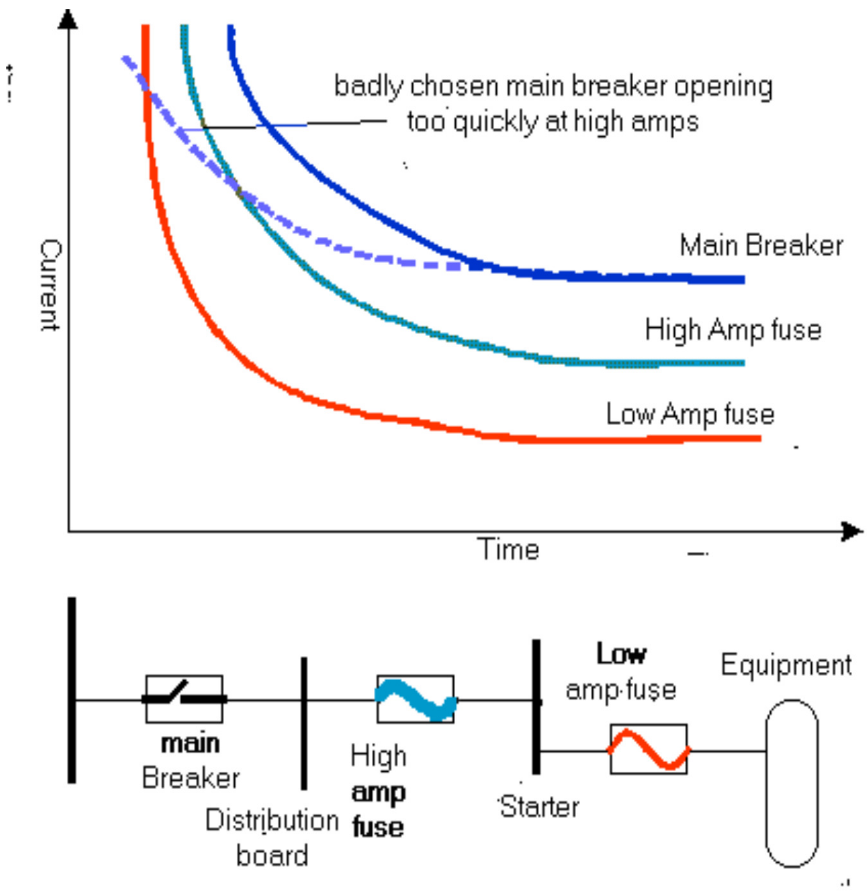
The author is not able to offer an explanation as to the mechanism of failure of the busbar. I would suggest that the damage and been caused previously due to the bolt being loose. The bolt had been tightened without further investigation or recording of this action

Discrimation and Fuses

Discrimation

A circuit fed from a distribution board may be fed through three or even four fuses or circuit breakers e.g. a heating circuit may be connected to a 15amp fuse in a fuse box fed from a section box in turn from a 500A circuit breaker on the main board.

Discrimination occurs when the fuses nearest to the fault operates leaving all the other fuses or protective devices intact. Discrimination may be required between fuse and fuse, or between fuse and overcurrent device such as a circuit breaker.



Fuses

A fuse is a protective device which is there to prevent overloading. If too heavy a fuse or if the fuse is overridden then there is a possibility of overheating, deterioration of insulation and failure.

Materials used are; Tin, Lead, or silver having low melting points. Use of copper or iron is dangerous, though tinned copper may be used.
Unlike some other forms of circuit protection devices (oil switches for instance), which are suitable for a.c. only, solid filled cartridge fuses have an approximately equal breaking capacity for D.C. and A.C. and the action of the fuse does not depend on breaking circuit at the zero point on the current cyclic wave

Requirements of a fuse;

- Have a high cut off speed on short circuit
- Operate on a sustained overload
- Make a complete break after operation with high insulation resistance between terminals
- Have a maximum temperature rise on continuous full load rating such that it will not be injurious to rudder cables connected to its terminals
- Be mechanically robust and capable of withstanding the large magnetic and gaseous forces exerted during operation under short circuit conditions

A fuse must not;

- Operate on continuous full load
- operate on momentary overload
- Deteriorate under continuous operation at full load
- Burst or emit flame or otherwise damage the fuse carrier and base when it operates

Regulations

I.E.E. and classification society rules now specify high breaking capacity (high category) fuses on main switch boards where the total normal generator capacity exceeds 400kW at 200v, this is for short circuit or low resistance protection of the very high currents that can be generated in these conditions.

In addition;

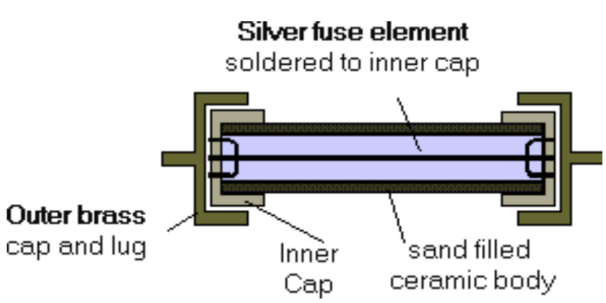
- Fuses on shipboard must be made to approved standards.
- Breaking capacity not less than prospective short circuit current at point of installation
- Fuses over 300A are not used for overload protection but may be used for short circuit protection
- Cartridge fuses only on tankers

To control the extent of heavy fault currents on large installations the protective device must have a very high speed performance or High Rupture Capacity (H.R.C.) H.R.C. fuses will operate quickly before the short circuit current exceeds 3 times the full load current.

Cartridge fuses

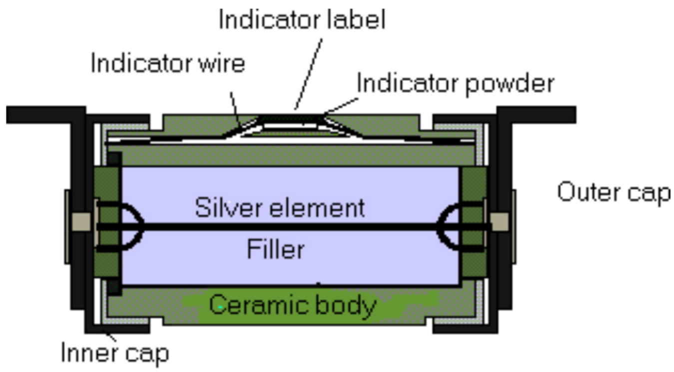
Are capable of handling large short circuits. Because of standardisation of manufacture they have very consistant time/current fusing characteristics making them accurate, dependable and non-deteriorating in service. Suitable filling powders such as silicon sand are used in cartridge fuses having the property of quenching the arc of the fused element.

Enclosed fuses



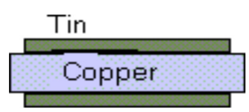
The element usually made of silver is much smaller than the tinned copper used in semi-enclosed fuses so that the amount of vaporised metal is less and this contributes to a better performance. The enclosed casing and use of silver ensures no degradation due to oxidation. After the silver element has fused the indicator wire will heat up sufficiently to ignite the indicator powder and the fuse will be shown to be blown.

Except in the lowest ratings there are two or more elements in parallel which increase the contact area in contact with the filler, and this increases the breaking capacity. The ends of the element are reinforced by larger wires to reduce resistance and therefore heat losses.
The indicator type should in the construction below consists of an indicator wire which ignites an explosive powder which chars the indicator paper. On other designs the indicator wire releases a spring and pop up indicator



Semi-enclosed fuses

Tinned copper fuse wire exposed to the atmosphere tends to deteriorate and will vary in performance after long periods in service. Also there is a temptation to increase the gauge of the wire, or the number of wires after a fuse has blown. However, rewireable fuses are cheap, easily replaceable, blown fuses are easily detected and within reason if the circuit is uprated slightly no new fuse holders are required.



Tin-fast heating and failure (expensive)
Copper-Slow heating and failure (cheaper)

On overload the tin will fail rapidly increasing the current through the core speeding up its failure.

Rating

Is that current the fuse will carry continuously e.g. for a circuit rated at 30 amp, a 30 amp fuse will be appropriate. Fuses and circuit breakers on switchboards and distribution boards are intended primarily for the protection of the cables and not the apparatus. Overload protection of the apparatus usually provided at the motor starter.

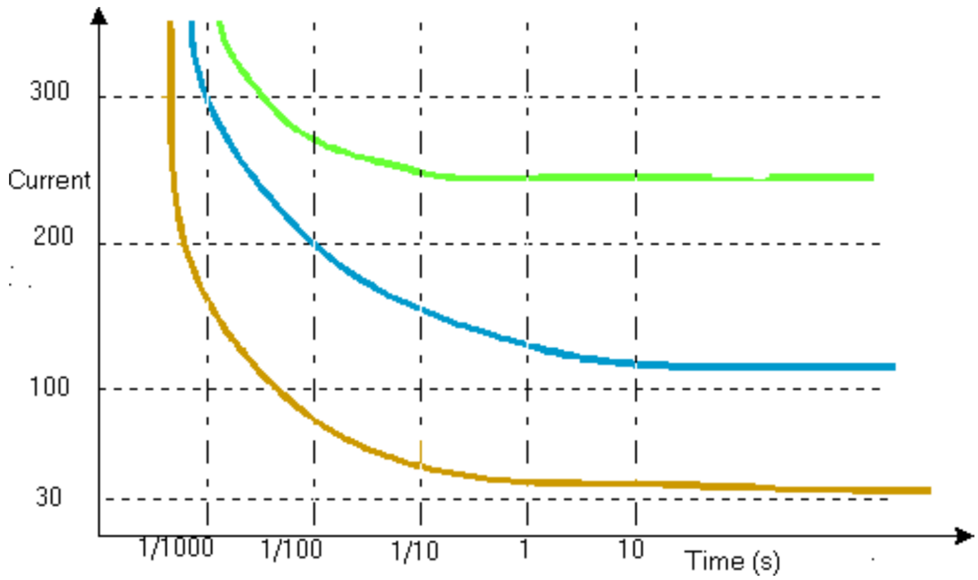
The fusing factor = Minimum fusing current/ Current rating

There are three standards

Class P	Fuses protect against relatively small but sustained overloads with fusing factor of 1.25 (25% overload rating)
Class Q	Fuses where protection against relatively small overcurrents is not required, with a fuse factor not exceeding 1.5 for cartridge and 1.8 for semi-enclosed

	fuses. Motor overload protection to back up motor starter protection
Class R	Fuses require for protection against relatively large overcurrents (e.g. short circuit protection) 3 x Full load current

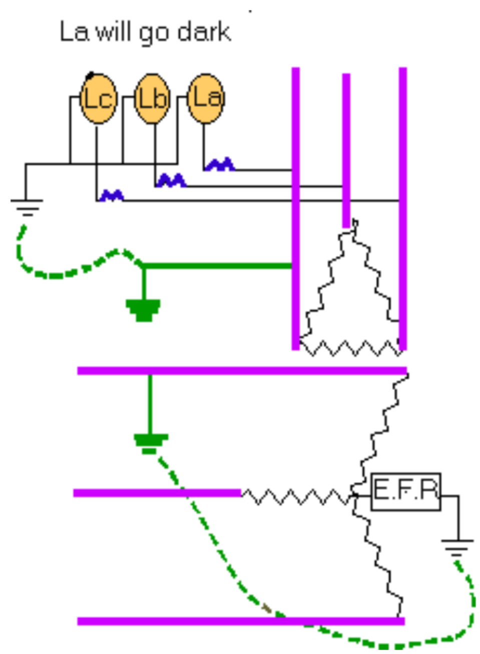
Minimum fusing current



is affected by length of fuse element. A short element with large terminals, or with special graded construction of wire will have its fusing current raised because of heat conduction away from the element. Alternately, the cross section of element can be reduced for a fuse of a given rating. This method is adopted in some designs of semi-enclosed and filled cartridge fuses.

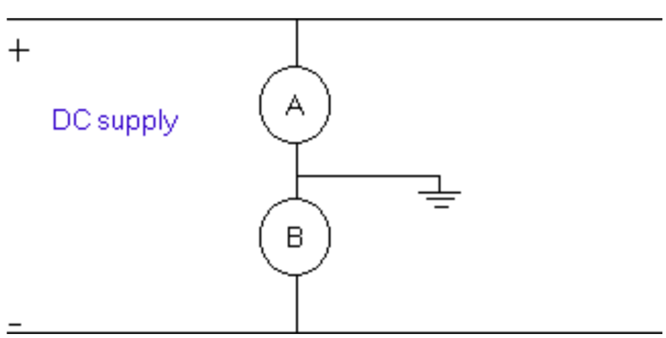
Earth fault detection

AC



Earth fault detection

DC



Preferential tripping

It is essential to prevent interruption of services necessary to maintain propulsion and navigation. These must be safeguarded even if the other services such as domestic supplies are temporarily sacrificed.

There are two ways to safeguard these services. First there must be at least two generators, the rating of which must be such that essential services can be maintained if one set is out of commission. Secondly, a protection must be provided that if sea load is too much for one generator a system of preferential selection will operate.

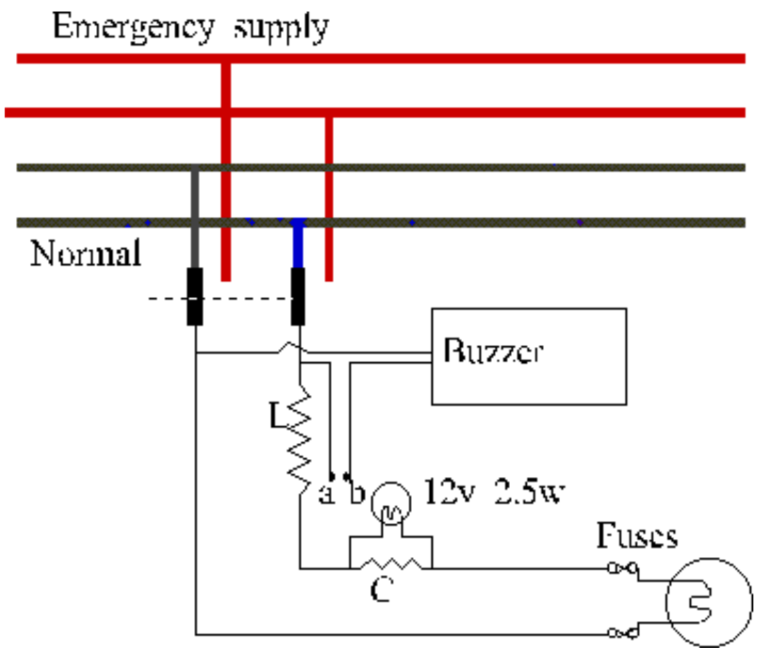
In some cases the non essential load is relatively too small to warrant additional switchgear. It is generally in larger installations where loads not under direct control of the engineer that they must be fitted. If the heating, lighting and galley were all switched on without prior warning, then the generators could become overloaded. Without preferential trips this may so overload the generators as to cause a complete shutdown. Therefore non essential services are fed through one or more circuit breakers fitted with shunt retaining coils or shunt tripping coils. Over current relays with time lags are provided for each generator. When overloaded, appropriate relays operate and trip out the non essential services. Some being more important than others, degrees of preference may be given.

Setting

Usual setting is 150% (50% overload) with a time delay of 15 seconds for generator overload protection and the following times come into operation when the generator reaches 110%.

First tripping circuit	5 seconds
Second tripping circuit	10 seconds
Third tripping circuit	15 seconds

navigation lighting



Operation-When the double pole switch is closed the navigation light is illuminated. Current in the relay circuit causes the relay coil to energise so contact 'a' ,may be attracted to 'b'. A low voltage lamp only is needed for the indicating lamp, so there is a small voltage drop across that part of the circuit. If the indicating lamp fails the circuit is completed through the resistance C, so the navigation light does not fail.

If the navigation light fails, or if a fuse blows the current in the circuit ceases and the relay de-energises. Contact 'a' springs back to contact 'b' and the buzzer circuit is completed.

In case of failure of ships mains, the double pole switch may be switched over to emergency supply.

Requirements

- Circuit supplied from distribution board provided for that purpose which is easily accessible to the officer of the watch.
- Must be connected directly or through a transformer to the main or emergency switchboard. No switches in between.
- Provision on the bridge to transfer lights to alternative source of supply.
- Each navigation light must be controlled and protected at both poles by a switch and fuse, or circuit breaker, mounted ON the distribution board.
- Each provided with automatic indication of extinction of light by aural and/or visual indication.
- The visual device must be so connected that its failure does not extinguish the navigation light circuit

Types of fluorescent lights

Discharge lamps

Cold cathode type-only used for decorative lighting

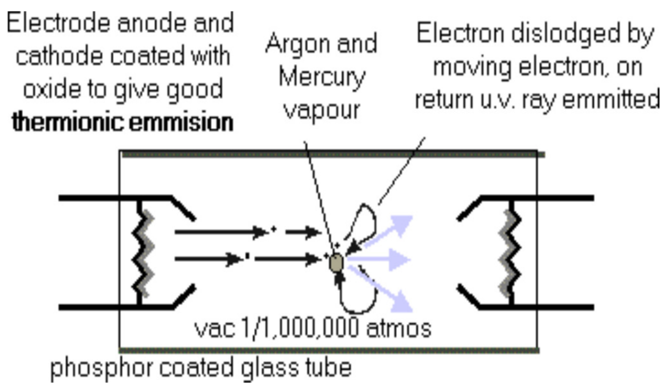
Hot cathode

a, High pressure fluorescent

(i)Mercury vapour types)Used mainly for street lighting

(ii) Sodium type ,)but sometimes used for deck lighting

b, Low pressure Hot Cathode Fluorescent type discharge Lamp



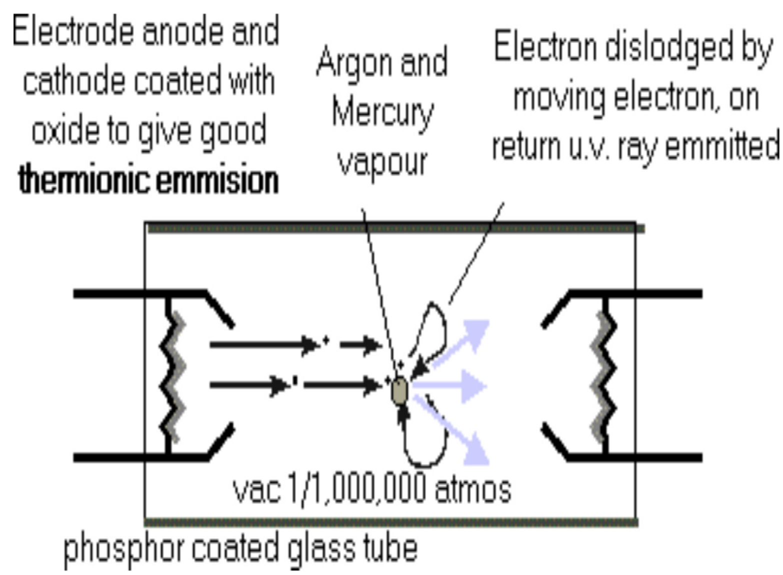
Principle- A length of glass tubing contains a small amount of mercury vapour and argon gas, at a very low pressure (10-6 atmospheres). A heater element forming an electrode is situated at each end of the tube. These electrodes may be coated with an oxide to improve thermionic emission. The interior of the tube is coated with fluorescent powder (a Phosphor coating)

If a suitable voltage is applied between the two electrodes a DISCHARGE strikes between them and the mains voltage is then sufficient to maintain the discharge. This occurs in low pressure so that the lamp will run at a comparatively low temperature and so will not effect the fluorescent coating. The electrons from the electrode collide with the mercury atoms. This dislodges an electron from the atom making the mercury atom a positively charged ION. As the dislodged electron returns to the influence of the ION (i.e. the electron changes from one energy level to another) a certain amount of electro-magnetic radiation (i.e. a photon) is given off in the form of Ultra-violet light. These rays activate the fluorescent coating and the luminous surface provides a glare free efficient light.

Operation -With switch start circuits to start a discharge across the tube a large Voltage Impulse is required.

This may be obtained by the following methods;

a. Glow type switch and choke
b. Thermal type switch and choke



There are also methods using starterless circuits, referred to as rapid start or instant start,. where a drop in potential between the electrode and an earth strip is sufficient to ionise the gas adjacent to the electrode and this ionisation then spreads across the whole tube.

C1- Radio suppresser
C2- Power factor correction

Glow type switch starter circuit

When the control switch is closed the contacts on the bimetal strips which are open form the electrodes of a small discharge lamp. The mains voltage is sufficient to cause a glow discharge in the starter which warms the bimetal strips. The strips bend until contacting and a large current flows through the electrodes of the main tube, forming an electrode cloud around their cathodes (thermionic emission)

Shortly the bimetal strips cool sufficiently to break contact, This sudden reduction in current flow causes a large e.m.f to be generated in the choke (typically four to five times mains)

The voltage surge across the tube is sufficient to ionise the gas, reducing the resistance to electron flow and allowing the discharge to occur and be sustained by the mains voltage.

Operation may still occur if the mains voltage is reduced, however the tube is unlikely to start hence this type of light is not used for emergency lighting

The choke has a second purpose other than providing the start voltage. It maintains a constant correct potential difference across the tube when the mains is an alternating current.. If a d.c is used then a ballast resistor (which may be an incandescent light) must be used

Advantages-

- Greater efficacy, about 5 times the lumens per watt of tungsten filament
- Longer light source, tungsten originating from a relatively small area
- About 5 times the life of filament (5000 Hrs approx.)

Disadvantages-

- Initial cost
- Power loss in d.c plant due to ballast resistor

- Stroboscopic effect, two may be place in 90o out of phase

Cables

General

On Tankers all cables must be either lead alloy sheathed and armoured, mineral insulated copper sheathed (the ends must be sheathed to prevent moisture being absorbed by the hygroscopic insulation material) or non-mineral impervious sheathed and wire braided so long as they are laid in a pipe (the csa of the wire must be less than 30% of pipe bore.

Glands fitted to bulkheads must allow for expansion and be weather tight, water tight bulkheads should only be penetrated by a suitable gland.

Cables should be laid away from hot surfaces

All installations must be flame proof

Metal casing should be adequately rust protected and earthed. PVC conduit must not be used in fridge spaces or on deck unless specially approved as liable to breakdown in cold. Cable sheathing, unless galvanised, should have a rust preventative coating. The cable should not be laid behind insulation.

Insulating material

- Polyvinyl Chloride (P.V.C)
- Butyl Rubber
- Ethylene Propylene Rubber (E.P.R)
- Polythene
- Cross linked Polythene (X.L.P.E)
- Silicone Rubber
- Mineral insulation

Flame test of insulation

A standard 4ft length of cable is held vertical and is burnt by a flame of known strength

i. *If the flame travels the full length the cable is graded as flame extending,(not in common use.*
ii. *If the flame is extinguished before it reaches the top end, it is classified as Flame retardant,*
iii. *, If a cable is graded as flame retardant it must be able to resist the flame, and also after cooling be able to withstand an a.c voltage of twice the rated voltage for one minute.*

Relays and Solenoids

The wire coil of the electromagnet, without its core of magnetic material is called the solenoid. If this solenoid is provided with a movable soft iron core and current flows through the turns of the coil , the magnetic field tends to pull the plunger in to the centre of the coil. Accordingly the coil with its moving centre is called the solenoid.

The plunger can be used to operate a great many mechanical applications. A spring is often fitted above the plunger to positively return it to its start position once the current is turned off. The plunger may also be used via an non-magnetic extension be used as a pusher, a spring again returning it to the start position.

Either a direct or alternating current may be used to energise the solenoid, since either type will produce the magnetic field around the coil. There is one precaution however. The core of the electromagnet finds itself in the magnetic field of the coil. If a steady direct current flows through the coil , no current will be induced in the core since both the core and field are stationary. But if an alternating current flows through the coil, the changing magnetic field will cause a current to be induced in the core. This is called the eddy current.

The eddy current is undesirable on two counts. The flow of current through the core represents a power loss , which must come from the source. Also the flow of current may cause the core to get quite hot. To reduce the eddy current, the core is not built solid but is made up of many thick slices, called laminations. Each lamination is insulated from its neighbour by a coat of varnish or similar material. This offers considerable resistance, and as a result, the eddy currents are cut down. In solenoids operating on alternating current, the plunger is built up of laminations.

An alternating current coil will offer a greater resistance to current flow than a direct current coil of same ohm resistance due to its inductive reactance. Hence, if a coil designed to be operated by an alternating current is connected to a source of direct current at the same voltage, the flow of current may be great enough to burn out the windings.

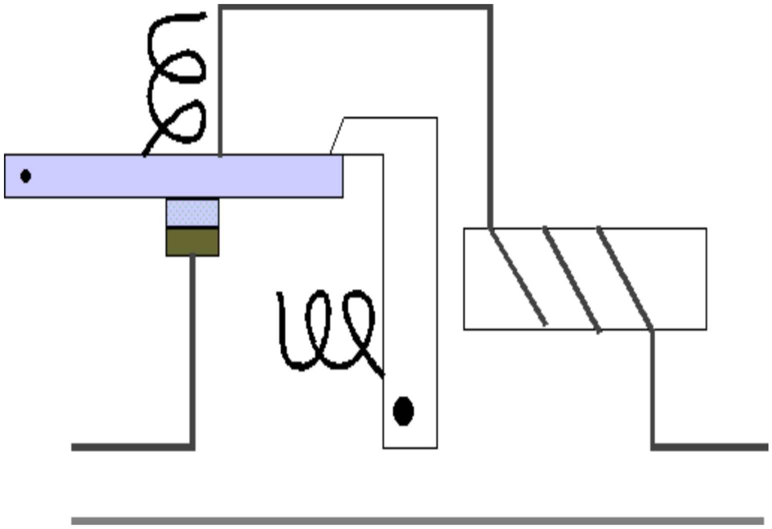
On very common application of an electromagnet is in the operation of an electric switch. In this form it is known as an electromagnetic relay.

The sensitivity and current draw of a relay is determined by the wire wound on the core. This is determined by size and therefore breaking capacity of the contacts.

The relay coil may be energised by either direct or alternating current. Where direct current is employed, there are no special problems. Alternating current may be employed since the polarity does not effect the attraction of the armature. However, the rapid alternations of the magnetic field cause the armature to vibrate, or 'chatter'. Since the contacts are controlled by the armature, the controlled circuit too, will be affected..

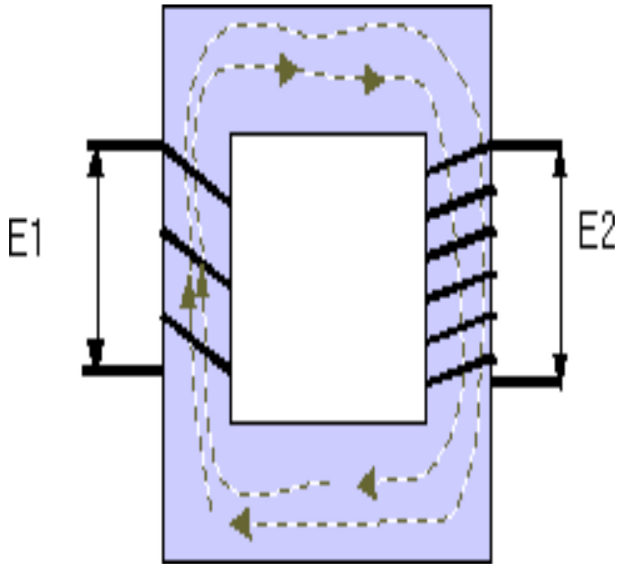
One method of remedying the fault is to rectify the alternating current before applying it to the relay. Small semi conductor diodes are employed. Another method is to connect a fairly large capacitor across the coil. Frames are laminated to prevent eddy current losses.

Overload circuit breaker is a variation on a relay.



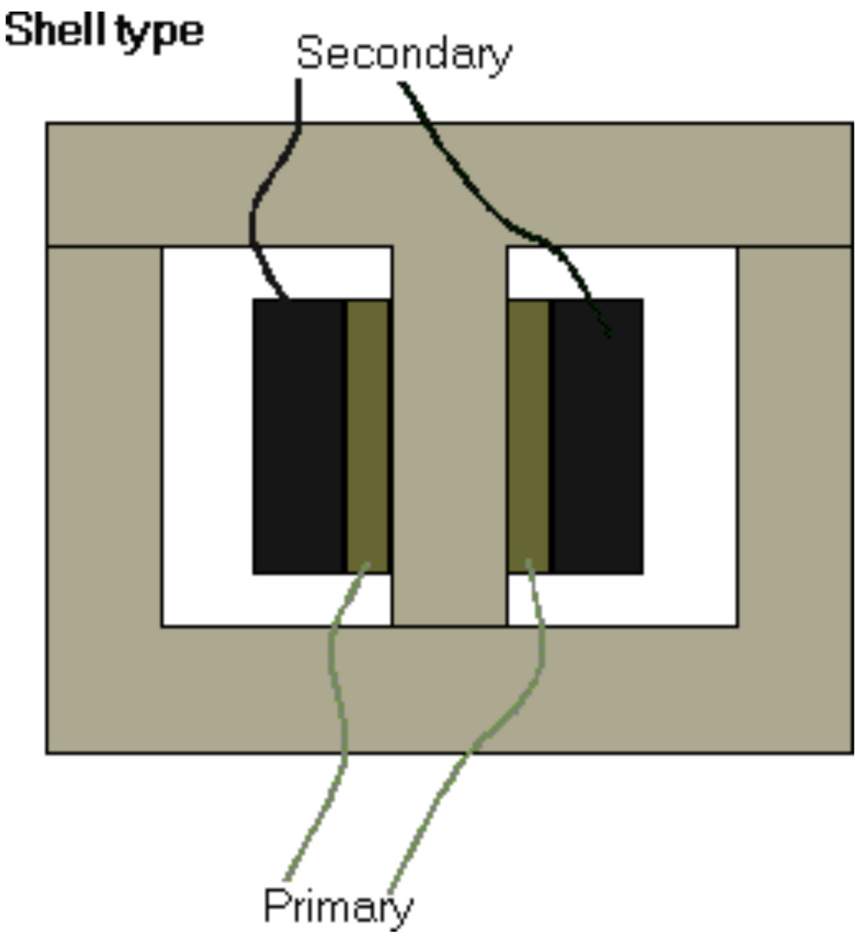
Transformers

A big advantage of A.C. transmission is the ability to easily change voltage by means of a transformer. As there are no moving parts maintenance is very low and efficiency very high (typically 98%).
A transformer consists of two insulated coils wound separately over a closed magnetic field, usually iron, of low reluctance. An alternating supply E1 acts across a coil called the primary, a voltage is induced in the secondary coil E2.

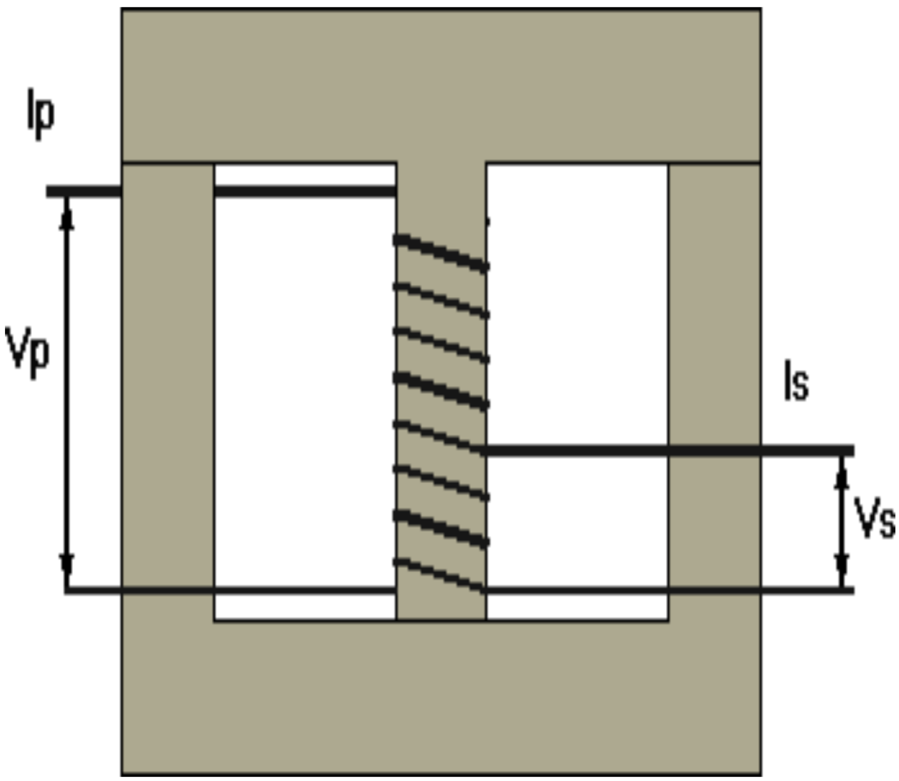


Details of a small transformer-the core is built up of stamped laminated sheets of silicon iron about 0.35 mm thick insulated from one another by a thin layer of paper or varnish. The purpose of laminating the core is to reduce the loss due to eddy currents induced by the alternating magnetic flux. The vertical portions of the yoke are called the 'limbs' and the horizontal portions are called the 'yokes'

Shell type



Auto transformer



Auto transformers are used in;

a. Starting motors
b. In power factor corrections with capacitance's.
c. Incorporated in portable appliances such as radios.

Transformer losses

Iron losses- As the magnetic field sweeps across the conducting material a voltage is induced which sets up a current within it. When this current, the **EDDY CURRENT**, flows the resistance within the material causes heat to be produced. The material does not have to be magnetic for the eddy currents to be set up but must be a conductor.

If the material is magnetic the magnetic field around the coil magnetizes that material and rearranges its molecules. Each time the magnetic field reverse the molecules are rearranged. As the result of molecular friction called **HYSTERESIS LOSS** this rearrangement produces heat

1. **Eddy currents- losses reduced by laminating material**
2. **Hysteresis loss-reduced by using soft iron or annealed steel.**

Copper losses-These are the I2R losses in the copper wires of the primary and secondary coils. Increase in temperature of these coils will increase their resistance.

Iron losses are constant, but copper losses are proportional to the square of the current.

Vs/Vp approx equals Ns/Np approx equals Ip/Is

Efficiency = Output power/ I nput power

= Output power/ Output power - Iron losses + Copper losses

= Vs Is Cosf/ Vs Is Cosf + Iron losses + Ip2Rp + Is2Rs

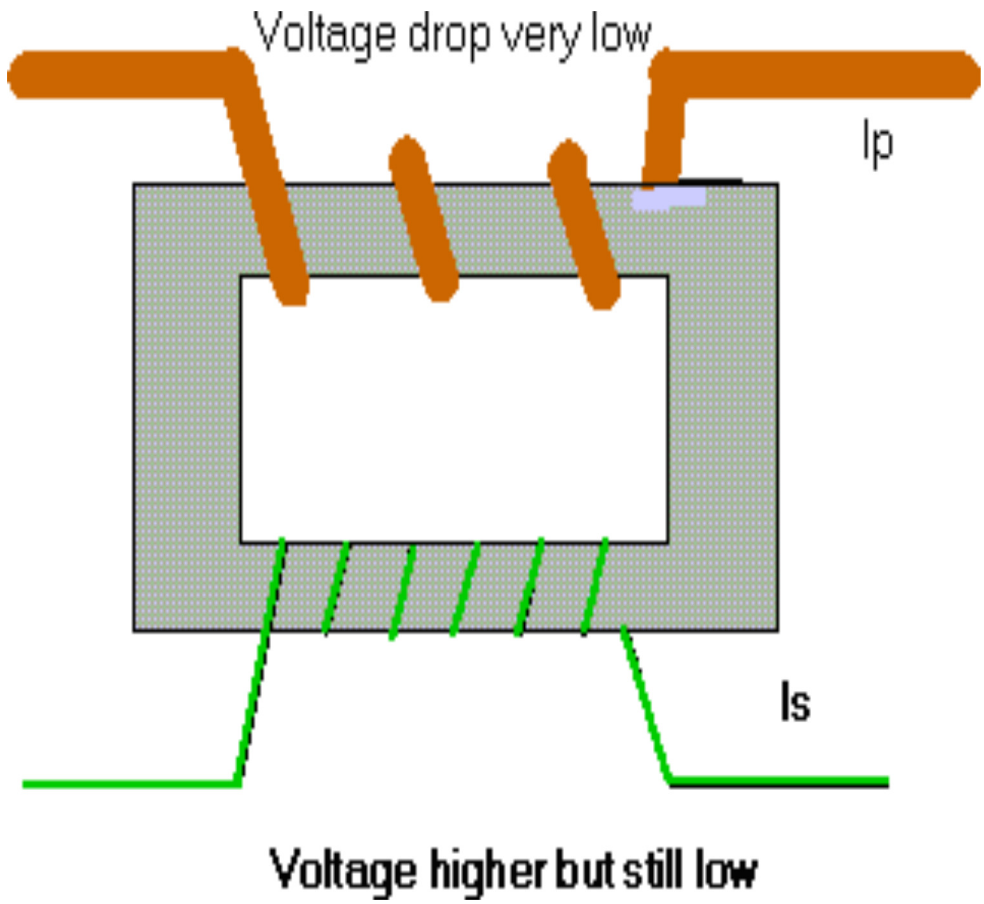
Maximum efficiency occurs when iron losses and copper losses are equal. The losses in a transformer for a given frequency are largely determined by the value of the working flux density in the windings. With a small transformer it is possible to work with fairly high densities in both the iron and the copper without exceeding the maximum temperature so air cooling is satisfactory. However in larger transformers either the flux density or the current density must be reduced or somemethod of cooling used. This is normally achieved by immersing the transformer in insulating oil in a chamber with cooling fins or tubes.

Instrument transformers

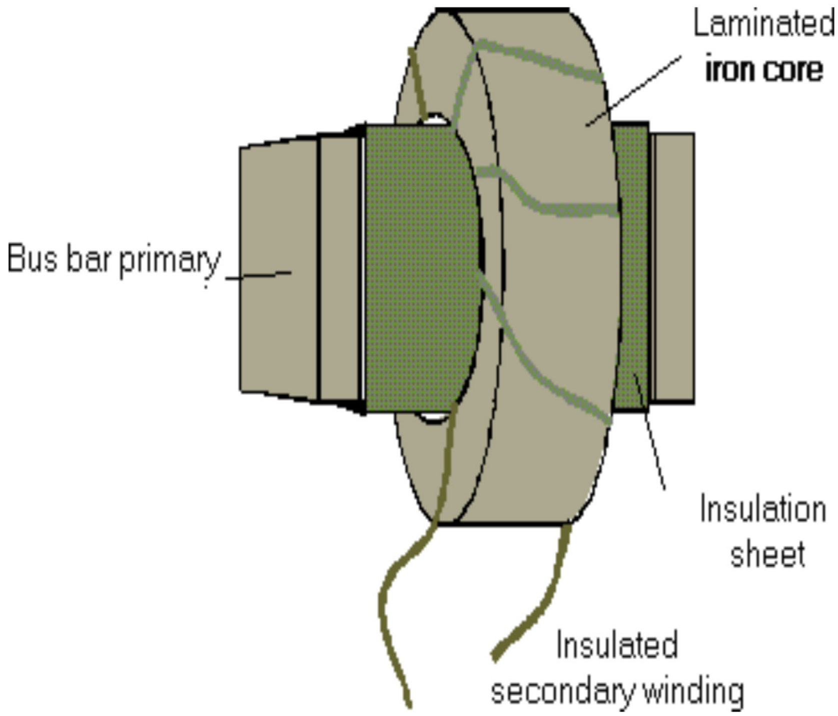
It is usual in A.C. installations to fit the ammeter to the secondary circuit of a current transformer. This avoids heavy current connections to the meter and allows an ammeter switch to be fitted to read the current in each phase. The same current transformer can be used for the wattmeter and the reverse power relay. Voltage transformers are also normally provided for use with voltmeters, wattmeters, synchroscopes and reverse power relays.

Safety-The secondary circuit of a current transformer must never be opened or left open under load. The large voltage induced (due to high flux density produced in the core with no 'back' ampere turns from the secondary coil) will cause the transformer to overheat. The secondary circuit must be such that short circuit conditions will not cause damage.

In the event of breakdown of insulation between primary and secondary windings it is a requirement that one end of the secondary winding of the current transformer and the voltage transformer and the metal cases of the instruments shall be earthed.

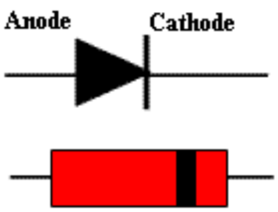


The principle of the current transformer is that the primary winding carries the full load current and as such is made of large diameter low resistance wire. The secondary winding steps up the small volt drop that occurs over the length of the primary wire.

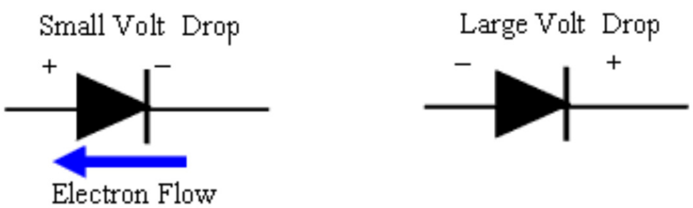

Laminated
iron core
Bus bar primary
Insulation
sheet
Insulated
secondary winding

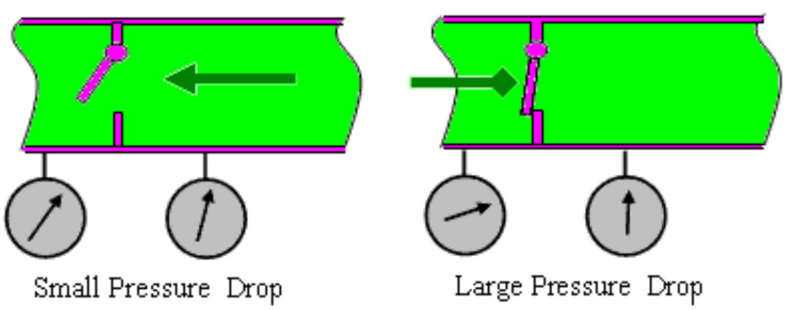
Diodes

Basics



The diode is a electronic version of the non-return valve. It allows electron flow in one direction but not the other. It should be noted that the symbol is pointing to the 'conventional flow' where current is said to flow from the positive to the negative. The reality is that electron flow is from the negative to the positive and understanding on how the diode functions requires investigating this.

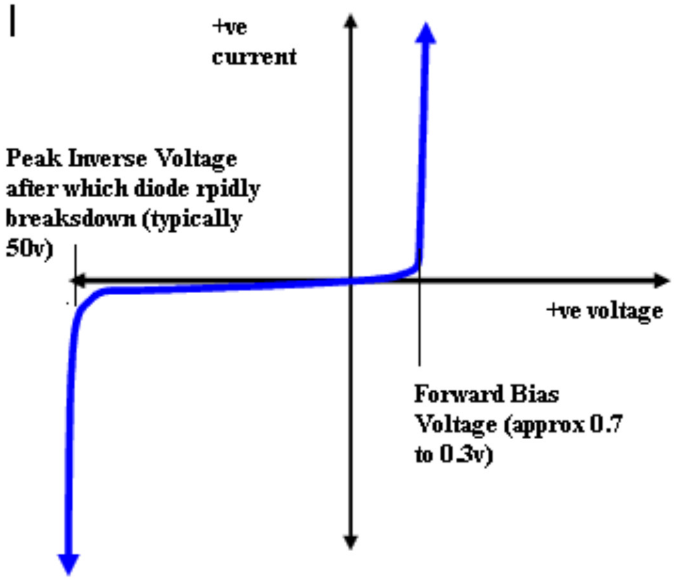




When the voltage is applied across the diode so that electron flow is allowed this is referred to as **Forward-Bias**, when the voltage is applied so that electron flow is blocked this is referred to as **Reverse Bias** .

There is a small volt drop when the diode is Forward Biased which remains virtually constant independent of Current flow. This is about 0.7v for Silicon and 0.3v for Germanium.

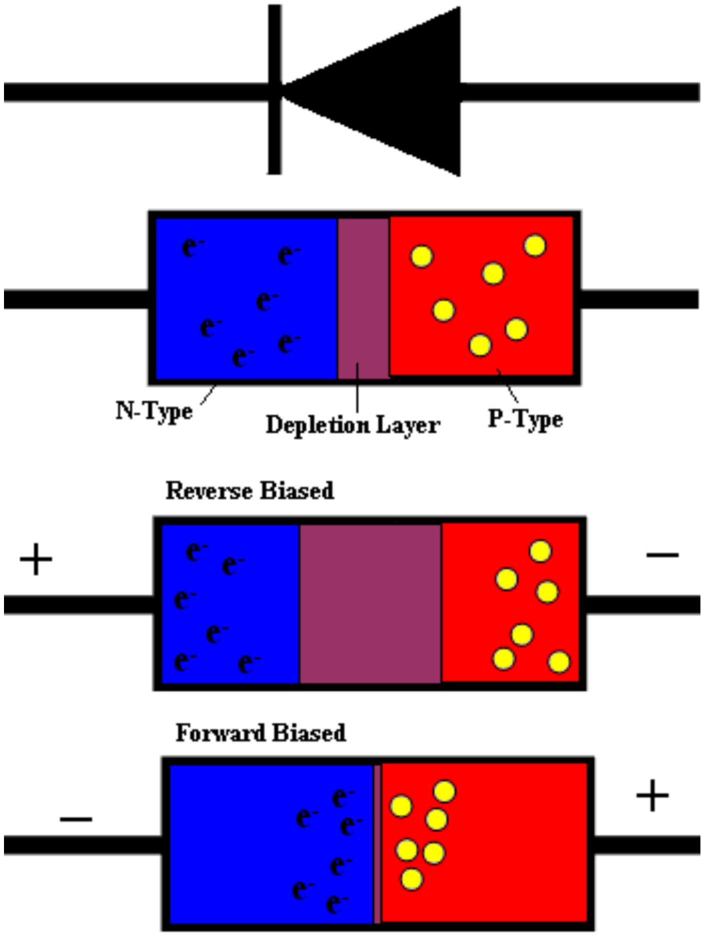
In Reverse bias electron flow other than a small **Leakage current** is blocked up until the Diode **breaksdown**. The voltage this breakdown occurs is called the **Peak Inverse Voltage (PIV)**, when the PIV is exceeded the diode will generally have failed although there are specialist diodes (called **Zener Diodes**) used in voltage regulation which are designed to normally work in Reverse Bias.



Working Principal

A diode consists of **P-type** (material with slight electron deficit sometimes imagined as having positive holes) and **N-type** (material with slight electron excess). This may be manufactured by the use of doping agents in semiconductor material such as Germanium or Silicon. The juncture of the two materials is called the **depletion zone** as it contains niether excess electrons or postivie holes into which the electrons can enter.

When a forward bias voltage is applied there is a tendency for the electrons and positive holes to be drawn into the depletion layer collapsing it until current can flow freely. When a reverse bias is applied the electrons and positive holes are drawn away from the depletion layer expanding it and preventing current flow

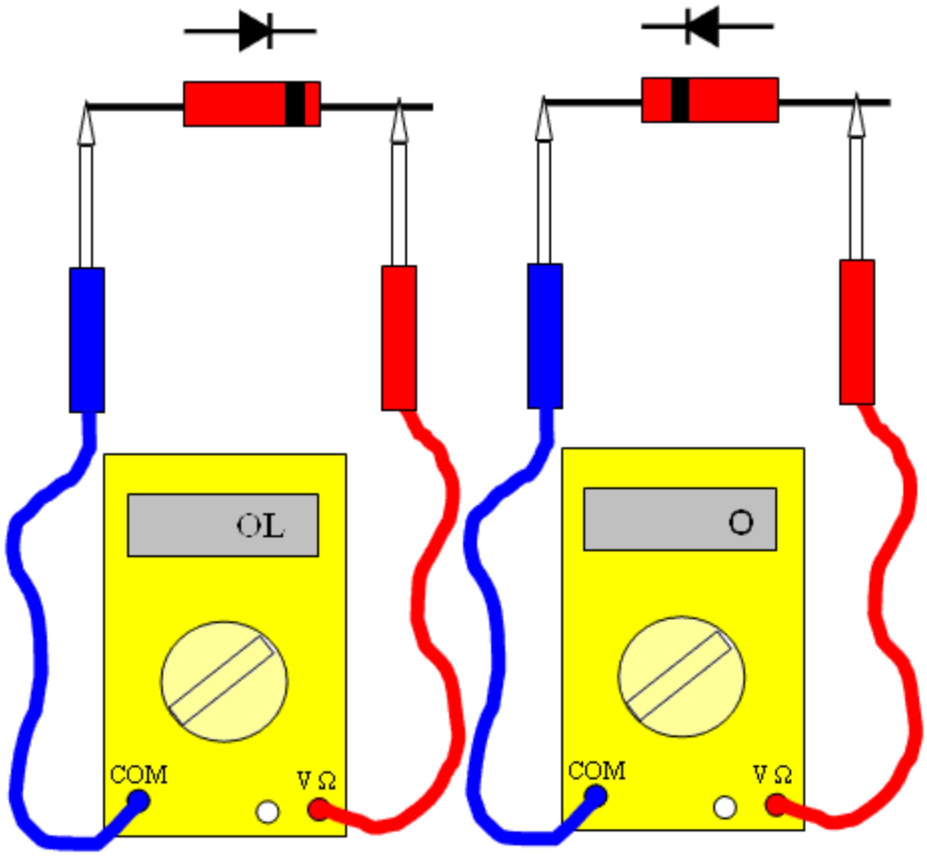


Although for most circumstances the voltage drop may be considered fixed there are a few instances were the slight increase in voltage drop with increaseing current is part of the design of the circuit so must be understood. The actual current flow for a given voltage drop is give by the **Diode Equation** and contains variables such as Saturation current, applied voltage and diode temperature.

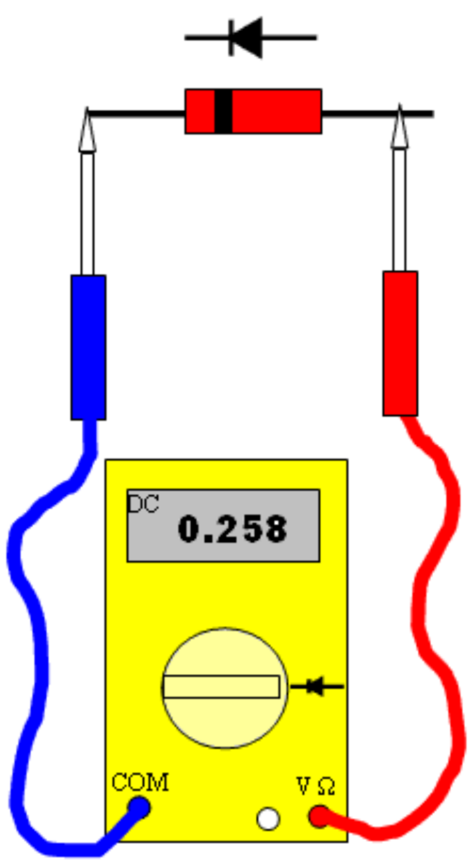
Testing

In the following the red lead on a meter is considered to be postive and the black negative. Although this may seen obvious it should be noted that for some older type analogue meters this polarity is reversed when it is set to read Resistance

Most modern meters are able to forward bias a diode when set to measure resistance. No meaningful information can be read off the meter however as it is an ohmic value dependent on variables of the meter itself.



Some meters have a **Diode Check** facility. Use of this will in Forward bias will give a Voltage value equivalent to the nominal forward bias voltage.

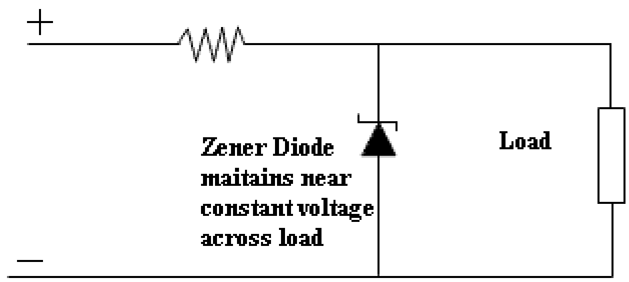


It is unlikely that the meter will be able to generate the 50v required to exceed the Peak

Inverse Voltage to cause the diode to breakdown. As for most Diodes this would caue there destruction this becomes unecessary. However, devices such as an Insulation Tester (Megger) can easily exceed this and for this reason all diodes should be disconnected from a device before they are used.

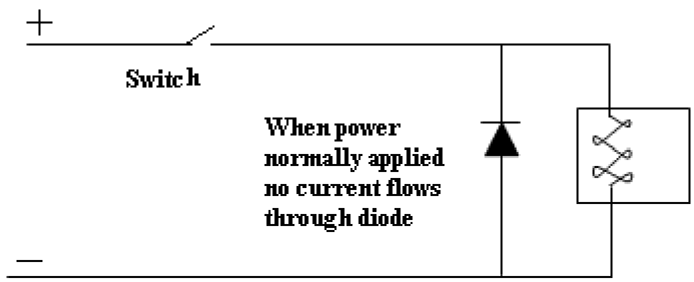
Specialist Types

Zener Diode- these are diodes which may be used in the Reverse biased mode where they breakdown at a known voltage and allow current flow. They are used primarily in voltage stabilising circuits



. The stabiliser circuit consists of the Zener diode and a **Dropper Resistor** across which takes the excess voltage.

Free Wheeling Diodes - sometimes referred to as Inductor Commuting are a standard diode placed across the coil of a coil. These are typically found on relays.



When the supply is turned off the coil the collapsing magentic field causes a high voltage to be generated which can cause arcing at the switch. The diode disapates the current slowing down the collapse of the field (and thereby slowing the repsonse of the relay which may cause problems in some electronic circuits)

Light Emitting Diode- Electrons flowing through a PN junction experience a change in energy level emitting radiant energy when doing so. Constructing diodes containing elements gallium, Arsenic and phosphorus creates radiant energy at visible wavelengths. A Limited number of Colors can be created by changing the chemical constituency, more colors can be created by adding more than on LED using the same Lens.

Constant Current Diode- These limit the current flowing a circuit. These are seen in LED circuits and charging devices for Secondary Batteries

Requirements for Electrical machinery

Machinery requirements

It is a standard requirement that all propulsion and auxiliary machinery fitted should be capable of operating when upright and when inclined at an angle of list up to 15o either way under static conditions and 22 Ho under dynamic conditions either way and when simultaneously inclined dynamically 7 1/20 by bow and stern. The emergency generating sets shall be capable of functioning when the ship is inclined 22 1/2o from upright and inclined 100 bow to stern. The two main factors of concern are lubrication and the functioning of contactors, switchgear and relays having unsymmetrical or unbalanced magnetic systems when the magnetic pull required to operate increases with tilt. Apparatus, such as transformers or switches, containing oil could be affected.

Temperature effects

Extremes of temperature will affect the performance and the effective life of the electrical apparatus. Devices which depend on electromagnetic operation by shunt coils will find resistance of the coil increases with temperature so with less current both the ampere turns and the field strength is reduced.

Contactors and relays may fail to operate correctly if overheated.

The total temperature is determined partly by ambient air temperature and partly by heating effect of the current windings.

This heating effect gives a temperature rise and this is always about the same for similar load.

The total temperature, which will affect the life of the insulation and the performance of the equipment, will be maximum at the maximum ambient temperature. For unrestricted service the cooling air temperature is 45^{o}C . For restricted service and vessels intended for northern and southern waters outside of the tropical belt the temperature is 40^{o}C.

Adequate ventilation and avoidance of hot pockets where electrical apparatus operates is important.

When considering suitable operating temperature for a device the 'hot spot temperature' is important. In the field coil the hot spot is somewhere in the centre of the winding and there is a temperature gradient form there to the surface. Previous recorded surface temperature values corresponding to specified hot spots temperature are acceptable for recording the machines performance. Another method is to record changes in resistance due to temperature in the winding.

When carrying out temperature tests on machines the maximum surface temperature of the windings is found just after the machine has stopped and it is no longer cooled by windage. The temperature bulb should be covered by a pad of felt to prevent heat loss when the surface winding readings are taken.

Installation and maintenance

To reduce end play and avoid hammering during rolling machines should be installed with their axis of rotation in the fore and aft direction or vertically. If unavoidable that the machine is placed athwartships suitable thrust bearings should be provided against the hammering effect. Special attention should be paid to the lubrication of ring lubricated sleeve bearings.

The main cause of overheating in electrical joints is loose connections usually due to vibrational problems. All screws and nuts should be locked and periodically checked and tightened if necessary.

Heavy current circuits, control and shunt field circuits should all be checked.

Machine rating

The recognised standard is the Continuous maximum rating (C.M.R.), motors and generators are seldom if ever called upon to operate under sustained overload.

Momentary overloads (15s for test purposes) of 50% in generators is allowed. Motor overload is determined by function and size.

C.M.R. machines will still carry moderate overloads for reasonable duration's. An example of this may be an oil pump on start up may experience high loads as the oil is initially cold.

Circuit protection

For example;

- **Motor drawing 100A on 220v supply 218v measured at motor terminals giving a 2 volt drop across cables**
- **Cable resistance therefore is 0.02 Ohm's.**

If the motor is bypassed the PROSPECTIVE SHORT CIRCUIT current would be 11,000A

The main circuit breaker may be protected by fuses or a circuit breaker having at least the necessary breaking capacity and fast enough operative time. This is 'back up' protection. Generator circuit breakers must not be used for this purpose.

In motor circuits the breaking capacity of motor starters is usually very limited and does not greatly exceed the starting current of the motors, If a fuse is fitted for 'back up' protection of the motor starter it should be able to carry the starter current for the time necessary to start the motor plus a suitable margin. If correctly chosen it will not blow except under maximum mechanical fault or electrical fault or overload conditions. It will still give protection should the fault current exceed what the motor starter can handle.

If A.C. generators and their excitation systems undergo steady short circuit conditions they should be capable of maintaining a current of at least three times its rated value for 2 seconds unless requirements are made for a shorter duration. The safety of the installations must be insured.

Performance

The standard condition for generator performance is based on the starting kVA of the largest motor, or group of motors which can be started simultaneously and this kVA should not exceed 60% of the generator capacity.

Voltage should not fall below 85% or rise above 120% of the rated voltage when such a load have a power factor from zero to 0.4 is thrown on or thrown off the board.

Voltage must be restored to within 3% of the rated voltage within 1.5s. For emergency generators 4% in 5s is allowed. The transient effect when a load is suddenly thrown on is to cause a voltage dip. This dip may be made less if the generator is designed to have a lower reactance during transient conditions. However, too low a reactance with a smaller voltage dip may involve high short circuit currents in excess of capabilities of the available protective devices.

The designer must consider the opposing conditions of low transient voltage dip and low short circuit currents and balance these conditions against possible increase in machine size, weight and cost.

Functional systems generally operate faster than error operation systems. Nevertheless most functional systems use an A.V.R. for trimming purposes because of practical difficulties of maintaining normal voltage within narrow limits. Methods normally supplied will maintain voltages within +/- 2 H % with many attaining +/- 1 H %

Hazardous Zone areas

Ships are segregated into zones determined by the level of hazard with regard to likelyhood of the atmosphere containing an explosive atmosphere. A plan of the vessel indicating this segregation is to be submitted to class.

Hazardous Areas Zone 0	Certified Intrinsically safe Circuits
Hazardous Areas Zone 1	Certified Intrinsically safe Circuits Certified Flame proof equipment Certified Increased safety equipment; for increased safety motors due consideration is to be given to overcurrent protection Pressurised enclosure equipment Equipment contained in a dielectric filled enclosure Cables with suitable earthed sheathing
Hazardous Areas Zone 2	Certified Intrinsically safe Circuits Certified Flame proof equipment Certified Increased safety equipment; for increased safety motors due consideration is to be given to overcurrent protection Pressurised enclosure equipment Equipment contained in a dielectric filled enclosure Cables with suitable earthed sheathing Any equipment which ensures an abscence of hot spots or sparks during normal operation

Ingress Protection (IP)

First Digit (solids)	Second Digit (Fluids)	Third Digit (Impact)
0 No Protection	**0** No Protection	**0** No Protection
1 Solid Objects over 50mm e.g. accidental touch by hand	**1** Vertically falling drops of water	**1** Impact of 0.225 joule (150g weight dropped from 15cm)
2 Solid Objects over 12mm e.g. fingers	**2** Direct sprays of water up to 15^{o} from the vertical	**2** Impact of 0.375 joule (250g weight dropped from 15cm)
3 Solid Objects over 2.5mm e.g. tools and wires	**3** Direct sprays of water up to 60^{o} from the vertical	**3** Impact of 0.5 joule (250g weight dropped from 20cm)
4 Solid Objects over 1mm e.g. small wires	**4** Water sprayed from all direction - limited ingress permitted	**4** (no meaning)
5 Dust - Limited Ingress (no harmful deposits)	**5** Low pressure water jets from all directions - limited ingress permitted	**5** Impact of 2.0 joule (500g weight dropped from 40cm)
6 Dust - Total; No ingress	**6** Strong pressure water jets from all directions - limited ingress permitted	**6** (no meaning)
7	**7** Immersion between 15cm to 1m	**7** Impact of 6.0 joule (1.5Kb weight dropped from 40cm)
8	**8** Long periods of immersion under pressure	**8** (no meaning)
9	**9**	**9** Impact of 6.0 joule (5Kb weight dropped from 40cm)

Sewage systems

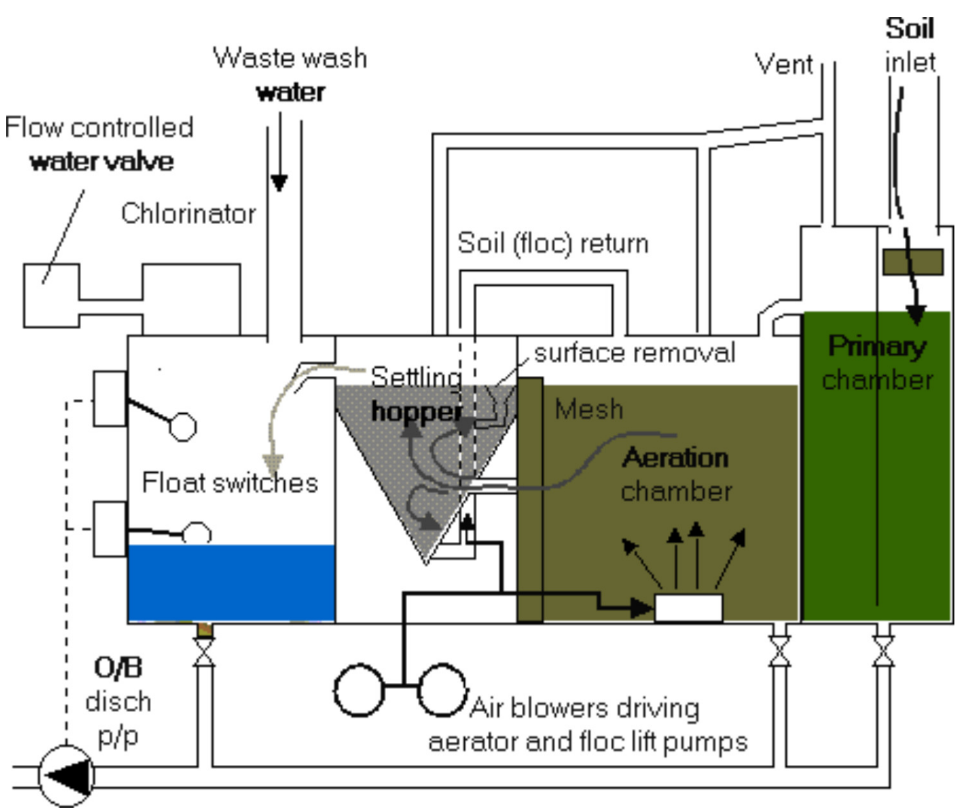
Regulations.

Legislation preventing the discharge of untreated waste overboard has been in place for some time with a requirement that it should be retrofitted where not already in use. American legislation defines three types of sewage treatment units.

Type 1	A device capable of discharging effluent having no floating solids and a coliform count of less than 1000 per 100ml of effluent.
Type II	A device capable of discharging effluent with suspended solids not in excess of 150mg/litre and a coliform count of less than 200 per 100ml
Type III	A device to prevent the discharge overboard of treated or untreated waste.

Ventilation systems are to be kept independent of other vents A log is to be kept of any discharge overboard from a holding tank

Aerobic (Biological) Treatment plant (Flow through system)



Principle

Biological system require a steady and relatively constant flow of solid sewage so the bacteria can exist in sufficient quantity to maintain effluent discharge at the correct quality. sludge build up is a possible problem although extended residence in the aeration chamber greatly reduces the amount. For example, sewage with 80% solid waste is reduced to 20% of its original weight after 12 hours in the aeration tank.

The process of aerobicity strips oxygen from the water and creates more water, carbon dioxide and bacteria.

Operation

The Trident sewage treatment unit shown above consists of three chambers.
Sewage enters the **aeration chamber** via a coarse mesh filter where large solids are broken down. The aeration chamber is where the main biological action takes place. Here air blowers mounted on the outside of the unit oxygenate and stir the effluent and bacteria mix via a series of pipes and nozzles. The sewage remains in this aeration tank for some time.

Incoming sewage displaces some effluent of the **settling tank (or hopper)** where under inactive conditions biological floc, activated sludge and bacteria, settle out and is returned to the aeration chamber via air lift pumps also driven by the blowers. A second transfer pipe scum's the surface of the settling tank and returns it back to the aeration chamber. This returned sludge contains the bacteria to digest the incoming sewage. Thus the importance of this floc return can be seen

Authors note:
This is a common question in orals

Effluent passing over from this chamber should be clean and ready for disinfecting in the **chlorinating chamber**. The level in this chamber is controlled by a pump and float switch arrangement. typical chlorine levels at discharge is 5ppm.

Valves are fitted to the aeration and primary chambers to allow them to be pumped out and back flushed as necessary.

The bacteria are susceptible to water conditions including temperature and the presence of toilet cleaning agents. In this way the system is fitted with by-pass valves so passing contaminated water overboard. Should the bacteria be killed it takes some time before a new colony forms. There are special 'feeds' which promote the reestablishment of these colonies.

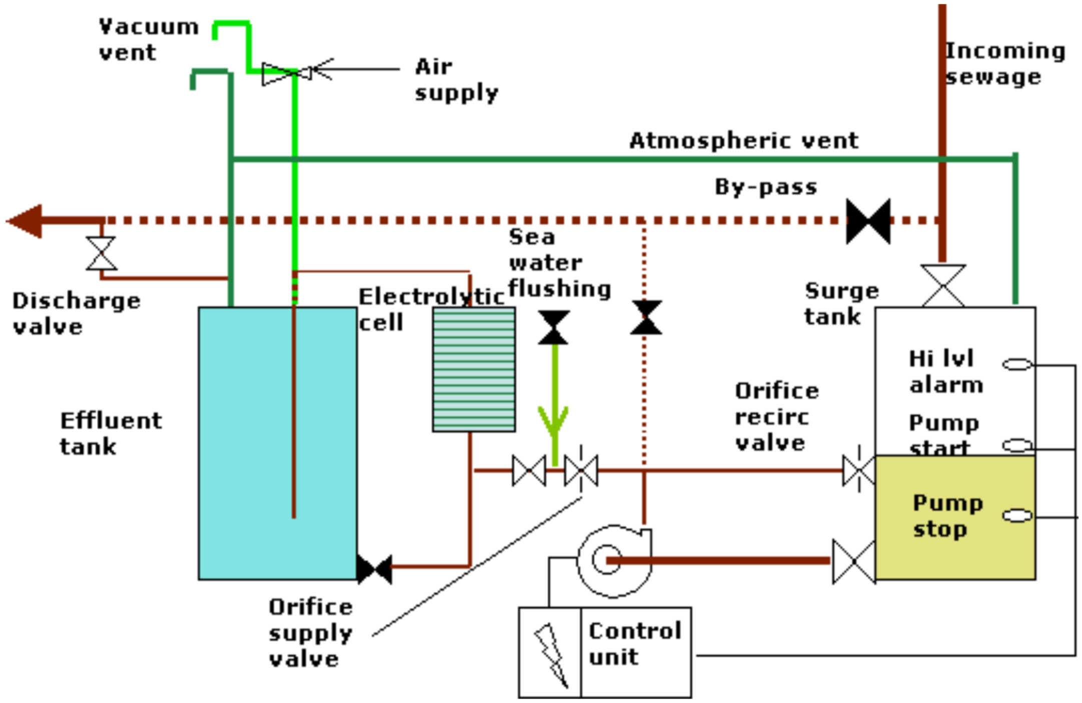
Physical-Chemical Sewage system

This is based on the separation of the liquid element from the sewage flow. This is disinfected in a 5% chlorine for 30 minutes to kill off coliform bacteria and then discharged overboard in full MARPOL compliance.

One problem with this system is the required space, Only a finite amount of space can be set aside for the storage of the solid part of the waste which can only be discharged in port or outside territorial waters when allowed. If these facilities are unavailable the system become inoperative.

There is also the need to carry quantities of Calcium Hypochlorite for conversion to Sodium HypoChlorite for the disinfection of sewage flow. Calcium Hypochlorite requires very careful handling.

Electrocatalytic Oxidation



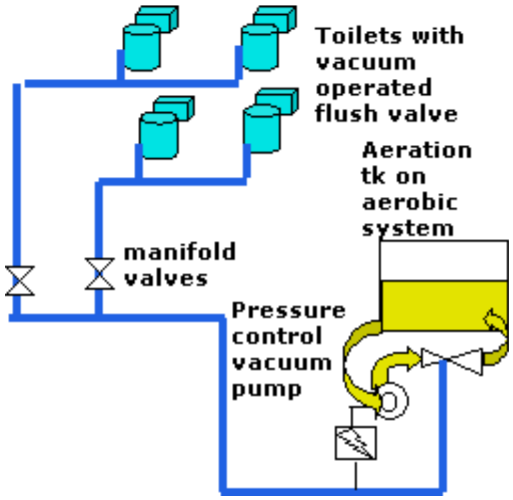
Sewage is collected, macerated and passed through a electrolytic cell.

Electrolysis produces Sodium Hypochlorite which is used to oxidise organic material before discharge. Alternately dosing by chlorine may be used. The effluent passes on through to a settling tank were the oxidation process is completed

These type of plants can be 50% smaller than biological types, this and the fact that pass through times are extremely short-typically 30 minutes compared to the several hours of the biological unit- are the main advantages of this system.The discharge contains no solids and is totally free of coliform bacteria.

A disadvantage of this system is due to the short exposure time in the oxidiser relatively high levels of chlorine are required to ensure destruction of the coliform bacteria. It is possible that this chlorine level can be present to some degree in the discharge. Dechlorination plant may be fitted

Vacuum sewage systems



Shown is a simple layout for a vacuum sewage system.

Operation

Liquid flows from the aeration tank of an aerobic sewage tank to a coarse impeller centrifugal pump. This delivers the liquid under pressure via an eductor and back to the tank. The eductor reduces the pressure in the sewage system pipework to a set point after which the pump is stopped. When the pressure in the pipework rises above a set value it is restarted.

The pipework consists of a network of mainly pvc pipes connected into separate zones- typically by deck- and brought down to a common manifold via isolating valves. These valves allow work on sections of the system whilst still maintaining others in use.

The toilets are connect to the system via a vacuum operated foot valve. Vacuum timers are also fitted which allow measured quantities of flushing water to be applied.

Where toilets are connected in the same zone but exist at different heights non-returning valves may be fitted. In addition filter boxes may be fitted along with additional isolating valves to improve operation.

Advantages and disadvantages

Very little flushing water is required and the volume of sewage dealt with can be much reduced with the downsizing of relevant equipment and cost saving.This has made them very popular for passenger vessels.Lloyds regulations state that the capacity of a sewage system for flushing water with conventional plant is 115 litres/ person/ day and 15 litres for vacuum systems.

The main disadvantage is blockage due to drying and crystalisation of urea. Over a period of time this can be so severe as to completely close the pipes. Chemicals are on the market which can be added in very small doses which help remove and prevent this deposits but there success is not guarenteed.

In the event of vacuum failure a method must be in place to prevent dangerous gasses passing back into the accommodation.

The Hazards and regulations regarding the Sewage Systems

Raw sewage discharged into restricted waters will eventually overwhelm the self purification ability of the limited quantity of water. In a closed dock the effect can be seen in a black sludgy water which when disturbed gives off an unpleasant smell possibly Hydrogen Sulphide.

When the quantity of sludge is reasonable aerobic bacteria digest the sewage breaking it down to simple compounds and Carbon dioxide using up Oxygen in the process. These compounds and Carbon dioxide promote plant life which returns oxygen to the water.

When the quantity of Oxygen becomes so depleted that the aerobic bacteria can no longer function, anaerobic or bacteria not requiring Oxygen to function will take over. The breakdown of the sludge is then associated with the same process of decay with foul smelling and dangerous gasses being produced. Therefore the principal means of sludge conditioning on board is that of aerobic action, Types of sewage disposal

There are four main types of sewage disposal systems fitted to ships;

a. Discharge from the toilet bowl into a common drain leading to overboard via storm valves
b. As above except common drain leads to a storage tank with or without aeration. Contents discharged ashore or at sea when appropriate.
c. Sewage treatment systems with sewage being collected and treated to produce an effluent suitable to discharge without effect on environment.
d. Vacuum collecting system where the drains are kept at a slightly negative absolute pressure , on flushing water, sewage and air are drawn into the drains being led to a collecting or treatment tank which is kept at atmospheric pressure.

Aerobic and anaerobic bacterial action

When the sewage enters the drainage system it is acted upon by aerobic bacteria and is broken down, during this process the naturally occurring Aerobic Bacteria strip the water of oxygen and produce; more water, Carbon Dioxide, and more bacteria.

If, however, there is insufficient oxygen for these bacteria then alternative bacteria dominates. These Anaerobic Bacteria produce Hydrogen Sulphide, Methane and Ammonia. These gasses are either highly toxic or flammable or both. In particular Hydrogen Sulphide is toxic to humans in concentrations down to 10ppm and its flammable vapours are heavier than air so may build up in lethal pockets in enclosed spaces.

Safety Parameters

The generation by anaerobic bacteria these toxic and flammable gasses is present in all types of systems to some degree. The possibility of anaerobic action within a sewage treatment plant should be reduced as far as possible.

Should these gasses be generated and allowed to enter the accommodation could lead to disaster.

The following are some methods which may help to reduce the risks;

- The fitting of proper ventilation in toilet spaces and the fitting of water traps can only be seen as secondary measures to reducing the risk. The primary concern is to eliminate the possibility of generating the gasses in the first place.
- Where sewage is stored in tanks for discharge, some method of maintaining an adequate level of

oxygen in the water must be in place. Examples of these may be by direct air injection or by air entraining into the liquid whilst pumping through a nozzle.

- Where active aeration is not fitted then the contents of the storage tank should be changed within a maximum of a 24 hour period unless some other means of treatment is used.. The conditions in the tank should be closely monitored
- Where aerobic treatment plants are used then manufacturers operating instructions should be closely adhered to. A system of maintenance should be in place.

Maintenance of Aerobic treatment units.

1. *Thorough , regular cleaning and inspection with particular attention being paid to areas behind internal division plates*
2. *Checks on alarms and trips*
3. *Checks on aeration equipment*
4. *Checks on transfer systems in the tanks*

It is recommended that a low air pressure switch rather than a motor failed alarm be fitted to the air blower motor hence eliminating the danger of the fan belts snapping and going undetected.

Tank Ventilation arrangements.

Ventilation pipes should be in good condition and free from obstructions. They should be of a size to minimise pressure drop and ensure good gas clearance. They should be self draining to prevent blockage by water.

Any flame gauze's or other fittings should be checked for cleanliness.

Toilets, showers, washbasins, etc.

The condition of drainage pipes should be checked regularly, as should the operation of the water seal or other fitted arrangements to prevent the back flow of gasses.

Accommodation ventilation arrangements

The ventilation should be sufficient to ensure proper balance allowing each compartment to be correctly supplied. The ventilation system should be correctly maintained and checked for cleanliness.

Air extraction is of vital importance and the cleanliness of grills should be checked, the opening under doors should not be blocked, vent louvers should be correctly position to ensure all spaces are properly vented.

The forced ventilation equipment should be regularly checked and maintained.

Operational aspects

Only approved toilet cleaning agents should be used, the use of excessive quantities of bleach should be avoided as this may kill the bacteria.

. Complaints of foul or musty smells should be dealt with immediately as these may indicate anaerobic action. The dangers of these gasses should be explained to all crew.

Suspended solids

The quantity of solid waste in the effluent is weighed. After drying on an asbestos mat filter element.

Biological Oxygen demand (B.O.D.)

Aerobic bacteria use Oxygen in the process of breaking down the sewage. At the end of the process the action of the bacteria reduces and so does the Oxygen demand. The effectiveness of a sewage treatment plant may be gauged by taking a one litre sample and incubating it for 5 days at 20^oC. The amount of Oxygen consumed in milligrams per litre or ppm is termed the B.O.D.

Coliform count

It is possible that the effluent contain bacteria and viruses hazardous to health if it has not been properly treated at the final stage. An indication of this is a count of the Coliform bacteria which are found in the intestine.

A coliform count in a 100ml sample incubated for 48 hrs at 35^oC. Another test at the same temperature but over a 24 hour period produces a colony of bacteria.

Regulations

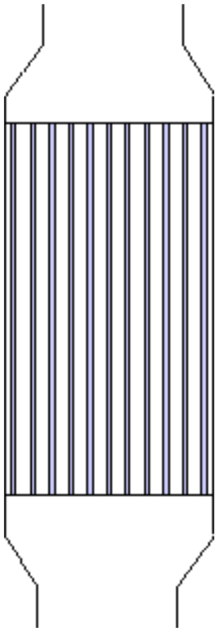
Annex IV of MARPOL 73/78 (IMO) regulates the disposal of waste from ships internationally. In addition certain countries have their own national and regional controls.

In general this means that untreated sewage can only be dumped outside 12 miles offshore, and treated disinfected waste outside 4 miles.

For further information see m-notice M.1548

Motor ship steam plant

Silencer boiler (Spanner)



Spanner exhaust gas boilers can be provided as steam raising boilers or hot water boilers or economisers. These boilers recover from 20% to 50% more heat at a higher working pressure than some other designs.

They utilise the heat contained in the exhaust gases from diesel engines and gas turbines. Spanner boilers of this type have tubes expanded and then seal welded into the tube plate thus designed to be able to be run dry or with varying water levels giving varying steaming rates. In the dry condition access doors are opened to allow air circulation.

They may be fitted with an integral by-pass with either manual or automatic control so that steam output can be controlled by varying the amount of gas passing over the heating surface.

The boiler is designed to offer the minimum of resistance to gas flow with a back pressure less than 150mm water.

There are therefor three ways of controlling steam pressure/generation rate

1. *via a gas by-pass valve*
2. *via a steam dump system*
3. *via changing water levels(thus changing generating surface)*

There is no capability for oil firing therefore a donkey package boiler is required for use in port.

SWIRLYFLO tubes are used

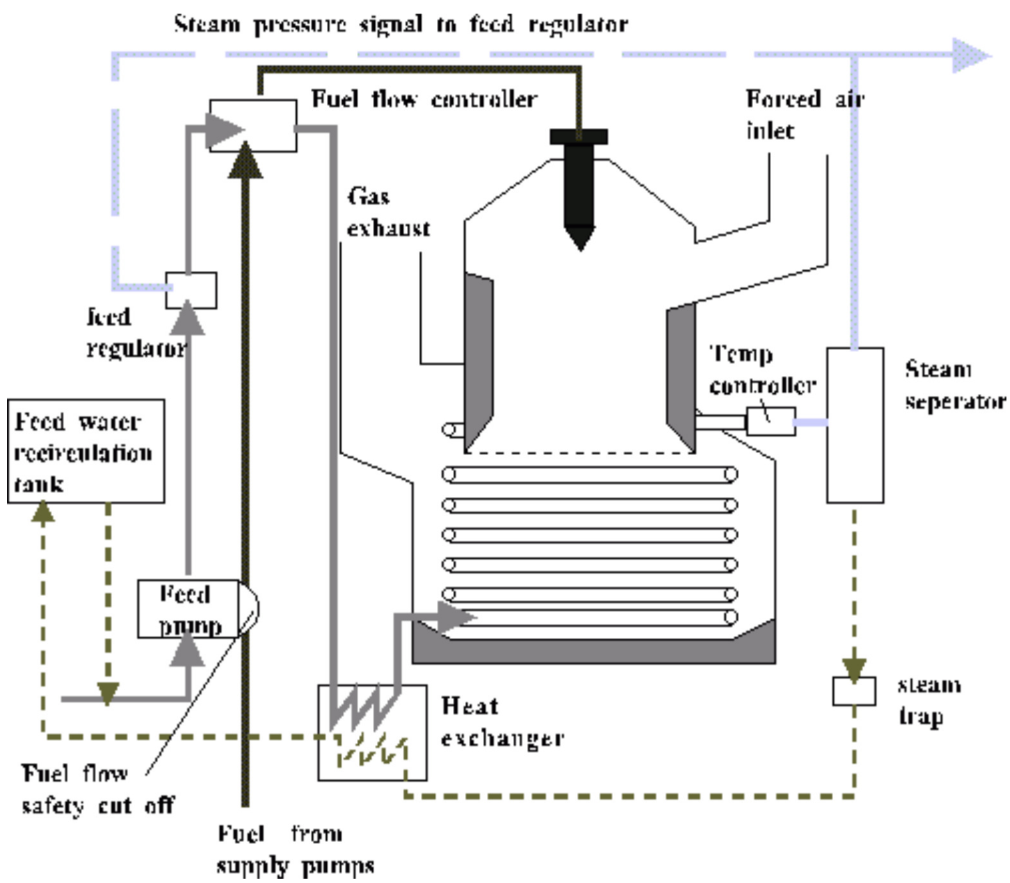
Stone vapour boiler.

The steam generating part of the unit consists of sets of coiled tubes nested and connected in series to form a single tube several hundred feet long. Water is pumped into the coil inlet and converted to steam as it progresses through the coils. Heat is furnished by combustion of diesel fuel oil which is sprayed by compressed air through an atomising nozzle in the fuel sprayhead into the firepot above the coils. Here fine oil spray mixes with air supplied by the fan and is ignited by a continuous electric spark. The heat flow is first downward, then outward through the nest of coils.

The fuel supply is regulated such that the steam generated is equal to 80% to 90% of the water supplied, and any scale or sludge formed is carried out of the system by the water. And deposited in a separator. This ensures that the inner surfaces of the tubes are kept clean, the outside is cleaned by filling the chamber with water and bubbling steam through the water for about 12 Hrs.

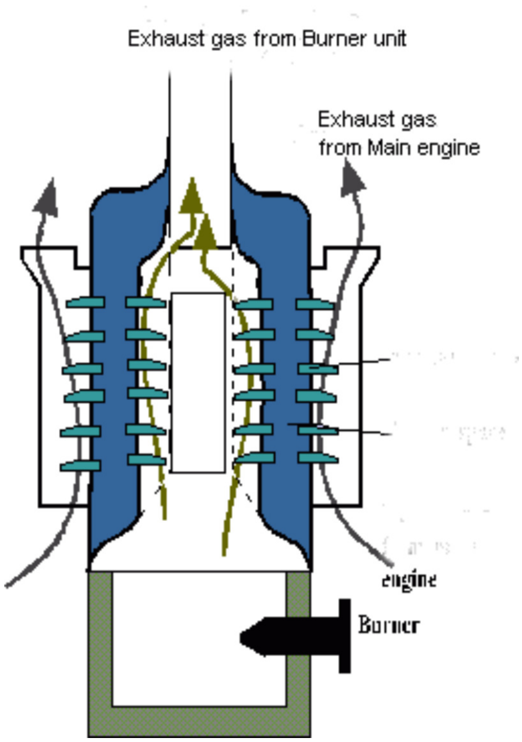
In the separator the sludge etc, settles to the bottom and is removed periodically by blowdown. When water level reaches overflow level it is removed via a steam trap back to the water supply tank but some of its heat energy is first used to heat the incoming feed water. Feed pumps are driven at constant speed, regulation is by a by-pass valve. When demand for steam falls, the steam pressure at outlet increases, this acts on the feed regulator in such a way as to increase the proportion of by-pass. Fuel and air control is by feed flow into the boiler, thus if the by-pass is opened and feed flow to the boiler reduced, so the fuel/air flow is adjusted accordingly.

Water pressure relief valve	40bar
Fuel pressure regulator	10.9 bar
Atomising air pressure	4.9bar
Max evaporation at 7bar	1250 Kg/Hr
Fuel consumption	114 litres hr
Water capacity	77 litres



The advantage of this type of boiler is a very short warm up time, the disadvantage is of course the disastrous consequence of a perforated pipe

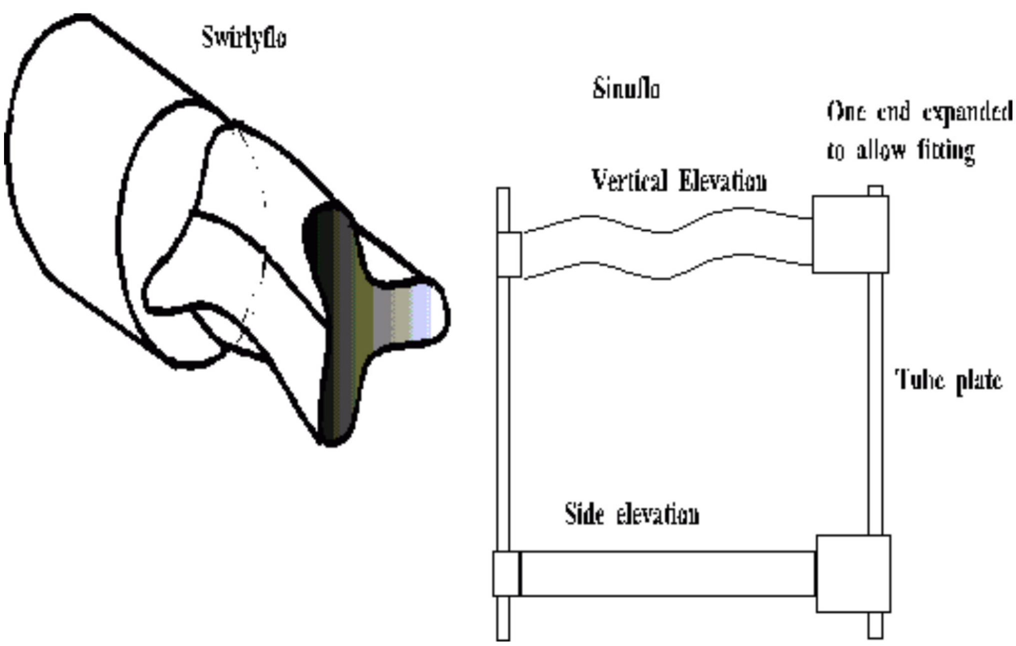
Composite boilers-(Clarkson thimble tube)



This type of boiler will generate steam by means of exhaust gas and oil firing, many different arrangements are possible, the one shown is the Clarkson composite boiler which makes use of thimble tubes for heat steam generation. The only restriction is that it must not be possible to have oil firing and exhaust gas firing on the same heating surface at the same time. If this were the case there would be the possibility of exhaust gas entering the engine room through the burner section or of blowback due to the action of exhaust gas and oil firing. There would also be a risk of poor engine performance due to exhaust back pressure, in order to avoid problems and ensure that full use is made of exhaust gases even at slow speeds it is usual to have completely separate oil and exhaust fired heating sections.

Boiler tubes

In order to promote better heat transfer between gas and water it is necessary to provide as large a surface area as possible. Specially shaped tubes will allow for this. Heat transfer is also improved by giving the water a swirling action and the tubes shown will achieve this, for plain tubes twisted strips of metal known as retarders were sometimes inserted in order to cause turbulence in the water flow.



The Swirlyflo tube is formed from plate and rolled into seamless tubes. The Cochran sinuflo is straight when viewed from the side, to prevent deposits building up in the depressions.

Swirlyflo tubes may be inserted anyway around but the sinuflo tubes must be inserted as shown. In addition they can only be fitted through one tube plate and hence only removed the same way.

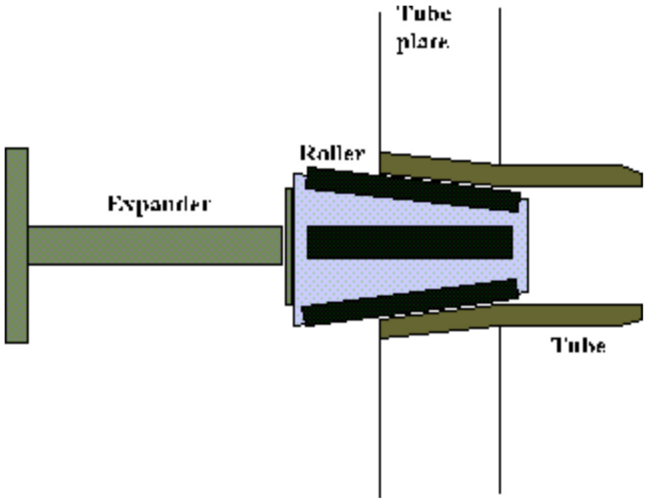
With any tubes deposits and corrosion can occur on the water side. The nature of deposits and the degree of corrosion if any will depend upon the quality of the feed and the effectiveness of treatment. The amount of treatment is important too, too or too much both causing problems. Circulation of water will also influence corrosion especially if stagnant flow areas are allowed to develop. Stresses induced in the tube and the tube plate due to expansion can cause cracking in the area of the tube plate connection. Vibration can also weaken this expanded connection.

On the gas side the nature of the deposits and there quantity depends upon the quality of the fuel burnt and the combustion process. Vanadium, sulphur and carbon can all form deposits with the sulphur leading to corrosion. Carbon will impair the heat transfer as will Vanadium which can also cause corrosion.

Severe corrosion on either side of the tube means that it must be replaced but the degree of corrosion must be considered in terms of thickness, operating conditions and history. I.e. has the corrosion been reduced.

Tubes should be expanded if signs of leakage are evident. Over expansion damages the tube plate and may cause problems when replacing the tube. A leaking tube can be plugged as a temporary measure but only if that leakage is from the tube itself and not from the expanded connection.

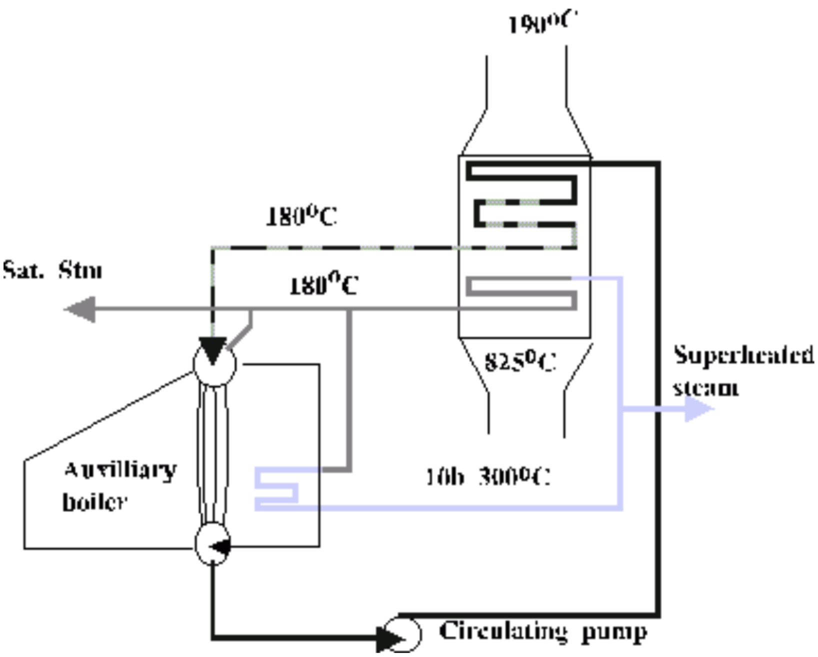
Replacing a tube requires the old tube to be removed usually by cutting three grooves through the tube at the expanded connection and collapsing the ends and then punching the tube out.



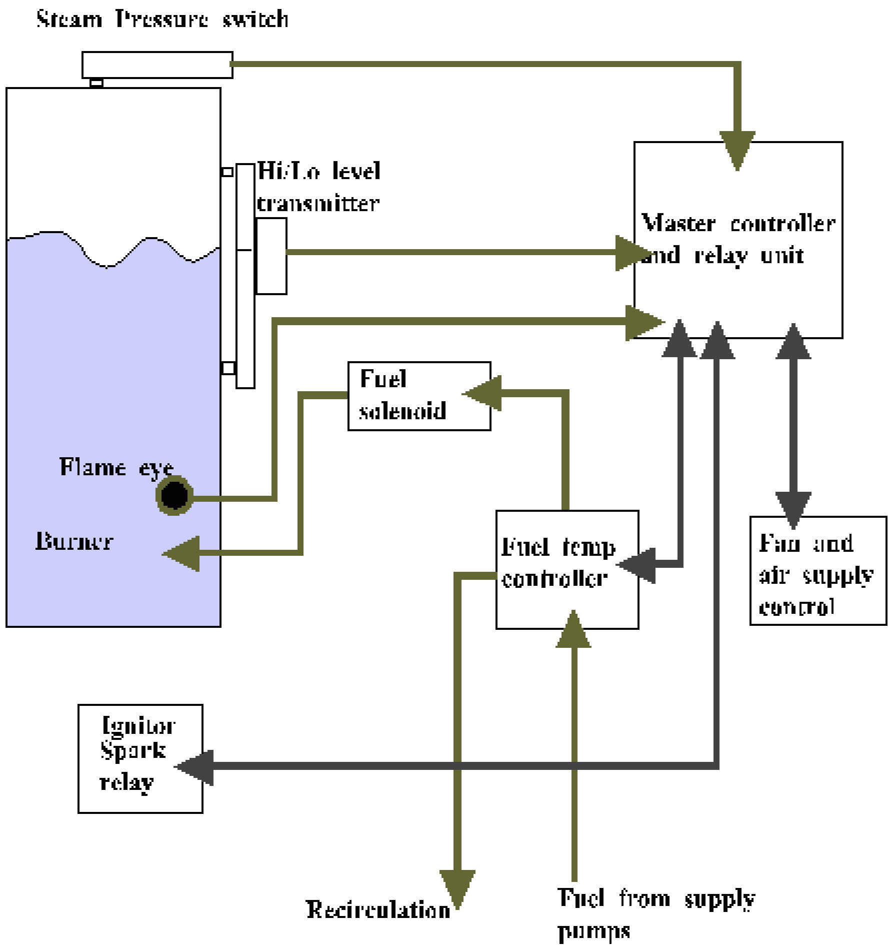
Motor ship steam plant

Were a large quantity of exhaust gas is available for extended periods of time it is economical to make use of the exhaust gas to improve the quality of the steam generated by superheating. This allows for the use of a turbine which connected to a generator can provide electricity. Diesel generators are required as back up in the event of failure. For in port a boiler with an independent superheater will be required.

The steam generator part of the waste heat unit does not generate 100% dry steam at out let. 10% remain as water which carries back any sludge to the boiler where it can be removed. The waste heat unit should have sufficient reserve capacity to allow several minutes of operation after engine load reduction to allow the in port boiler to be flashed



Motor ship steam plant control



For the burner control to be fully automated transducers must be fitted to monitor such things as fuel and air flow, steam pressure and water levfel. Steam pressure is the main controlling parameter and the controller will adjust fuel to maintain this at a set level .

The water level is monitored and kept within a certain range. Should the level become too low then firing is ceased. Automated restarting after this trip is not allowed and a manual reset must be operated. A high level shut off may also be fitted by tradition tripping the feed supply pumps.

With this system fuel is delivered at a constant rate.Therefore before commencement of firing the fuel may be circulated through the heater so is available at the correct temperature. The diverter valve can deliver a varying quantity of oil to the burner dependent on the master controller signal.

When flashing the fan will operate for a certain period at full flow to purge the furnace of gasses. The spark relay operates and the fuel solenoid opens. A period is allowed for ignition. If the photocell fails to detect a flame at the end of this set period the fuel solenoid is shut down. Depending upon set up a second attempt may be made or an alarm output signal will be generated.

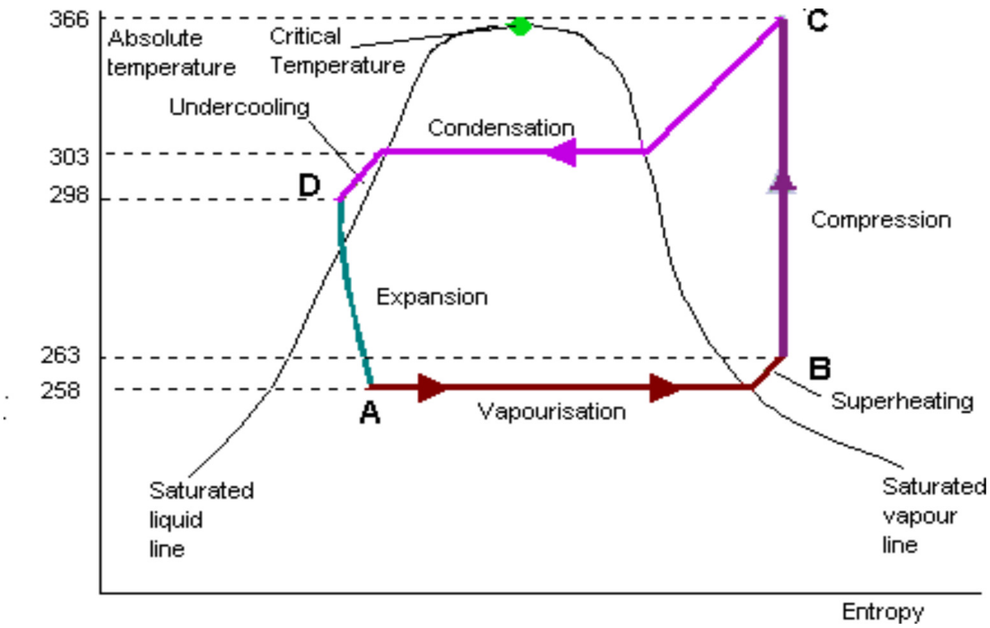
Each item in the system must be tested on a regular basis for correct operation by simulated failures.

This came up in my class one motor paper!!

Fridge system

Vapour-compression theoretical graphs

Absolute temperature - Entropy



A-B, Isobaric Heat absorption in the evaporator

B-C, Isentropic compression in the compressor (frictionless adiabatic compression in ideal cycle)

C-D, Isobaric Heat removal in condenser

D-A, Constant enthalpy expansion in expansion valve

Heat energy equivalent of work done = Heat energy rejected- heat energy received

= Area ABCDA + Area under AD

Coefficient of performance = heat energy received/ Heat energy equivalent of work done

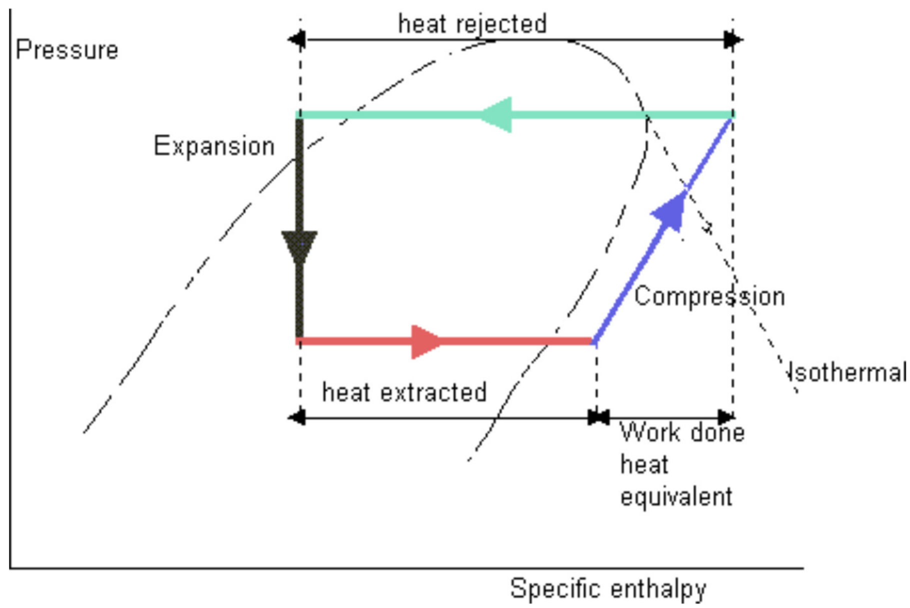
The coefficient of performance for freon is about 4.7

It should be noted that undercooling increases the heat received by moving point A to the left increasing the refrigerant effect.

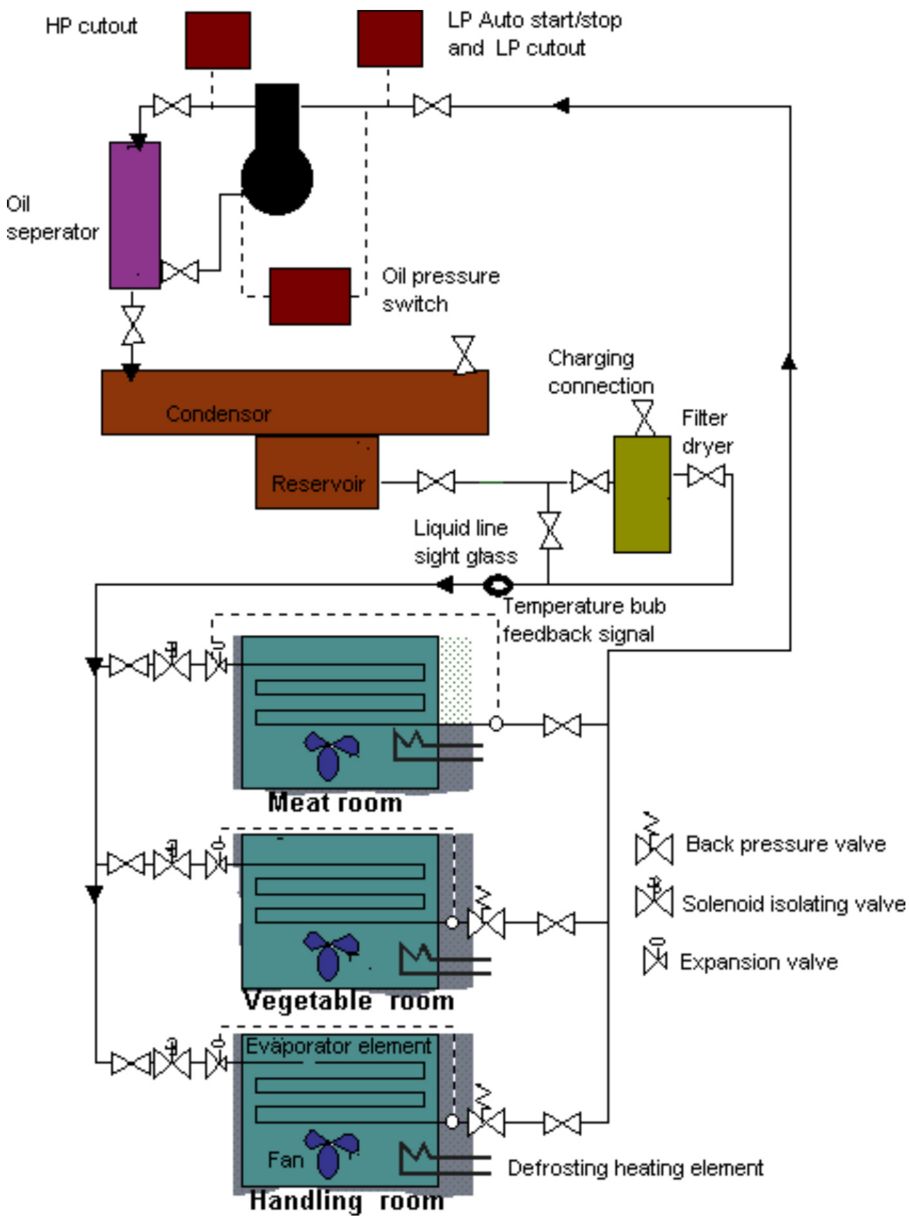
The critical point is the poiunt above which

a. the gas will not liquify by the action of pressure alone. This is an important temperature for refrigeration systesm which rely on the change of state for heat transfer.
b. The gas will not liquify by cooling alone

p-h diagram (Mollier)



Typical system



The system shown above and described below is typical of that fitted on may ships other than it is more common to have two low temperature rooms rather than one.

Components

Cold rooms

Meat Room-Low temperature room typically working at -17^{o}C

Veg/ handling room-typically working at +4^{o}C

Compressor

Generally of the single stage, reciprocating type. Larger systems have multple cylinders with an unloader system using the suction pressure as its signal.

Refrigerant is compressed in the compressor to a pressure dependent upon the temperature of the cooling water to the condenser, and to a lesser extent the volume of gas in the system. As the temperature of the cooling water rises so does the minimum temperature of the refrigerant liquid rise, and with it the corresponding saturation pressure.

Compressor safety devices

The compressor is protected by three safety switches;

The **OP switch or Oil Differential Pressure switch** compares the measured lubricating oil pressure to the Suction (crankcase) pressure. Should the differential pressure fall below a pre-set minimum (about 1.2 bar) then the compressor will trip and require a manual reset to restart. A time delay is built into the circuit to allow sufficient time for the lubricating oil pressure to build up when starting before arming the circuit.

The **HP or High Pressure switch**, is fitted to the outlet of the compressor before the isolating valve. On over pressurisation (dependent on the refrigerant, up to about 24bar bar for R22) the switch will trip the compressor and a manual reset is required before restart.

The **LP or Low Pressure switch** when activated (at about 1 bar for R22) will trip the compressor and require a manual reset before the compressor can be restarted.

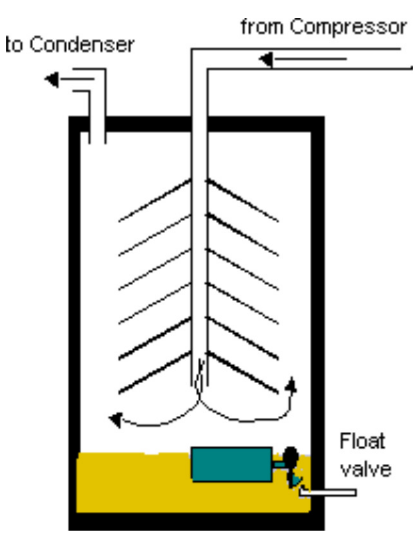
Compressor control devices

This normally takes the form of an LP cut out pressure switch with automatic reset on pressure rise. The cut out set point is just above the LP trip point say at about 1.4bar. An adjustable differential is set to about 1.4bar to give a cut in pressure of around 2.8 bar. The electrical circuit is so arranged that even when the switch has reset, if no room solenoid valves are open the compressor will not start. This is to prevent the compressor cycling due to a leaky solenoid valve.

In addition to this extra LP switches may be fitted which operate between the extremes of the LP cut in and cut out to operate compressor unloaders.

Some modern systems contain a rotary vane compressor with variable speed (frequency changing) control

Oil Seperator



The purpose of the oil seperator, situated on the compressor discharge line, is to return oil entrained in the gas, back to the compressor sump.

The oil return may be float controlled as shown, electric solenoid controlled on a timer, or uncontrolled with a small bore capillary tube allowing continuous return.

With all of these methods a shut off valve is fitted between separator and compressor to allow for maintenance.

The oil gas mix enters the separator where it is made to change direction, the heavier oil droplets tend to fall to the bottom.

Condensor

Generally a water cooled tube cooler.A safety valve and vent are fitted. The purpose of the vent is to bleed off non-condensibles such as air which can enter the system when the suction pressure is allowed to fall below atmospheric or can be contained within the top up gas. The presence of non-condensibles is generally indicated by a compressor discharge pressure considerably above the saturation pressure of the refrigerant.

The coolant flow to the condenser is sometimes temperature regulated to prevent too low a temperature in the condenser which can effect plant efficiency due to the reduction in pressure.

Below the condenser, or sometimes as a separate unit, is the reservoir. Its purpose is to allow accurate gauge of the level of refrigerant in the system. In addition to this it also allows a space for the refrigerant liquid when the system is 'pumped down'. This refers to the evacuation of the refrigerant gas to the condenser to allow maintenance on the fridge system without loss. For systesm not fitted with a reservoir, a sight glass is sometimes incorpotated on the side of the condenser. Care should be given to ensuringthat the liquid level is not too high as this reduces the surface area of the cooling pipes available for condensing the liquid and can lead to increased discharge pressures.

Sight Glass

Often of the Bulls eye form. This allows the operator to ensure that it is only liquid, and not a liquid/gas mix going to the expansion valves. On some designs a water indicator is incorporated, this is a coloured ring in contact with the liquid, when water is detected it changes colour, typically from pink to blue.

Filter Drier

Can be either a compacted solid cartridge or bags of dessicant. The main purpose of this unit is to remove the moisture from the refrigerant.

Moisture cause two main problems. Firstly it can freeze to ice in the evaporator and cause blockage. Secondly it can form acids by reaction with the freon refrigerants. This acid attacks the copper in the lines and deposits its in other parts of the system. This can become particularly troublesome when it is deposited on the compressor mechanical seal faces leading to damage and leakage.

Fine particles which could possible block the expansion valve are removed.

Topping up the refrigerant

A filling connection is fitted in way off the filter dryer, either directly onto it or on the inlet line after the inlet shut off valve. This allows additional refrigerant to be introduced into the system via the dryer element.

The normal procedure is to shut or partially shut the inlet to the filter. The compressor is now sucking from the system and delivering to the condenser where the gas liquifies. The filter dryer is on the outlet from the condenser therefore with its inlet valve shut the liquid level begins to rise in the reservoir. As the only gas entering the system is now coming from the top up line the compressor will tend to reduce the suction side pressure as it evacuates the system into the condenser.

The inlet valve can be briefly opened to allow more refrigerant into the system.

Thermostat and Solenoid Valve

These two elements form the main temperature control of the cold rooms.

The Thermostat is set to the desired temperature and given a 3 to 4 degree differential to prevent cycling. When the temperature in the room reaches the pre-set level the thermostat switch makes and the room solenoid is energised allowing gas to the refrigerant liquid to the expansion valve.

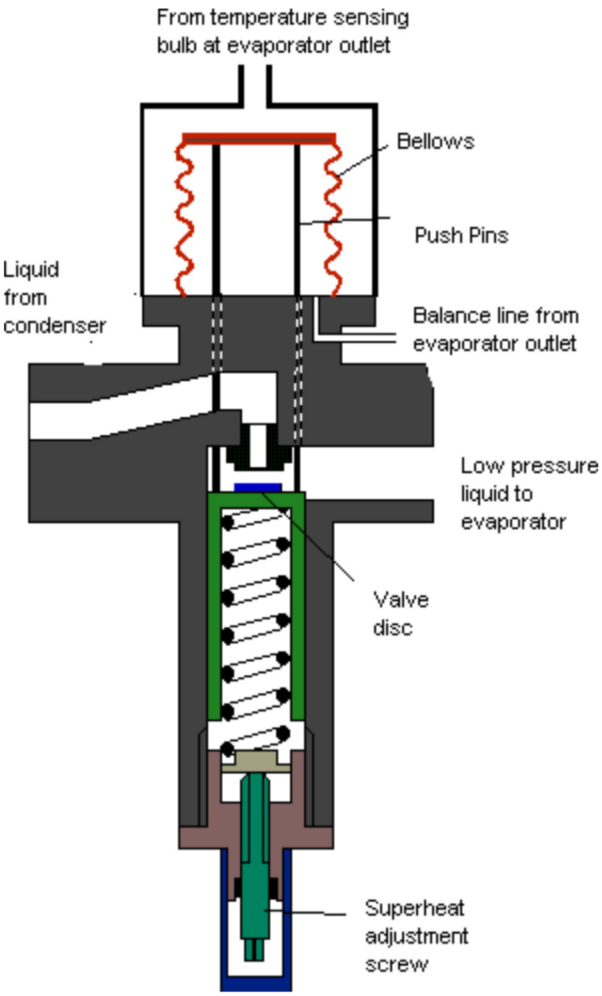
A manual overide switch is fitted as well as a relay operated isolating contact which shut the solenoid when the defrost system is in use.

System operation

Assume that the rooms are all warm and the compressor is running with all the solenoid valves open supplying refrigerant to the respective expansion valve and evaporator.

Should one or two rooms be down to temperature the solenoids close thus reducing the volume of gas returning to the compressor. The suction pressure drops and the compressor unloads. If more rooms shut down then the suction pressure will drop to cut out point and the compressor will stop. When the rooms warm the solenoids open again, refrigerant passes back to the compressor, the suction pressure rises and compressor starts. With more rooms opening, the suction pressure increases and the compressor loads up more cylinders.

Thermostatic expansion valve-



The purpose of this valve is to efficiently drop the pressure of the refrigerant. It achieves this by passing the liquid through a variable orifice giving a constant enthalpy pressure drop. The refrigerant at lower pressure has a corresponding lower boiling point (saturation temperature). Undercooling in the condenser increases the efficiency of the plant by allowing more heat to be absorbed during the vapourisation process. In addition it also reduces the internal heat absorption process that occurs during the expansion stage which is due to a small degree of flash off as latent heat (of vaporisation) is absorbed from surrounding liquid to reduce the temperature of the bulk liquid to the new corresponding saturation temperature for the reduced pressure

By this process of boiling (vapouriation) and latent heat absorption i.e. change of state, the refrigerant removes heat from the cold rooms.

The expansion process is controlled by the action of the bellows and push pins acting on the orifice valve plate. The bellows is controlled by a bulb which measures the temperature of the gas at outlet from the evaporator. To ensure no liquid passes through to the compressor, the expansion valve is set so that the gas at outlet from the evaporator has 2 to 3 degrees of superheat.

For larger systems where a significant pressure drop exists across the evaporator it is necessary to fit a '**Balance line**'. This is a small bore tube which feeds the outlet pressure back to the thermostatic valve 'motor' element. Therefore the measured temperature is directly related to the superheat temperature at outlet pressure.

Some systems are designed so 5% liquid is available through the evaporator to coat the internal surfaces of the tubes increasing heat transfer efficiency.

Author Note

Careful note should be taken that system temperatures are set by the room solenoid and not by the expansion valve which are generally factory set and do not require adjustment.

This may seem an obvious fact but you would be amazed as to the number of broken valve plates removed from compressors due to the mal adjustment of the superheat.

Adjustment of the back pressure valves- which if they have not been touched by ships staff should be unnecessary- can allow better system balance especially when certain rooms are being starved of gas.

Back pressure regulator valve

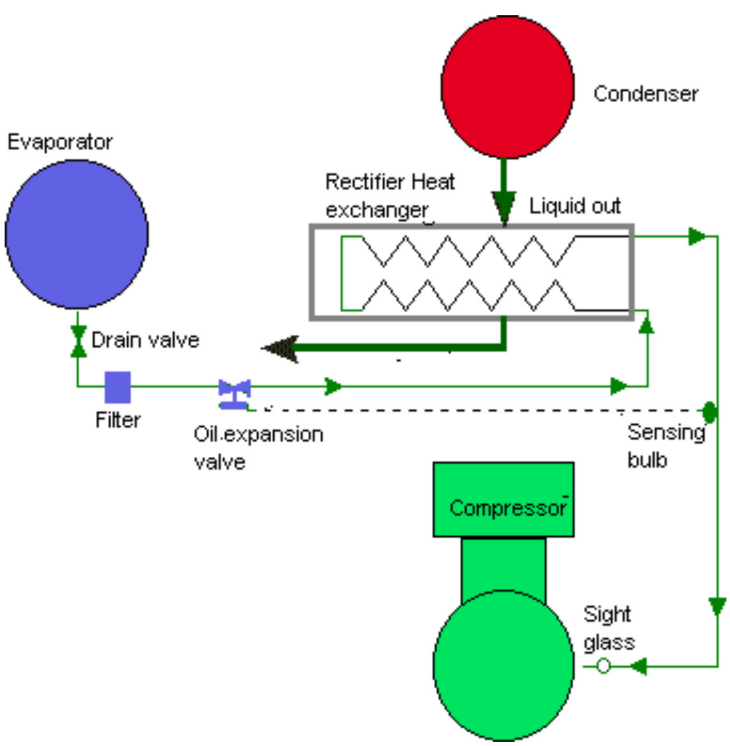
This valve is fitted to the higher temperature rooms, vegetable and flour (+5^{o}C) only and not to the Meat and Fish rooms (-20^{o}C).

They serve two main purposes.

Firstly when all solenoid valves are opened they act as system balancing diverters, that is they restrict the liquid flow to the rooms which can be kept at the higher temperature and deliver the bulk to the colder rooms.

Secondly they serve to limit the pressure drop across the expansion valve by giving a set minimum pressure in the evaporator coil. This in turn limits the temperature of the refrigerant thereby preventing delicate foodstuffs such as vegetables from being damaged by having air at very low temperatures blown over them. Ultimately they may also be set to provide a safety limit to the room temperature by restricting the pressure to give a corresponding minimum saturation temperature of 0^{o}C.

Oil rectifier



In some installations there is a tendency for oil to collect in the evaporator under certain conditions such as low load when the speed of movement and agitation of the evaporating refrigerant are insufficient to keep the oil moving. To prevent loss of oil from the sump to the system, an oil rectifier may be fitted. The oil is automatically bled from the evaporator to a heat exchanger in which liquid refrigerant mixed with the oil is vaporised. The heat for vaporising the refrigerant is obtained by passing warm liquid freon from the condenser, through the heat exchanger. Vapour and oil are passed to the compressor where oil returns to the sump while the freon passes to the compressor suction. The regulator is thermostatically controlled valve which operates in the same way as the expansion valve on the main system. It automatically bleeds the oil from the evaporator so that the gas leaves the heat exchanger in a superheated condition.

Defrost system

Moisture freezes onto the evaporator eventually causing a restriction and reducing the efficiency of the plant. This must be periodically removed. For Veg and Flour rooms, were not restricted to 0^oC minimum by the back pressure valve, this is carried out once per day. For the Meat and Fish rooms this has to be carried out two or more times. Due to the low temperature in the rooms it is necessary to fit a drain heater.

When on defrost the solenoid valve is shut and the fan is off. On some systems at end of defrost the solenoid valve is opened momentarily before the fan is started. This allows moisture to be snap frozen onto the surface of the element, creating a rough increased surface area and thereby increasing the heat transfer rate.

Author note

Care should be taken after loading any great quantity of stores especially into the vegetable rooms. The fresh stores tend to sweat and icing up of the evaporator can become rapid. The only solution is constant monitoring and defrosting as soon as necessary.

Effects of under and over charge

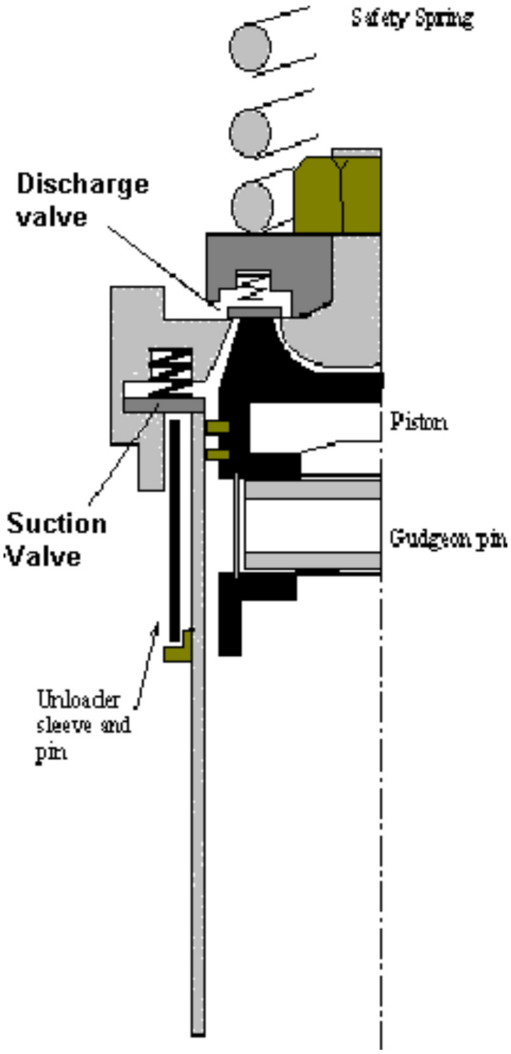
The effects of overcharge are a full condenser/receiver gauge glass. System pressures are not effected until highly overcharged when a possibility of excessive HP pressure exists. Undercharge causes failure to maintain cold room temperatures and compressor cycling. Compressor cycling is caused by there being insufficient gas to maintain the compressor loaded even with all room solenoids open. In extreme the compressor will cut in and out. Undercharge is detected by low levels in the condenser/receiver gauge glass/ bubbles in liquid sight glass, compressor cycling and low suction pressures.

Troubleshoot

A ship had real problems with the control of room temperatures, one room in particular. attempts to 'balance' the system using the back pressure valves usually resulted in rooms starved of gas and/or the compressor tripping on Low Pressure trip. It turned out that sag on one or two of the liquid line pipes allowed oil and debris to build up in this section and restrict flow.

On another ship the lagging around a penetration piece had been damaged and water had got behind it into the insulation. This liquid had frozen and exerted a crushing force on the pipe sufficient to severely restrict *the flow. This was only found after some searching as before the lagging was removed nothing wrong could be seen.*

Fridge Compressors



Compressor bodies are normally of close grained castings of iron or steel. Modern valves are of the reed or disc type mounted in the head and are of high grade steel on stainless steel seats with a usual lift of about 2mm. Connecting rods are aluminium with steel backed white metal big ends. The crankshaft is spheriodal graphite iron.

The pistons are made from cast iron in older units, and of aluminium alloy more recently. The piston is attached to the crankshaft by con rod in the normal manner. It should be noted that the crankcase is full of refrigerant gas at suction pressure.

Liners are made from high tensile cast iron. Lubrication is generally splash only for smaller compressors with a crankshaft driven gear pump supplying bearings on larger machines.It is important to understand that actual pumped lube oil pressure is the indicated pressure less this crankcase pressure.

The properties of the Lubricating oil used in are compressors are critical and specific to the refrigerant gas used. The properties of this oil will be dealt with in the tribology section.

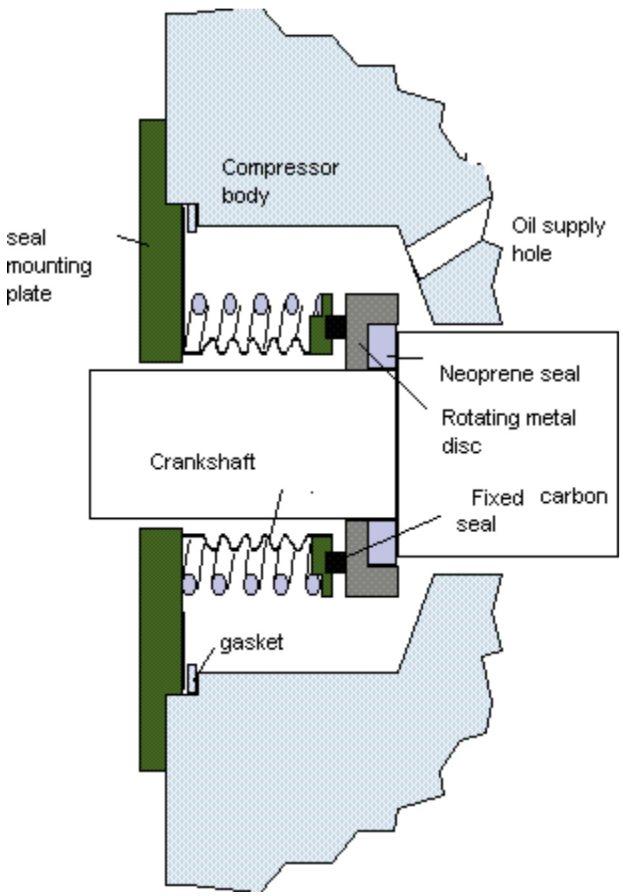
By the nature of the system a possibility exists whereby liquid may be passed to the compressor suction. To prevent serious damage, some form of unloading device is normally fitted. In this case the suction valve assembly is held on the liner by a heavy gauge spring. In the event of liquid passing to the compressor the suction valve will lift against this spring.

Author note
Should water enter the system, acids may be formed by the reaction with the refrigerant gas. This is especially true for freon systems. These acids attack the copper in the system- typically the pipework- and allow it to be transported through the system. It is not uncommon to find this deposited on the suction valve plate. More troublesome is when the deposit finds its way to the crankcase seal destroying the running face.

Thus the importance of maintaining filter dryers in good condition can be seen. These should be changed at least on a schedule determined by the ships planned maintenance system. In addition to this it is common to have liquid line flow bullseye which incorporate a water detection element. Blockage of the filter dryer can be gauged by feeling the filter. If it is cooler than the surrounding pipework then the gas is being throttled through it.

Although not considered good practice in an emergency I have 'dried' the filter drier element in the galley oven although this practice is not recommended.

Mechanical seal

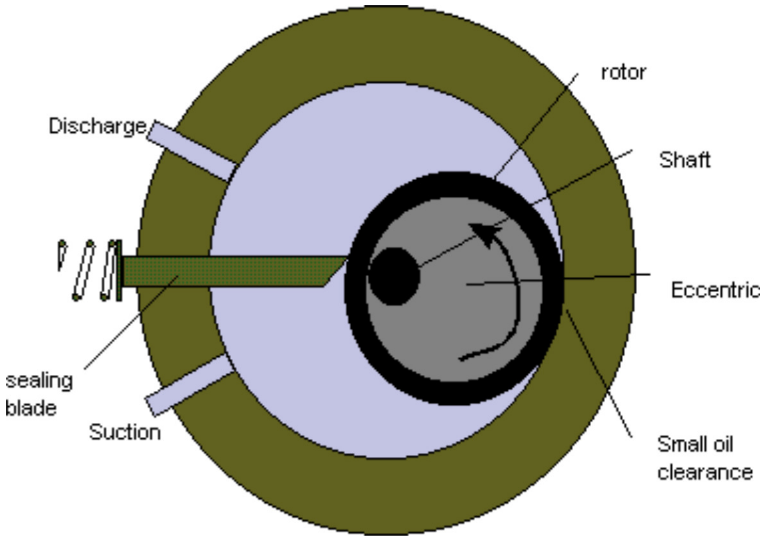


It should be noted that for this design the carbon seal and flexible bellows is fixed in way of the mounting plate and the hard running surface is allowed to rotate. This is the opposite to the set up for seals mounted on pumps.

Author note

The finish of the running surface of the seal is extremely fine. However, in extenuating circumstances i.e. when the surface has been damaged say by the deposit of copper, it is possible to lap the face of the carbon. The method I would recommend is metal polish such as brasso, on a true flat surface on which is laid chart paper. The chart paper absorbs the wear particles as they are removed an a reasonable finish is possible.

Rotary Compressor



Such compressors are used mainly in house hold applications but modern practice sees there use in cargo conditioning.

A variation on this is the multi blade type where the rotor has slots cut in it, fitted to which are spring loaded blades. Alternately the blades may rely on centrifugal force.

With both these types , when the compressor is stopped the sealing pressure and oil film are broken and there fore the suction and discharge are common. This reduces starting loads but requires a suction non return valve to be fitted.

Where these are fitted to large refrigeration systems it is possible to use variable speed thyristor controlled electric motors. Thereby the compressor can run at optimal revolution to maintain plant efficiency.

Air conditioning

The basic principals of air conditioning

Air conditioning is the control of humidity, temperature, cleanliness and air motion. Winter conditioning relates to increasing temperature and humidity whilst summer conditioning relates to decreasing temperature and increasing humidity

Specific humidity-Is the ratio of the mass of water vapour to the mass of dry air in a given volume of mixture.

Per cent relative humidity-is the mass of water vapour per m^3 of air compared to the mass of water vapour per m^3 of saturated air at the same temperature. This also equals the ratio of the partial pressure of actual air compared to the partial pressure of the air if it was saturates at the same temperature. i.e.

$m/m_g = p/p_g$

Partial pressure, Dalton's Laws

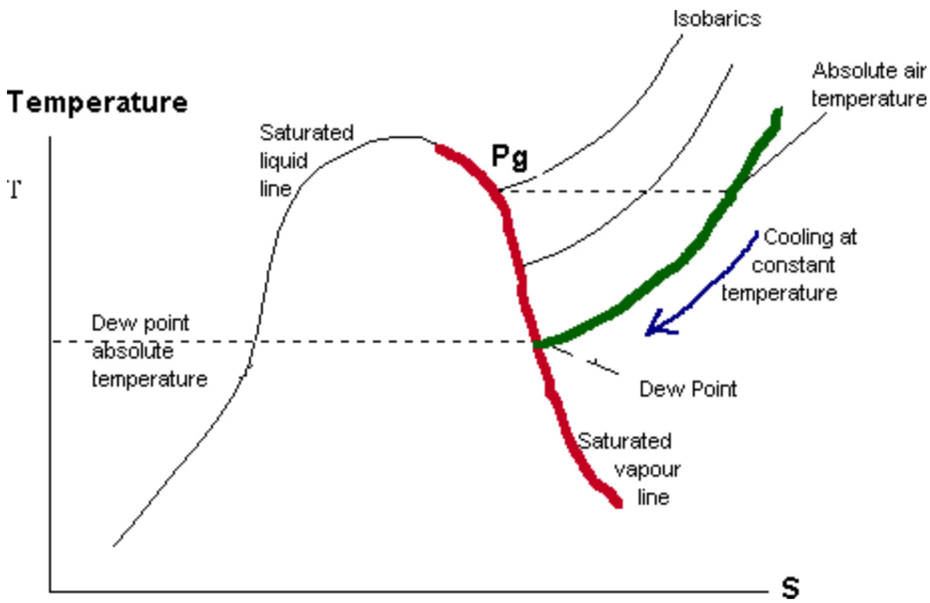
Barometer pressure = partial pressure of N_2 + p.p.O_2 + p.p.H_2O,

from Daltons Law viz:

- Pressure exerted by, and the quantity of , the vapour required to saturate a given space (i.e. exist as saturated steam) at any given temperature, are the same whether that space is filled by a gas or is a vacuum.
- The pressure exerted by a mixture of a gas and a vapour, of two vapours, or of two gasses, or a number of same, is the sum of the pressure which each would exert if it occupied the same space alone, assuming no interaction of constituents.

Dew point

When a mixture of dry air and water vapour has a saturation temperature corresponding to the partial pressure of the water vapour it is said to be saturated. Any further reduction of temperature (at constant pressure) will result in some vapour condensing. This temperature is called the dew point, air at dew point contains all the moisture it can hold at that temperature, as the amount of water vapour varies in air then the partial pressure varies, so the dew point varies.



It can be seen that cooling a superheated vapour at constant pressure will bring it to the saturated vapour line, or Dew point. It can also be seen that cooling at constant temperature raises the partial pressure until the dew point is reached.

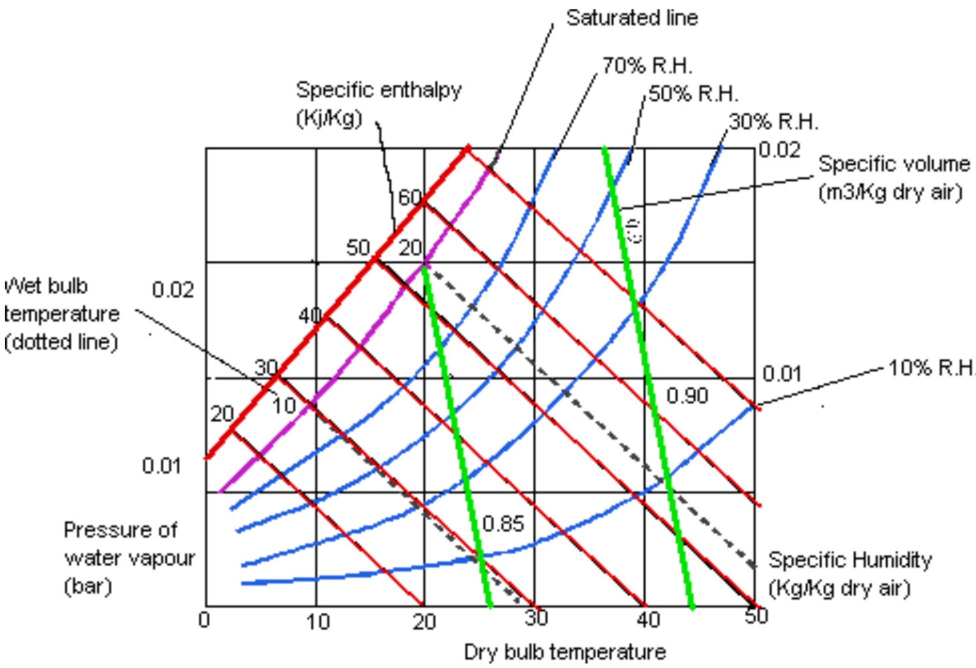
Therefore from the above equation for determining the relative humidity,

%R.H. = m/m_g x 100 = p/p_g x 100

= p_{dew}/p_g point x 100

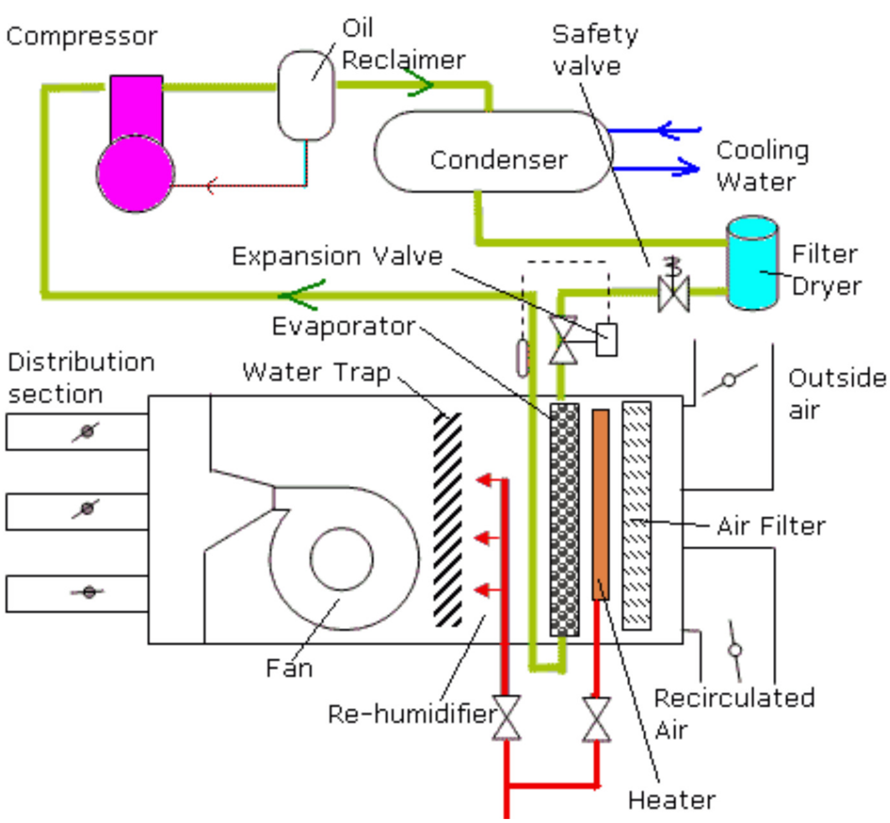
where g refers to the sat condition. This means dry air contains the maximum moisture content (100% R.H.) at the saturation conditions.

Psychrometric chart



This chart is used for finding the relative humidity of air which has been measured using a 'wet and dry bulb' thermometer. This is a pair of thermometers, one of which has its bulb wrapped in a damp cloth. The drier the air,the greater the evaporation of water off the cloth and therefore the lower the reading on the 'wet bulb' thermometer.

Typical system



The core components of the system such as the oil seperator, filter drier and condenser are dealt with on the Fridge system page, instead described are those components which are generally unique to air conditioning plant.

Compressor

May be reciprocating or rotary. In nearly all cases a method of varying the quantity of delivery is incorporated. For reciprocating compressors this may take the form of an unloader and for rotary variable speed drive.

Protection

The compressors have protection systems similar to their fridge counterparts with High Pressure and Low Pressure cut outs that require manual resets. In addition to this an interlock is fitted so that the compressor cannot be started if the air handling unit fan is not running. Should the fan be stopped the compressor will cut out.

An alternative to this is to fit solenoid valves before the compressor, as in the diagram above, which open only when the fan is running. The compressor will trip on Low suction pressure.

The purpose of both these systems is to prevent liquid returning to the compressor.

Air Handling Unit

One or more is fitted. In the diagram above a single unit contains two individual evaporators which are independently supplied by a compressor. A belt driven fan delivers air to the evaporators via a fine mesh air filter. This filter is removed on a regular basis and washed in a soapy solution containing disinfectant.

The air passes over the evaporator where it is cooled and releases water vapour. The water condenses and is fed away via a drip tray and pipework, the water is quite clean and can be used for domestic purposes after treatment although this practice is not common. On the above design a catcher has been fitted to remove water droplets entrained in the air, these are not always fitted.

A perforated pipe is fitted after the evaporator allowing low quality steam to be fed into the air improving its humidity when too dry.

Contamination of ships air conditioning systems by legionnella bacteria

Legionnaires disease is caused by bacteria which flourishes in stagnant water or sludge . It can also be found in wet matrix filters, which may be found in the ships filtration system for the air conditioning plant.

Main danger areas

Air inlet arrangements-This may be direct or indirect from the air conditioning room via jalousies, which, when incorrectly designed may lead rain water onto the filters. It may also be allowed to accumulate in the space where drainage is not efficient

Filters-These filters made of a 25mm thick synthetic material can trap water as well as insects and soot and provide a rapid growth area for the bacteria. Regular washing is essential

Cooler unit (dehumidifier)-Ineffective drainage can allow water to stagnate in the catchment sumps. Also, where air velocities are high over the block, air can become entrained and carry moisture into the air stream. An efficient moisture eliminator is required.

Humidifier-Steam humidifiers, where fitted, do not appear to be a problem. However, adiabatic humidifiers of which the water spray type appears to offer a special hazard. The enclosed tank and matrix elements provide an ideal breeding ground for the bacteria which may then be carried into the air stream when sprayed.

Plenum Insualtion-Where the PVC GRP facing of the rock wool insulation and sound deadening breaks down the considerable levels of water may be present.

Recommended countermeasures.

Filters-Should be washed in 50ppm solution on a regular basis

Coolers-Special attention to drainage arrangements as well as superchlorinating the condensate sump every 3months.

Plenum insulation-Insulation to be examined at refit and damaged areas resealed.

Refrigerants

Desirable properties of a refrigerant

1. *Low boiling point (otherwise operation at high vacua becomes a necessity)*
2. *Low condensing pressure (to avoid heavy machine plant scantling and reduce the leakage risk)*
3. *High specific enthalpy of vaporisation (to reduce the quatity of refrigerants in circulation and lower machine speeds, sizes etc.)*
4. *Low specific volume in vapour state (reduces size and increases efficiency)*
5. *High critical temperature (temperature above which vapour cannot be condensed by isothermal compression)*
6. *Non corrosive and non solvent (pure and mixed)*
7. *Stable under working conditions*
8. *Non flammable and non explosive*
9. *No action with oil (the fact that most refrigerants are miscible may be advantageous e.e. the removal of oil films, lowering pour points etc, provided separators are fitted*
10. *Easy leak detect*
11. *Non toxic*
12. *cheap, easily stored and obtained*

The production of **R12** and **R11** has now stopped under the Montreal Protocol and EU regulation on ozone depleting gasses. A short term solution has been conversion to HCFC's such as **R22** (HCFC's have an Ozone Depletion Rate {ODP} 2-15% of CFC's) but this refrigerant also has a harmful effect on the environment, although far less damaging than R12. HCFC's are also targeted for eventual production phase out as controlled substances, with usage totally banned by the EU in new equipment rated at 150kW and over from the 1st Jan 2000. In some countries such as Germany and Sweden tighter restrictions are in force.

New refrigerants such as **R134a** and **R404A,** which are HFC's may offer a longer term solution against harmful emissions. They contain no chlorine atoms and thus do not attack the ozone layer but they are greenhouse gasses and may be subject to future legislation.

An uncertainty over the long term future of HFC's has led to growing interest in old natural refrigerants such as ammonia and carbon dioxide or hydrocarbons such as propane and iso-butane. Using the refrigerants, however, dictates more stringent safety measures which are being drafted by the appropriate classification societies.

The naming of freon (or Arcton) refrigerants comes from the constituents.

For R12, formed by reacting methane with flourine and chlorine. This forms a molecule containing 1 carbon atom, 2 flourine atoms and 2 chlorine atoms		
Number of Carbon atoms minus 1	number of hydrogen atoms plus one	number of flourine atoms
0 (1-1)	*1 (0+1)*	*2*
For R22, again formed by reacting methane with flourine and chlorine. This forms a molecule containing 1 carbon atom, 1 hydrogen atom and 2 chlorine atom		
0	2	2
the remaining bonds are taken by chlorine atoms		

Refrigerant 12

R12 is halogenated hydrocarbon derived from methane (CH_4) with the hydrogen being displaced by chlorine and fluorine. The resulting compound is Dichlorodifluoromethane (CCl_2F_2) also known as

Freon 12

R12 is considered non-toxic except in high concentration producing oxygen deficiency. However on contact with flame it breaks down to form chlorine gas and phosgene ($COCl_2$).

R12 escaping under pressure can cause skin damage on contact. It is non-irritant and not considered flammable.

Working pressures and temperatures are moderate and the high critical temperature (112^oC) is well above the working range.

Methyl Chloride

CH_3CL_4, banned by the UK administration.

Refrigerant 11

suitable for air conditioning installations (monoflourotrichloromethane CCl_3F), production has now ceased.

Refrigerant 13

$CClF_3$

Refrigerant 22

Is suitable for a lower temperature range than R12 because the pressure on the evaporator side of the system is higher than atmospheric at low temperatures thus reducing the risk of drawing air into the system. Its performance is better than R12 approaching that of ammonia.

The chemical and other properties are similar to R12 except that it is not miscible with oil over the whole temperature range. The compound is Chlorodifloromethane ($CHClF_2$)

Refrigernat 113

$CCl_2F/CClF_2$

Refrigerant 134a (Tetraflouroethane)

A HFC and suggested replacement for R12 in existing plant.

Refrigerant 502

Composed of 48.8% R22 and 51.2% R115 (C_2ClF_5). It is particularly suited for use with hermetic compressors.

Refrigerant 717 (Ammonia)

Thermodynamically a good refrigerant but it is explosive, poisonous and an irritant. The explosive mix is 16 to 25% in air. It is corrosive to copper and its alloys so that ferrous materials are used in components in the system.

Ammonia is a reactive compound. It is highly soluble in water with which it forms ammonium hydroxide a strong alkali. About 1300 volumes of ammonia can be dissolved in one volume of water at low temperatures, however it can be easily expelled by boiling. This action makes the vapour absorption refrigerator possible. The high solubility in water also means that a wet cloth held to the face will give some protection against an ammonia leak in an emergency although a breathing apparatus would be worn in such a case. Because of the hazards it is normally found in shore or fishing vessels.

An additional disadvantage of ammonia is that it can not be used in a direct expansion system. The required three or four tonnes of ammonia onboard for direct system is not acceptable, dictating a combined brine distribution system. Even then, special precautions have to be taken with ammonia to eliminate toxic risks to personnel in yards during construction and crew members when in service. Safety and isolation costs associated with ammonia can erode otherwise attractive cosy advantages

Carbonic anhydride

(CO_2, Carbon Dioxide)

Comparison of some refrigerants

Property	CCl_2F_2- R12	CO_2	NH_3
Discharge pressure	0.8	72	11.7
Suction pressure	7.4	23	2.4
Critical pressure	40	73.8	113.7
Critical temperature	112	31	133
Boiling temperature at atmos	-30	-78	-33
Liquid specific heat capacity Kj/Kg K	0.96	3.23	4.65
Corrosive (pure)	no, attacks rubber, Copper if moisture present	no	no will attack brass and bronzes if moisture present
Toxic	no, liberates phosgene gas in fire	no	Yes
Flammable	no	no	Yes
Explosive	no	no	Yes
Miscible with oil	Yes	no	Slightly

Refrigerant 404a (R125 (Pentaflouroethane), R134a, R143A(triflouroethane))

a suggested replacement for R22, has been used in shore based air-con and refrigeration installations for the past few years and could replace R22 in the reefer market without technical problems.

Refrigerant R507 (R125, R143A)

) It is very comparable in blend to R502 which has been in use for several decades.

Refrigerant 407c (R32, R123, R134a)

another blend but has a very high glide of 6-7^{o}C (the difference between the boiling points of the blended components). Its efficiency has some attraction for the reefer market, particularly with regard to its performance in cooling down bananas when chillers are expected to operate at their maximum capacity. The problem today is that R407c has only been used in tests and offers little, if any, industrial experience.

One component of the blend is **R32**,it is expensive and will continue to be for some time and also introduces problems with regard to lubrication. Maintenance could present another difficulty, calling for skilled personnel in handling the blends.

A major concern is the composition change in the event of leakage.

Refrigerant 407d

A chlorine free replacement for R12 in reefer container systems, is claimed to be 20% more efficient than R134a and able to operate at box temperatures as low as -25^{o}C

Refrigerant 410a

Does not have a high degree of glide, the blend facilitating a reduction in swept volume of compressor units. The main disadvantage is that it requires a 50% higher working pressure than R22, although compressor and plant size is reduced.. The availability of compressors for this refrigerant is thus limited, increased safety precautions are necessary due to this increased pressure.

The blend contains R32 giving the same cost drawback as for R407c.

Refrigerant 410b (R32, R125)

Does not have a high degree of glide, the blend facilitating a reduction in swept volume of compressor units. The main disadvantage is that it requires a 50% higher working pressure than R22, although compressor and plant size is reduced.. The availability of compressors for this refrigerant is thus limited, increased safety precautions are necessary due to this increased pressure.

The blend contains R32 giving the same cost drawback as for R407c.

Refrigerant	Industrial experience	Service and maintenance requirements	Availability	cost/Kg R22 = 1
R407C	On-going	Special	Starting	5.4
R507	Yes	Easy	Good	5.3
R410a	No	Special	Very few	7.4
R134a	Yes	Easy	World wide	1.6

SUVA 9100

Is a near azeotropic mix of HFC 32 and HFC 125. DuPont has recently changed its mix from 45/55 R32/R125 to 50/50 simplifying the HCFC replacement process.

Azeotropic mix-is a blend of one or more pure substances in precise proportions. The blend specifically exhibits a boiling point temperature independent of the boiling points of its components. Constant pressure evaporation and condensation phase is realised at a constant temperature.

Table of relationship between saturation temperature and pressure [^oC]

Bar	**-0.5**	**0**	**1**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
R12	-46	-30	-12	-1	17	28	39	48	56	63	68	73	78
R22	-51	-41	-24	-14	0	11	20	28	35	41	46	51	55
R502	-57	-46	-28	-19	-4	7	17	24	31	38	43	47	51

Water Fixed Fire fighting systems

Capacity of fire pumps

The capacity of the fire pumps is calculated as a product of the breadth, depth and length of the vessel but need not exceed 25m^3 per hour

Fire pumps

For cargo ships of 150 gross tons or more, a minimum of one fixed power pump and one portable pump are to be provided.
For cargo ships of less than 150 gross tons, one portable pump or alternative , is to be provided. which meets the criteria listed later
For fishing vessels, not less than one fixed power pump is to be provided.
Sanitary, ballast, bilge or general service pumps may be accepted as fire pumps, provided that they are not normally used for pumping oil, and that, if they are subject to occasional duty for the transfer or pumping of fuel oil, suitable changeover arrangements are fitted.
In cargo ships and fishing vessels classed for navigation in ice, the fire pump sea inlet valves are to be provided with ice clearing arrangements .
Relief valves are to be provided in conjunction with any fire pump if the pump is capable of developing a pressure exceeding the design pressure of the water service pipes, hydrants and hoses. These valves are to be so placed and adjusted as to prevent excessive pressure in any part of the fire main system.

Portable Pumps

- The pump is to be self-priming.
- The suction head in operation is not to exceed 4,5 m.
- The portable fire pump, when fitted with its length of discharge hose and nozzle , is to be capable of maintaining a pressure sufficient to produce a jet throw of at least 12 m, or that required to enable a jet of water to be directed on any part of the engine room or the exterior boundary of the engine room and casing, whichever is the greater. In the case of ships less than 150t, it is to be ensured that a jet of water can be directed to any part of the ship.
- The pump set is to have its own fuel tank of sufficient capacity to operate the pump for three hours. (e) Details of the fuel type and storage location are to be submitted. If the fuel type has a flashpoint below 60AC, further consideration to the fire safety aspects will be given.
- The pump set is to be stored in a secure, safe and enclosed space, accessible from open deck and clear of the Category 'A' machinery space. In the case of ships less than 150ton , it is to be ensured that access to the pump will not be cut off in the event of a hold fire.
- The pump set is to be easily moved and operated by two persons and be readily available for immediate use.
- Arrangements are to be provided to secure the pump at its anticipated operating position(s).
- The overboard suction hose is to be non-collapsible and of sufficient length to cater for the ship's motion under all operational conditions. A suitable strainer is to be fitted at the inlet end of the hose.
- Any diesel-driven power source for the pump is to be capable of being readily started in its cold condition down to a temperature of 0 AC by hand (manual) cranking.

If it is not possible to comply with the requirements of the above, an additional fixed fire pump will be required, which is to comply with the following:

- The pump, its source of power and sea connection are to be located in accessible positions outside the Category 'A' machinery space; or in a different space to the main fire pump, if the main fire pump is located outside the Category 'A' machinery space. In the case of ships less than 150t, the pump may be situated in the Category 'A' machinery space, if so desired.

-) The sea valve is to be capable of being operated from a position near the pump.
- The room where the fire pump prime mover is located is to be illuminated from the emergency source of electrical power, except for ships less than 150t, and is to be well ventilated.
- If the pump is required to supply water for a fixed fire-extinguishing system in the space where the main fire pump is situated, it is to be capable of simultaneously supplying water to this system and the fire main at the required rates.
- The pump may also be used for other suitable purposes, subject to approval in each case.
- Pressure and quantity of water delivered by the pump being sufficient to produce a jet of water, at any nozzle, of not less than 12 m.
- In the case of ships lisee than 150t, a fire main, hydrants and hoses are to be installed of suitable construction

Means to illuminate the stowage area of the portable pump and its necessary areas of operation are to be provided from the emergency source of electrical power.

Fire main

The diameter of the fire main is to be based on the required capacity of the fixed main fire pump(s) and the diameter of the water service pipes are to be sufficient to ensure an adequate supply of water for the operation of at least one fire hose.
The wash deck line may be used as a fire main provided that the requirements of this sub-Section are satisfied.
All exposed water pipes for fire-extinguishing are to be provided with drain valves for use in frosty weather. The valves are to be located where they will not be damaged by cargo.

When the fixed main fire pump is delivering the quantity of water required , or the fire pump described as the alternative the portable pump , through the fire main, fire hoses and nozzles, the pressure maintained at any hydrant is to be sufficient to produce a jet throw at any nozzle of not less than 12 m.

Number and position of hydrants

The number and position of the hydrants are to be such that at least one jet of water may reach any part normally accessible to the crew while the cargo ship or fishing vessel is being navigated and any part of any cargo space when empty. Furthermore, such hydrants are to be positioned near the accesses to the protected spaces. At least one hydrant is to be provided in each Category 'A' machinery space.

Pipes and hydrants

Materials readily rendered ineffective by heat are not to be used for fire mains. Where steel pipes are used, they are to be galvanized internally and externally. Cast iron pipes are not acceptable. The pipes and hydrants are to be so placed that the fire-hoses may be easily coupled to them. The arrangement of pipes and hydrants are to be such as to avoid the possibility of freezing. In ships where deck cargo may be carried, the positions of the hydrants are to be such that they are always readily accessible and the pipes are to be arranged, as far as practicable, to avoid risk of damage by such cargo. Unless one hose and nozzle is provided for each hydrant in the ship, there is to be complete interchangeability of hose couplings and nozzles.
A valve is to be fitted at each fire hydrant so that any fire-hose may be removed while the fire pump is at work.

Where an additional fixed fire pump is fitted in as an alternative to the portable pump:

- an isolating valve is to be fitted in the fire main so that all the hydrants in the ship, except that or those in the Category 'A' machinery space containing the main fire pump, can be supplied with water by the additional fixed fire pump. The isolating valve is to be located in an easily accessible and tenable position outside the Category 'A' machinery space; and
- the fire main is not to re-enter the machinery space downstream of the isolating valve.

Fire Hoses

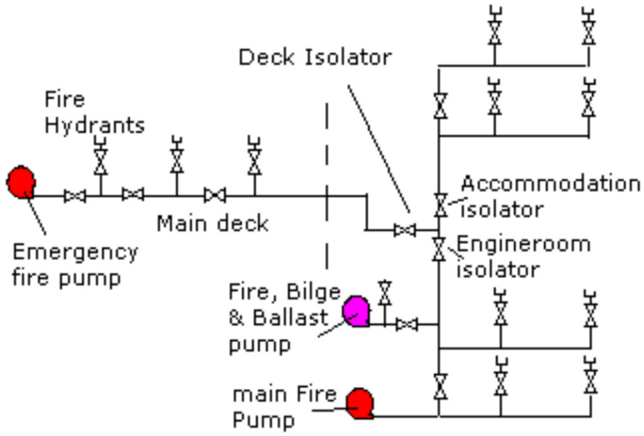
Fire-hoses are to be of approved non-perishable material. The hoses are to be sufficient in length to project a jet of water to any of the spaces in which they may be required to be used. Their length, in general, is not to exceed 18 m. Each hose is to be provided with a nozzle and the necessary couplings. Fire-hoses, together with any necessary fittings and tools, are to be kept ready for use in conspicuous positions near the water service hydrants or connections.
The number of fire-hoses to be provided, each complete with couplings and nozzles, is to be one for each 15 m length of the cargo ship or fishing vessel but in no case is there to be less than three. These numbers do not include any hoses required in any engine room. If necessary, the number of hoses is to be increased so as to ensure that hoses in sufficient number are available and accessible at all times.

Nozzles

For the purpose of this Chapter, standard nozzle sizes are to be 12 mm, 16 mm or 19 mm, or as near thereto as possible, so as to make full use of the maximum discharge capacity of the fire pump(s).
For accommodation and service spaces, the nozzle size need not exceed 12 mm.

The size of nozzles intended for use in conjunction with a portable fire pump need not exceed 12 mm.
All nozzles are to be of an approved dual purpose type (i.e. spray/jet type) incorporating a shut-off.

Typical system



Shown above is a typical system which may be found on most vessel. Of note are the large number of fire main isolator valves. The system may be so arranged as to split the supply between port and stbd sides over all deck levels. Thereby in the event of damage on one side of the vessel a nearby supply of water is ensured. In addition to the required main and emergency fire pumps, on this vessel a standy by pump capable of serving the fire main as well as the ballast and emergency bilge suction systems is available. (note that a special arrangement must be made to ensure that bilge water is not delivered through the fire main.

One vessel I have served on has Main, Emergency, Fire & ballast, Potable water cargo & Fire pumps all cabable of supplying the main fire main as well as a 3600m^3/hr main engine driven pump for supplying fire monitors.

halon 1301 Bromotrichlhoromethane CF_3Br

A colorless odourless gas. As a gas it is non-corrosive, when it is dissolved in water it is highly corrosive .Nitrogen for super-pressurisation is added due to the low pressure energy of halon, typically to 42bar at 20^oC

by a little understood process it disrupts the chain of reaction that is combustion thus extinguishing fires.

Toxicity

When comparing toxicity to extinguishing concentration halon is the safest agent. Concentrations upt to 7% can be breathed for 5 minutes without effect, at 10% this is reduced to 1 minute.

At a temperature above 510^oC halon will decompose. Two of the most important products are Hydrogen Bromide (HBr) and Hydrogen Fluoride (HF). In small concentrations these gases are an irritant which will forewarn personnel of increasing concentrations.

It is considered that these gases pose a much lesser threat than the other products of fire- poisonous smoke, carbon monoxide etc.

Required concentration

A concentration of 4.25 to 5% by volume is required

Advantages

- clean with no residue
- Easy and safe to store
- Electrically non-conductive
- Good penetration
- Suited to automatic release
- Low working concentrations means relatively safe for personnel
- Fast

Regulations

- Only permitted machinery space, pump rooms or cargo spaces solely for carriage of vehicles not carrying cargo.
- No new installations
- System designed so minimum quantity of medium is discharged to space based on liquid phase within 20s
- Means of safely checking pressures
- Volume 0.16m^3/Kg
- Fire resistant release mechanism
- Over pressure device fitted
- Leakage warning alarm
- for locally operated devices the concentration should not go above 7% not halon 1301 and 5.5% for halon 1211 at 20^oC, discharge time for liquid phase no more than 10s

Montreal convention

Following the Montreal protocol the usage of Halons was agreed to be phased out by the year 2000 and halved by the year 1995.

In response to this, IMO has planned the following;

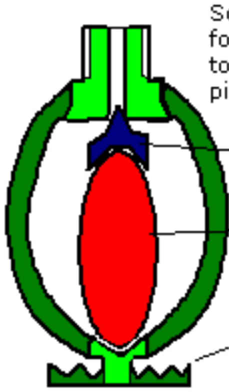
- No new installations after July 1992
- Testing of systems banned by January 1992, integrity test on spaces required
- A requirement that stocks of Halons be recorded
- Existing Halon systems phased out by 2000

With regard to the second requirement, guidelines state that Halon should only be used as a fire fighting medium in a space where there is no other suitable means of extinguishing the fire to protect personnel and property. This guideline is only valid until January 2000. Companies are required to replace there fire fighting Halon with a suitable alternative, it is envisaged that companies will have difficulty in restocking Halon systems as the production of these gasses is phased out by industry. It is a requirement that they have a suitable alternative method fitted should the system be utilised and so it is in the operators best interest to replace the system at their convenience rather than as necessary. Halon systems are still in use as of August 2000

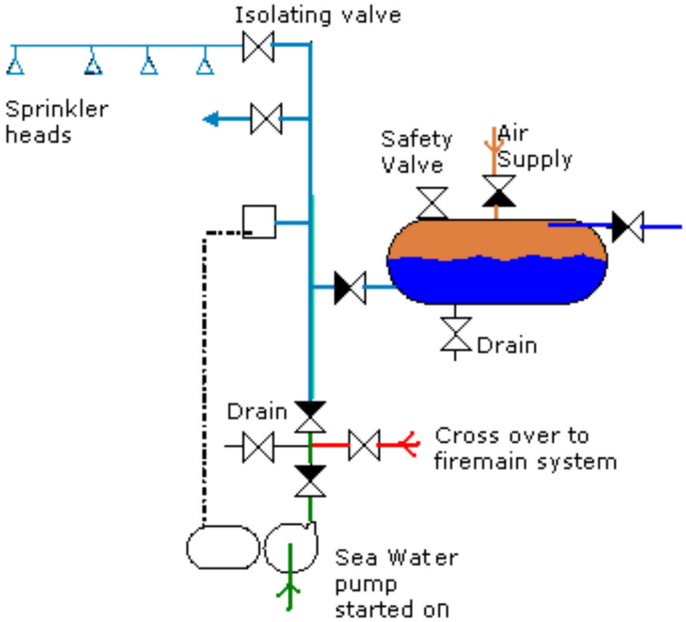
Sprinkler systems

Must be fitted to passenger ships carrying less than 36 passengers in the accommodation spacesand other areas considered necessary be the administration. For pasenger ships carrying greater than 36 passengers it must be fitted to accommodation spaces, corridors, stairwells and to control stations (the latter may be served by an alternative system to prevent damage). The system must be of an approved type. See below for full requirements.

Generally takes the form of a wet pipe (line continuosly flooded) on to which are connected a number of sprinkler head. These heads consist of a valve held shut by a high expansion fluid filled quartzoid bulb.A small air space is incorporated.



When a fire occurs in an adjacent area to this bulb the fluid expands until the air space is filled, increasing internal pressure causes the bulb to fracture. The size of the air gap determines the temperature at which this failure occurs. The valve plug falls out and a jet of water exits , striking the spray generator where it is then distributed evenly over the surrounding area. In acting this way only the area of the fire is deluged and damage is minimised.

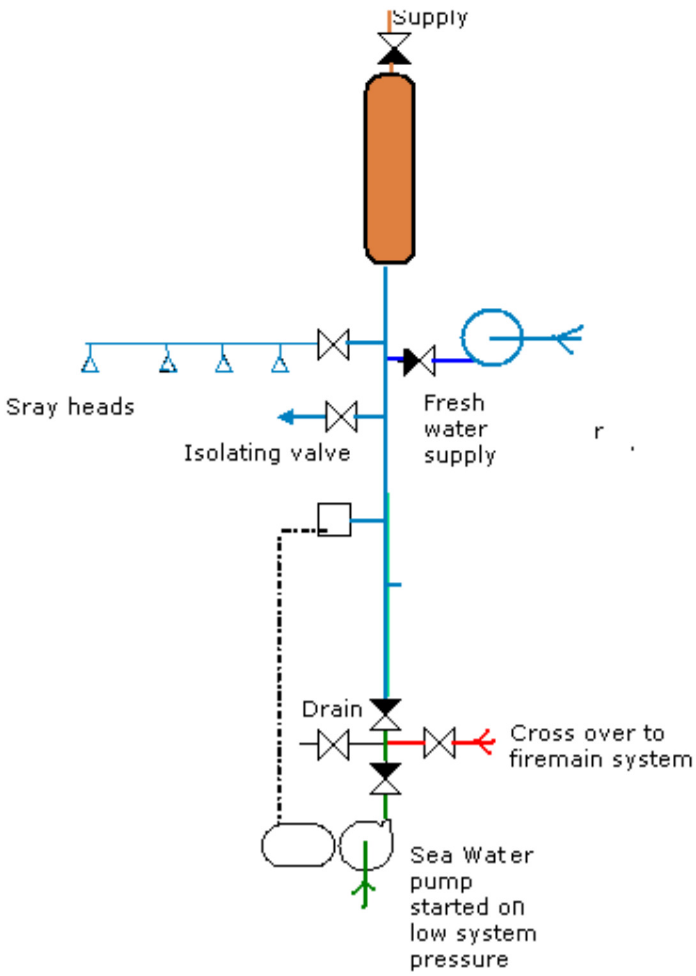


Water is supplied from an air pressurised water tank (thus the system functions without electrical power), this water is fresh water to minimise damage. The tank is half filled with water and the rest is compressed air at pressure sufficient to ensure that all the water is delivered to the highest sprinkler at sprinkler head working pressure. Once this source of water is exhausted, falling main pressure is detected by a pressure switch. This activates a sea water supply pump. A valve is fitted on the system to allow proper testing of this function. After sea water has entered the system proper flushing with fresh water is required to prevent corrosion

A shore connection may be connected to the system to allow function during dry-dock

High Pressure Water spray system

A similar but essentially different system exists for the supply of water under pressure to dry pipes onto which sprinkler heads are fitted. These sprinkler heads do not have the bulb and valve arrangement. Instead when an area is to be served a relevant isolation valves is opened. The fundamental difference between this and the sprinkler system is that human intervention is required, whereas the sprinkler system is required to be fully automated. Commonly a cross connection vai a non-return valve exists able to deliver to the water from the high pressure spray system to the sprinkler system



When an isolation valve is opened pressure in the line falls and the sea water pump is started. The air vessel is there to prevent cycling of the pump due to slight water leakage. The fresh water pump is there for flushing and initial filling of wet pipe only.

Regulations

Taken from SOLAS 1974 Regualtion II/2A

Regulation 12 Automatic sprinkler, fire detection and fire alarm systems

1.1 Any required automatic sprinkler, fire detection and fire alarm system shall be capable of immediate operation at all times and no action by the crew shall be necessary to set it in operation. It shall be of the wet pipe type but small exposed sections may be of the dry pipe type where in the opinion of the Administration this is a necessary precaution. Any parts of the system which may be subjected to freezing temperatures in service shall be suitably protected against freezing. It shall be kept charged at the necessary pressure and shall have provision for a continuous supply of water as required in this regulation.

1.2 Each section of sprinklers shall include means for giving a visual and audible alarm signal automatically at one or more indicating units whenever any sprinkler comes into operation. Such alarm systems shall be such as to indicate if any fault occurs in the system. Such units shall indicate in which section served by the system fire has occurred and shall be centralized on the navigation bridge and in addition, visible and audible alarms from the unit shall be located in a position other than on the navigation bridge, so as to ensure that the indication of fire is immediately received by the crew.

2.1 Sprinklers shall be grouped into separate sections, each of which shall contain not more than 200 sprinklers. In passenger ships any section of sprinklers shall not serve more than two decks and shall not be situated in more than one main vertical zone. However, the Administration may permit such a section of sprinklers to serve more than two decks or be situated in more than one main vertical zone, if it is satisfied that the protection of the ship against fire will not thereby be reduced.

2.2 Each section of sprinklers shall be capable of being isolated by one stop valve only. The stop valve in each section shall be readily accessible and its location shall be clearly and permanently indicated. Means shall be provided to prevent the operation of the stop valves by any unauthorized person.

2.3 A gauge indicating the pressure in the system shall be provided at each section stop valve and at a central station.

2.4 The sprinklers shall be resistant to corrosion by marine atmosphere. In accommodation and service spaces the sprinklers shall come into operation within the temperature range from 68AC to 79AC, except that in locations such as drying rooms, where high ambient temperatures might be expected, the operating temperature may be increased by not more than 30AC above the maximum deckhead temperature.

2.5 A list or plan shall be displayed at each indicating unit showing the spaces covered and the location of the zone in respect of each section. Suitable instructions for testing and maintenance shall be available.

3 Sprinklers shall be placed in an overhead position and spaced in a suitable pattern to maintain an average application rate of not less than 5 l/m2/min over the nominal area covered by the sprinklers. However, the Administration may permit the use of sprinklers providing such an alternative amount of water suitably distributed as has been shown to the satisfaction of the Administration to be not less effective.

4.1 A pressure tank having a volume equal to at least twice that of the charge of water specified in this subparagraph shall be provided. The tank shall contain a standing charge of fresh water, equivalent to the amount of water which would be discharged in one minute by the pump referred to in paragraph 5.2, and the arrangements shall provide for maintaining an air pressure in the tank such as to ensure that where the standing charge of fresh water in the tank has been used the pressure will be not less than the working pressure of the sprinkler, plus the pressure exerted by a head of water measured from the bottom of the tank to the highest sprinkler in the system. Suitable means of replenishing the air under pressure and of replenishing the fresh water charge in the tank shall be provided. A glass gauge shall be provided to indicate the correct level of the water in the tank.

4.2 Means shall be provided to prevent the passage of seawater into the tank.

5.1 An independent power pump shall be provided solely for the purpose of continuing automatically the discharge of water from the sprinklers. The pump shall be brought into action automatically by the pressure drop in the system before the standing fresh water charge in the pressure tank is completely exhausted.

5.2 The pump and the piping system shall be capable of maintaining the necessary pressure at the level of the highest sprinkler to ensure a continuous output of water sufficient for the simultaneous coverage of a minimum area of 280 m2 at the application rate specified in paragraph 3.

5.3 The pump shall have fitted on the delivery side a test valve with a short open-ended discharge pipe. The effective area through the valve and pipe shall be adequate to permit the release of the required pump output while maintaining the pressure in the system specified in paragraph 4.1.

5.4 The sea inlet to the pump shall wherever possible be in the space containing the pump and shall be so arranged that when the ship is afloat it will not be necessary to shut off the supply of seawater to the pump for any purpose other than the inspection or repair of the pump.

6 The sprinkler pump and tank shall be situated in a position reasonably remote from any machinery space of category A and shall not be situated in any space required to be protected by the sprinkler system.

7.1 In passenger ships there shall be not less than two sources of power supply for the seawater pump and automatic alarm and detection system. Where the sources of power for the pump are electrical, these shall be a main generator and an emergency source of power. One supply for the pump shall be taken from the main switchboard, and one from the emergency switchboard by separate feeders reserved solely for that purpose. The feeders shall be so arranged as to avoid galleys, machinery spaces and other enclosed spaces of high fire risk except in so far as it is necessary to reach the appropriate switchboards, and shall be run to an automatic change-over switch situated near the sprinkler pump. This switch shall permit the supply of power from the main switchboard so long as a supply is available therefrom, and be so designed that upon failure of that supply it will automatically change over to the supply from the emergency switchboard. The switches on the main switchboard and the emergency switchboard shall be clearly labelled and normally kept closed. No other switch shall be permitted in the feeders concerned. One of the sources of power supply for the alarm and detection system shall be an emergency source. Where one of the sources of power for the pump is an internal combustion engine it shall, in addition to complying with the provisions of paragraph 6, be so situated that a fire in any protected space will not affect the air supply to the machinery.

7.2 In cargo ships there shall not be less than two sources of power supply for the seawater pump and automatic alarm and detection system. If the pump is electrically driven it shall be connected to the main source of electrical power, which shall be capable of being supplied by at least two generators. The feeders shall be so arranged as to avoid galleys, machinery spaces and other enclosed spaces of high fire risk except in so far as it is necessary to reach the appropriate switchboards. One of the sources of power supply for the alarm and detection system shall be an emergency source. Where one of the sources of power for the pump is an internal combustion engine it shall, in addition to complying with the provisions of paragraph 6, be so situated that a fire in any protected space will not affect the air supply to the machinery.

8 The sprinkler system shall have a connection from the ship's fire main by way of a lockable screw-down non-return valve at the connection which will prevent a backflow from the sprinkler system to the fire main.

9.1 A test valve shall be provided for testing the automatic alarm for each section of sprinklers by a discharge of water equivalent to the operation of one sprinkler. The test valve for each section shall be situated near the stop valve for that section.

9.2 Means shall be provided for testing the automatic operation of the pump on reduction of pressure in the system.

9.3 Switches shall be provided at one of the indicating positions referred to in paragraph 1.2 which will enable the alarm and the indicators for each section of sprinklers to be tested.

10 Spare sprinkler heads shall be provided for each section of sprinklers to the satisfaction of the Administration.

Fixed Fire Fighting Installations for enclosed Spaces rules and regulations

Gas fire-extinguishing systems in machinery spaces

The use of a fire-extinguishing medium which, either by itself or under expected conditions of use, gives off toxic gases in such quantities as to endanger persons is not permitted. New installations that use fire-extinguishing media, which have ozone-depleting properties under the Montreal Protocol, are not permitted.

The necessary pipes for conveying a fire- extinguishing medium into protected spaces are to be provided with control valves which are to be so placed that they will be easily accessible and not readily cut off from use by an outbreak of fire. The control valves are to be so marked as to indicate clearly the spaces to which the pipes are led. Suitable provision is to be made to prevent inadvertent admission of the medium to any space. Where pipes pass through accommodation spaces they are to be seamless and the number of pipe joints are to be kept to a minimum and made by welding only.

The piping for the distribution of fire-extinguishing medium is to be of adequate size and so arranged, and discharge nozzles so positioned that a uniform distribution of medium is obtained. All joints are to be made by suitable barrel couplings, cone connections or flanges. Screwed and running couplings are not allowed except that threaded sleeve joints may be allowed where connecting the nozzles to the distribution piping in the protected spaces. All pipes are to be arranged to be self-draining and where led through any refrigerated spaces, the arrangement will be specially considered. A means whereby the individual pipes to all protected spaces can be tested using compressed air is to be provided. Distribution pipes are to extend at least 50 mm beyond the last nozzle.

Steel pipes fitted in spaces where corrosion is likely to occur are to be galvanized, at least internally.

Means are to be provided to close all openings which may admit air into, or allow gas to escape from, a protected space.

Where the volume of free air contained in air receivers in any space is such that, if released in such a space in the event of fire, such release of air within that space would seriously affect the efficiency of the fixed fire-extinguishing system, an additional quantity of fire-extinguishing medium is to be provided.

Means are to be provided for automatically giving audible warning of the release of fire-extinguishing medium into any space in which personnel normally work or to which they have access. The alarm is to operate for a suitable period before the medium is released.

Where pneumatically-operated alarms are fitted which require periodic testing, carbon dioxide is not to be used as an operating medium. Air-operated alarms may be used provided that the air supply is clean and dry.

Where electrically-operated alarms are used, the arrangements are to be such that the electric operating mechanism is located outside the pump room, see also Ch 2,16.8.

The means of control of any fixed gas fire- extinguishing system are to be readily accessible and simple to operate and are to be grouped together in as few locations as possible at positions not likely to be cut off by a fire in a protected space. At each location, there are to be clear instructions relating to the operation of the system having regard to the safety of personnel.

Automatic release of fire-extinguishing medium is not permitted.

Where the quantity of extinguishing medium is required to protect more than one space, the quantity of medium available need not be more than the largest quantity required for any one space so protected.

Means are to be provided for the crew to safely check the quantity of medium in the containers.

Containers for the storage of fire-extinguishing media and associated pressure components are to be designed and tested to Codes of Practice recognized by LR, having regard to their locations and the maximum ambient temperatures expected in service.

The fire-extinguishing medium is to be stored outside a protected space, in a room which is situated in a safe and readily accessible position and effectively ventilated. Any entrance to such a storage room is to preferably be from the open deck and in any case be independent of the protected space. Access doors are to open outwards, and bulkheads and decks including doors and other means of closing any opening therein, which form the boundaries between such rooms and adjoining enclosed spaces are to be gastight.

In systems where containers discharge into a common manifold, non-return valves are to be provided at the connections of the container discharge pipes to the manifold to allow any container to be disconnected without preventing the use of other containers in the system and to prevent the discharge of extinguishing medium into the container storage room in the event of the system being operated. Manifolds are to be tested by hydraulic pressure to 1,5 times the design pressure. The design pressure is the maximum gauge pressure to which the system may be subjected and is not to be less than the gauge pressure corresponding to the maximum ambient temperature expected in service. After the hydraulic test, manifolds are to be carefully cleaned and dried before the non-return valves are finally fitted.

For ships on unrestricted service, spare parts for the system are to be stored on board. As a minimum, these are to consist of:

- 1 actuator;
- 1 flexible hose (cylinder to manifold); and
- the cylinder bursting discs and sealing washers for all cylinders.

Carbon dioxide systems

Carbon dioxide systems are to comply with 7.1 in addition to the remaining requirements of this sub-Section.

For the purpose of this Chapter, the volume of free carbon dioxide is to be calculated at 0,56 m3/kg.

For machinery spaces:

- the quantity of carbon dioxide carried is to be sufficient to give a minimum volume of free gas equal to the larger of:
  30 per cent of the gross volume of the largest machinery space protected, including the casing;
- the fixed piping system is to be such that 85 per cent of the gas can be discharged into the space within two minutes; and
- the distribution arrangements are to be such that approximately 15 per cent of the required quantity of carbon dioxide is led to the bilge areas.

Two separate controls are to be provided for releasing carbon dioxide into a protected space and each is to ensure the activation of the alarm. One control is to be used to discharge the gas from its storage cylinder(s). A second control is to be used for opening the valve of the piping which conveys the gas into the protected space. The two controls are to be located inside a release box clearly identified for the particular space. If the box containing the controls is to be locked, a key to the box is to be in a break-glass type enclosure conspicuously located adjacent to the box. There is to be a dedicated release box for each protected space, in which personnel normally work or to which they have access, see also 7.1.7. The space served is to be identified at the release box.

Distribution pipes for carbon dioxide are not to be smaller than 20 mm bore.

High-expansion foam systems

Any required fixed high-expansion foam system in machinery spaces is to be capable of rapidly discharging through fixed discharge outlets a quantity of foam sufficient to fill the greatest space to be protected at a rate of at least 1 m in depth per minute. The quantity of foam-forming liquid available is to be sufficient to produce a volume of foam equal to five times the volume of the largest space to be protected.

The expansion ratio of the foam is not to exceed 1000 to 1.

Alternative arrangements and discharge rates will be permitted provided that equivalent protection is achieved.

Supply ducts for delivering foam, air intakes to the foam generator and the number of foam-generating units are to be such as will provide effective foam production and distribution.

The arrangement of the foam generator delivery ducting is to be such that a fire in the protected space will not affect the foam-generating equipment.

The foam generator, its sources of power supply, foam-forming liquid and means of controlling the system are to be readily accessible and simple to operate and are to be grouped in as few locations as possible at positions not likely to be cut off by fire in the protected space.

Foam concentrates carried for use in fixed foam fire-extinguishing systems are to be of an approved type. They are to be tested at least twice during each five year period to verify that they remain fit for service. Evidence in the form of a report from the foam manufacturer or an independent laboratory will be accepted.

Pressure water-spraying systems

Any required fixed pressure water-spraying fire-extinguishing system in machinery spaces is to be provided with spraying nozzles of an approved type.

The number and arrangement of the nozzles is to be such as to ensure an effective average distribution of water of at least five litres per square metre per minute in the spaces to be protected. Where increased application rates are considered necessary, these will be specially considered. Nozzles are to be fitted above bilges, tank tops and other areas over which oil fuel is liable to spread and also above other specific fire hazards in the machinery spaces.

The system may be divided into sections, the distribution valves of which are to be operated from easily accessible positions outside the spaces to be protected and which are not to be readily cut off by fire in the protected space.

The system is to be kept charged at the necessary pressure, and the pump supplying the water for the system is to be put automatically into action by a pressure drop in the system.

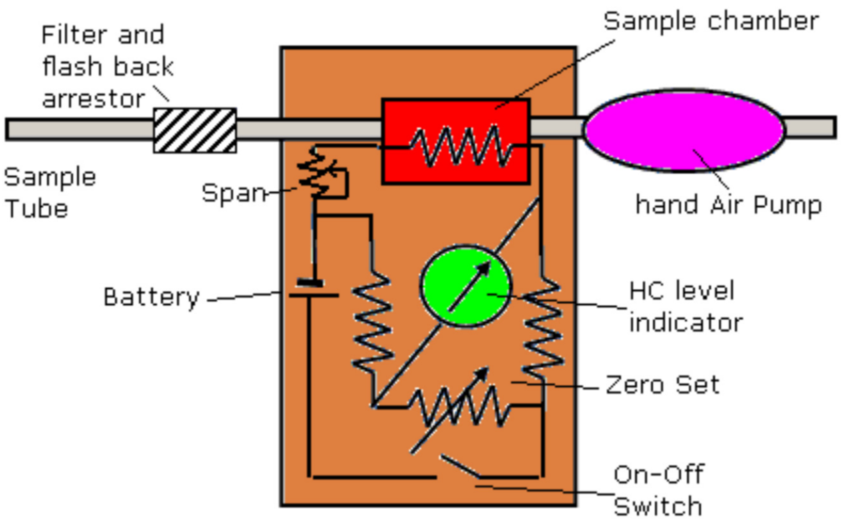
The pump is to be capable of simultaneously supplying, at the necessary pressure, all sections of the system in any one compartment to be protected. The pump and its controls are to be installed outside the space(s) to be protected. It is not to be possible for a fire in the space(s) protected by the water-spraying system to put the system out of action.

The pump may be driven by independent internal combustion type machinery, but if it is dependent upon power being supplied from the emergency generator, that generator is to be arranged to start automatically in case of main power failure so that power for the pump required by 7.4.5 is immediately available. When the pump is driven by independent internal combustion machinery, it is to be so situated that a fire in the protected space will not affect the air supply to the machinery.

Precautions are to be taken to prevent the nozzles from becoming clogged by impurities in the water or corrosion of the piping, nozzles, valves and pump.

As an alternative to 7.4.1 to 7.4.7, the arrangement described in MSC/Circ.668, and amendments thereto contained in MSC/Circ.728 will be accepted or equivalent.

Explosimeter

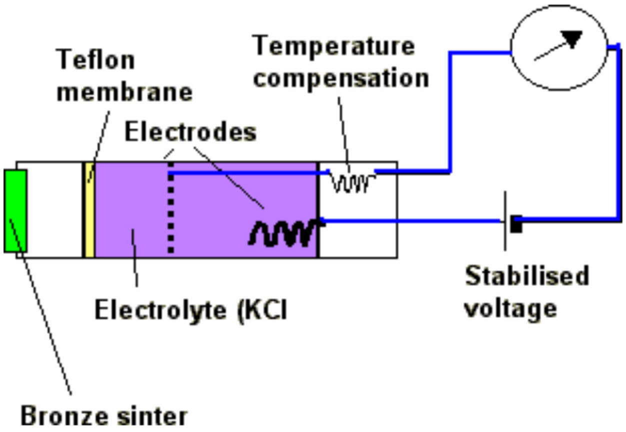


A sample of gas is drawn into the sample chamber using the hand pump. Any combustibles land on the surface of the hot wire and burn increaseing the temperature of the wire thereby increaseing the resistance. This causes an imbalance in the wheatstone bridge arrangment indicated on the display. This display is scaled in percent lower explosive limit and is calibrated for hydrocarbons. Note that the unit will operate against any combustible gas although the readout would be erroneous.

calibration gas is used to check the accuracy of the meter. In addition the unit must be landed on a regular basis for formal calibration.

Oxygen analysers

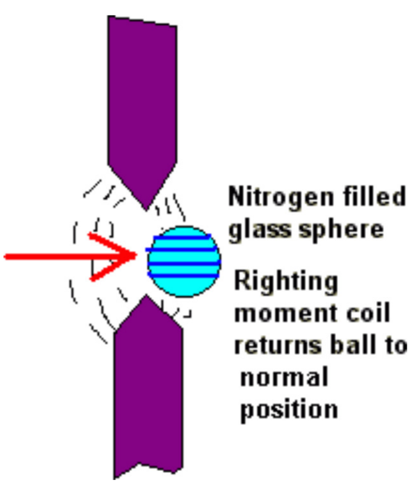
Chemical



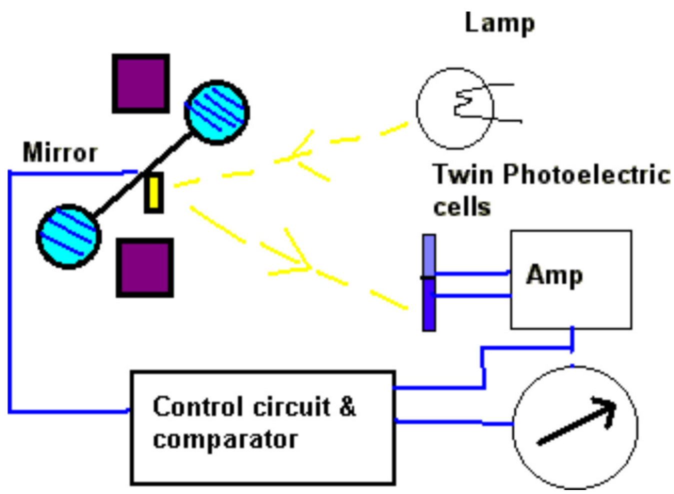
The teflon is semipermeable letting in gasses and not moisture.

The instrument functions by the oxidation of the electrolyte which increases or decreases the conductivity of the cell depending on the oxygen content.

Paramagnetic (Servomex)



The off centre ball is further forced off centre when the oxygen moves in the lines of the magnetic field. This movement is detected.



A mirror is mounted on the arm. A light source is reflected off the mirror to a pair of photelectric cells. The position of the arm governs the light falling on the cells. The unit balances the light by adjusting the current in the righting coil. This current forms the measured value and is directly related to the oxygen in the sample.

Dirt and moisture can be extremely destructive for these instruments and as such should be left on rather than switched off. For fixed installations the cell is kept at 60'C

Certificate Index

Registry		
Certificate of Registry	Indefinitely Valid	
Statuatory		
International Load Line	5 Years	All Ships.Required Under LOadline convention. Subject to Annual Endorsement. **International Load Line Exemption Certificate** must be carried were exemptions under Loadline 1988 protocal applies
IOPP	5 Years	All tankers above 150GRT and all other ships above 400GRT. Required under MARPOL 73/78. Subject to Annual and intermediate Endorsements. The certificate is supplemented by a Record of Construction and Equipment for ships other than Oil Tankers (Form A) or a Record of Construction for Oil Tankers (Form B)
Cargo Ship Safety Construction Certificate	5 Years	All Cargo ships over 500GRT.SOLAS Requirement. Suplemented by Record of Construction and Equipment. Subject to Annual and intermediate Endorsements
Pasenger Ships Safety Certificate	1 Year	All Passenger vessels. SOLAS Requirement. Suplemented by Record of Equipment. Associated to this may be an **Exemption Certificate**, **Special Trade Passenger Ship Certificate**, Special Trade Passenger Ships Space Certificate as well as Search and Rescue Co-operation plan, List of operational limitations and Decision Support System for Masters
Cargo Ship Safety Equipment certificate	2 Years	All Cargo ships over 500GRT. Supplemented by Record of Equipment. Subject to Annual and intermediate Endorsements
Safety Radio Certificate	1 Year	SOLAS Requirement. All Cargo ships over 300GRT.
Dangerous Goods Manifest	per Voyage	SOLAS/MARPOL. Any vessel carrying dangerous goods.
Documentation of authorisation for Carriage of Grain	Indefinitely Valid	Issued to every vessel loaded in accordance with International Code for the Safe Carriage of Grain in Bulk
Document of Compliance for Ships Carrying Dangerous Goods	5 Years	SOLAS.Document giving evidence that construction and equipment is appropriate to goods carried.
Noxious Liquid Substances	5 Years	Subject to Annual and intermediate Endorsements.MARPOL.

SOPEP Manual	Approved by administration	MARPOL. Every oil tanker over 150GRT and every ship over 400GRT
US Coast Guard Letter of Compliance	2 Years	Annual Inspections
ISM		
Document of Compliance	5 Years	Subject to Annual and intermediate Endorsements.SOLAS
Safety management Certificate	5 Years	Subject to intermediate survey
Marine management Agreement		
Class		
Cargo Securing Manual		Class Approved. All Ships carrying carogs other than solid and liquid bulk .SOLAS.
Class Automation	5 Years	
Classification Certificate:	5 Years	Subject to Annual, intermediate , Continuous (CSH) and Special Surveys
Classification Certificate:Hull	5 Years	Subject to Annual, intermediate , Continuous (CSH) and Special Surveys
Classification Certificate:Machinery	5 Years	Subject to Annual, intermediate , Continuous (CSM) and Special Surveys
Classification Certificate:Refrigeration	5 Years	Subject to Annual, intermediate , Continuous and Special Surveys
Dry-Docking	5 Years	Intermediate to be held between 2nd and 3rd anniversary dates.
In- Water Surveys		Special case survey which may replace intermediate docking under certain circumstances
Exhaust Gas Boiler	5 Years	Intermediate to be held between 2nd and 3rd anniversary dates.
Inert gas Plant	5 Years	
Oil Fired Boiler	5 Years	Intermediate to be held between 2nd and 3rd anniversary dates.
TailShaft	5 Years	
Hull Thickness Measurements	5 Years	Special surveys 1st to 5th Special surveys
Documents		
Intact Stability		Every passenger ship and every cargo ship over 24m.
Damage Control Booklets		For all pasenger and Cargo Ships. Plans showing watertight boundaries, compartments etc

Minimum Safe manning Document		
Certificates for Masters, Officers and Ratings		STCW 95
Oil Record Book		Every Oil Tanker over 150GRT and every ship over 400GRT must have Part 1, Oil tankers over 150GRT must have part 2
Garbage management Plan		Every ship over 400GRT and every ship carrying 15 persons
Garbage Record Book		Every ship over 400GRT and every ship carrying 15 persons
Document of Compliance with the requirements for ships carrying dangerous goods		A suitable document giving evidence of construction and design
Certificate of Insurance or other financial security in respect of civil liability for oil pollution damage		Each ship carrying 2000tons or more of oil in bulk
Enhanced Survey Report File		Bulkers and tankers
Record of OIl Discharge Monitoring and control system for last balast voyage		MARPOL Requirement. Record of oil content in any continuous discharge
Bulk Carrier Booklet		To prevent over stressing of hull
Cargo Record Book		Every ship to which Annex II applies of MARPOL,
International Pollution Prevention Certificate for the Carriage of Noxious iquid Substances in Bulk		Including certificates under Bulk Chemical Code
Proceedures and Arrangements Manual		Evry ship certified to carry Noxious liquid substances in bulk
Certificate of Fitness for the Carriage of dangerous chemicals in Buk		Mandatory under Annex II
Certificate of Fitness to carry Liquid Gasses in Bulk		

SURVEY CHECKLIST

ANNUAL SURVEYS

INTERMEDIATE SURVEYS

DOCKING SURVEYS

IN ACCORDANCE WITH THE CLASSIFICATION REGULATIONS.

SURVEY REQUIREMENTS FOR CARGO SHIPS INCLUDING OIL TANKERS AND BULK CARRIERS.

(See separate check lists for Chemical Tankers and Gas Carriers)

FOR ANNUAL OR INTERMEDIATE SURVEY MARK 'X' TO INDICATE 'YES' IN APPROPRIATE CIRCLE FOR EACH ITEM. IF AN ITEM IS NOT APPLICABLE MARK 'NA' IN APPROPRIATE CIRCLE. ALL REQUIRED DATES SHOULD BE RECORDED AT THESE SURVEYS. FOR DOCKING SURVEY COMPLETE SECTION 7 ONLY.	
ANNUAL SURVEY:	TO BE HELD WITHIN 3 MONTHS BEFORE OR AFTER THE ANNIVERSARY DATE.
INTERMEDIATE SURVEY:	IN LIEU OF THE 2ND OR 3RD ANNUAL SURVEY.
DOCKING SURVEY:	TO BE HELD AT 2H YEAR INTERVALS.
IN-WATER SURVEY:	IN LIEU OF THE DRYDOCKING BETWEEN SPECIAL SURVEYS.

1. GENERAL (ANNUAL AND INTERMEDIATE SURVEYS)		
1.1	Have modifications been made to the ship or equipment which would affect the class? (any modifications are to be reported)	Yes/No*
1.2	Are the periodical surveys required for boilers and other pressure vessels overdue?	Yes/No*
1.3	Are the CSM and CSH Cycles up to date in accordance with the current survey status?	Yes/No*
1.4	Is the Periodical Survey of the automation and/or remote controls for the main propulsion plant overdue? (see also section 4)	Yes/No*

1.5	Is the Periodical Survey of the Inert Gas System overdue? (see also section 6)	Yes/No*

2. DOCUMENTATION (ANNUAL AND INTERMEDIATE SURVEYS)

2.1	List the following:	(a) Cargo Ship Safety Construction Certificate (b) Cargo Ship Safety Equipment Certificate (c) Cargo Ship Safety Radio Certificate (d) International Load Line Certificate (e) International Oil pollution Prevention Certificate	*EXPIRY DATE*	*A.S. OR I.S.* *ENDORSEMENT DATE*	*CERTIFICATE* *ISSUED BY*

2.2	The Log entries record that the following have been checked or tested and found satisfactory within twelve (12) hours before departure from any port. (a) Steering gear. (The tests included, where applicable, the operation of the main steering gear, the auxiliary steering gear, remote control systems, bridge steering position, emergency power supply, rudder angle indicators, steering gear system power unit failure alarms, automatic isolating arrangements and other alarms) (b) Communications system bridge to steering gear compartment. (c) Full movement of the rudder. (d) Visual inspection of steering linkage.	
2.3	The log entries record that emergency steering drills have been carried out every three (3) months.	
2.4	The change-over procedure diagrams of steering gear are posted.	
2.5	All Officers are reportedly familiar with steering gear change-over procedures.	
2.6	The approved stability/loading information is on board.	
2.7	For ships assigned timber loadlines the approved timber deck cargo loading and lashing plan is on board.	
2.8	The required documentation for Oil Tankers (including Combination Carriers) and Dry Bulk Cargo Ships (Bulk Carriers) is on board.	

3. HULL SURVEY (ANNUAL AND INTERMEDIATE SURVEYS)		
3.1	The condition of the hull and its closing appliances is satisfactory as far as could be seen. The following items should be included as applicable. Weather decks, hatchways, vents and air pipes, casings, fiddley openings, skylights, flush deck scuttles, deckhouses and companionways; superstructures, side, bow and stern doors; windows, sidescuttles and deadlights; chutes and other openings; scuppers, sanitary discharges and valves; guardrails and bulwarks; freeing ports, gangways, walkways and lifelines; and permanent fittings for timber deck cargoes.	
3.2	The condition of the anchoring and mooring equipment is satisfactory, as far as could be seen.	
3.3	The watertight doors in the watertight bulkheads have been examined, operationally tested (remotely and locally) and found satisfactory.	
3.4	The condition of the watertight bulkhead penetrations is satisfactory, as far as could be seen.	
3.5*	The structural fire protection arrangements remain unchanged (Alterations are to be reported)	
3.6*	The manual and/or automatic fire doors have been operationally tested and found satisfactory.	
3.7	The operation of the loading instrument has been verified.	
3.8	The freeboard marks have been verified. (Report summer freeboard mm)	
3.9	Hatch covers and coamings have been checked and tested where necessary and found weathertight.	
3.10	**Salt Water Ballast Tanks** The tanks where protective coating was not applied at construction or has been reported in POOR condition and not repaired have been examined and found satisfactory. (Report tanks.) Note: THOSE TANKS WHICH MAY REQUIRE TO BE EXAMINED AT ANNUAL SURVEY ARE INDICATED IN THE SURVEY STATUS	

3.11	**Dry Bulk Cargo Ships (Bulk Carriers)** (a) Overall survey of a forward and an after cargo hold carried out and found satisfactory. (Report holds.) (b) For ships over 15 years old. Overall survey of all cargo holds and close-up survey of lower part of shell frames and attachments in one forward cargo hold carried out and found satisfactory. (Report holds.)	
3.12	**Oil Tankers including Combination Carriers and Dry Bulk Cargo Ships (Bulk Carriers)** Close-up survey and thickness measurement of areas of substantial corrosion identified in the Survey Status or the Executive Summary carried out satisfactorily. (Report area(s) and thicknesses.)	

4. MACHINERY AND ELECTRICAL INSTALLATION SURVEY (ANNUAL AND INTERMEDIATE SURVEYS)		
4.1	The machinery and boiler spaces and essential machinery have been generally examined and found satisfactory.	
4.2	The emergency escape routes from the machinery and boiler spaces are free of obstruction.	
4.3	The machinery and boiler spaces are free of all visible fire and explosion hazards.	
4.4	The main and auxiliary steering arrangements, including their associated equipment and control system, have been examined, operated and found satisfactory.	
4.5	All the means of communication between navigating bridge, machinery control and alternative steering positions have been tested and found satisfactory.	
4.6	The bilge pumping systems, including bilge wells, extended spindles, pumps and level alarms where fitted, have been examined and operated as far as practicable and all found satisfactory.	
4.7	An external examination of boilers, pressure vessels, including safety devices, foundations, controls, relieving gear, insulation, gauges and piping has been carried out as far as practicable, and found satisfactory.	

4.8	An examination and test, as far as practicable, of emergency sources of power, including control and change-over arrangements have been carried out and all found satisfactory.	
4.9	An examination and test, as far as practicable, of emergency sources of power, including control and change-over arrangements have been carried out and all found satisfactory.	
4.10	A general examination of the following, where applicable, has been carried out and operation considered satisfactory: 4.10 (a) Automatic equipment (b) UMS, CCS, ICC or IP system (delete those not appropriate) (c) DP ( ) and PCR (enter detail of notation and delete PCR if not appropriate) (d) Condition monitoring system	
5. FIRE FIGHTING EQUIPMENT SURVEY (ANNUAL AND INTERMEDIATE SERVICES)		
5.1*	The fire control plan and duplicate have been examined and are properly posted.	
5.2*	All fire and/or smoke detection and alarm systems have been examined and tested, as far as practicable, and found satisfactory.	
5.3*	An operative test of the fire main system and each fire pump, including the emergency fire pump, has been carried out separately, to demonstrate that the two required jets of water could be provided simultaneously from different hydrants.	
5.4*	All fire hoses, nozzles, applicators and spanners are situated at their respective stations and in satisfactory condition.	
5.5*	The fixed fire fighting system controls, piping instructions and markings are properly maintained and serviced. Date of last reported system test:	
5.6*	All semi-portable and portable extinguishers are fully charged, in their stowed position and with valid service dates.	
5.7*	The remote controls for stopping fans and machinery and shutting off fuel supplies in machinery	

	spaces are in working order.	
5.8*	The closing arrangements of ventilators, annular spaces, skylights, doorways and tunnel where applicable are satisfactory.	
5.9*	The fireman's outfits are complete and in satisfactory condition.	

6. OIL TANKERS, INCLUDING COMBINATION CARRIERS (ANNUAL AND INTERMEDIATE SURVEYS) **(In addition to Sections 1, 2, 3, 4 & 5)**		
Weather Deck		
6.1	Cargo tank openings including gaskets, covers, coamings, P/V valves and flame screens are all satisfactory as far as could be seen	
6.2	Flame screens on vents at all bunker, oily ballast and oily slop tanks and void spaces are satisfactory as far as could be seen.	
6.3	An examination of cargo, crude oil washing, bunker, ballast and vent piping systems including vent masts and headers has been carried out and all found in satisfactory condition.	
6.4	The condition of electrical equipment in dangerous zones is satisfactory as far as could be ascertained.	
Cargo Pump Room		
6.5	Potential sources of ignition (in or near the cargo pump room) such as loose gear, excessive product in bilges, excessive vapours, combustible materials, etc. have been eliminated.	
6.6	The access ladders are in satisfactory condition.	

6.7	All electrical equipment is on satisfactory condition as far as could be ascertained.	
6.8	The pump room bulk heads are free of signs of oil leakage or fractures.	
6.9	The sealing arrangements of bulkhead penetrations are satisfactory.	
6.10	An external examination of piping systems has been carried out and all found in satisfactory condition	
6.11	The cargo, bilge, ballast and stripping pumps examined as far as practicable and found satisfactory for: (a) Excessive gland seal leakage (b) Operation of electrical and mechanical remote operating and shutdown devices (c) Integrity of pump room bilge system and pump foundations	
6.12	The pump room ventilation system is operational, and the ducting intact, the dampers are operable and the screens are clean.	
6.13	As far as could be seen, the installed pressure gauges on cargo discharge lines and level indicator systems are operational.	
Inert Gas Systems (where fitted)		
6.14	From external examination, all components and piping found free of signs of corrosion or gas/effluent leakage.	
6.15	Both inert gas blowers are operational.	
6.16	The scrubber room ventilation system is operational.	
6.17	The deck water seal filling and draining system is operational and without evidence of water carry-over.	
6.18	The non-return valve is operational.	

6.19	The operation of all remotely operated or automatically controlled valves, in particular the flue gas isolating valve(s) found satisfactory.	
6.20	The interlocking feature of the soot blowers checked and found satisfactory.	
6.21	The gas pressure regulating valve automatically closes when the inert gas blowers are secured.	
6.22	The following safety devices of the inert gas system have been checked, as far as practicable, using simulated conditions where necessary and found satisfactory. a. High oxygen content of gas in the inert gas main b. Low gas pressure in the inert gas main c. Low pressure in the supply to the deck water seal d. (d) High temperature of gas in the inert gas main (e) Low water pressure to the scrubber (f) Accuracy of portable and fixed oxygen measuring equipment by means of calibration gas (g) Water level in the scrubber (h) Failure of the inert gas blowers (i) Failure of the power supply to the automatic control system for the gas regulating valve and to the instrumentation for continuous indication and permanent recording of pressure and oxygen content in the inert gas main (j) High gas pressure in the inert gas main system	
Fire extinguishing arrangements		
6.23*	All isolating valves and piping of the cargo tank and cargo pump room fixed fire fighting system were externally examined as far as practicableand found satisfactory.	
6.24*	The deck foam and deck sprinkler systems were found to be operable and in satisfactory condition.	

7. DOCKING SURVEYS		
7.1	A satisfactory examination of the shell including bottom, side and bow plating, sea inlet boxes, keel, stern, sternframe and rudder was carried out.	

7.2	The clearances of rudder bearings are satisfactory. Report clearances:	
7.3	The sea suctions and overboard discharge valves and their connections to the hull were generally examined and all found satisfactory.	
7.4	The propeller and fastenings, sternbush fastenings, and the gratings at the sea inlets were examined and found satisfactory.	
7.5	The propeller shaft seal(s) were found satisfactory and tight or the propeller shaft(s) clearance(s) were satisfactory. Report Clearances/Poker gauge readings:	
7.6	The anchoring and mooring equipment was examined as far as practicable, the anchors and cables partially raised and lowered using the windlass and found satisfactory. THE EXAMINATION OF ANCHORS, CHAIN CABLES, CHAIN LOCKERS AND THE REQUIREMENTS FOR THICKNESS MEASUREMENT ARE TO BE DEALT WITH AT DOCKING SURVEYS HELD IN CONNECTION WITH THE SPECIAL SURVEY.	
Oil Tankers (including combination carriers) 5 years old and over		
7.7	(a) A satisfactory general examination of the electrical equipment and cables in dangerous zones such as cargo pump rooms and areas adjacent to cargo tanks was carried out. Note: (b) The insulation resistance of the circuits was satisfactorily tested or there is a recent record of insulation resistance testing, that is considered acceptable. (See Intermediate Survey.)	

8. ADDITIONAL SURVEY REQUIREMENTS: INTERMEDIATE SURVEYS		
All ships		
8.1	*Ships of 5 years to 10 years old* (a) The electrical generating sets have been examined under working conditions and found satisfactory. (b) Representative salt water ballast tanks, including any protective coating, have been generally examined internally and found satisfactory. (Report tanks.)	

	Ships of 10 years old and over (c) All salt water ballast tanks, including any protective coating, generally examined internally and found satisfactory. (Report tanks.) (d) The anchors have been partially raised and lowered satisfactorily using the windlass.	
Dry Cargo Ships 15 years old and over		
8.2	(a) An overall survey of a forward and an after cargo hold has been carried out and found satisfactory. (Report holds.)	
Oil Tankers (including Combination Carriers)		
8.3	(a) Cargo, crude oil washing, bunker, ballast, steam and vent piping on weather decks, also vent masts and headers examined and found satisfactory. (b) The insulation resistance of the circuits was satisfactorily tested or there is a recent record of insulation resistance testing that is considered acceptable. (See Docking Survey.) (c) *Oil tankers over 10 years and less than 15 years old, in addition to 8.3(a) and (b)*(1) An overall survey of combined salt water ballast/cargo tanks, including any protective coating, has been carried out and found satisfactory. (Report tanks.) (2) An overall survey of at least 2 representative cargo tanks, including any protective coating, has been carried out and found satisfactory. (Report tanks.) (3) A close-up survey of all salt water ballast tanks and 2 combined salt water ballast/cargo tanks, including any protective coating, has been carried out and found satisfactory. (Report tanks.) (4) Machinery and boiler spaces including tank tops, bilges and cofferdams, sea suctions and overboards have been generally examined and found satisfactory. (d) *Oil tankers 15 years old and over in addition to 8.3 (a), (b) and (c)* (1) A close-up survey of one cargo tank, including any protective coating, has been carried out and found satisfactory. (Report tanks.)	
Dry Bulk Cargo Ships (Bulk Carriers) 5 years old and over		
8.4	(a) An overall survey of all cargo holds, including any protective coating, was carried out and found satisfactory. (Report holds.) (b) A close-up survey of a forward cargo hold and one other cargo hold, including any protective coating, was carried out and found satisfactory. (Report holds.) Any necessary thickness measurements to be reported.	

10. NOTES/COMMENTS		
1	Sections 1-8 and Appendix 1 of the checklist are to be completed at classification surveys (ie AS, ITSS or DS) as applicable. Items marked thus* (ie Section 3 items 3.5 and 3.6, Section 5 items 5.1-5.9 and Section 6 items 6.23 and 6.24) are only required to be dealt with on ships to which Part 6, Chapter 4 of the Rules and Regulations for the Classification of the Ships apply.	
2	Where LR is authorised to carry out the PLI and/or SCA on behalf of the National Authority provided the AS/ITSS is satisfactorily completed appropriate in accordance with the checklist requirements then the PLI, SCA survey dates may be recommended and the certificates endorsed accordingly provided:	
2.1	Confirmation that the following information is on board: (a) Manning requirements and certificates (b) Manoeuvring booklet with information displayed on bridge (c) Damage control plans for ships built 1/2/92 and after.	
2.2	Confirmation that the following is satisfactory: (a) Structural fire protection and fire doors including remote stopping of ventilation systems (b) Ventilation of machinery spaces (c) Noise protection in machinery spaces d) Engineers alarm is audible in the engineers accommodation area (e) Domestic gaseous fuel arrangements (f) First start arrangements (g) Arrangements for escape from working spaces(	

APPENDIX 1 - BOW, INNER BOW, SIDE AND STERN DOORS					
1	Operation of doors and power units witnessed and found satisfactory	**B**	**I**	**S**	**S** t
2	Door structure and surrounding ship structure examined and found satisfactory				
3	The door sealing arrangements including gaskets and retaining bars found to be				

	satisfactory				
4	The door cleating, locking and securing arrangements are complete and operate satisfactorily				
5	The door hinging arrangements have been examined and found to be satisfactory				
6	The local and/or remote operation of securing devices/cleats found to be satisfactory				
7	All equipment associated with the opening, closing and securing of the doors, that is wire ropes, chains, sheaves, rollers, guides, shackles etc. examined and found to be satisfactory				
8	The tightness of the doors has been confirmed				
9	The remote control panels and associated indicator lights, closed circuit television system, water leakage indicator lights and alarm systems have been examined and found to operate satisfactorily				
10	The required notice boards are in place and the ships log entries confirmed				
11	The bilge system for the space between the inner and outer bow doors tested satisfactorily				
12	The bilge system for vehicle deck(s) has been tested satisfactorily				
13	(a) The power units used for the opening, closing and securing of the doors has been found to operate satisfactorily (b) The hydraulic system (or other power systems) has been tested to confirm that in the event of system failure the hydraulically operated securing devices remain locked. (c) The hydraulic system (or other power systems) has been tested to confirm that in the event of system failure the hydraulically operated securing devices remain locked. (d) All associated electrical equipment examined and found satisfactory				
14	It is confirmed that the Report C11 on board provides sufficient information regarding the door arrangements as fitted, including details of securing devices, remote control				

	devices and associated indicator lights, CCTV system , water leakage indicators and bilge system.				
15	Has this ship a special feature class notation "LA" with respect to bow doors, stern doors or side doors used as cargo ramps for vehicle loading and discharging operations?	Yes/No*			
16	Has this ship an optional descriptive notation (CR) in column 6 of the Register of Ships with respect to bow doors, stern doors or side doors used as cargo ramps for vehicle loading and discharging operations?	Yes/No*			
If yes for 15 or 16, are the surveys required by the Cargo Gear Register up to date		Yes/No*			
*For doors with a clear opening of 12m 2 or more this is a Rule requirement. **N.B. B = BOW DOOR I = INNER BOW DOOR S = SIDE DOORS S** t **= STERN DOOR** Note: The above are intended to apply to doors on "Roll on - Roll off" ships but maybe applied as necessary to other shell doors in 3.1					

The International Safety Management (ISM) Code for the safe operation of ships and for pollution prevention and its application in the Marine Environment

The ISM code sets an international standard for the safe management and operation of ships and requires companies to document and implement clear procedures, standards and instructions for safety management ashore and afloat.

The ISM code does not replace the requirement for compliance with existing regulations.

The purpose of the code is to provide an international standard for the safe management and operation of ships and for prevention of pollution

The objectives of the code are to ensure safety at sea, prevention of human injury or loss of life, and avoidance of damage to the environment.

The Code will be introduced on a mandatory basis in three stages depending on the type of vessel but regardless on date of construction.

European requirement- Ro-Ro Passenger vessels will require to comply by 1 January 1996, Ro-Ro ferries from 1 July 1996

International requirements- The new chapter IX to SOLAS 1974, Management for the Safe Operation of Ships requires compliance of Passenger Vessels and high speed Passenger Craft over 500 GRT by 1 July 1998. Oil Tankers, Cargo high speed craft, Chemical Tankers, Gas Carriers and Bulk Carriers to comply by 1 July 1998. Other Cargo ships and mobile Offshore drilling rigs of over 500 GRT to comply by 1 July 2002

The MSA will be responsible for the system audit, issue and renewal of ISM Convention Certificates and the periodic verification. The use of independent organisations to guide and assist in the setting up of the SMS is encouraged but the choice such consultants is a company decision.

Certification

The application of the code will lead to the issue of two certificates

The Document Of Compliance (DOC)

- will be issued to the company following a successful audit of the shore side aspects of the Safety Management System
- evidence required that the system as been in operation on at least one type of ship in the companies fleet for a period of three months.
- Specific to ship types at time of audit
- valid for 5 years
- subject to annual verification (within 3 months of anniversary date)

The Safety Management Certificate (SMC)

- issued to each ship following audit
- evidence that SMS has been in operation for 3 months prior to audit
- valid DOC required
- valid for 5 years
- subject to one verification between the second an third anniversaries with a proviso for more

frequent audits if necessary. This is more likely in the early days of ISM Code implementation.

Temporary certification-A 12mth valid DOC may be issued to a newly formed company or a company acquiring a new type of vessel as long as they have a SMS meeting the minimum requirements of the ISM code and can demonstrate plan for full compliance.

- A 6 mth valid SMC may be issued to a new building or when a company takes of the responsibilities for the running of a vessel.

Safety Management System

Safety Management objectives of the company.

1. *provide for safe working practices and a safe working environment*
2. *establish safeguards against possible risks*
3. *continuously improve safety management skills of personnel ashore and aboard ships,*

A Safety Management system (SMS) meeting the requirements of the ISM code requires a company to document its management procedures and record its actions to ensure that conditions, activities and tasks that affect safety and the environment are properly planned, organised, executed and checked. A SMS is developed and implemented by people and clearly defines responsibilities, authorities and lines of communication. A SMS allows a company to measure its performance against set criteria hence identifying areas that can be improved. The increase in Safety Management skills improves morale and can lead to a reduction in costs due to an increase in efficiency and a reduction in claims

The safety management system should ensure;

1. *compliance with mandatory rules and regulations*
2. *applicable codes and guidelines both statutory and organisational are taken into account.*
3. *Promulgation and understanding of company and statutory regulations and guidelines. (It is the task of a visiting surveyor to test the general knowledge of company and statutory regulations and instructions)*

The functional requirements for a safety management system;

1. *a safety and environmental policy*
2. *instructions and procedures to ensure that safe operation of the vessel in compliance with relevant international and flag state legislation*
3. *defined levels of authority and communication between shore and ship personnel*
4. *procedures for reporting accidents and non-conformities with the code*
5. *procedures for responding to emergency situations (drills etc)*
6. *procedures for internal audits and management reviews*
7. *A system is in place for the on board generation of plans and instructions for key shipboard operations. These tasks may be divided into two categories*
   Special operations-*those where errors only become apparent after a hazardous situation or accident has occurred. E.g. ensuring water tight integrity, navigational safety(chart corrections, passage planning), maintenance operations, bunker operations*
   Critical shipboard operations- *where an error will immediately cause an accident or a situation that could threaten personnel, environment or vessel. e.g. navigation in confined waters, operation in heavy weather, bunker or oil transfers, cargo operations on tankers. .*

Safety and environmental protection policy

1. *The company should establish a safety and environmental protection policy which describes how objectives listed above will be achieved.*
2. *The company should ensure that the policy is implemented and maintained at all levels of the organisation both ship based as well as shore based.*

Company responsibilities and authority

1. *There must be disclosure from the owner to the administration as to who is responsible for the*

operation of the ship. The company should define and document responsibility, authority and interrelation of all personnel who manage, perform and verify work relating to and affecting safety and pollution prevention

2. *The company must ensure there are adequate resources and shore based support for the designated person or persons to carry out their function.*

Designated Person(s)

1. *A person or persons who has direct access to the highest levels of management providing a link between the company and those on board.*
2. *The responsibility and authority of the designated person is to provide for the safe operation of the vessels. He should monitor the safety and pollution prevention aspects of the operation of each vessel and ensure their are adequate shore side resources and support*

Master's responsibility and authority

1. *The roles and responsibilities of the Master should be clearly defined by the company with regard to the implementation of the companies policies with respect to SMS and methods for review and reporting deficiencies to the shore based management.*
2. *The company should ensure that the SMS operating onboard the vessel contains a clear statement emphasising the masters authority. The company should make it clear that the Master has the overall responsibility for decision making and has overriding authority with the option of adequate shore back up.*

Resources and Personnel

1. *The company should ensure that the Master is suitably qualified and fully conversant with the SMS. They should also ensure that the ship is correctly manned.*
2. *The company should ensure that there is adequate familiarisation with safety and protection of the environment for new personnel. They should ensure that the personnel has an adequate understanding of the relevant rules, regulations, guidelines and codes.*
3. *Training is to be provided where necessary. Relevant information for the SMS should be promulgated and be written in an easy to understand method.*

Development of plans for ship board operations

1. *The company should establish procedures for the generation of shipboard plans and instructions with regard to the prevention of pollution and that these should be generated by qualified personnel*

Emergency Preparedness

1. *The company should establish procedures for the response actions to potential emergency situations. Programmes for drill should be established and measures taken to ensure that the company's organisation can respond to hazards and accidents.*

Reports and analysis of non-conformities, accidents and hazardous occurrences

1. *The company should ensure there is a procedure for the reporting and analysis of accidents, hazardous occurrences and non-conformities, and for the corrective action.*

Maintenance of the ship and equipment

1. *The company is to ensure that the vessel is properly maintained. Procedures within the SMS should be in place to identify, record and plan for repair defects. A system of preventive maintenance should be in operation.*
2. *Regular inspections integrated with the ships operational maintenance routine should take place to ensure that the vessel is in compliance with relevant regulations.*

Documentation

1. *The company should establish and maintain procedures for the control of all documentation relevant to the SMS. This should include;*
   i. *valid documents are available at all relevant locations*
   ii. *changes to documents are reviewed and approved to authorised personnel*
   iii. *obsolete documents are promptly removed*
2. *All documents, carried in a company approved relevant form, should be present on board*

Company verification, review and evaluation.

1. *The company should carry out periodic audits to verify that safety and pollution prevention's are complying with SMS. The audits and corrective actions should be carried out as per laid down procedures.*
2. *Personnel carrying out the audits should be independent of the areas that they are carrying out the audit unless size of the company is such that this is impractical.*
3. *Deficiencies or defects found should be brought to the attention of the personnel in that section and the management team so effective corrective action can be carried out*

Certification, verification and control

1. *The following documentation is issued by which ever administration, complying with ISM, is relevant to the shipping company.*
2. *A DOC is issued to all company's who can demonstrate that they have complied with the code should be held.*
3. *A copy of the DOC should be held on board to allow the Master to produce it to the relevant authorities is required.*
4. *An SMC is issue to the ship following verification that the ship and company comply with the requirements of SMS.*
5. *Future verification that compliance with SMS should be carried out by the administration.*

Requirements on board ship

1. *Proof that the vessel is being maintained in a satisfactory condition at all times, and not only at the time of surveys-objective evidence in the form of no overdue surveys, no overdue recommendations from port or flag state inspections and that planned maintenance is being carried out and records kept.*
2. *Applicable codes and guidelines are being taken into consideration when operating the vessel. Vessels staff must be able to demonstrate that operations are carried out in a controlled manner utilising information contained in these codes, guidelines and standards.*
3. *That emergency situations have been identified and drills are conducted to ensure the vessel and company are ready to respond to emergency situations.*

The master is expected to be fully conversant with Company safety management system. Officers and crew would be expected to be familiar with the parts of the system relevant to their safety responsibilities as well as a thorough understanding of their operational responsibilities- auditors will ensure compliance.

Examples of the type of documentation the auditor will wish to see to verify compliance with the ISM are as follows;

- Log books
- Safety and management meeting minutes and follow up actions
- Medical log
- Company circular letters
- Planned maintenance records
- Records of verification
- Records of masters review of the system
- Records of internal audits and follow up
- Records of chart corrections
- Class quarterly listings
- Records of passage planning
- Oil record books
- Garbage logs
- Company manual and forms

Pollution prevention and OPA 90

Tied into the ISM code are the requirements to meet OPA90 to wit a Federal Response Plan. Each company that trades in US coastal waters must have in place a suitable response plan. They must have a designated person resident in the United states ready to act as consultant.

There is an IMO regulations which is equivalent to OPA90. A company must be in possession of a valid DOC to trade, and it must be able to clearly demonstrate its ability to respond to situations such as oil spillage.

Dry-Docks

Dry Dock Periods

A docking survey should be carried out twice within a 5 year period. The intermediate survey must be completed within 3 years. One of the two docking surveys within the 5 year period should coincide with a special survey. A Docking Survey is considered to coincide with the Special Survey when held within the 15 months prior to the due date of the Special Survey

An in water survey may be accepted in lieu of the intermediate survey

For vessels operating in fresh water special consideration may be given.

In-water Surveys

An In-water Survey may be accepted in lieu of the intermediate docking between Special Surveys, an *IWS notation is assigned. This requires suitable underwater protection for the hull in part taking the form of high resistance paint. This survey is to provide information normally obtained from a docking survey.
The In-water Survey is to be carried out at agreed geographical locations under the surveillance of a Surveyor to LR, with the ship at a suitable draught in sheltered waters; the in-water visibility is to be good and the hull below the waterline is to be clean. The Surveyor is to be satisfied that the method of pictorial presentation is satisfactory. There is to be good two-way communication between the Surveyor and the appropriately qualified diver.

Should damage be found a dry dock may be required for better inspection

Dry Dock file

Preparation for dry dock begins after the ship sails from its previous one. A dry-dock list of new items is created with specification sheets describing individual jobs. These sheets are compiled into a dry dock file which some time before the due date of the docking is submitted to several dry docks for pricing.
The jobs are priced individually and as a whole. This allows the ship managers to streamline the jobs to provide maximum value for money.

Preparation

The vessel must be prepared before entering the dry dock. Structural loading must be taken into account as the vessel is to be point supported on blocks. A docking plan of the ships which shows such things as drain plugs, sea boxes, underwater attachments etc is sent to the dry dock. Added to this are indications where hull repairs are required. This allows the drydock ship managers to place the blocks on which the vessel will sit.
The vessel must be trimmed so as to be equal draught with zero list. Special attention should be made when planning this for any tanks whose contents may be varied due to repair or housekeeping requirements.

In dock

The safety and fire fighting responsibilities of the vessel are handed over to the dry dock safety department for the duration of the dry and wet dock period. All hot work, tank entry or jobs requiring special safety measures carried out by ships crew must be first agreed with the dry dock safety department. A daily meeting is held to discuss forth coming jobs and any special requirements. This also allows the vessels staff and company representatives to monitor the progress of the dock.

Inspections & Measurements

- Where a ship is in dry-dock or on a slipway it is to be placed on blocks of sufficient height, and proper staging is to be erected as may be necessary, for the examination of the shell including bottom and bow plating, keel, stern, sternframe and rudder. The rudder is to be lifted for examination of the pintles if considered necessary by the Surveyor.
- Attention is to be given to parts of the structure particularly liable to excessive corrosion or to deterioration from causes, such as chafing and lying on the ground, and to any undue unfairness of the plating of the bottom.
- The clearances in the rudder bearings are to be measured.
- The sea connections and overboard discharge valves and their attachments to the hull are to be examined.
- The propeller, sternbush and sea connection fastenings and the gratings at the sea inlets are to be examined.
- The clearance in the sternbush or the efficiency of the oil glands is to be ascertained.
- When chain cables are ranged, the anchors and cables are to be examined by the Surveyor

Discharge of Oily Water Regulations

Control of discharge of oil

1. *Subject to regualtions regarding discharge of oil mixtures in special areas or in exceptional circumstances listed below, any discharge into the sea of oil or oily mixtures from ships shall be prohibited except when all the following conditions are satisfied:*
    a. for an oil tanker, except as provided for in subparagraph (b) of this paragraph:
        i. *the tanker is not within a special area;*
        ii. *the tanker is more than 50 nautical miles from the nearest land;*
        iii. *the tanker is proceeding en route;*
        iv. *the instantaneous rate of discharge of oil content does not exceed 30 litres per nautical mile;*
        v. *the total quantity of oil discharged into the sea does not exceed for existing tankers 1/15,000 of the total quantity of the particular cargo of which the residue formed a part, and for new tankers 1/30,000 of the total quantity of the particular cargo of which the residue formed a part; and*
        vi. *the tanker has in operation an oil discharge monitoring and control system and a slop tank arrangement as required under regulation 15 of Annex 1 of MARPOL 73/78. (this sets out requirements for approved installations for the handling of tank washings and dirty ballast)*
    b. from a ship of 400 tons gross tonnage and above other than an oil tanker and from machinery space bilges excluding cargo pump-room bilges of an oil tanker unless mixed with oil cargo residue:
        i. *the ship is not within a special area;*
        ii. *the ship is proceeding en route;*
        iii. *the oil content of the effluent withoput dilution does not exceed 15 parts per million; and*
        iv. *the ship has in operation equipment as required under regulation 16 16 of Annex 1 of MARPOL 73/78.(Oil discharge monitoring and control system and oil filtering equipment)*
2. *In the case of a ship of less than 400 tons gross tonnage other than an oil tanker whilst outside the special area, the Administration shall ensure that it is equipped as far as practicable and reasonable with installations to ensure the storage of oil residues on board and their discharge to reception facilities or into the sea in compliance with the requirements of paragraph (1)(b) of this regulation.*
3. *Whenever visible traces of oil are observed on or below the surface of the water in the immediate vicinity of a ship or its wake, Governments of Parties to the Convention should, to the extent they are reasonably able to do so, promptly investigate the facts bearing on the issue of whether there has been a violation of the provisions of this regulation or regulation 10 (discharge in special areas) of this Annex. The investigation should include, in particular, the wind and sea conditions, the track and speed of the ship, other possible sources of the visible traces in the vicinity, and any relevant oil discharge records.*
4. *The provisions of paragraph (1) of this regulation shall not apply to the discharge of clean or segregated ballast or unprocessed oily mixtures which without dilution have an oil content not exceeding 15 parts per million and which do not originate from cargo pump-room bilges and are not mixed with oil cargo residues.*
5. *No discharge into the sea shall contain chemicals or other substances in quantities or concentrations which are hazardous to the marine environment or chemicals or other substances introduced for the purpose of circumventing the conditions of discharge specified in this regulation.*
6. *The oil residues which cannot be discharged into the sea in compliance with this regulation shall be retained on board or discharged to reception facilities.*
7. *In the case of a ship, referred to in regulation 16(6) of this Annex, not fitted with equipment as required by regulation 16(1) or 16(2) of this Annex, the provisions of paragraph (1)(b) of this regulation will not apply until 6 July 1998 or the date on which the ship is fitted with such equipment, whichever is the earlier. Until this date any discharge from machinery space bilges into the sea of oil or oily mixtures from such a ship shall be prohibited except when all the following conditions are*

satisfied:

a. the oily mixture does not originate from the cargo pump-room bilges;
b. the oily mixture is not mixed with oil cargo residues;
c. the ship is not within a special area;
d. the ship is more than 12 nautical miles from the nearest land;
e. the ship is proceeding en route;
f. the oil content of the effluent is less than 100 parts per million; and
g. the ship has in operation oily-water separating equipment of a design approved by the Administration, taking into account the specification recommended by the Organization.

Special Areas

1.
   a. Any discharge into the sea of oil or oily mixture from any oil tanker and any ship of 400 tons gross tonnage and above other than an oil tanker shall be prohibited while in a special area. In respect of the Antarctic area, any discharge into the sea of oil or oily mixture from any ship shall be prohibited.
   b. Except as provided for in respect of the Antarctic area under subparagraph 1(a) of this regulation, any discharge into the sea of oil or oily mixture from a ship of less than 400 tons gross tonnage, other than an oil tanker, shall be prohibited while in a special area, except when the oil content of the effluent without dilution does not exceed 15 parts per million.

2.
   a. The provisions of paragraph (1) of this regulation shall not apply to the discharge of clean or segregated ballast.
   b. The provisions of subparagraph (1)(a) of this regulation shall not apply to the discharge of processed bilge water from machinery spaces, provided that all of the following conditions are satisfied:
      i. *the bilge water does not originate from cargo pump-room bilges;*
      ii. *the bilge water is not mixed with oil cargo residues;*
      iii. *the ship is proceeding en route;*
      iv. *the oil content of the effluent without dilution does not exceed 15 parts per million;*
      v. *the ship has in operation 15ppm oil filtering equipment of approved design*
      vi. *the filtering system is equipped with a stopping device which will ensure that the discharge is automatically stopped when the oil content of the effluent exceeds 15 parts per million.*

Exceptions

a. the discharge into the sea of oil or oily mixture necessary for the purpose of securing the safety of a ship or saving life at sea; or
b. the discharge into the sea of oil or oily mixture resulting from damage to a ship or its equipment:
   i. *provided that all reasonable precautions have been taken after the occurrence of the damage or discovery of the discharge for the purpose of preventing or minimizing the discharge; and*
   ii. *except if the owner or the master acted either with intent to cause damage, or recklessly and with knowledge that damage would probably result; or*
c. the discharge into the sea of substances containing oil, approved by the Administration, when being used for the purpose of combating specific pollution incidents in order to minimize the damage from pollution. Any such discharge shall be subject to the approval of any Government in whose jurisdiction it is contemplated the discharge will occur.

MARPOL 73/78 Annex VI Regulations for the Prevention of Air Pollution from Ships

MARPOL 73/78 Annex VI Regulations for the prevention of Air Pollution from ships came into force from 19 May 2005

The adoption of MARPOL Annex VI has followed some years of debate within organisations. At the same time IMO Technical code on the Control of Emissions of Nitrogen Oxides from Marine Diesel Engines was adopted. MARPOL Annex VI and the Technical Code have retroactive requirements for diesel engines 130 KW and above installed on ships keel-laid on or after 1 January 2000, and Incinerators installed onboard on or after 1 January 2000.

MARPOL Annex VI will apply to all ships, fixed and floating drilling rigs and other platforms from 19 May 2005, but the certification requirements are depending on size of the vessel and time of periodical survey.

Ships of 400 gross tons and above engaged in international voyages involving countries that have ratified the conventions, or ships flying the flag of those countries, are required to have an **International Air Pollution Prevention Certificate (IAPP Certificate)**.

This certificate must be on board at delivery for a ship constructed (keel laid) after 19 May 2005.

For ships constructed before this date, the IAPP certificate must be on board at the first scheduled dry-docking after 19 May 2005, but not later than 19 May 2008.

The IAPP certificate will be issued following an initial survey carried out by the Flag Administration or by a recognised organization (e.g. Det Norske Veritas) on behalf of the Flag Administration, confirming compliance with MARPOL Annex VI. For ships with the flag of an Administration that have not yet ratified Annex VI, a **Certificate of Compliance with Annex VI** may be issued by DNV.

Annex VI also requires diesel engines (as described above) to carry individual certificates with regard to NOx emissions, named **Engine International Air Pollution Prevention (EIAPP) Certificates**.

Annex VI requires that every ship of 400 gross tonnage or above and every fixed and floating drilling rig and other platforms shall be subject to the following surveys:

- An initial survey before the ship is put into service or before the IAPP Certificate is issued for the first time.
- Periodical surveys at intervals specified by the Administration, but not exceeding five years.
- A minimum of one intermediate survey during the period of validity of the certificate.

In the case of ships of less than 400 gross tons, the Administration may establish appropriate measures in order to ensure that Annex VI is complied with.
The Administration shall arrange for unscheduled inspections during the period of validity of the certificate. If the Administration establishes mandatory annual surveys, these unscheduled inspections shall not be obligatory, and for this purpose DNV has so far considered that all Administrations will apply a system with mandatory annual surveys.

Annex VI has requirements to the following main issues, which will be highlighted more in detail in this paper.

- Regulation 12 - Emissions from Ozone depleting substances from refrigerating plants and fire fighting equipment.
- Regulation 13 - Nitrogen Oxide (NOx) emissions from diesel engines

- Regulation 14 - Sulphur Oxide (SOx) emissions from ships
- Regulation 15 - Volatile Organic compounds emissions from cargo oil tanks of oil tankers
- Regulation 16 - Emissions from shipboard incinerators.
- Regulation 18 - Fuel Oil quality.

Application for ships keel-laid before 1 January 2000

Ships constructed (keel-laid) before 1 January 2000 need to comply with operational requirements in MARPOL Annex VI from 19 May 2005. Unless existing engines are subject to major modification, or new engines or incinerators are fitted, the requirements in Regulation 13 and constructive requirements in Regulation 16 do not apply.

Formal certification of the ships applies at the first scheduled dry-docking after 19 May 2005.

Regulation 12 Ozone depleting substances

Annex VI prohibits any deliberate emissions of ozone-depleting substances. Ozone-depleting substances, and equipment containing such substances, shall be delivered to appropriate reception facilities when removed from a ship.
New installations which contain ozone-depleting substances are prohibited on all ships after the entry into force date, except that new installations containing hydrochlorflourocarbons (HCFCs) are permitted until 1 January 2020.

The use of Halon in fire extinguishing systems and equipment is already prohibited for newbuildings. For newbuildings, this requirement in Annex VI will therefore always be complied with.
More restrictive requirements for ozone depleting substances are in place regionally, e.g. in the European Union (EU).

Regulation 13 Nitrogen Oxides (NOx)

Regulation 13 of Annex VI concerns NOx-emission from diesel engines and shall apply to:

- each diesel engine with a power output of more than 130 kW which is installed on a ship constructed on or after 1 January 2000; and
- each diesel engine with a power output of more than 130 kW which undergoes a major conversion on or after 1 January 2000.

This regulation does not apply to Emergency diesel engines, engines installed in life boats or for any equipment intended to be used solely in case of emergency.

The phrase major conversion, means a modification of an engine where the engine is replaced by a new engine built on or after 1 January 2000, or any substantial modification is made to the engine, as described in the NOx

Major Modifications

a. changing camshaft, fuel injection system
b. other NOx-related settings or components
c. the maximum continuous rating of the engine is increased by more than 10%

Substantial Modification is defined as follows

a. For engines installed on vessels constructed on or after 1 January 2000, a Substantial Modification means any modification to an engine that could potentially cause the engine to exceed the emission standards set out in Regulation 13 of Annex VI. Routine replacement of engine components by parts specified in the **Technical File** that do not alter emission characteristics shall not be considered a Substantial Modification, regardless of whether one part or many parts are replaced.
b. For engines installed on vessels constructed before 1 January 2000, a Substantial Modification means any modification made to an engine which increases its existing emission characteristics established by the simplified measurement method in excess of the allowances set

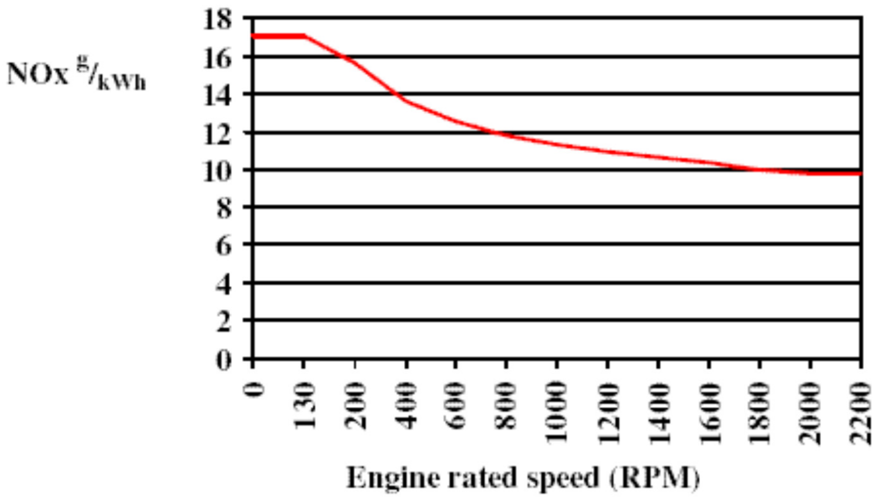
These changes include, but are not limited to, changes in its operations or in its technical parameters (e.g. changing camshaft, fuel injection systems, air systems, combustion chamber configuration, or timing calibration of the engine)

According to Annex VI the operation of applicable diesel engines are prohibited except when the emission of nitrogen oxides from the engine is within the following limits:

i. *17,0 g/kWh when n is less than 130 rpm*
ii. *45,0 з n(-0,2) g/kWh when n is 130 or more but less than 2000 rpm*
iii. *9,8 g/kWh when n is 2000 rpm or more*

where n = rated engine speed (crankshaft revolution per minute) and the emission of nitrogen oxides are calculated as total weighted emission of NO2

The table below illustrates the allowable NOx emissions from diesel engines:



Certification and onboard verification

The **EIAPP (Engine International Air Pollution Prevention) certificate** is required for all diesel engines as described above, and will be issued for marine diesel engines after demonstrating compliance with NOx emission limits. The certification process is to be carried out in accordance with the **NOx Technical Code** issued by IMO.

The following engines require EIAPP Certificates:

- Engine power output above 130 kW
- Is the vessel constructed (keel laid) before or after 1 January 2000?
- Major conversion of the engine on or after 1 January 2000?

For vessels whch require to carry EIAPP Certificates but do not currently, approach should bemade to the engine manufacturer for assistance. The certificate will be held with a **Technical File**that contains the engines specifications

The NOx Technical Code opens for 3 different onboard verification procedures:

- Engine parameter check method
- Simplified measurement method
- Direct measurement and monitoring method

The applicable onboard verification procedure is initially decided by the engine manufacturer, and is usually a specific chapter in the engines Technical File.

Methods of Checking Compliance

Engine parameter check method

Rather than having to measure the actual level of NOx it is acceptable that a record be kept to ensure the current status of the engine is equivalent to that when NOx readings were taken initially. The engines Technical File identifies the components, settings and operating values that influences the exhaust emissions and these must be checked to ensure compliance during surveys and inspections.

To satisfy the requirements of this method the following must be available:

- Technical File including the onboard verification procedure.
- Record book of engine parameters for recording all of the changes made relative to an engines components and settings. Also to include technical documentation in case of modification of any of the engines designated components.
- EIAPP certificate (Statement of Compliance) for each applicable engine.

The NOx-influencing components and settings depend on the design of the particular engine, and shall be listed in the engines Technical File. The below list shows typical NOx-influencing parameters:

- Injection timing
- Injection system components (nozzle, injector, fuel pump)
- Injection pressure
- Camshaft components (fuel cam, inlet- and exhaust cam)
- Valve timing
- Combustion chamber (piston, cylinder head, cylinder liner)
- Compression ratio (connecting rod, piston rod, shim, gaskets)
- Turbocharger type and build (internal components)
- Charge air cooler/charge air pre-heater
- Auxiliary blower
- NOx reducing equipment 'water injection'
- NOx reducing equipment 'emulsified fuel' (fuel/water emulsion)
- NOx reducing equipment 'exhaust gas recirculation'
- NOx reducing equipment 'selective catalytic reduction'

The actual Technical File of an engine may include less components and/or parameters other than the list above, depending on the particular engine and the specific engine design.

One of the main consequences of MARPOL Annex VI is that the onboard verification procedure 'Engine parameter check method' requires identification markings on the NOx influencing components. These components are typically those specified in above list. All the components listed are to be fitted with identification markings according to the Technical File. Please note that these markings may not be the same as the article nos usually found on the engine components (spare parts numbers, serial numbers). It may be the case that parts are available built under liscence. These must be stamped with the same number otherwise they are not acceptable. These parts must be accepted by the Administration overseeing the issue of certification.

There may be situations where the engine maker comes up with a new design for one of the NOx-influencing components, with a different Id No from whats stated in the Technical File. The new design should then be approved by the Administration (or DNV on behalf of a Flag Administration when authorised) and the change is to be documented in the **'Record book of engine parameters'**. The same is applicable for all other changes the engine may be approved for during its lifetime.

Simplified measurement method

This involves full load running of the engine for about 20 minutes, and will in most cases require a test trial.

Due to the possible deviations when applying the simplified measurement method, an allowance of 10% of the applicable limit value is accepted for confirmation tests and during periodical and intermediate surveys.

Direct measurement and monitoring method

The ship-owner will have the option of direct measurement of the NOx emissions during the engine operation. Such data can either take the form of spot checks logged with other engine operating data on a regular basis and over the full range of engine operation, or they can result from continuous monitoring and date storage. Data must be taken within the last 30 days, and must have been acquired using the test procedures given in the NOx Technical Code. These monitoring records are to be kept onboard for at least three months for verification purposes.

To demonstrate the compliance by the direct measurement method, sufficient data shall be collected to calculate the weighed average NOx emissions in accordance with the NOx Technical Code.

It should be noted that the two methods that involve measuring of the exhaust emissions do not include any kind of identification markings of the NOx-influencing components.

Surveys and inspections

Following the regime of the IAPP certificate, the diesel engines will also be subject for the following surveys:

- An initial survey before the ship is put into service or before the IAPP Certificate is issued for the first time.
- Periodical surveys at intervals specified by the Administration, but not exceeding five years,
- A minimum of one intermediate survey during the period of validity of the certificate.
- Annual Surveys (or a Flag Administration may instead implement unscheduled inspections as an alternative to Annual surveys)
  If the 'Engine Parameter Check Method' is the selected onboard verification procedure, the surveyor will typically want to see:
  i. *EIAPP Certificates for all applicable diesel engines onboard*
  ii. *Approved Technical Files including Onboard verification procedure for all the applicable diesel engines onboard*
  iii. *Record Book of Engine parameters for all the applicable diesel engines onboard*
  iv. *One or all of the identified components, settings or operating values specified in the engines Technical File*

  If the 'Simplified Measurement Method' is the selected onboard verification procedure, the surveyor will witness the testing in addition to review the following documentation:

  i. *EIAPP Certificates for all applicable diesel engines onboard*
  ii. *Approved Technical Files including Onboard verification procedure for all the applicable diesel engines onboard*
  iii. *All recommendations from engine manufacturer and approvals from the Administration concerning the 'Simplified Measurement Method'*
  iv. *Test results*

  If the 'Direct Monitoring and Measurement Method' is the selected onboard verification procedure, the surveyor will typically want to see:

  i. *EIAPP Certificates for all applicable diesel engines onboard*
  ii. *Approved Technical Files including 'Onboard verification procedure' for all the applicable diesel engines onboard*
  iii. *Documentation/Approval of the installed measuring equipment*
  iv. *Logged measurement results in order to verify that the engines comply with the NOx Technical Code.*

Regardless of what onboard verification procedure the Ship-Owner chooses, the IAPP Certificate for the vessel will be issued if all other requirements are found to comply with the applicable requirements.

Engines with EIAPP certificates issued by another company

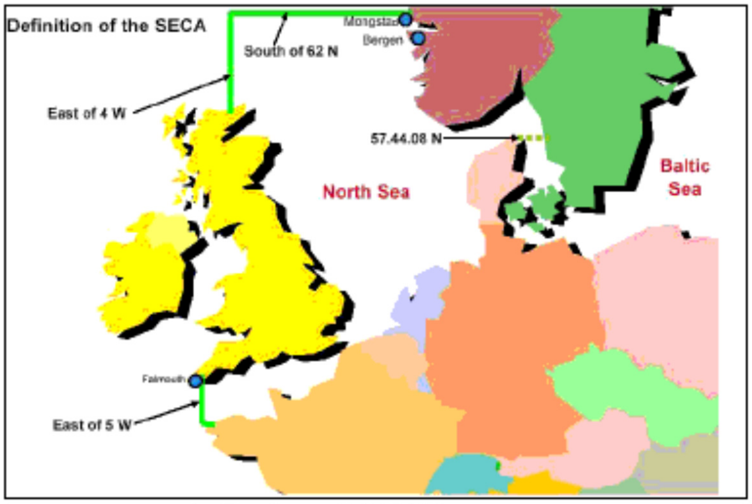
Although there are several companies able to certify engines only those approved by flag State will be acceptable to the administration (generally Class) who have been authorised to issue certification.

Regulation 14 - Sulphur Oxides (SOx)

General

Upon entry into force of Annex VI to MARPOL on the 19 May 2005, the sulphur oxide (SOx) emissions from ships will be controlled by setting a limit of 4.5% on the sulphur content of marine fuel oils.

Further, a limit of 1.5% on the sulphur content of marine fuel oil will apply in designated **SOx Emission Control Areas (SECAs)**. IMO has currently agreed on the designation of two SECAs as per below. The first designated SECA is the Baltic Sea Area which has been agreed that will enter into force on the 19 May 2006. The second area, the North Sea Area and the English Channel has also been agreed, but due to the amendment process in IMO, it has been indicated that it will not enter into force as a SECA until 19 November 2007. It is expected that further SECAs will be designated in the future and IMO has set forth certain criteria for designating such SECAs.



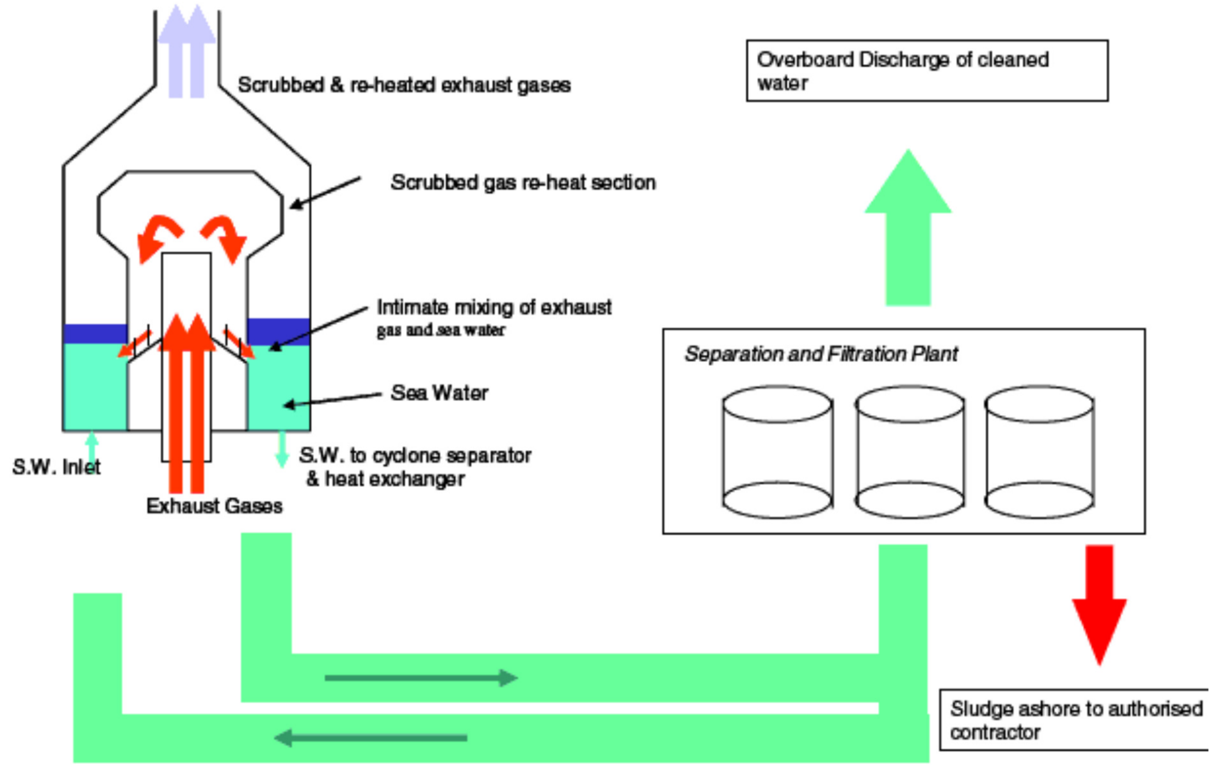
Indication of SECA's

The limitations in sulphur content applies to all fuel oils (heavy fuel oils, marine diesel oils and gas oils) and regardless of use on board (i.e. in combustion engines, boilers, gas turbines etc.).

Currently, the average sulphur content in fuel oils is in the region of 2.7% with only 0.2% having Sulphur content above 4.5%. However only 4% of fuels have less than 1.5%.

Exhaust Gas Cleaning systems

As an alternative to using marine fuel oil with a 1.5% sulphur content in SECAs, an exhaust gas cleaning system or other equivalent system may be used (abatement technologies). The emission criteria for such systems are 6 g SOx/kWh.



Exhaust gas cleaning system

Development of a type approval standard for such systems is ongoing in IMO. The current available abatement technology is based on seawater scrubbing principles.

There is however a few concerns related to these types of scrubber type systems:

- Annex VI states that port states may prohibit discharge of scrubber effluent overboard in ports within SECAs unless it can be documented that the effluent complies with criteria set by that port state. A mitigating measure is installation of filtration/treatment systems.
- It has been indicated that conventional scrubber technology may be struggling to meet the emission criteria at high exhaust gas discharge flows.
- It has been indicated that there is a risk of blue-sheen originating from the scrubber overboard discharge. Although, not necessarily constituting an environmental hazard, the mere risk of such occurrences is to some operators unacceptable.
- There are space considerations in the engine room and more specifically the funnel. Although it has been indicated that the more advanced scrubber types can replace standard silencers, the associated piping systems may represent a challenge. Pressure drop in scrubbers has also been indicated as a limitation, particular in way of main engines uptakes.
- Tanker owners have had mixed experiences with corrosion of inert gas scrubbers and associated piping systems.
- The EU has been reluctant to accept scrubbers. Based on trials they have indicated that they may accept abatement technology as an equivalent to low sulphur fuel. Note that EU has indicated that it will develop criteria for resulting waste streams in their ports.

The author understands that the trial of this scrubbers have been pretty disastrous and have often ended up being expensive follies

EU Directive 1999/32/EC with proposed amendments

In connection with MARPOL Annex VI one cannot disregard ongoing low-sulphur developments in the EU.

EU directive 1999/32/EC has been amended a number of times, and in force today is the following:

- Member states to ensure that Marine Distillates used within their territory from July 2000 do not exceed 0,2% Sulphur (0,1 % from January 2008). In other words, ships must ensure that if they are using Marine Distillates in EU territory (territorial waters including seas 12 nautical miles from shore and inland waterways), their sulphur content is below 0,2%. Marine Distillates in this context include both marine gas oils and marine diesel oils (DMX, DMA, DMB and DMC). As far as DNVPS has been informed this requirement is currently only enforced by Dutch Authorities Amendment to EU directive 1999/32/EC reached a common position in July 2004, and although the amendment process is in its final stages, implementation date is highly uncertain and further amendments cannot be ruled out. As of July 2004 the following is in the pipeline:
- A 1.5% sulphur limit for fuels used by all ships in the Baltic Sea, North Sea & Channel in accordance with the implementation dates of Annex VI to MARPOL (i.e. starting in 19 May 2006 for the Baltic Sea Area). As of 19 May 2006, EU member states shall ensure that the sulphur content in marine diesel oils (ISO 8217 grades DMB and DMC) supplied within their territory does not exceed 1.5%.
- A 1.5% sulphur limit for fuels used by passenger vessels on regular services between EU ports as of 19 May 2006.
- A 0.1% sulphur limit on fuel used by inland vessels and by seagoing ships at berth in EU ports. The Council agreed this limit delayed until 1 January 2010, to allow single-fuel ships time to adapt their fuel tanks.
- A further two year delay has been proposed given to 16 unifuel (vessels using heavy fuel oil for both main and auxiliary engines) ferries serving the Greek islands.
- As of 1 January 2010, EU member states shall ensure that the sulphur content in marine gas oils (ISO 8217 grades DMX and DMA) supplied within their territory does not exceed 0.1%.
- For ships arriving from outside the EU, the requirement need only be complied with upon leaving the EU port of call.

Low sulphur heavy fuel

It has been indicated that experience in terms of low sulphur residual (or heavy) fuel oil blending is varying and that quality problems are to be expected. Although there is limited usage of (blended) low sulphur fuel oils, DNV Petroleum Services has already seen indications that the low sulphur processing of fuel oils may lead to additional quality problems such as instability, incompatibility, ignition and combustion difficulties and an increase of catalytic fines levels. Regrettably one has also seen cases where chemical waste has been introduced in such fuel.

Anyone who has bunkered in Singapore will not be unfamiliar with this

Fuel tank/system configuration

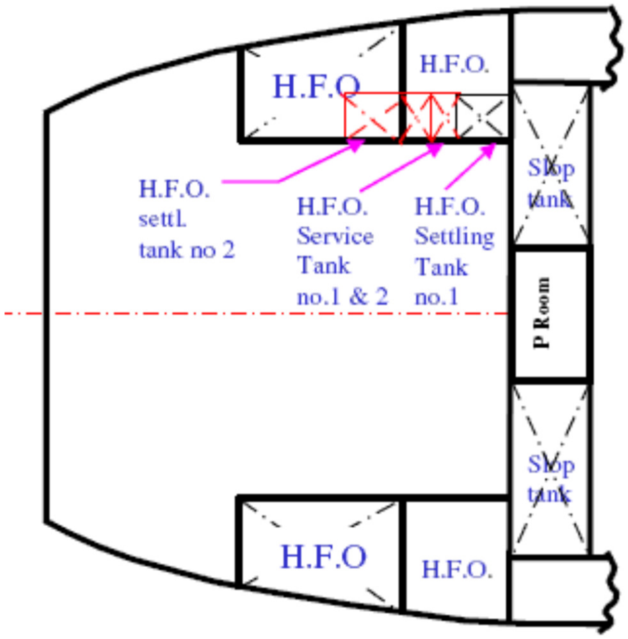
It should be noted that when approaching a SECA the fuel must be changed over to the 1.5% sulphur content fuel and completed before entering the SECA. That is all the fuel lines to the engine must have this fuel only.

There are two approaches to this

1. ***FLushing*** *- low sulphure fuel is used to flush out the higher sulphur fules from the settling/service tank*
2. ***Duplication of tanks****- seperate Settling/service tanks are installed for the two types of fuels. This has the potential to simplify the change over proceedure and reduce risk of fuel imcompatibilities.*

Inadequate availability of low sulphur heavy fuel oils may force owners to increase the consumption of low sulphur diesel oils within SECAs. Owners will therefore have to assess whether the diesel oil tank capacity needs to be upgraded. Taking into account the current EU requirements to use of ultra low sulphur distillates within its territories, and not to mention the proposal for ultra low sulphur fuel at berth in EU ports, there is also an issue of whether to allocate or convert existing fuel tanks to tanks for marine gas oil.

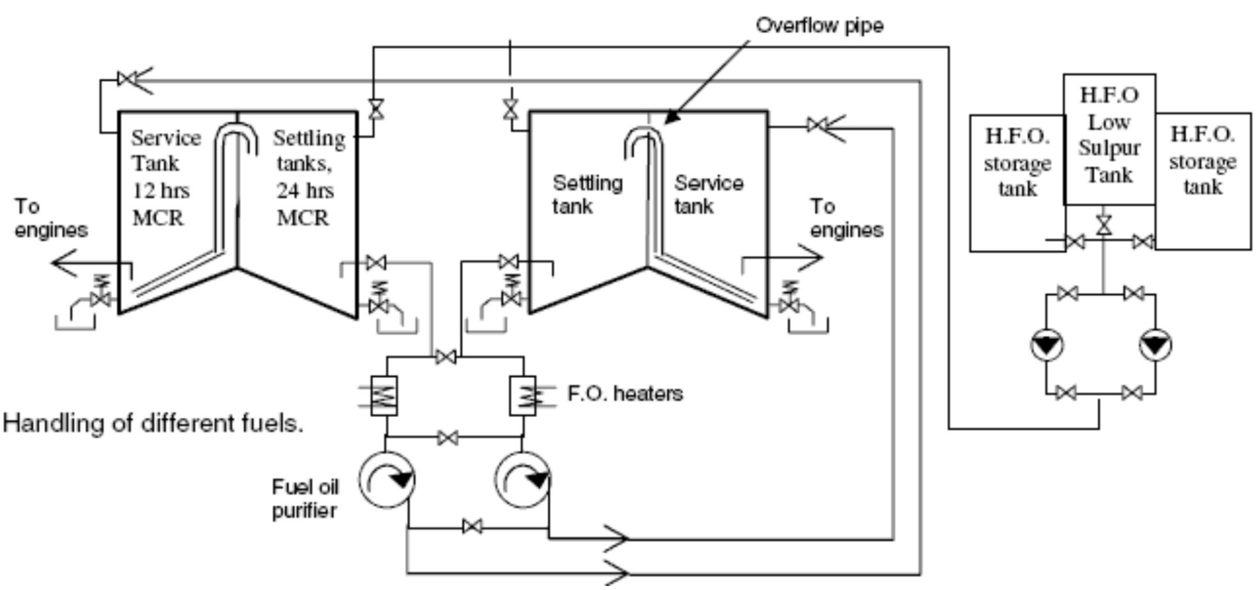
The differences in cost between low and high sulphur heavy fuel oils as well as between heavy fuel oils and low sulphur diesel oils, has led some owners to consider separating fuel treatment and service piping systems. This is increasingly important with respect to potential requirements to use of ultra low sulphur fuels in EU ports



Possible arrangement for additional fuel oil tanks.

In order to facilitate safe and simple change-over, the installation of separate marine gas oil/diesel oil supply piping with heating capabilities should be considered. (While separate direct diesel oil supply lines are often arranged for auxiliary diesel engines, the same is less frequently encountered for boilers and main engines.)

The below serves as examples of proposed modifications regarding duplicated heavy fuel oil service and settling tanks and piping systems.



Handling of different fuels.

Change-over procedures

The time, ships positions at the start and completion of change-over to and from 1.5% fuel oil must be recorded in a logbook (e.g. ER log. book), together with details of the tanks involved and fuel used. It can be anticipated that the same will be applicable with respect to the EU proposal upon entry into force.

Regulation 15 Volatile Organic Compounds

Emissions of volatile organic compounds (VOCs) from tankers may by each party to Annex VI be regulated in its ports and terminals. Such requirements shall be given in a list published by IMO. The list shall also specify size of tankers, and which cargoes, that requires vapour emission control system.

All tankers which are subject to vapour emission control in accordance with above list shall be provided with an approved vapour collection system, and shall use such system during the loading of such cargoes.

Existing tankers which are not fitted with vapour collection systems may be accepted for a period of three years after the terminal was included in the above list. DNV has for many years had class notations VCS 1 and 2 for vapour control systems complying with IMO Guidelines (MSC/Circ.585), and USCG regulations. It may be noted that a vessel complying with VCS- 1 or 2 will comply with regulation 15. This regulation shall only apply to gas carriers when the type of loading and containment systems allow safe retention of non-methane VOCs on board, or their safe return ashore.

Regulation 16 Shipboard Incineration

Onboard incineration outside an incinerator is prohibited except that sewage sludge and sludge oil from oil separators may be incinerated in auxiliary power plants and boilers when the ship is not in ports, harbours and estuaries.

Incineration of Annex I, II and III cargo residues, of PCB's (Polychlorinated biphenyls), of garbage containing more than traces of heavy metals and of refined petroleum products containing halogen compounds is always prohibited.

Incineration of PVCs (polyvinyl chlorides) is prohibited except in shipboard incinerators type approved according to resolutions MEPC 59(33) or MEPC 76(40).

Monitoring of combustion flue gas outlet temperature shall be required at all times and waste shall not be fed into a continuous-feed shipboard incinerator when the temperature is below the minimum allowed temperature of 850AC. For batch-loaded shipboard incinerators, the unit shall be designed so that the temperature in the combustion chamber shall reach 600AC within 5 minutes after start-up. It must be ensured that the incinerators' flue gas outlet temperature monitoring system is operational.

All incinerators installed on or after 1 January 2000 shall be type approved in accordance with Resolution MEPC 76(40) giving the IMO standard specification for shipboard incinerators. For such incinerators a manufacturer's operating manual is required.

Regulation 18 Fuel Oil Quality

General While fuel oil quality is currently primarily a matter between owners/managers (and charterers) and suppliers, it will under Annex VI of MARPOL 73/78 also become a statutory matter.

In addition to requirements limiting the sulphur content of oil fuel, Annex VI contains requirements preventing the incorporation of potentially harmful substances, and in particular waste streams (e.g. chemical waste), into fuel oils.

Regulation 18 specifically requires that fuel oil supplied to ships is to be free from inorganic acids or chemical wastes that could jeopardise the safety of the ship, be harmful to ships' personnel, or which would contribute overall to additional air pollution. The addition of small amounts of additives intended to improve performance is however permitted.

Incidentally, the requirements to fuel oil quality in Regulation 18 are more or less identical to the general requirements of ISO 8217, although no references are made to the same. Accordingly one question raised has been whether a fuel found off-spec compared to ISO 8217 test parameters is in violation of Regulation 18. Consultations with certain port states indicate that this will likely not be the case. Instead it has been indicated that Regulation 18 may be enforced in case a ship is involved in accidents or near-accidents where fuel quality is a suspected contributor.

Isn't that disgraceful

Operational issues

It is important to note that elaboration and clarifications relating to Regulation 18 are found in Resolution MEPC. 96(47) 'Guidelines for the sampling of fuel for determination of compliance with Annex VI of MARPOL 73/78'. Although this is a guideline, it is expected that the guideline will be used as requirements by port state inspectors. It should be noted that Intertanko has issued a thorough and useful guideline related to Annex VI which elaborates on the issues at hand.

Bunker delivery notes

It is a requirement of Regulation 18 that any fuel oil for combustion purposes delivered to and used onboard shall be recorded by means of a **Bunker Delivery Note (BDN)**. This implies that a bunker delivery note shall be presented for every barge delivery and every grade.

Bunker Delivery Notes are required to contain all specific information as follows:

- Name and IMO number of receiving ship
- Bunkering Port
- Date of commencement of bunkering
- Name, address, and telephone number of marine fuel oil supplier
- Product name
- Quantity (metric tons)
- Density at 15 oC (kg/m3)
- Sulphur content (% m/m)
- A declaration signed and certified by the fuel oil supplier's representative that the fuel oil supplied is in conformity with regulation 14 and 18 (I.e. that the fuel supplied has a sulphur level below 4.5% and that the fuel is free from inorganic acid, does not include any added substance or chemical waste which either jeopardises the safety of ships, adversely affects the performance of the machinery, is harmful to personnel, or contributes overall to additional air pollution).
- Resolution MEPC.96(47) recommends that the seal number of the associated MARPOL Annex VI fuel sample is included in the BDN's for crossreference purposes.

The BDN's are to be kept on board and readily available for inspection at all times. It shall be retained for a period of three years after the fuel oil has been delivered on board.

MARPOL 73/78 Annex VI fuel oil samples

Regulation 18 requires that every BDN is to be accompanied by a representative sample of the fuel oil delivered, taking into account the guidelines in Resolution MEPC.96(47).

The sample is to be sealed and signed by the supplier's representative and the master or officer in charge of the bunker operation on completion of bunkering operations, and retained under the ship's control until the fuel oil is substantially consumed, but in any case for a period of not less than 12 months from the time of delivery. Although MEPC.96(47) specifies that the volume of the sample bottle should be no less than 400 ml, due to potential need for repetitive testing, Intertanko has recommended that the sample volume is not to be less than 750 ml.

For the sake of good order it should be noted that the practical purpose of this sample is to enable port states to verify the sulphur content of the fuel, as well as to verify that the fuel oil quality is in accordance with Regulation 18.

As Annex VI specifies that the Annex VI sample is not to be used for commercial purposes, DNV Petroleum Services recommends that for ships already participating in a fuel oil quality testing scheme, the Annex VI sample should be the fourth sample (in addition to the sample sent to laboratory for testing, suppliers sample and the retained onboard sample). The reason is that it is considered an advantage to always have an Annex VI sample onboard in case of port state controls.

Sampling procedures

Note that the referred to Resolution MEPC.96(47) specifies in detail that the fuel sample is to be obtained at the receiving ships inlet bunker manifold and is to be drawn continuously throughout the bunker delivery period. The term continuously drawn is specified to mean a continuous collection of drip sample throughout the delivery of bunker fuel. Sampling methods are further clarified as either; manual valve-setting continuous-drip sampler (equivalent to DNV Petroleum Services Line sampler), time-proportional automatic sampler, or flow-proportional automatic sampler.

Further the guidelines specify that sample bottle labels are to contain the following information:

- Location at which, and the method by which, the sample was drawn
- Bunkering date
- Name of bunker tanker/bunker installation
- Name and IMO number of the receiving ship
- Signatures and names of the suppliers representative and the ship's representative
- Details of seal identification
- Bunker grade.

Sample inventory

Resolution MEPC.96(47) also contains recommendations on sample storage location.

Suppliers responsibility

While most IMO conventions place full responsibility on the ships and ship owners, Regulation 18 places a certain responsibility on the suppliers (fuel oil quality declaration, BDN and the Annex VI fuel oil sample by continuous drip and at the receiving ships manifold).

Annex VI of MARPOL also contains instruments to encourage port states to ensure that suppliers fulfil their obligations. Port states are therefore required to:

- Maintain a register of local suppliers of fuel oil;
- Require local suppliers to provide the BDN and sample, certified by the fuel oil supplier that the fuel oil meets the requirements of regulations 14 and 18.
- Require local suppliers to retain a copy of the bunker delivery note for at least three years for inspection and verification by the Port State as necessary;
- Take action as appropriate against fuel oil suppliers that have been found to deliver fuel oil that does not comply with that stated on the Bunker Delivery Note;
- Inform the Flag Administration of any ship receiving fuel oil found to be noncompliant with the requirements of regulations 14 or 18 of this Annex.
- Inform IMO for transmission to Parties to the Protocol of 1997 of all cases where fuel oil suppliers have failed to meet the requirements specified in regulations 14 or 18.

However, despite the suppliers responsibilities and the instruments available, previous experience from Port State Controls indicates that it is advisable for owners/managers themselves to ensure compliance. In order to assist ships in ensuring that the operational requirements are met, it should be considered to include clauses related to MARPOL Annex VI compliance in bunker contracts and agreements with suppliers, as well as charter parties.

Third party inspections

It can be expected that upon implementation, class surveyors, port state inspectors and possibly also vetting inspectors will scrutinise onboard documentation and records (e.g. sampling procedures, change-over procedures, ER log books, BDN's, sample inventory log books etc.), as well as the fuel oil sample inventory.

The updated list showing state of ratification can be found on IMO's web pages (www.imo.org/home.asp) under 'conventions' and 'status of conventions by country. For further information, please contact: Annex VI in general: DNV, Cargo Handling, Piping Systems, Marpol and Gas Carriers (MTPNO880@dnv.com) NOx and engine related inquiries:
DNV, Section for machinery, Ships in Operation
(MTPNO867@dnv.com)
DNV, Section for machinery, Newbuilding
(MTPNO373@dnv.com)

SOx and fuel related inquiries:
DNV, Cargo Handling, Piping Systems, Marpol and Gas Carriers (MTPNO880@dnv.com)
DNVPS, DNV Petroleum Services (DNVPS.OSLO@dnvps.com)

Hand Arm Vibration Syndrome HAVS

INTRODUCTION

Control of Vibration at Work Regulations 2005 came into force in July 2005. The Merchant Shipping and Fishing Vessels (Control of Vibration at Work) Regulations 2007 (SI 2007/3077) (the Vibration Regulations) implement Directive 2002/44/EC on requirements for the protection of workers from the risks related to exposure to vibration at work. The Vibration Regulations build on the Merchant Shipping and Fishing Vessels (Health and Safety at Work) Regulations 1997 (SI 1997/2962), as amended, (the "General Duties" Regulations), by requiring that the risk assessment required by the General Duties Regulations considers additionally the risks to workers arising from exposure to vibration.

The Health and Safety Executive have implemented the Vibration Directive for land based workers and the Vibration Regulations which come into force on 23 February 2008 complete the United Kingdom's implementation of these Directives by extending their coverage to seafarers and other workers on ships and fishing vessels.

DEFINITIONS

User- Person who has been or potentially may be exposed to Vibration to whom this policy applies Exposure Action Value (EAV) means the daily amount of vibration exposure of an employee above which action must be taken to reduce the exposure. For hand-arm vibration the EAV is a daily exposure of 2.5 m/s2 A(8) or 100 Exposure Points (EP).

Exposure Limit Value (ELV) means the maximum amount of vibration an employee may be exposed to on any single day. For hand-arm vibration the ELV is a daily exposure of 5 m/s2 A(8) or 400 Exposure Points (EP) .

Personal Exposure Action Value (PEAV) - This is normally the same as the EAV but may be reduced for those persons deemed at particular risk from exposure. See Exposure Limits Personal Exposure Limit Value (PELV) - This is normally the same as the ELV but may be reduced for those persons deemed at particular risk from exposure. This limit should not be normally exceeded. Where it is necessary to exceed special risk assessment should be carried out by the Medic and Safety Coach.

Exposure Points (EP) - A representative non unit based value representative of the Daily exposure level mm/s2 A(8) mm/s2

A8- Daily exposure level, a summation of Vibration magnitude and Exposure time over a standardized period of 8 hours.

Working Day - means a daily working period irrespective of the time of day when it begins or ends and whether it begins or ends on the same calendar day.

Hand Arm Vibration(HAV) - is vibration transmitted from work processes into workers' hands and arms. It can be caused by operating hand-held power tools such as disc grinders, or by holding materials being processed by machines, such as pedestal grinders which .entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological or muscular disorders.

Hand Arm Vibration Syndrome (HAVS) -A disorder resulting from prolonged exposure to vibration, specifically to the hands and forearms while using vibrating tools. Symptoms include numbness, tingling, and loss of nerve sensitivity. The hand-arm vibration syndrome (HAVS) is a painful and potentially disabling condition of the fingers, hands, and arms due to vibration. There is initially a tingling sensation with numbness in the fingers. The fingers then become white and swollen when cold and then red and painful when warmed up again. Cold or wet weather may aggravate the condition. Picking up objects such as pins or nails becomes difficult as the feeling in the fingers diminishes and there is loss of strength and grip in the hands. The pain, tingling, and numbness in the arms, wrists and hands may interfere with sleep.

Sources of vibration that can cause HAVS are very varied and include pneumatic drills, chipping tools, needle guns and scabblers, polishers, power jigsaws, sanders and angle grinders, riveters, compactors and even electronic games in which the hand controls vibrate.

HAVS was first widely recognized as a potential occupational hazard in the mid-1980s. It was first known as "vibration white finger."

Whole-Body Vibration (WBV)is defined as the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular, lower back morbidity and trauma of the spine. Whole-body vibration may be most apparent in smaller, fast craft such as fast rescue boats, RIBs or work boats, particularly when operating in choppy conditions.

Vibration Sources (VS) and Vibration Source Equipment (VSE)- are defined at sources or equipment which generate as part of their normal function vibration Health Surveillance The ongoing assessment of any harmful effects associated to vibration Health Service Provider. An independent provider of health surveillance.

Personal Vibration Handbook (PVH)- This is a book supplied to all permanent staff and contains information and advice for the User pertaining to HAVS and WBV as well as anniversary dates for Annual Assessment and values for PEAV and PELV

Personal HAV Record - This is a form to be filled out by the User each day which he is exposed to Vibration source equipment Vibration Source Equipment Record- A record of vibration taken from a Vibration Source Equipment. This record may be contained in software Vibration Source Equipment Register A register of all Vibration Source Equipment, it contains last measured values, due date for next measurement and where appropriate due date for next service.

This register may be contained in software Management Interface Agreement an agreement between Well-Ops UK and a third party which in terms of this policies gains agreement for a third Party employee to be assessed under this policy or for Well-Ops UK to supply the information required by that third party to properly manage risk.. This does not absolve that third parties contractor from their duty of care

SCOPE

This Policy deals specifically with Hand Arm Vibrations Syndrome, Whole Body Vibration is dealt with separately although commonality means that certain elements are mutual

TEST EQUIPMENT

HAVS and WBV Test Equipment- This is a vibration monitoring device which when used by a trained person following procedures laid down in this policy allows determination of a Exposure Limit

MANAGEMENT OF RISK ASSOCIATED TO THE USE OF VIBRATION SOURCE EQUIPMENT

Control of Vibration at work and management of hazardous effect is seen as a three part process;

EVALUATION AND MANAGEMENT OF RISK

This looks at the daily exposure to vibration sources, the magnitude of this exposure, the assessment of this daily exposure and the formulation from which useful information can be gained of risk

ELIMINATION OR REDUCTION OF EXPOSURE

Looks at the control of risks associated to working with Vibration source equipment. Although more specifically affecting whole body vibration it will also look at methods to eliminate the effects from Vibration Sources This section sits between the Evaluation and health surveillance sections and ties the two together, it thereby forms the core element.

HEALTH SURVEILLANCE

Looks at a User previous or potential exposure to vibration. It also looks at a persons susceptibility to the effects of vibration and feeds back into the risk evaluation for that person in the work place

MITIGATION OF EXPOSURE BY CONTROL OF THE ENVIRONMENT, EQUIPMENT AND PRACTICE

EQUIPMENT SELECTION

New equipment should be selected which is of sound ergonomic design taking into account proposed usage. It should, where possible, be so designed as to reduce vibration effects to the user. Manufacturers are required to release information on Vibration levels, where it is practical to do so a comparison of types should be carried out and selection based on factors to include vibration levels. See Section 10 Vibration Source Equipment

EQUIPMENT MAINTENANCE

Equipment likely to be a source of Vibration exposure are to be properly maintained to manufactures instruction. Any equipment where there is suspicion of knowledge of defect that may affect the measure vibration level is to be removed from service until such time repair can be made as required and the vibration reading ascertained. See Section 10 Vibration Source Equipment

WORKING AREAS

The working environment should be designed or modified as far as is reasonably practical to prevent the operator from adopting a posture, position or location liable to increase the harmful effects of vibration. Contributory factors could be temperature, dampness or any other factors

TRAINING

Were appropriate training is to be given to techniques which may reduce the harmful effects of vibration

CLOTHING AND PERSONAL PROTECTIVE EQUIPMENT

Clothing

The operator should wear clothing of the appropriate type and amount so that he is comfortable in the working environment without being too hot or too cold. **Coveralls**

Should not be so tight as to restrict blood circulation when in the working position.

HAND GLOVES

Investigation by HSE has found the mitigating effects of the use of anti-vibration gloves is limited and therefore no allowance is made for their use. The use of such gloves is to the operators preference although they should be aware that wearing these gloves does not effect the maximum exposure time. Recommendation is that any gloves worn ensure comfort and warmth.

Portable Appliance testing PATS

INTRODUCTION

Introduction

The Electricity at Work Regulations state that all electrical systems and equipment used in the working environment should be in a safe condition. The Health & Safety Executive recommend that to comply with the regulations, an inspection and testing regime be implemented at all places of work.

Part of the PATS testing regime should include all portable appliances, defined as any item of electrical equipment which has a plug top.

Definitions

Portable Appliance - An appliance of less than 18kg in mass that is intended to be moved while in operation or an appliance which can easily be moved from one place to another e.g. Toaster, Food mixer, vacuum cleaner

Movable/Transportable Equipment- equipment which is 18kg or less and is not fixed or is so designed as to be facilitate movement (e.g. castors, rollers on base)

Hand-Held Appliances or Equipment This is portable equipment intended to be held in the hand during normal use e.g. Hair Dryers, Drill, Soldering irons.
Note, testing under PATS is done in conjunction with other requirements under PUWER for relevant equipment

Stationary Equipment Equipment of mass greater than 18Kg without carrying handle

Information Technology Equipment Information technology equipment such as computers, faxes etc.

Fixed Equipment Equipment which is fastened to a support or otherwise secured in a specific location

Personnel equipment - equipment which is brought to, removed from and used on the vessel solely by its Owner

Public equipment - equipment that remains on the vessel, or is brought to and removed from the vessel, but is in general use. This equipment may be owned either by the vessel owner/operator or by any other person(s)

PATS Test Equipment Equipment used to test appliances against a number of defect criteria.

Equipment Class I, II, III see table at end of article

PATS Test Equipment

- Should provide the following facilities;
- Earth continuity with one or more pre-set currents
- Insulation resistance with applied voltage typically 500v
- In addition it may be capable of

- Dielectric Strength Testing (Not normally carried out as part of In-service Testing)
- Insulation resistance measurement by earth leakage method
- Load Test
- Earth Continuity (may be carried out using suitable continuity or low resistance ohmmeter)

All test equipment used to comply with this policy should be subject to annual verification

User Checks

All users of electrical equipment are responsible to ensure that, as far as reasonably practical, equipment for their use is free from defect liable to cause harm. This should take the form of an external inspection of such equipment to ensure that no obvious defect exists.

Where doubt exists then the equipment should be disconnected from the supply if possible to do so, and the Electrican/ETO informed. This equipment should be labeled as not available for use until tests are completed

Basic Testing Procedures for Portable, appliances, hand held appliances and IT Equipment

All items will be tested in isolation. That is: Any equipment interconnected by means of mains or data cables will first have these interconnections removed (this includes the disconnection of "networked" equipment from the network cabling system). If necessary, operations must be requested to "shutdown" systems prior to testing.

The portable appliance tester must be plugged into a 13A socket outlet and the correct date set by following the prompts on the display panel and using the appropriate keys. The appliance and site codes will be entered for each test.

The test code facility will only be used to alter the test parameters where necessary.
NOTE: Hard wired equipment will be disconnected from the associated outlet, having first isolated the mains supply at a suitable point. **EARTH BOND IMPEDANCE TEST** - The earth impedance limit will be set according to the size and length of the connecting flexible cord.
NOTE: The British Standards for most IT. Equipment specify an earth bond impedance of 0.1 Ohms. This figure does NOT include the additional impedance/resistance of a flexible cord and plug top. Generally speaking a reading of 0.25 Ohms or less can be considered within acceptable limits for equipment using a 2 metre length cord with 0.5 square millimetres or greater conductors.
The tests engineer will take sufficient care when connecting the earth clip to CLASS 1 appliances to ensure that proper contact is made and thereby reduce the possibility of incorrectly failing an appliance (earth connections can be looked for with a simple Ohm Meter prior to testing with a PAT). Prior to failing any items as a result of an abnormally high earth impedance, the test engineer shall first check that all associated equipment has been disconnected (thus removing potential parallel earth paths) and that the Test clip is securely attached to the item in question. It is recommended that this test be repeated at least three times to eliminate such problems. **INSULATION RESISTANCE TEST** - Unless the equipment manufacturer/supplier specifies otherwise, insulation resistance testing (at 500V dc) will take place with the appliance mains switch in the "OFF" position. This is due to the fact that the majority of IT. Equipment power supplies utilize filters and protective devices. These are generally rated at 240 Volts, or just above, and tend to be connected across designated Live and Neutral and earth. Thus a standard PAT insulation test would greatly over stress these components and would in fact reduce the longevity and safety of the appliance. It may, in some cases, be possible to remove these "sensitive" components prior to testing, but generally speaking this is considered impracticable. **LOAD TEST** - A load test will be carried out to protect the test engineer from possible hazards produced by a very low impedance (short circuit) being present between Live and Neutral designated lines during the OPERATION TEST. The test will be performed with the equipment turned "ON", and failure will halt further testing. **OPERATION TEST** - An

operation test will be performed to ensure that the equipment under test does NOT draw excessive current (the results obtained will not differ significantly from the manufacturer specification). Abnormally low currents will indicate open circuits or ruptured fuses which will be reported/repaired.
EARTH LEAKAGE TEST - This test will take place to measure the total current from Live and/or Neutral to earth under operating conditions. A result of not greater than 3.5 mA will be recorded.
NB: Certain noise suppression components may give rise to a failure result. The equipment manufacturer/supplier will be consulted where there is any doubt

Portable appliance and Hand Held Equipment Register

A register is to be made of all relevant equipment. This database may be held, where available, within the PATS tester software.

Failures

For any equipment failing Electrical Safety tests, the equipment should be immediately considered Not Fit for Service and remain so until such time that repair be carried out to the satisfaction of the Electrician with agreement of the Safety Coordinator. Should it be decided to remove any equipment from service, the flexible cord will be turned around the plug and secured with a nylon cable tie in such a manner so that the plug top cannot be inserted into a socket outlet. A "FAILED - DO NOT USE" label will be affixed in a prominent position on the equipment. A "FAIL" status will be entered against the item on the Equipment Register. A list of all FAILED items will maintained until such time those components are repaired or removed from the vessel..

On Site Repairs

Where a plug tops, fuses or flexible cords are replaced/repaired, the appropriate entry will be made on the equipment register. The repairs will be carried out prior to electrical safety testing unless other irreparable defects are apparent which would cause the appliance to fail.

Testing of IT Equipment

G This specification relates to the inspection and testing of Information Technology Equipment (and related), connected to a 240v 60Hz single phase supply by means of a flexible cord and plugtop.
NOTE: For hard wired IT. Equipment, testing is required once every 5 years and will generally follow a similar procedure as outlined below, although a suitable adapter will be required to make the necessary connections to the PAT tester. All work carried out will be done so in a manner that complies with the Electricity at Work Regulations 1989.
All applicable equipment on each site will be inspected, electrically safety tested, labelled and repaired where possible. Relevant details will be entered onto an Information Technology Equipment Register and all test results will be archived via an appropriate database.
Equipment with removable mains cords will have the cords tested as an integral part. h2 class= "Black">Labeling of Equipment Tested An identification label (see Appendix A) will be affixed to each item of equipment and will be visible when the equipment is installed in it's normal working environment. Tags for cord sets will be securely affixed to the flexible cord adjacent to the plug top. All old labels and tags will be removed and replaced with new ones in subsequent testing phases. h2 class= "Black"> Equipment Register A register is to be made of all relevant equipment. This database may be held, where available, within the PATS tester software. h2 class= "Black">Visual Inspection

Before each item of equipment is tested a visual inspection will first be carried out. This preliminary check will include the inspection of the following items:

- PLUG TOPS - Plug tops will not be cracked or otherwise damaged and will comply with the relevant British Standard (BS1363/A). Cord grips will be in good condition and must be properly adjusted. The correct size of fuse (to BS1362) will be fitted, and must be appropriate for the cord set conductor diameter and the equipment to which it is attached (as specified by the equipment manufacturer). Access to live parts should not be possible without the use of a tool. Plug tops and/or fuses will be replaced as necessary in order to comply with these requirements. NOTE: Moulded plug tops will be inspected for physical damage only.

- FLEXIBLE CORDS - All flexible cords will have two layers of insulation throughout their length, and will show no signs of excessive ware or physical damage. Cord sets intended to be permanently attached to an item of equipment will be securely clamped to that equipment (internally or externally). Cords will be inspected at the plug top (unless of the moulded type) for correct polarity, security of connections and general condition at the point of termination. Flexible cords will be replaced, or cut back and re-terminated as necessary. Replacement cords will be of an equal type to the existing, comply with the relevant British Standard Specification and be BASEC Approved. NOTE: Cut back and re-terminated cables will not be reduced in length to the point where they may present a "tripping", or related hazard.
- EQUIPMENT ENCLOSURES - All enclosures will show no sign of damage to castings, outlets, switches or other controls. Access to live parts will only be possible with the use of a tool. All retaining screws and fastenings will be present and correctly tightened. Any damage or missing items will be reported/replaced as necessary.

Schedule

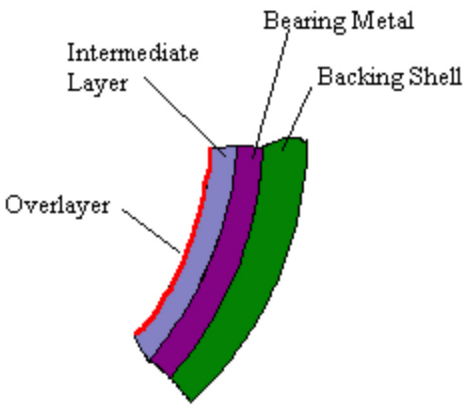
Electricity at Work regulations 1989 require that equipment be maintained so as to prevent danger

All equipment covered by the scope of this policy is to be tested prior to first use or following repair

For equipment for which no formal record of testing exists then a visual and PATs test should be carried out at earliest opportunity

Equipment/environment	User Checks	Class I (or where class is unknown)		Class II & III	
		Formal Visual Inspection	Visual and PATS test	Formal Visual Inspection	Visual and PATS test
Battery-operated:(less than 20 volts)	Not Required	Not Required	Not Required	Not Required	Not Required
Extra low voltage(less than 50 volts AC) egtelephone equipment, low voltage desk lights	Not Required	Not Required	Not Required	Not Required	Not Required
Portable Appliances	Weekly	3 Monthly	Annually	6 Monthly	Annually
Moveable Appliances (included as recommendation)	Weekly	6 Monthly	Annually	Annually	Bi - Annually
Hand Held Appliances (110 v)	Weekly	3 Monthly	Annually	6 Monthly	Annually
Hand Held Appliances	Weekly	3 Monthly	6 Monthly	6 Monthly	Annually
Information Technology	Weekly	6 Monthly	Annually	None	Annually
Extension cables or supply leads	Pre-Use	3 Monthly	Annually	6 Monthly	Annually

Shell Bearings



Thin shell bearings are used for most bearing applications in the main engine. They consist of a steel backing strip coated with a layer of white metal. Bearings may be bi-metal or tri-metal. typical materials are steel-babbitt, steel-bronze or steel-tin/aluminium (tin-aluminium has slightly greater load bearing capacity than white metal and maintains its fatigue strength over a greater range of temperatures. The bearing metal thickness is 0.5 to 3mm. An **Overlay** of 20 -40 micrometersmay be applied to improve conformity . This is generally a ductile coating of lead and tin. In addition new bearings may have a **flashlayer** of a few microns of tin to prvent oxidation

An intermediate layer may be used between the overlay and main bearing metal to avoid diffusion. This is particularly found where bearing loads are very such as in the lower half of the cross head bearing. The layer is galvanically applied.

Compared with the traditional cast bearing they have a number of advantages.

1. *Shells are prefinished thus allowing for quicker and easier replacement.*
2. *The bearings are made under strict controlled conditions giving consistent high quality products*
3. *In many cases the top and bottom halves are interchangeable in an emergency.*
4. *Thin layer of white metal cools quickly giving fine grain structure which has high strength and fatigue resistance.*

Shell bearings sometimes have a layer of copper or bronze between the steel and the white metal in order to improve adhesion of the white metal. This layer will also provide safe guard in the event that the white metal being worm away.

For camshafts shell bearings are still used in preference to ball or roller race, the action of the cam followers provides impact loading which can must be supported by the bearing. Ball or roller race would tend to suffer fatigue or brinelling damage. In addition to this replacement is simpler with the plain bearing.

Bearing wear must be checked as this can allow the camshaft to drop thus altering the timing.

WHITE METAL BEARING CORROSION

White metals are tin based, that is they contain a higher proportion of tin then other compounds. A typical composition might be 86% tin, 8.5% Antimony, 5.5% lead.

In the presence of an electrolyte corrosion of the tin can occur forming extremely hard, brittle, stannous and stannic oxides (mainly stannic oxide Sn_20) normally in the presence of moisture. These oxides are usually of a grey to grey black coloured surface layer on the white metal, either in local patches or completely covering the bearing. The hardness of this brittle oxide layer could be as high as twice that of steel and if it became detached, possible due to fatigue failure, serious damage to bearing and journal surfaces could occur. The formation of the oxide layer is accompanied by an upward growth from the white metal, which can considerably reduce clearances and could lead to overheating and seizure etc.

Factors which appear to contribute towards the formation of tin oxides are

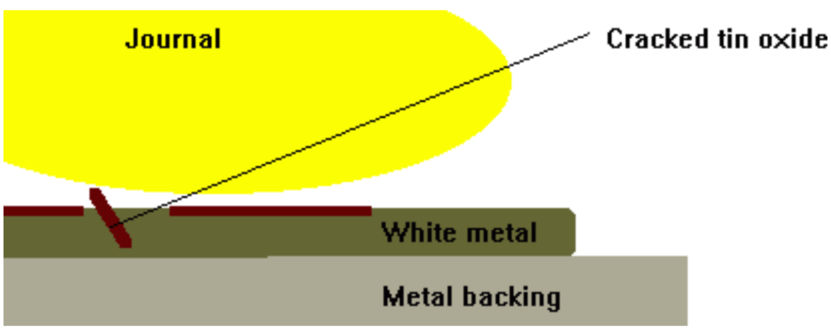
1. *Boundary lubrication e.g starting conditions*
2. *Surface discontinuities*
3. *Concentration of electrolyte e.g. fresh or salt water or other contamination*
4. *Oil temperature*
5. *Stresses in the bearing metal*

Additives in the lubricating oil can add some degree of protection as can efficient centrifuging.

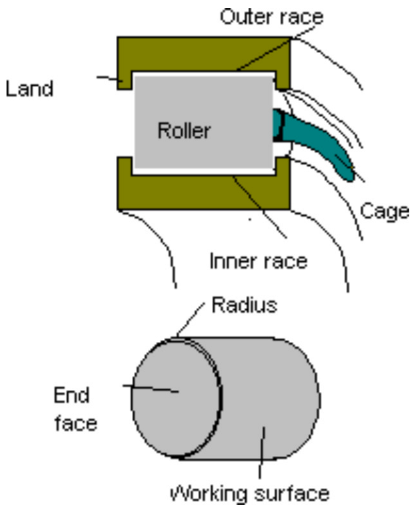
Stannic Oxide being much harder than the white metal causes two problems:-

i. *Prevents absorption of dirt particles.This is normally carried out when abrasive particles are stuck to the surface of the white metal. Local overheating and melting occurs and the particle falls into the white metal*
ii. *The oxide is brittle and can crack with the piece edge projecting out (causing machining type failure of thrust collars especially.)*

Both these result in scoring of the journal, these are normally considered as a low temperature type of failure. In addition the presence of water in the lub oil can cause the oxidation of the metals in the bearing causing the metal to grow. This reduces clearance and can lead to bearing failure.



Rolling Element Bearings



The advantages and disadvantages of rolling bearings

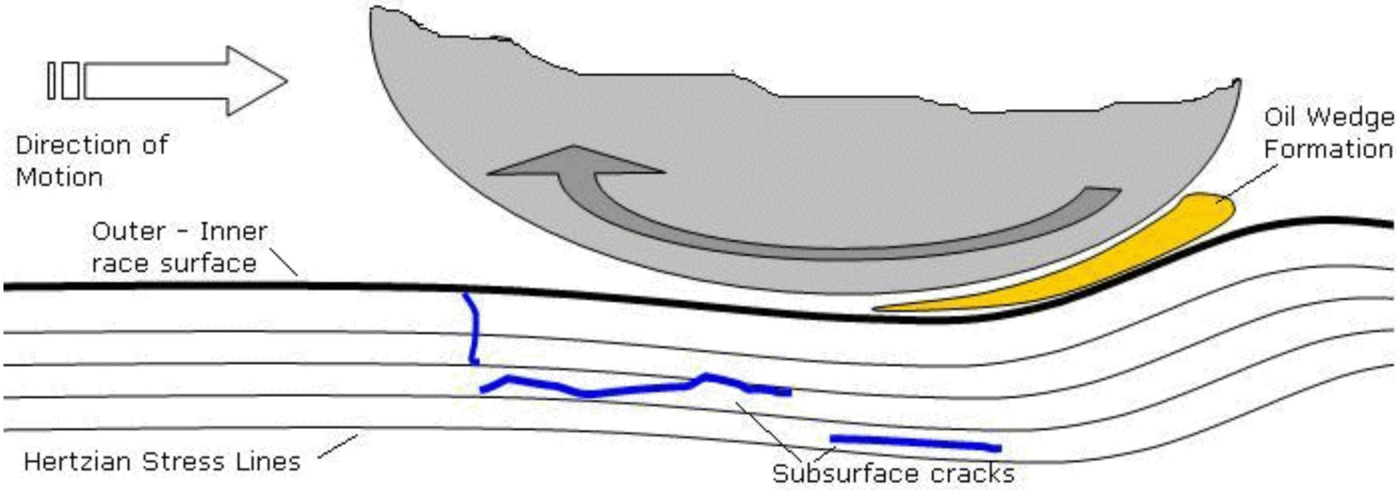
Advantage

1. *Low starting torque*
2. *compact and ready to install machine members*
3. *It is generally easier to lubricate rolling bearings than plain bearings*
4. *Combined radial and thrust loads can be carried readily in a rolling bearing*
5. *High overloads can be carried for short periods without undue or adverse effects*
6. *Rolling bearings become noisy when nearing the end of their natural life.*
7. *Running clearances is less than plain bearings, preloading can reduce deflection and increase accuracy.*
8. *Standardisation by international agreement makes replacement and servicing easier*
9. *Better electrical insulation is possible than with plain bearings*
10. *Can be multifunctional e.g. combined water pump and fan on the same shaft*

Disadvantage

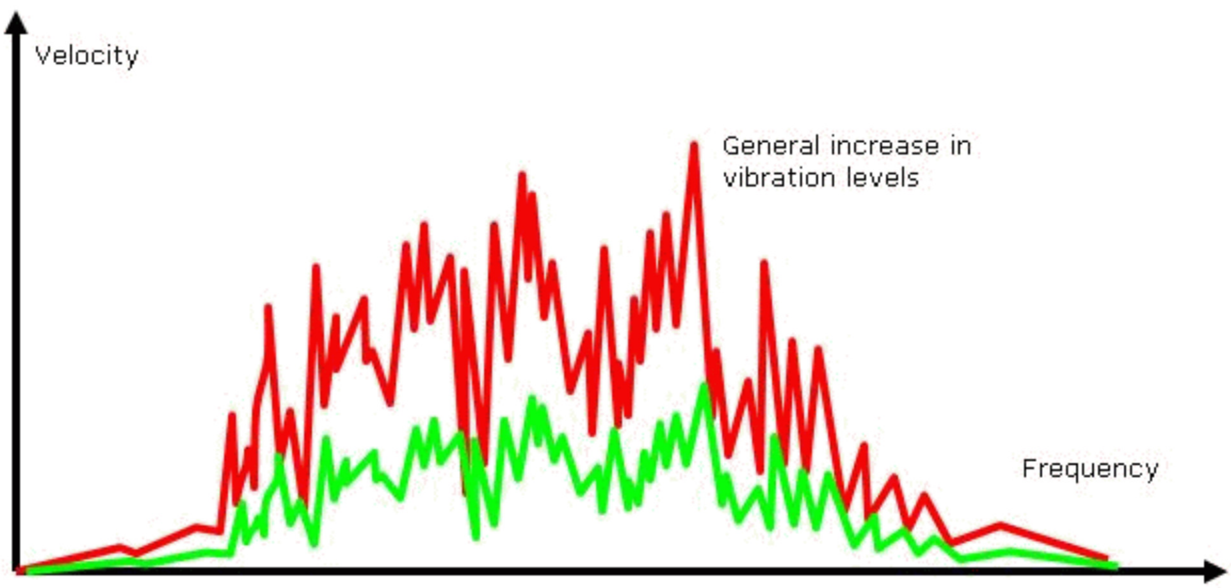
1. *More expensive than plain bearings with more parts to go wrong*
2. *They are noisier than plain bearings*
3. *Their use at high speeds and loads are limited by centrifugal, fatigue and brinelling effects. Plain bearings can run faster and carry heavier loads.*
4. *Brinelling, fretting can occur during static conditions when the bearing is subjected to vibration*
5. *All rolling bearings have a finite life. If a large number of a particular bearing are produced for a particular application a percentage of premature failures can be anticipated*
6. *Repair of rolling bearings is almost impossible in an average workshop. The entire unit has to be replaced when worn or failed*

Rolling element bearing use Elasto-hydrodynamic lubrication. That is, the surface material deforms to assist with the formation and shape of the oil wedge.



As the roller moves over the surface the latter deforms in a pressure wave. Hertzian stress build up parallel to the surface of the material in which defects can occur. Defects may also form due to the pressure wave. This defects may open and close freely with the passing of the element. Should liquid enter the defect then hydraulic lock occurs and the defect grows to relieve the stress. When the surface defects join the subsurface hydraulic locking again occurs and these also grow. Eventually that portion of the material become weakened to an extent a portion is displaced. This is a generalisation of the mechanism associated to pitting. Anouther significant mechanism for the failure of rolling element bearing is spalling where subsurface defects lead to the detachment of sections of material

The most effective method for detection of bearing failure is by vibration monitoring. This may be by observing the vibration velocity history. Theoretically the vibration characteristic should have well defined nodes at such frequencies as outer race element pass. This is of use in determining that high vibration with an assembly is specifically caused by the rolling element bearings

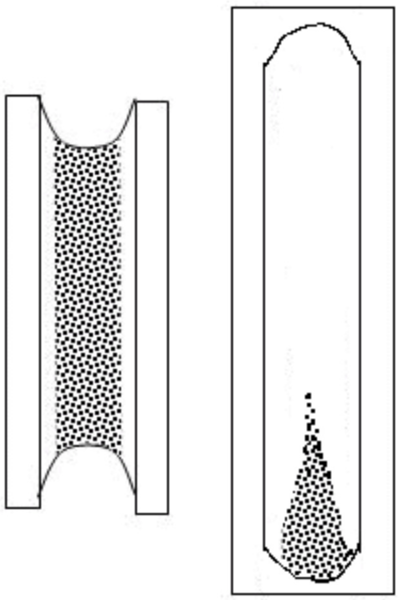


Rolling element bearings traditionally generate vibrations over a wide frequency range. Trending of this vibration over a period of time will allow estimation of the current condition of the bearing. A general increase in the high frequency vibration is generally associated with the creation of microscopic cracks and spalling too small for human eye to detect. Although this is not considered destructive in itself it is a preliminary stage that leads to further degradation

Alternately the vibration acceleration level may be measured. In both cases deteriorating bearing conditions is indicated by increased vibration levels. Other methods include bearing temperature measurements and analysis of lubricating oil

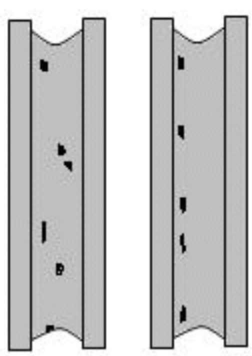
Early detection of bearing failure prevents damage such as housing fretting and shaft distortion due to overheating remedy of which far exceeds that of bearing replacement only.

Normal Life Failure



Wear pattern on bottom for vertically loaded shaft

Shown is a bearing demonstrating normal wear pattern for a vertically loaded shaft with rotating inner ring and fixed outer race. The pattern on the outer race is displaced depending on the line of action of the loading.



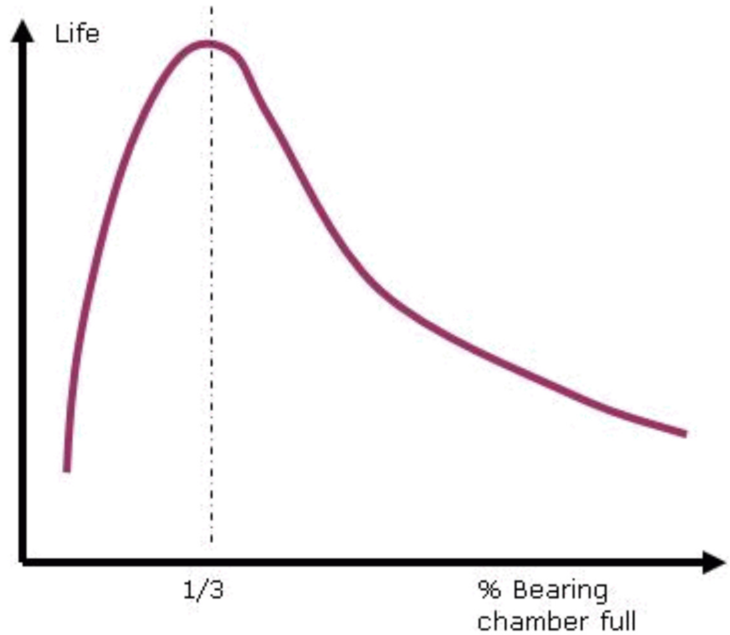
Normal Wear patterns | Unusual Wear pattern

Although shown unifrom the actual wear can be of a more random pattern and careful interpretation is required.

Premature failure

Bearing failure not associated with fatigue can occur due to several reasons but most commonly misalignment, over greasing and contamination

Over greasing



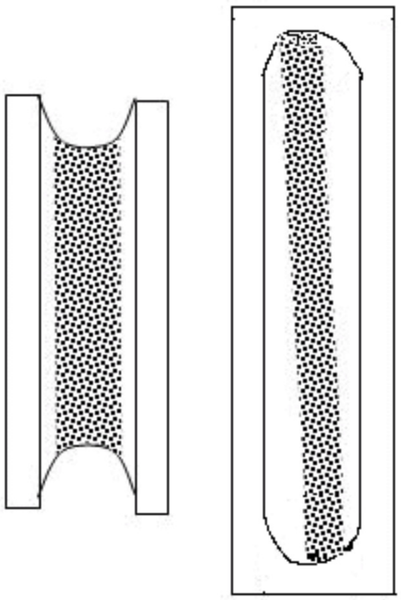
Typically 1/3rd of the available space should be filed with grease . For some installations a weight of grease is given by the manufacturer.

Contamination

Contamination is the most common cause of premature failure. This occurs usually during bearing installation and typically is caused by poor house keeping or dirt loaded grease. Excessive wear is indicated by a dulled appearance and indented running surface.

Bearings damaged due to this tend to have indentations, and scratches both on the race and the rolling elements. This effect is sometimes referred to as **Scoring**

Misalignment



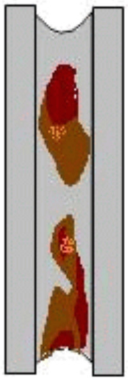
Is sometimes identified by a wide contact track on the inner race and a thinner non perpendicular track on the outer race. Misalignment by as small amount as 1/1000 can lead to serious reductions in life expectancy

Lubrication failure

In the short term the removal of manufacturing asperities leads to a highly polished mirror like appearance. This may progress to a surface crystalline with dark lines showing a crystalline structure. This is caused by incorrect specification for lubrication or overheating reducing viscosity

Generally leads to overheating to a blue/black colour on the load surface reducing to a straw/gold color on the edges of the bearing

Rusting

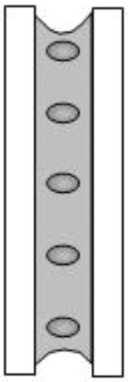


Caused by water ingress into the bearing leading to red of black patches on all surfaces. Generally associated with inefficient sealing and poor lubricant properties.

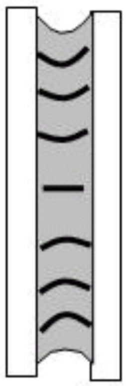
Brinelling

This comes in two forms;

True Brinelling



this caused when the elastic limit of the race material is exceeded and a permanent deformation occurs. Associated with a sharp impact loading sometimes occurring during poor installation procedures. Impacts occur at rolling element pitch **False Brinelling**
Sometimes referred to as 'washboarding' and is caused by relative movement of the elements without formation of an oil film. Hematite rust may be evident in the pits

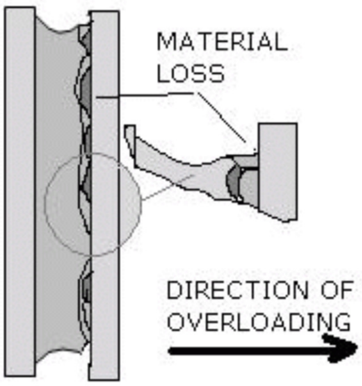


More associated with high background vibration. Damage appearance is distinctive and different to normal pitting. Shown is that seen with ball elements, roller elements are linear. Both are at element pitch or multiples of it. The use of quality EP additives can reduce progress of damage.

It should be noted that false brinelling can also lead to a similar fluting appearance but the pits are brighter and contain corrosion products, where due to the passage of electricity the pits are generally dark.

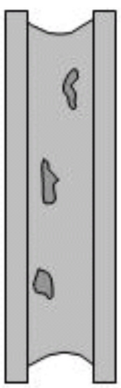
Roller bearings are generally more susceptible to this type of damage thus ball bearings are preferred in high vibration areas, part submersion in oil bath also reduces this effect.

Overloading



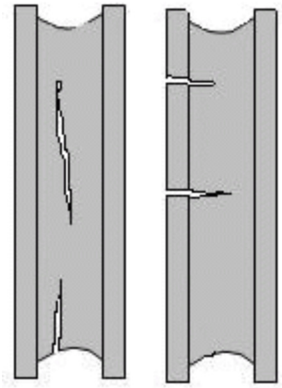
Leads to overheating and spalling (surface material loss) of the running surfaces typically in the direction of overload. May be remedied by more appropriate selection of bearings

Indentations



Typically uneven craters and pits. Associated with contaminated or harderned grease but also occurs with oil lubricated bearings containing wear debris

Cracking



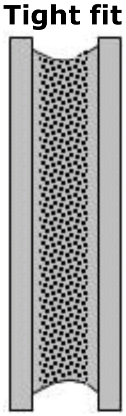
Associated with incorrect fit, uneven race support or severe overloading

Poor Fit

Loose fit
This leads to fretting between the contact areas of the bearing/housing or bearing/shaft. Indication that this is occurring is by the presence of black or dark red coloration or deposits on the landing areas. As this worsens the inner or outer race may begin to creep or rotate relative to the adjacent landing area

The initiator for this is often the increased vibration from the bearing as it begins to reach the end of its life. This vibration is destructive before noise, heat or vibration level reach is detectable without the use of an instrument. Once the fit is lost in this manner the bearing no longer can offer reliable load bearing capacity. The use of 'Loctite Bearing Fit' can solve minor fit problems. The technique of raising the surface, for example using a centre punch has very limited benefit

Tight fit



Where the interference fit is greater than the radial fit very high bearing temperatures are generated due to overloading and premature failure results Discoloured wide contact areas, at the extremes leads to very heavy overloading, high temperatures and cracking. May lead to restriction in movement of the rolling elements and lead to scuffing of the running areas through welding

Cage Wear

Associated with poor lubrication or incorrectly specified bearing type. Worsens to a point that the cage fails, the elements move allowing the relative positions of the outer and inner races to change.

Smearing

This is caused by lack of lubrication and relative sliding motion between the element surfaces. It is commonly seen on the ends of roller bearings where they have been subjected to axial forces.

The material is generally heated and some transfer occurs between the parts. Surface rehardening can occur with tear fractures evident.

This effect may be seen where rollers are subject to high accelerations when entering the load zone (this occurs as the elements are not driven out when out of the load zone and can be remedied by reducing bearing internal clearance), excessive preloading for taper bearings, or even in ball bearing where load is too light in relation to the speed of rotation. Careful selection of lubricant can avoid this damage.

Roller bearings may be subject to smearing on assembly due to poor assembly allowing the elements to 'scrape' the surface on the race

Smearing may occur on the non running outer edges of the races due to relative movements between housing/shaft and the bearing. This may be remedied by increasing the interference fit.

Electrical discharge

This causes either deep cratering or thin pits containing dark product (refered to fluting).

Installation

Installation of rolling element bearings should be done in as clean an environment as possible. The leading cause of premature bearing failure is contamination.

Care should be taken not to cause impact lading to the bearing which may lead to brinelling. It is preferable that the bearing be preheated by oil bath or induction heater before fit. Where not possible then the bearing should be evenly pressed

The correct quantity and type of grease should be used.

Although not common it is not unusual for bearings to initially run with high temperatures or increased load. This may be associated to stresses left over from when the bearing was pressed onto the landing areas Care should be taken that the bearings are not allowed to overheat.

For smaller motors this may be successfully compensated by light tapping of the shaft I opposite directions until and 'tightness' is reduced. For larger assemblies a sequence of running to a limited temperature followed by a period of cooling generally leads to a stabilization and then normal running temperatures.

Improving Bearing Life

Improved bearing life may be gained by the use of better or more appropriate greases. Where possible the grease should be replaced to remove wear particles and restore levels of EP additives. For Oil lubricated bearings the use of very fine filtration is essential

It is understood that 'Hybrid' bearings consisting of a relatively standard steel rolling element bearing into which is inserted a single ceramic element. The ceramic element is believed to polish the running surface removing surface defects.

For bearing used in electrical installations the use of Teflon coatings to the outer race landing surface prevents electrical discharge through the bearings.

Case Study- Running in rolling element bearings

Despite good alignment one bearing out of four on a gas freeing fan shaft was found to overheat within 10 minutes of first start up. The bearing was allowed to cool, from 100 to 65'C then restarted. On the second instance the fan run for 30 minutes before a temperature of 100'c was reached. After a cool down and restart this was extended to over one hour. After repeating this procedure several more times the bearing temperature stabilized and the fan was found to operate reliably.

A second instance was on a thruster motor where zero pitch amps was found to be 500 amps against 340 amps normal after motor overhaul. The bearing temperature and vibration where monitored and the unit run off load. The amps were found to reduced steadily over a period f 24hours until normal currents where experience. Again the unit entered into service successfully.

Case Study - Electrical discharge through bearing

There are benefits to inspecting all ball bearings removed from a machine to ascertain that no abnormalities exist within the installation

A vessel had experienced a history of failure over a 25 year period in its horizontal twin screw Cargo pumps. Inspection after one such failure of the intact bearing set indicated an unusual form of damage.

This took the form of axial deep grooves (sometimes referred to as Cratering) of a form not normally associated with false brinelling. A very similar form of failure is seen in electric motors caused by electrical discharge through the bearing. It should be noted that the pump was driven by a diesel engine which was also coupled to a generator. It was possible although not proven due to the vessel sale soon after that this was a partial cause.

It should be noted that false brinelling can also lead to a similar fluting appearance but the pits are brighter and contain corrosion products, where due to the passage of electricity the pits are generally dark.

Grease

A lubricating grease is a solid or semi-fluid lubricant containing a thickening agent in a liquid lubricant. Grease can be likened to a sponge soaked in lubricant. In cases of a soap based grease the soap can be likened to the sponge soaked in a mineral oil as the lubricant.

They are usually made from mineral oil stock of widely ranging viscosity but similar to those used for liquid lubricants. Synthetic oils may also be used were high temperatures are expected.

Grease can be divided into 6 general categories or types;

- **MINERAL OILS MIXED WITH SOLIDS**

  Specialised heavy equipment lubricant

- **HEAVY ASPHALTIC-TYPE OILS BLENDED WITH LIGHTER OILS**

  More a thick heavy oil, lighter oil blends improve pour point.

- **EXTREME-PRESSURE GREASES**

  Contains additives that improve wear resistance under extreme pressures. A chemical reaction between the metal and the chemical brought about by the heat generated by pressure as the faces come together.

  These aditives include compounds containing Chlorine, Phosphorous, Sulphur and phosphates.Zinc, lead or even asbestos may be added as a filler to cushion shock loading in gears

- **ROLL NECK GREASES**

  Semi solid grease exclusively used to lubrictate journal bearings. Typically the grease bar is profiled

- **SOAP THICKED MINERAL OILS**

  This is the largest category and is split up into groups stermined by the base oil or thickener

  Sodium-base (Sodium Hydroxide) greases are also general-purpose greases. They are used higher temperature stability is required having a drop point 300 to 350 ^{0}F
  Sodium-soap greases have a spongy or fibrous texture and are yellow or green in color. They may be used for luricating rolling element bearings more typically they are used in rough, heavy duty appilcations.Tend to be water soluble

  Barium-soap greases are general-purpose types, valued for their ability to work over a wide temperature range. The drop point is over 350^{0}F although it is not recommended to use them continously over 275^{0}F
  They are used in many applications although the high soap content makes them unsuitable for high speed or low temperature applications. They have a buttery of fibrous texture and are reddish-yellow or green in color.

  Lithium-soap (Lithium Hydroxide) grease is suitable for high and low temperature applications. It has a drop point of 350 ^{0}F and may be used at coninuous tempeatures over 300^{0}F
  They may be made with oils having a very low viscosity to make them suitable for very low temperature applications
  They have very good stability; good water resistance, and are also readily pumpable. They have a buttery texture and a brownish-red color. More expensive than sodium soap

  Calcium-soap(calcium Hydroxide) are inexpensive general purpose greases with a relatively low drop point of 80^0C due to water content drying out, also called lime-soap greases. Uses include axle grease, water pump grease and general machinery applications and have the major advantage of water resistance

Calcium complex greases has a very high heat resistance of over 500^oF making it particularly useful to extreme pressure applications although lack of mechanical stability has limited their usage Calcium-soap greases are yellow or reddish in color, and have a smooth buttery texture.

Aluminum-soap are special purpose greases which are inherently very sticky

- **MULTI-PURPOSE GREASE**

  Multi-purpose greases combine the properties of two or more specialized greases. This permits the use of a single type of grease for a variety of applications. Most of the multi-purpose greases have a soap base of barium, lithium, or calcium complex. For example, the lithium-soap greases discussed earlier. They are not only water-resistant and corrosion inhibiting, but they have very good mechanical and oxidation stability as well.

- **Bentonite(clay base)**- operational up to 200'c
- **Silicone**- operational up to 260'C

Bentonite(clay base)- operational up to 200'c
Silicone- operational up to 260'C

Additives to grease

- Extreme Pressure additives
- Oxygen and corrosion inhibitors
- Pour point depressants
- Water repellents
- Pigments

Advantages of grease lubrication

- Convenient to apply and replenish
- Easily retained in the housing and does not require complex seals
- Protects bearing surfaces from corrosion particularly when machinery is shutdown
- Serves as a seal preventing the ingress of dirt and moisture into the bearing.

Do not use grease when

- Temp' are high and the lube must function as a coolant for the bearing
- When a bearing is lubricated in conjunction with other components in a single lubrication system e.g. gearbox
- Where resistance to bearing rotation must be kept to a minimum e.g. light precision instruments
- When speeds are beyond the limit of grease lubrication

note: Spherical roller thrust bearings are almost designed to operate on oil lubrication

The larger the bearing the more frequent the re-lubrication

The higher the speed the more frequent the re-lubrication

Oxidation of mineral oil doubles every 25'C temperatures rise

Fill housing cavities 1/2 to 2/3 full, no more, or churning and overheating will occur

Grease relubrication

relubrication period(hrs) = K x (14 x 106/ N x D-1/2) - 4D

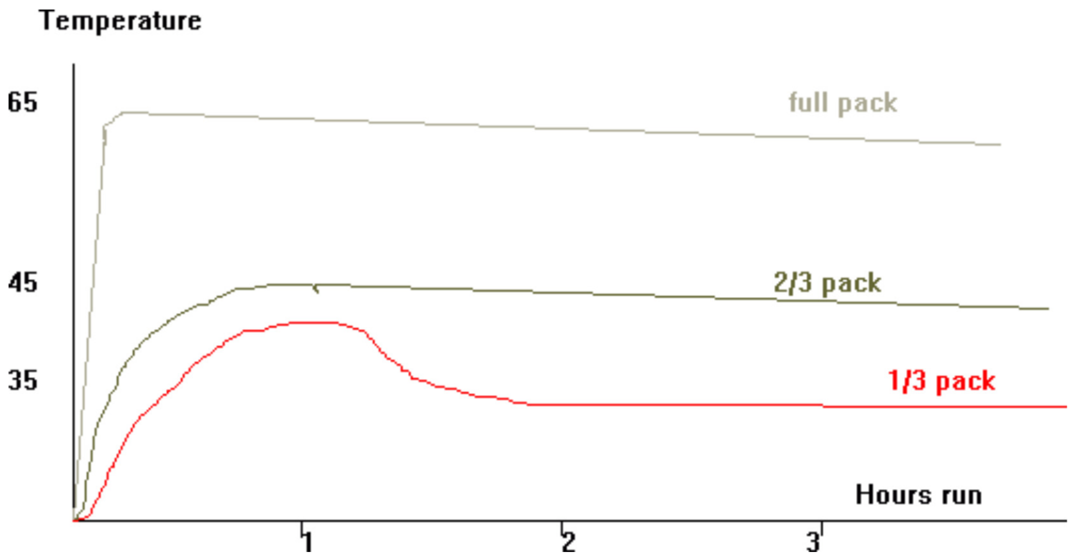
The amount of grease in ounces is determined from

$G = 0.00018\ DB$

where D= outside dia of bearing in mm

B= beairng width in mm

alternately amount(ounces)= DxB/6000



The relubrication interval of a bearing should be halved for every 15 to 20 ^{o}C increase in operating temperature. Before regreasing the old grease should be flushed out.

Drop point of grease

The drop point of grease is the temperature at which it begins to pass from a solid to a semi solid state, under standard test conditions. It is used as a rough guide to the resistance of a grease to heat. It is not the maximum allowable working temperature which may be several degrees higher. However if the drop point is exceeded the consistency of the grease will have deteriorated due to breakdown of the gel.

Other

Greases using the same thickener are usually compatible, different thickener are usually incompatible. Greases are very good at absorbing water and may take between 40 to 100% by volume without failure. Heavier grease have better water wash resistance.

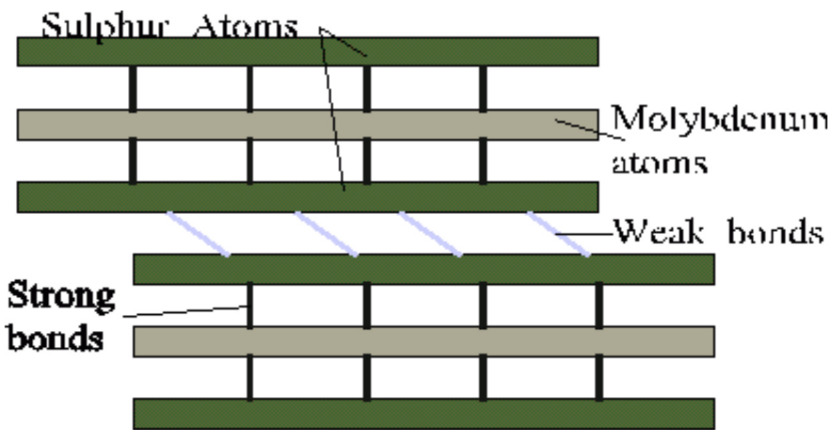
Service Deterioration

The base oil oxidises causing darkening of the grease. Acidic oxidant products causes softening of the thickener leading to oil bleeding

This oxidation tends to begin at localised hot points due to the poor heat conductivity of the grease, carbonisation and progressive hardening reduces the effectiveness of the grease

Grease has a maximum temperature at which it can safely be used. Therefore, it follows that it must also have a minimum temperature. This minimum temperature is the point where the grease becomes too hard for the bearing, or other greased component, to be used. Again, the base oil of the grease determines the minimum temperature. Obviously, the base oil of the grease for low-temperature service must be made from oils having a low viscosity at that temperature.

Molybdenum DiSulphide



MoS_2 is extracted from small veins in granite by crushing and flotation. In its purified state it has a low coefficient of friction, resists heat, oxidation, common solvents , and chemicals and can be used under extreme pressures. It shears readily and bond with ordinary engineering materials and plastics. Due to high cost it is not seen as a replacement lubricant but offers a solution to difficult problems.

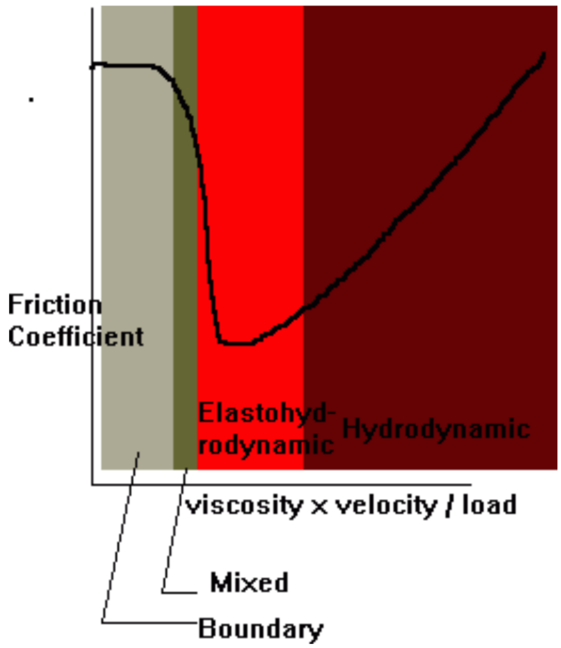
Molybdenised lubricants exist with combinations of MoS_2 and oils, greases, water, soap, solvents, silicones, and other fluids.

MoS_2 is in the form of a laminar structure with a slice of molybdenum atoms being held between to slices of Sulphur atoms. The low coefficient of friction is due to the ease of shear between adjacent Sulphur slices.

MoS_2 has a melting point of 1185^{o}C

Care should be taken with the use of this product in relation to tightening torques. Manufacturers may be quote figures under the assumption that lubrication of the nut is by light mineral oil only. Alternately they may give different torques for Light oil, copaslip and molykote.

Types of lubrication



Boundary

(i) fluid film thickness basically molecular 10-7cm

(ii) depends on molecular properties of lubricant and solid members, often chemical(E.P. additives actuated by high temperature generated by rubbing)

(iii) independent of shape and velocity in so far as these influence the temperature generated from rubbing.

(iv) obeys classical laws of friction

(v) Frictional coefficient = 0.05 to 0.1

Hydrodynamic

-self acting (i) fluid thickness 1 mm to 0.01 mm

(ii) Depends on the viscosity of the lube oil and the shape and relative motion of the solid surfaces

(iii) Independent of properties of the solid members; so long as the elasticity does not deform the shape. and thermal properties do not effect the temperature of the lubricant

(iv) does not obey classical friction laws.

(v) Friction coefficient = 0.001

(vi) film may form by self action or by Hydrostatic pressure of the lube oil.

Hydrodynamic

-externally pressurised as above except the separation of surfaces is caused by fluid being injected under pressure

Elastohydrodynamic

This is the type of lubrication used with rolling element bearings. To clarify, the material of the running surface deforms under high pressure as the rolling element passes over it. The oil wedge forms in this deformation.

(i) Deformation and increased viscosity with pressure are involved

(ii) Frictional coefficient = 0.05

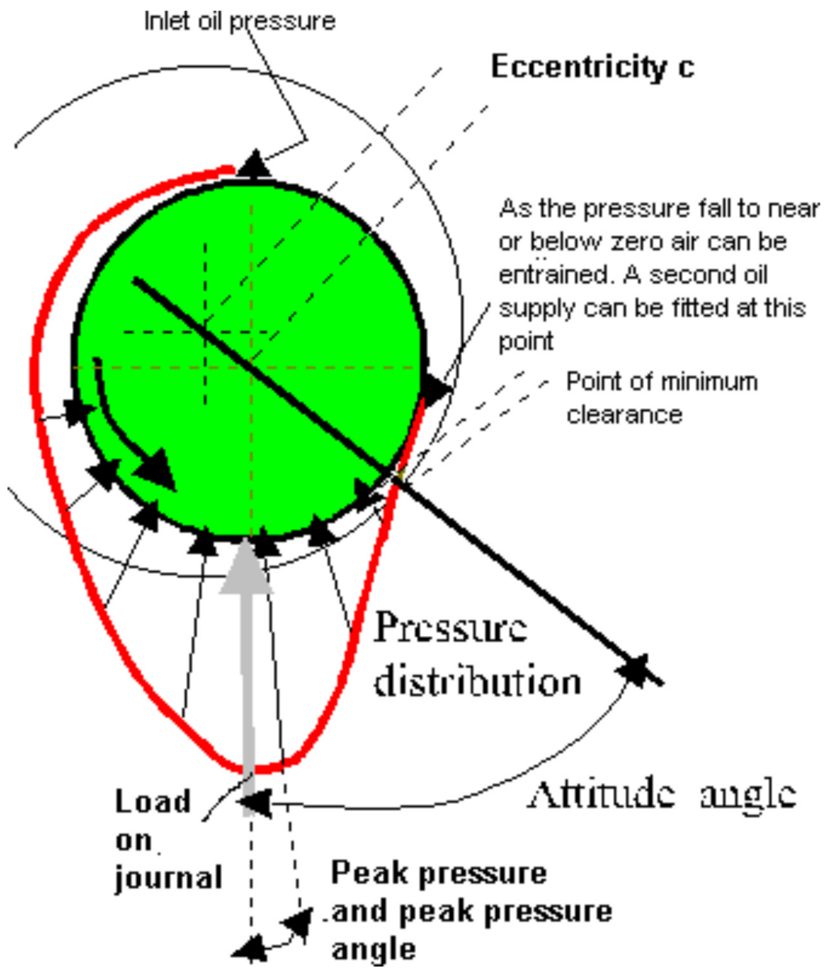
(iii) film thickness less than Hydrodynamic

How boundary lubrication got its name. *This is remembering a while back so bear with me. A chap was hired to investigate the cause of failure or train carriage wheels. He run test on journal bearings using pressure gauges mounted around the circumference of the bearing. After repeatedly blowing these gauges due to the very high pressure created in the oil wedge, he eventually came up with the idea of dynamic lubrication and the oil wedge.*

I believe the cause of failure of the carriage bearings was insufficient clearance preventing the journal from lifting and leading to rub.

Anyway, this chap gave a lecture to his peers. Someone in the audience said that he could understand his theory of dynamic lubrication, but asked to him explain how the bearing was lubricated during starting. To which our chap replied something along the lines of- " ....there are **boundaries** *of lubrication beyond our knowledge...".*

Oil distribution within a journal bearing



If the maximum radial clearance is **Cr**

then **Cr = e + Hm**

where **e** is the eccentricity between the shaft and bearing centreline and **Hm** is the minimum clearance (oil film thickness)

an eccentricity factor can be calculated from

n = e / Cr

Factors involved with the eccentricity factor n are; minimum oil film thickness, journal attitude angle, pressure distribution, peak pressure angle, friction, horsepower loss and oil flow through the loaded region. The latter three determine the temperature of the bearing which for high speed bearings can be a limiting factor.

Lube Oil requirements for Diesel Engines

Crankcase

The oil has to serve two purposes;

1. *reduce friction*
2. *Cool bearings*

A good quality mineral oil will serve the purpose of reducing friction to an acceptable level depending upon the metals involved and other conditions such as temperature. All oils will oxidise and this reduces its effectiveness as a lubricant. Oxidation will also cause deposits which can block passage ways and coat working parts. The rate of oxidation will depend upon temperature, the higher the temperature the more rapid the rate. Anti oxidants are available which reduce the rate, also additional properties can be achieved by the use of additives.

Under high temperatures an oil is liable to thermal degradation which causes discoloration and changes the viscosity. Additives cannot change an oils susceptibility to this degradation. The refining process can remove compounds which effect the thermal stability of the oil and also those that lower oxidation resistance. Most of the chemicals found in an oil will react more or less with oxygen, The effects of this oxidation is always undesirable. Hence, a major objective of the refining process of a mineral oil is to remove those hydrocarbons i.e. the aromatics, the small amount of unsaturates together with molecules containing sulphur, oxygen and nitrogen.

Unfortunately these same molecules are those that improve the boundary lubrication performance. Hence, a careful balance must be struck. The use of anti-oxidants make a slightly better balance although there usefulness is limited.

Tin based whitemetal is susceptible to hardening as an oxide layers from on the surface.

These tin oxides are a grey-black in appearance and are extremely hard. There formation reduces the bearing clearance as the oxide layer is thicker than the original white metal material from which it formed. The oxide has a lower coefficient of friction than the original white metal but it will cause problems if it brakes up as fragments will become embedded edge on in the white metal and can score the pin.

Contamination

Water

Water from,

1. *bilge's*
2. *Jackets*
3. *Sea via coolers*
4. *leaky seals or washing in purifiers*
5. *Condensation*

Problems caused by water contamination,

- Water leads to corrosion especially if there is sulphur present due to fuel contamination
- forms emulsions which are not capable of withstanding high loads
- removes water soluble additives when centrifuged out
- leads to possible bacterial attack

Fuel

May be heavy residual or light diesel/gas oil and can be sourced to faulty to cylinder combustion or faulty seals on fuel p/ps.

Problems

- Increases viscosity for hfo, reduces viscosity for D.O.
- reduces flashpoint
- Introduces impurities such as sulphur
- dilutes lub oil when in large quantities

Solid impurities

i.e. carbon from the cylinder combustion process, particularly of importance with trunk piston engines but also for crosshead engines with inefficient diaphragm. The carbon can lead to restrictions and blockages of oil ways causing bearing failure. Straight mineral oils hold 1% carbon in suspension, dispersant oils hold about 5%.

Bacterial attack

Certain bacteria will attack oil but water must be present. The bacteria may exist in a dormant state in the oil but water is required if they are to reproduce.. The bacteria digest the oil causing breakdown emulsions to be formed, acidity increases, dead bacteria block filters and corrosive films form on working surfaces.

In summary their must be three essential conditions for microbiological growth;

- There must be a source of carbon- present in the oil
- There must be some bacteria or fungal spores present-these are almost universally present in the atmosphere
- **There must be free water present**

Two other factors which encourage the growth are a slight acidity in the water (pH 5 or 6) and a slightly raised temperature (20 to 40^{o}C) which can lead to rapid growth.

Biocide additives are available but they are not always compatible with other desired additives and can lead to large organic blockages if treated in the machinery. The best solution is to avoid the presence of water. If mild attack takes place the oil may be heated in the renovating tank to above 90^{o}C for 24hrs before being returned to the sump via the centrifugal separator. For a severe attack the only solution is complete replacement of the charge followed by sterilisation of the system. It may be noted that on replenishment the bacteria may be present in a dormant state in the new charge.

Test results of crankcase oils

Viscosity-Increases due to thermal degradation or hfo contamination, reduces with diesel oil contamination, corrective action needed if it increases by 25% from new oil.

Water content-Corrective action required at 1%

Insoluble Sediments-basically the result of wear and oxidation, corrective action at 1% by weight

Ash-a measure of incombustibles in the oil sample, corrective action at 0.13% by weight

TAN-Total acid number consists of the strong acids (mainly sulphuric acid) formed in the combustion process and weak acids resulting form oxidation of the lub oil.

SAN-Strong acid number, the oil should be renewed if any is detected

TBN-Total base number indicates the alkaline reserve particulary important for trunk piston engines

Closed flash point-highlightd fuel contamination, corrective action if reduces by 30^{o}C from new

Cylinder lub oil

The type of cyl l.o. required will depend upon the cylinder conditions and the engine design e.g crosshead or trunk piston. However, the property requirements are basically the same but will vary in degree depending upon the fuel and operating conditions.

Normal properties required are;

a. adequate viscosity at working temperature so that the oil spreads over the liner surface to provide a tough film which resists the scrapper action of the piston rings
b. the oil must provide an effective seal between the rings and liner
c. only a soft deposit must be formed when the oil burns
d. alkalintiy level (total base number or TBN) must match the acidity of the oil being burnt
e. detergent and dispersant properties are required in order to hold deposits in suspension and thus keep surfaces clean

Additives

All oils for all purposes can be designed to give particular properties through the careful use of additives to the base mineral oil stock.

Common additives are;

- **Antioxidants**-these are used in all oils to reduce the rate at which oxidation occurs and are especially useful were the lub oil cools the piston
- **Extreme pressure agents** these are compounds of phosphorus, Sulphur or Chlorine which increase the strength of the oil film under conditions of high temperature or pressure.
- ,**Dispersants or detergents**-found in trunk piston engine oils and cyl l.o. these keep surfaces clean by holding deposits in suspension.
- **Viscosity index improvers**- these prevent excessive changes in viscosity with change in temperature
- Other additives can be defined by name such as **anti-wear**, **anti-corrosion**, **anti-bacteria**, **anti-foaming** etc.

When running in, the cylinder lube oil injector pumps may be filled with a a straight mineral oil without anti-wear properties- typically the crankcase oil- once this small reserve of oil is exhauted, running in carries on with normal cylinder lube oil. The flow of oil is increased to carry away metallic particles.

Problems caused by stuffing box leakage oil entering crankcase

Low speed engines are particularly at risk from crankcase lubricant contamination caused by cylinder oil drainage past the piston rod gland and combustion products. This can lead to severe damage of engine crankcase components and reduction of life of oil which is normally expected to last the lifetime.

There has been a general increase in the viscosity and Base number of crankcase oils over recent years particularly for engines built since the early 1980's. Increased alkalinity, viscosity and insolubles, fuel derived elements such as vanadium and oil additive derived elements such as calcium, suggest that the contamination is from the cylinder oil drainage.

Deterioration of the crankcase oil has led to the expensive necessity of replacing up to 50% of the sump, this is particularly of concern as it is often only a temporary measure.

Four causes are put forward,

1. *New crankcase oil contaminated with new cylinder oil-unlikely*
2. *Cylinder oil drainings being recycled and returned to the sump-very likely as it is a common practice to purify oil leaking through the gland, tests done on this purified oil found high amounts of insolubles*
3. *Leakage past rod gland- very likely, high pressure scavenge air can blow cylinder oil and dirt past the top scrapper ring and sealing rings into the piston rod drain tank, and even possibly directly into the sump. A problem that worsens with age and wear.*
4. *leakage of exhaust valve lubrication system-unlikely*

From above the suggestion is the most likely cause for contamination is leakage past the piston rod. It is seen that maintenance of the stuffing box is of the utmost importance. Tell tales and drainage lines should be proved free and use of oil drained from the uppermost drain should not be allowed even after purification due to the high level of contamination which can destroy the properties of the oil in the sump

I know of a case where due to the increased viscosity of the oil a 50% charge of hydraulic oil was added to the sump of a very large slow speed engine under advice from the manufacturer

Properties of Lubricating Oil

Composition of lubricating oils

Lubricating oil fractions extracted from crude oil are a widely varying mixture of straight and branched chain paraffinic, napthenic aromatic hydrocarbons having boiling points ranging from about 302^o to 593^{o}C. Some specialty lubricants may have boiling point extremes of 177 and 815^{o}C. The choice of grade of lubricating oil base is determined by the expected use.

General capabilities expected from an engine lubricant

- Dispersivity or capacity to the cold parts of an engine clean
- Detergency or capacity to keep hot parts of an engine clean
- Thermal strength or capacity to withstand temperature changes
- Anti-oxidant or capacity to resist the action of oxygen
- Anti-wear or capacity to contain wear
- Anti-scuffing or capacity to preserve oil film even in the presence of high pressures
- Alkalinity reserve or capacity to neutralise acids formed during combustion or other sources thereby preventing corrosive wear
- Demulsibility or capacity to separate contaminants
- Resistance to hydrolysis or capacity to withstand the action of water which can affect additives
- Pumpability
- Centrifugibility and filterability or capacity to separate insoluble elements
- Anti-rust,corrosive and anti-foam are just some of the other properties required

Properties ideal for bearings

- Soluble for high speed fluid film hydrodynamic lubrication, hence, low viscosity with reduced oil film friction.
- moderate bearing loads
- improved heat transfer behavior
- corrosion protection
- cooling
- low friction
- good low temperature viscosity
- good high temperature viscosity

Properties ideal for gear case

- high film strength to prevent metal to metal contact. Hence, high viscosity adhesive to resist sliding and centrifugal forces
- corrosion protection
- cooling
- reduces friction
- good low tempo viscosity
- good high tempo viscosity
  The thicker the oil film the greater the cushioning against shocks. Also less tendency for pit formation by hydraulic action in cracks,
- sound damping properties with cushioning effects
- antifoam properties

Turbine oil
Compromise between above two requirements

- Generally a good quality refined mineral oil derived from paraffanic base stock used with various additives including EP additives for highly loaded gearing.
- Anti-foaming properties important

Additives

Improvements in lubricating oil over the last twenty years have come about almost entirely from the use of additives.

These are added for three main reasons;

1. *to protect the lubricant in service by limiting the chemical change and deterioration*
2. *To protect the mechanism from harmful combustion products and malfunctioning lubricating oil*
3. *To improve existing physical properties and to create new beneficial characteristics in the oil*

Typical additives are; Barium, calcium, phosphorus, Sulphur, chlorine, zinc, oxidation inhibitor-increases oil and machinery life, decreases sludge and varnish on metal parts

Corrosion inhibitor-protects against chemical attack of alloy bearings and metal surfaces.

Antiwear improvers-protects rubbing surfaces operating with this film boundary lubrication. One such antiwear (and oxidation inhibitor) chemical is Zinc dithiophosphate or ZDDP

Detergent-tend to neutralise the deposits before formation under high temperature and pressure conditions, or as a result of using a fuel with high sulphur content. The principle detergents are soaps and alkaline metals, usually calcium (often referred to as 'matallo-organic compounds'). They are usually ash forming and spent additive will contribute to the insolubles loading of a used oil. It should be noted that additives which do not burn cleanly without ash tend to be avoided for use with Cylinder Lubricating Oils.

Dispersant-used to disperse or suspend the deposits forming contaminants. Typical dispersants, such as polyesters and benzlamides, are usually clean burning. The molecules have a polar charge at one end which attracts and holds the deposits

Alkaline agents-neutralises acids, htese form the TBN of the oil and includes additives such as the above dispersants and detergents. An excess of acid neutralising alkalis are present in the oil and these help to keep parts clean. Failure to keep an oil alkaline can lead to damage to bearings due to acidic attack as well as increased liner wear.

Rust inhibitors-

Pour point depressants-improves low temperature viscosity

Oiliness agent-reduces friction seizure point and wear rates

EP additives-increases film strength and load carrying capability

Antifoam agents-prevents stable bubble formation

Viscosity Improvers-an additive that improves the viscosity index of the oil. I.e. reduces the effect of temerpature of=n the viscosity of the oil. Shear stability property is measured indicating the effect of high rates of shar on the VI improver as the improver molecules are broken down into smaller molecules

Metal deactivators-prevent catalytic effects of metal

Antiseptic-bactericide.

Oxidation

Oxidation degrades the lube oil producing sludges, varnishes and resins. Presence of moisture, and some metals particularly copper tend to act as a catalyst. Once oxidation starts, deterioration of the properties of the oil is rapid.

Recharging

When recharging no more than 10 % of the working charge should be topped up due to heavy sludgeing that can occur due to the heavy precipitation of the sludge.

EP additive oils

Can assist in healing of damaged gear surfaces but should be used as a temporary measure only due to risk of side effects

Emulsification

This occurs due to water contamination; also, contamination with grease, fatty oils, varnish, paint and rust preventers containing fatty products can also promote emulsification.

The presence of an emulsion can be detected by a general cloudiness of the sample. Salt water emulsifies very easily and should be avoided.

Water entrained in the oil supplied to a journal bearing can lead to loss of oil wedge, rub and failure.

Fresh water contamination whilst not in itself dangerous can lead to rusting. The iron oxides catalyses the oil to form sludge's. The additives in the oil can leach out to change the water into an electrolyte.

Salt water contamination is very serious as it causes tin oxide corrosion, and also leads to electrochemical attack on the tin matrix in the white metal. The sea water act as then electrolyte.

A major problem of water within a lub oil is where the mix enters a bearing, here it is possible for the water to be adiabatically heated causing it to flash off collapsing the oil wedge.

Stresses on Lube oil

The main stresses experienced by Lube oils in diesel engines operating on heavy fuel oils are expressed as follows

Acid Stress- Caused by sulphuric and oxidation acids. This leads to increased corrosive wear, deposits, reduced Base Number and shorter oil life.Rapid depletion of the BN is the clearest sign of oil stress

Thermal/Oxidative stress-This caused by elevated temperatures leading to increased rates of thermal/oxidative breakdown of lubricant and fuel. This leads to increased levels of deposits, sludges, corrosive wear of bearing material, oil thickening and reduced oil life. In addition deposits on the under crown side of the piston can lead to increased hot corosion on the piston.

Asphaltene Stress-This caused by fuel contamination of the lube oil and can lead to increased levels of deposits, sludges, lacquers, oil thickening and reduced oil life. In addition deposits on the under crown side of the piston can lead to increased hot corosion on the piston

OIL ANALYSIS

Regular testing of crankcase lub oil is important to ensure that deterioration has not taken place. The results of in service deterioration could be a reduction in engine protection or actual attack on working points by corrosive deposits. Oil samples are generally tested every 3 to 4 months depending on the system and experience. Shipboard testing is taking a rising prominence to allow monitoring of oil condition between testing.

To ensure good representation, care should be taken where the sample is drawn

Correct

- Main supply line
- inlet or outlet from l.o. cooler
- Outlet from main l.o. pump

Incorrect

- standpipes
- purifier outlet
- purifier direct sump suction

Samples should be drawn over a period of several minutes

Viscosity

The viscosity is the most important property of the oil. Oil of correct viscosity will provide optimum film strength with minimum friction losses and leakage.

The viscosity of a L.O. may fall due to fuel dilution if running on gas oil, and rise if running on heavy f.o. Viscosity may also increase due to heavy soot loading if purifiers and filters not operating efficiently. Oil ageing caused by oxidation and thermal degradation increases viscosity.

A simple shipboard test is the Mobil flow stick where drops of new and used oil are placed in separate channels on an inclined 'stick'. The rate the oil flows down the stick is proportional to its viscosity.

Water content

Initially determined by 'crackle' test. The presence of Na and Mg in a 4:1 ratio indicates salt water contamination.

Limits are laid down by the manufacturer, but as a rule of thumb a limit of 0.2% should cause investigation into source and remedial action at 0.5%

Gross contamination can be remedied by placing the charge in a separate tank and heating to 70^oC and circulating through purifier.

Spectrometry

Indicates the presence of metal element composition and identifies additive and contaminant levels.

Zinc(Zn),Phosphorus(P)- are components of many oils such as diesel engine oils, hydraulic oils and gear oils, to enhance antiwear and over properties of the oil

Calcium(Ca)- primarily a component of engine oils, provides detergency,alkalinity and resistance to oxidation. Residual fuel engine oils have higher Ca levels

Nickel(Ni)- Bearings, Valves, gear plating, fuel derivative

Barium(Ba)- Multi purpose additive, declining importance

Magnessium(Mg)- as for Ca, may also be due to sea water contamination if found in Ratio of 1:4 of Na

Chromium(Cr)- Piston rings, hydraulic actuator cylinders

Manganese(Mn)- Cylinder wear

Aluminium(Al)- generally comes from wearing piston skirts, levels rise where new piston fitted to old engine. Typically 10ppm, but rises during bedding in. May also indicate the presence of catylytic fines in residual fuels.

Iron(Fe), Molybdenum(Mo), Chromium(Cr)- metals alloyed for piston ring etc, a rise in level may indicate ring pack/liner wear.

Copper(Cu), Lead(Pb) , Tin(Sn), Silver(Ag) - soft metals used in the overlay of shell bearings, and phosphor bronze gears.Note that high copper content can also occur when samples are drawn from copper pipes which have not been flushed as well as gear wear.

Silicon(Si)- Indicates poor air filtration, possible fuel derivative

Sulphur(S)- May indicate the presence of clay based (bentonite) greases

Sodium(Na)- With Mg indicates the presence of sw contamination, possible coolant system and fuel derivative

Vanadium(V)- Usually indicates the presence of fuel oil

Alkalinity and acidity

TBN-TOTAL BASE NUMBER- measure of alkaline additives available for the neutralisation of acids from combustion products and oxidation. Level governed by type of fuel.

For crosshead engines the TBN will tend to rise due to contamination by liner lubrication, it should not be allowed to raise more than twice that of the new charge.

As a guide, the TBN of fresh oil should be at least:

- 10 x fuel sulphur content (%) for trunk piston engines (10mgKOH/g)
- 20 x fuel sulphur content (%) for cyl oil in x-head engines (20mgKOH/g)

A simple shipboard go,no-go test is available for measuring the TBN, it involves the addition of an indicator and acid reagent to a 30ml sample. The quantify of acid reagent added is determined by the required level of TBN, for TBN2.5 0.5ml are added, for TBN20 4ml is added. After three minutes the colour is checked against a chart

- Purple:Good level of TBN
- Green:Borderline
- Yellow:Low level of TBN

TAN-TOTAL ACID NUMBER-measure of organic acid and strong acid content of oil. Where SAN is nil, the TAN represents the acidity in the oil due to both the acids in the additives and the oxidation of the hydrocarbons in the oil. The TAN of fresh oils varies with oil type, and tends to climb with age. A high TAN may indicate that an oil should be changed or freshened by top up. A high TAN may be accompanied with increased viscosity.

SAN-STRONG ACID NUMBER-indicates the prescience of strong, highly corrosive (inorganic) acids, usually formed from combustion products. If SAN is non zero the oil should be changed immediately

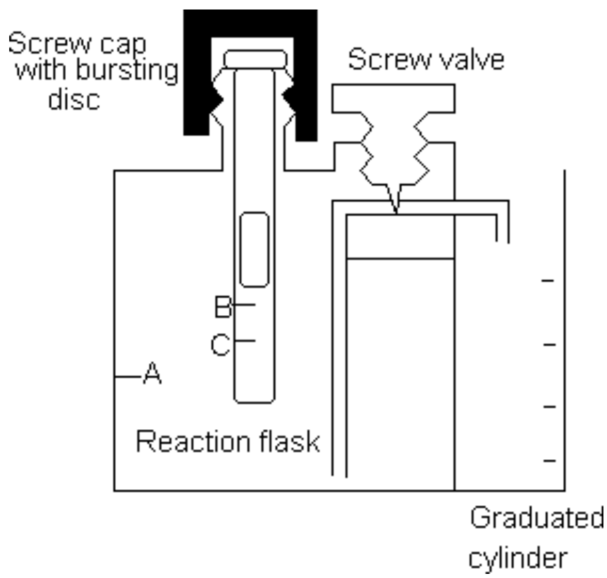
Oil cleanliness

IC-INDEX OF COMBUSTION-measures soot loading of oil

MD-MERIT OF DISPERSANCY-Ability of an oil to disperse contaminants, such as soot, wear debris and water and thereby carry them away from the critical areas. Measured by oil blot test and should not be allowed to fall below 50

DP-DEMERIT POINTS- combination of IC and MD: the lower the value, the healthier is the condition of the oil

Shipboard water content test

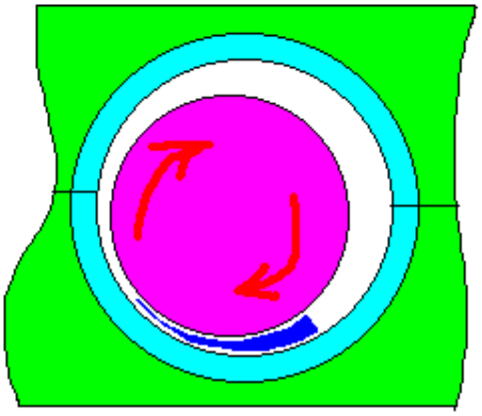


i. *The flask is filled to mark 'A' with kerosene*
ii. *A capsule of reagent (calcium hydride) is added. Any water in the kerosene will react with the calcium hydride and any gas vented off.*
T
iii. *he container is topped to mark 'B' with sample oil*
iv. *The screw valve and cap are closed.*
v. *The flask is inverted and shaken*
vi. *After 2 minutes the screw valve is opened. The hydrogen produced by the reaction between the reagent and water exerts a pressure which forces the kerosene through the open valve into the graduated cylinder. The amount discharged is proportional to the water content in the oil sample.*
vii. *If the water content is greater than 1.5% then the test should be repeated this time using a smaller sample by filling only to mark 'C'. The second scale on the graduated cylinder should then be used.*
viii. *If water is detected its type, sea or fresh , should then be determined by use of a special reagent the water*

Oil Whirl

Oil whirl is a problem associated with sleeve type bearings. This vibration occurs only in machines equipped with pressure lubricated sleeve bearings and operateing at relatively highspeed- normally above the second critical speed of the rotor. Oil whirl vibration is often quite severe, but easily recognised because the frequency is slightly less (5 - 8%) than one half the rpm of the shaft.

The mechanism of oil whirl can be explained by referring to the diagram below.



Under normal operation, the shaft of the machine will rise up the side of the bearing slightly. How far the shaft will rise depends on shaft RPM, rotor weight and oil pressure. The shaft, operating at an eccentric position from the bearing centre, draws oil into a wedge to produce a pressurised load bearing film. If the eccentricity of the shaft within the bearing is increased from this normal operating position, say be external shock or load transient, additional oil will immediately be pumped in to fill the space vacated by the shaft thus increaseing the oil film supporting the shaft. This oil film may drive the shaft in a whirling motion around the bearing. If damping in the design is sufficient then the system will return to its original position otherwise the whirling motion will continue.

lternately, a lightly loaded bearing may rise under normal conditions reducing the clearance above the bearing to a point where an oil wedge forms forcing the shaft back down. In doing so the clearance is restored at the top of the bearing and the oil wedge fails removing the downward pressure.
Steam Turbine bearings are susceptible to oil whirl as they tend to have larger than normal clearances to allow for high oil flows for cooling

Causes

Normally associated with poor bearing design, . Other problems are

- excessive bearing wear
- increase in lube oil pressure
- Change of oil viscosity
- External excitation caused by a transmitted in vibration at the natural oil whirl frequency.

Temporary Remedies

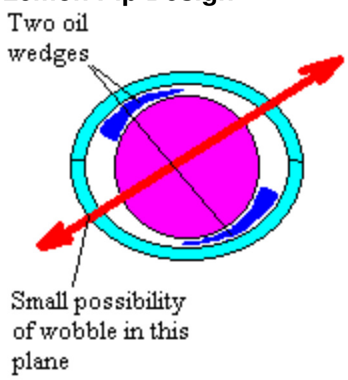
Temporary remedies include

- Changing oil temerpature or viscosity
- Increase bearing loading by introducing slight misalignement or imbalance
- Scrapping the sides of the bearing or grooving the bearing surface to disrupt the lubricant wedge

Improved Bearing Design

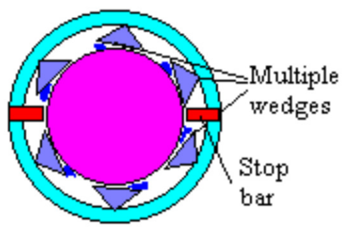
Shorter bearings increase the bearing load which can help prevent oil whirl

Lemon Pip Design



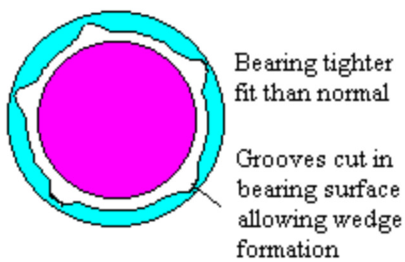
This is achieved by machining the two shells whilst shims are fitted between the faces

Tilting Pad-mitchell type



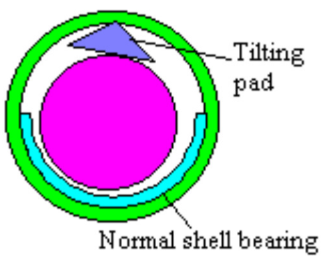
A thermocouplwe is fitted to the lowest pad

Grooved

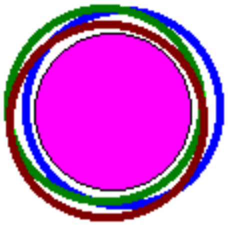
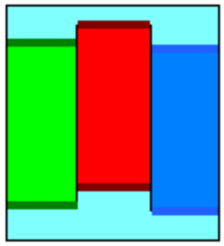


Loss of bearing material means reduction in load carrying capacity

Nut Cracker



Camella

Formed by boring non-concentric circular bearing surfaces in a bearing allowing th eformation of three wedges whilst maintaining the correct bearing clearance

Properties of distillate and residual fuels

Density

This is the mass per unit volume and is generally given as kg/m^3 at $15^{O}C$ and is specifcially given as that found in a vacuum. The density reduces with increasing temperature and alos reduces in air although the latter by only about 0.1%. These characteristics are important to allow proper description for commercial transactions and also for preparation (say purifiers) and in use (main engines). Density may also be given as **specific gravity**, this is a ratio of mass of the fuel to the same volume of water at the same temperature.

Viscosity

This is a measure of a fuels resistance to flow or more specifically resistance to shear of adjacent molecules. It is one of the most important characteristics of a fuel. It governs the method of handling, storage, pumping and combustion.

The coefficient of viscosity is referred to as the **absolute velocity** and has many accepted units of value, the SI units are MPa/s and is defined as the force required to shear a set area of liquid at contant velocity.

Kinematic viscosity is this is the ratio of dynamic viscosity of a fluid over its density. The units are accepted as stokes or centistokes although the SI unit is m^2/s or mm^2/s. The viscosity of a fuel generally varies considerably with temperature and this is particularly the case with resif=dual fuels.

Flash Point

This is the temperature of a fuel at which sufficient vapour is given off that momentary ignition occurs if an external flame is introduced. This temperature si quoted as **Open** or **Closed**. The closed temperature is about 15'C lower than the open

Pour Point

This is the temperature at which and below wax crystals begin to form. This is important for pumping

Specific energy or Calorific value

This is the total energy chemically available by a unit fuel. Heavier fuels tend to have lower values.

Ignition quality

Is a property related to distillated fuel and is that quality of combustibility during combustion process in a diesel engine, which causes ignition delay. It is a relative value on a scale of 0 to 100, known as cetane number. Paraffin as non-combustible substance is taken for zero and Cetane ($C_{16}H_{34}$) a highly combustible substance is taken as 100.

The International Standard for Marine Fuels

	IFO 40			IFO 80	IFO 180		IFO 380			
	RMA10	**RMB10**	**RMC10**	**RMD15**	**RME25**	**RMF25**	**RMG35**	**RMH35**	**RMK35**	**RML35**
Density @ 15 KC	0,975	0,991	0,991	0,991	0,991	0,991	0,991	0,991	---	---
Viscosity @ 50 KC	40,0	40,0	40,0	80,0	180,0	180,0	380,0	380,0	380,0	380,0
Viscosity @ 100 KC	10,0	10,0	10,0	15,0	25,0	25,0	35,0	35,0	35,0	35,0
Flash Point (KC)	60	60	60	60	60	60	60	60	60	60
Pour Point :Winter, Summer (KC)	0 6	24(0) 24(6)	24 24	30 30	30 30	30 30	30 30	30 30	30 30	30 30
Carbon Residue (%)	10	10	14	14	15	20	18	22	22	--
Ash (%)	0,10	0,10	0,10	0,10	0,10	0,15	0,20	0,20	0,20	0,20
Water (%)	0,50	0,50	0,50	0,80	1,0	1,0	1,0	1,0	1,0	1,0
Sulphur	3,5	3,5	3,5	4,0	5,0	5,0	5,0	5,0	5,0	5,0
Vanadium (ppm)	150	150	300	350	200	500	300	600	600	600
Al + Si (ppm)	80	80	80	80	80	80	80	80	80	--
Sediment Potential (%)	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	--

This doe not include
additional Quality Parameters, NOT covered by the ISO-8217 standard.
Such as : Sodium (Natrium), Lead, Calcium, Phosphorous,Zinc,
CCAI (Calculated Carbon Aromaticity Index), and whether or not
the bunkers you ordercontain Waste Automotive Lube Oil.

Low Sulphur Fuels

Sulphur contained in the fuel forms metallic sulphides that coat the internal surfaces of the fuel injection equipment including the fuel pumps and the fuel injectors. These sulphides have low shear resistance and act as EP additives similar to that found in lubrication oils. Extremely low sulphur fuels in use on the automotive transport industry have led to the use of lubricity additives. In the marine environment the reduction in sulphur content has been less dramatic.

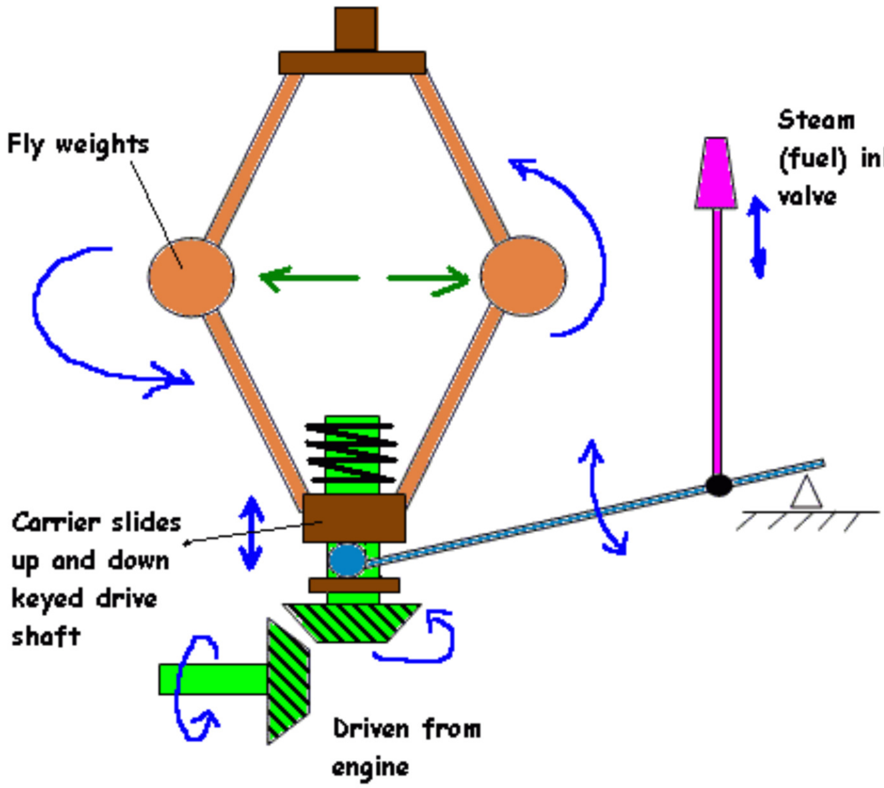
Marpol Annex VI(regulation 14) and the creation of Sulphur Emission Control Area means it wil be a requirement to use only fuels with a certain maximum sulphur content. In the addition to the increased cost of these low sulphur fuels it is necessary to factor in the possibility of increased wear and tear on the engine components.

Low sulphur fuels are normally low viscosity oils such as gas oil. Carefull planning has to be done both at the design level (to ensure sufficient storage capacity) and at the operational and maintenance levels due to the known difficulties in changing over from a heated fuel to a non heated or one with reduced heating capacity.

Mechanical governors

These fall into the oldest class of governors whose history goes back to the invention of the steam engine.

Watt type

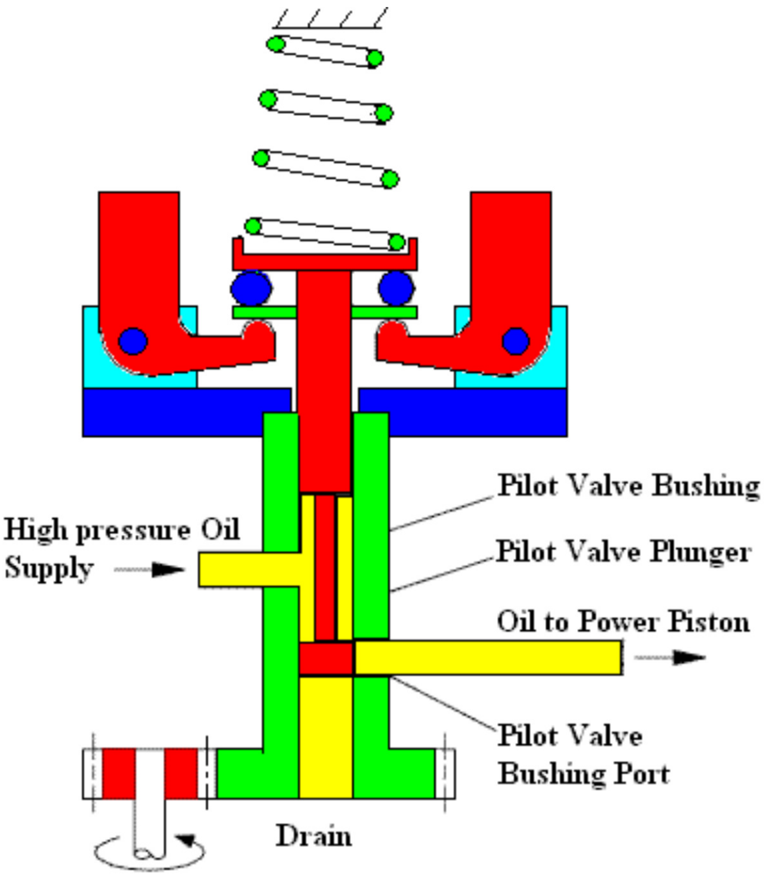


The governor assembly is directly driven from the engine. Flyweights are rotated and act to draw the slide up the drive shaft due to centifugal force pushing them out.

Hydraulic governors

A simple mechanical governor must overcome friction in the linkages and exert a controlling force. These forces act in different directions depending upon whether the load is increasing or decreasing.The effect of this friction is to create a deadband

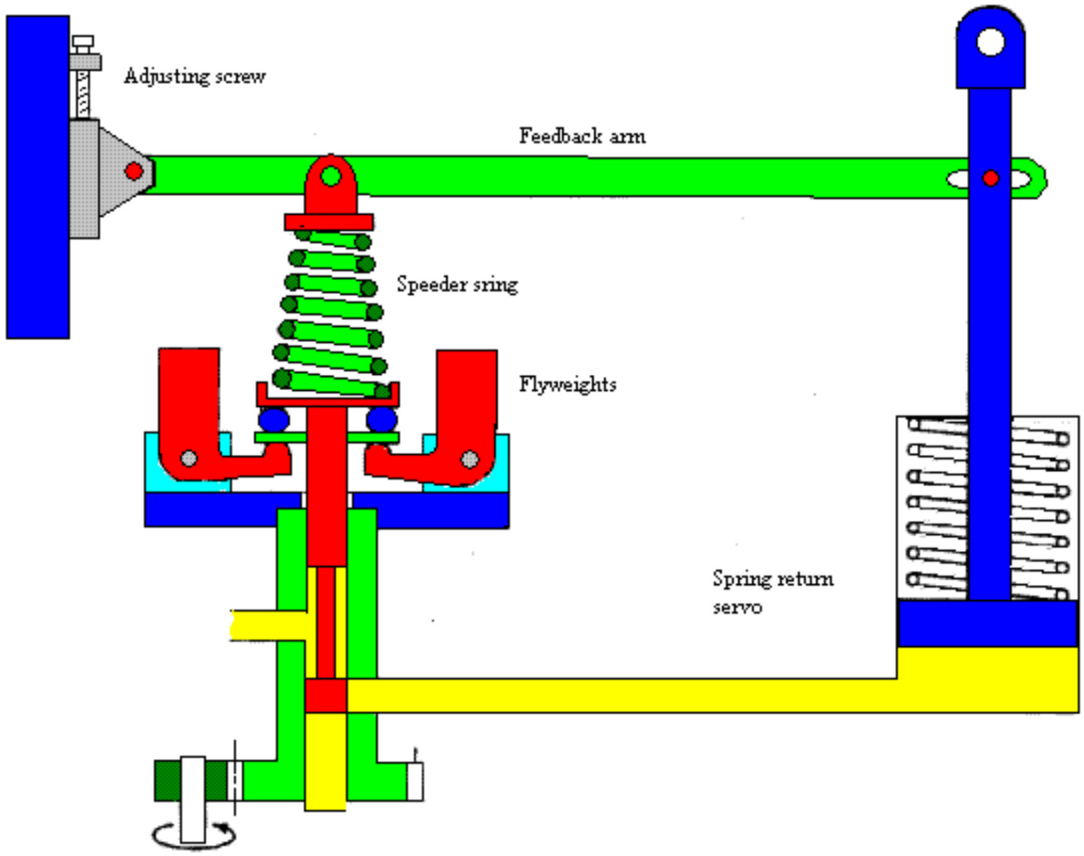
In hydraulic governors this effect is negated by having oil pressure act as the controlling force



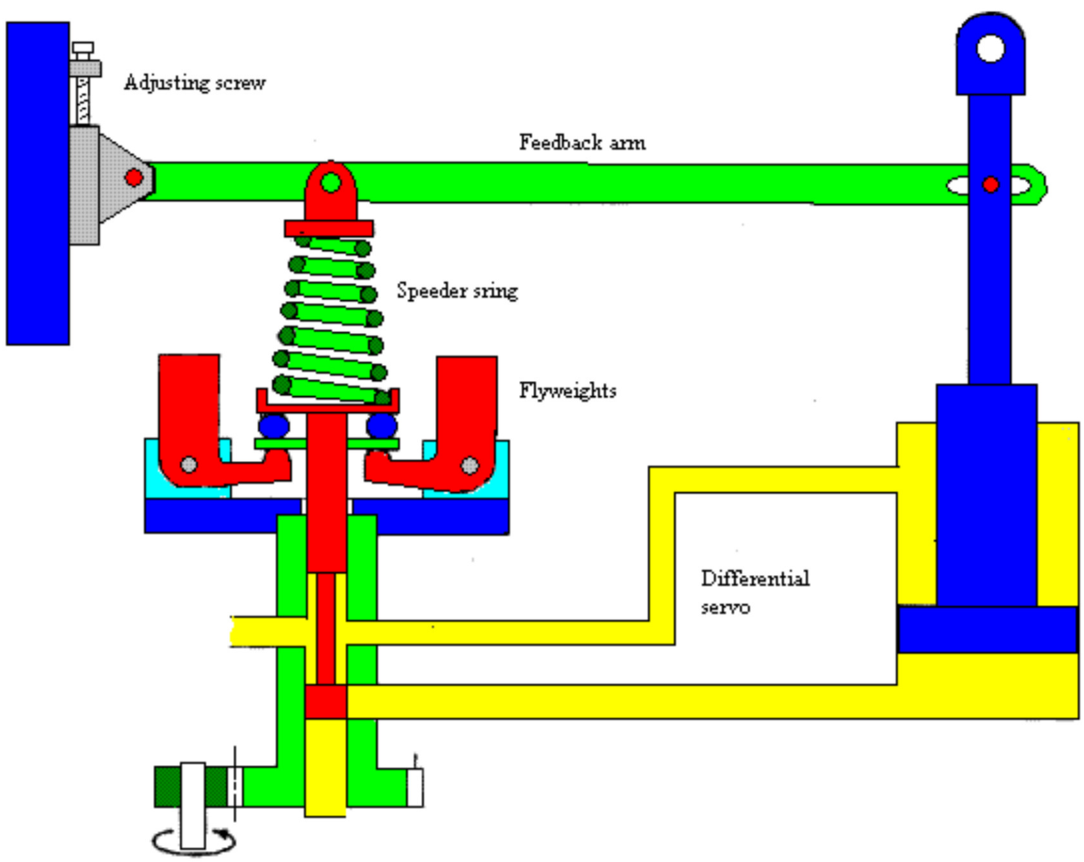
This simple system has inherent stability due to the the on/off nature of oil being suppled to the system control due to the control land just covering the outlet ports. Oversizing the land would create stability but at the expense of reintroducing a deadband

Servoed system with feedback

An Alternative is to lead the outlet oil to a servo system. The servo piston can be either spring return



or Differential



In the former case the servo is held in the decrease fuel position by spring pressure, in the latter the servo piston is pushed down by supply oil pressure. Note that the control side of the servo piston has greater areas than the supply oil side therefore when control oil is supplied it is able to lift the piston against it

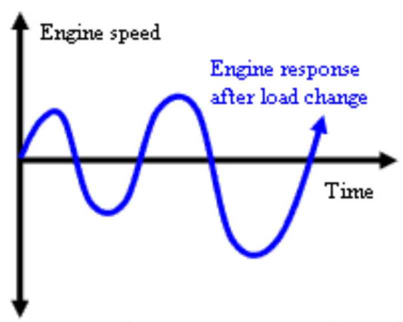
Should the engine speed fall the flyweights will tend to fall towards the axis rotation due to pressure from the speeder spring overcoming the reduced centrifugal force. The pilot valve moves down and the control land allows oil to flow to the servo piston raising it. When the engine speed increases the flyweights begin to overcome the speeder spring and the pilot valve moves up covering the servo supply port

In this design **Setpoint** may be varied by use of an adjusting screw altering the compression of the speeder spring. In addition **Feedback** is given to increase stability. The term applied to this is **Droop**

Droop

Droop is defined as the reduction in speed compared to set speed over full load change x 100 as is expressed as a percentage

When the governor reacts to load change then inertia of the engine response can lead to overshoot in speed change which can have a cumulative effect. To prevent this a feedback system is used. In the case of the governor systems above this has the effect of modifying the speed set point .

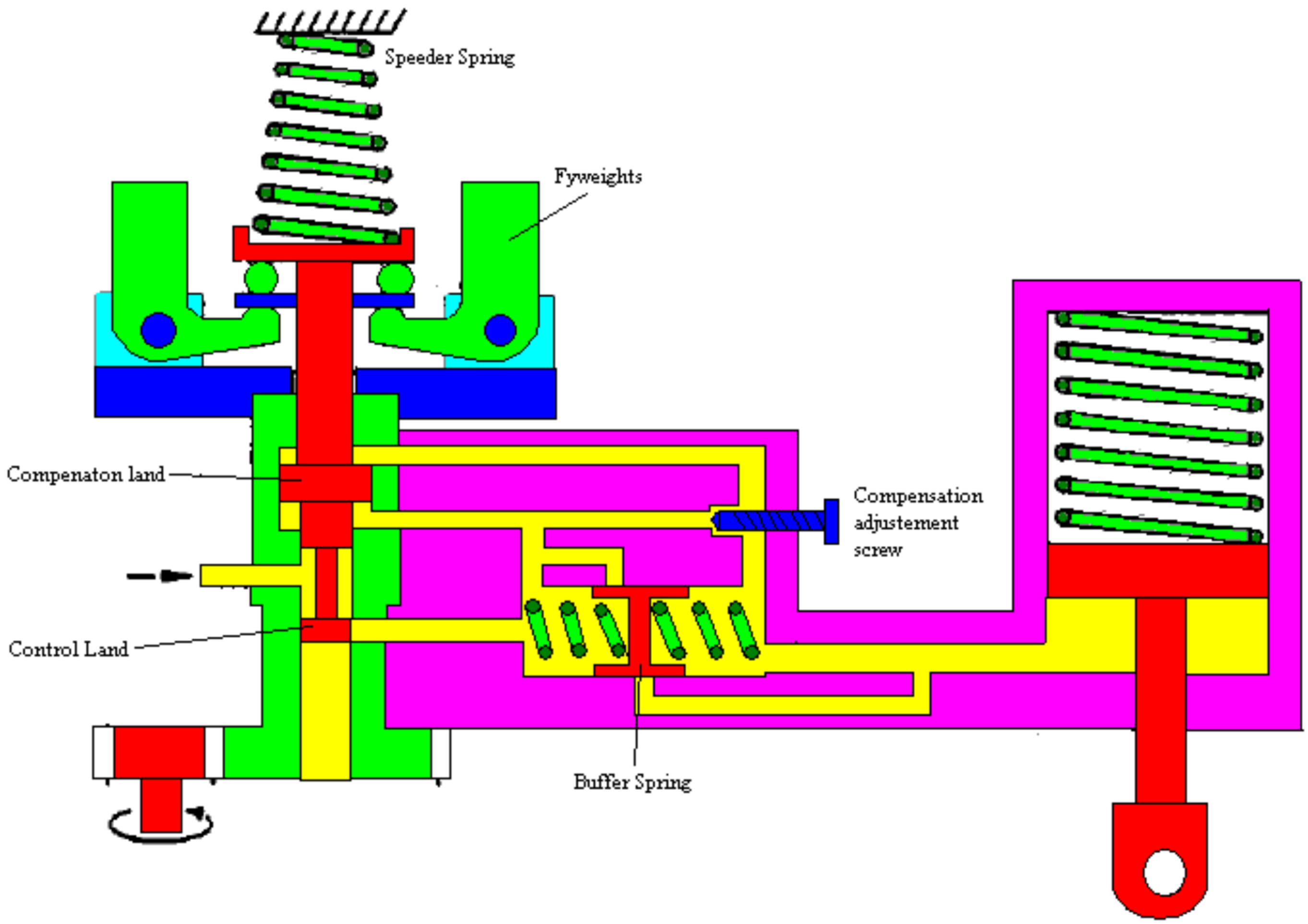


Should the engine speed fall the flyweights will tend to fall towards the axis rotation due to pressure from the speeder spring overcoming the reduced centrifugal force. The pilot valve moves down and the control land allows oil to flow to the servo piston raising it. This increases the fuel supply to the engine but also reduces the speed set point as the feed back lever is also raised moving the connection to the speed spring upwards reducing spring pressure. The Flyweights ar able to raise the pilot valve closing off the supply of oil to the servo

The engine will now run with some degree of stability. However it will not run at set speed.

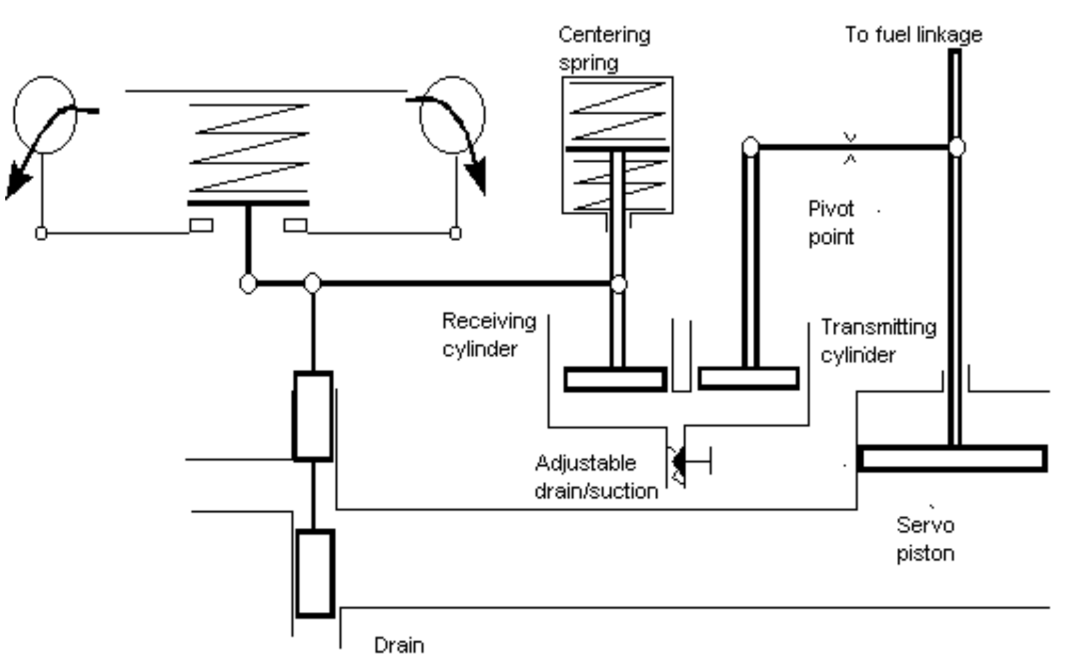
Compensation

This allows for the stabiiising effect of droop but maintains original set point speed.



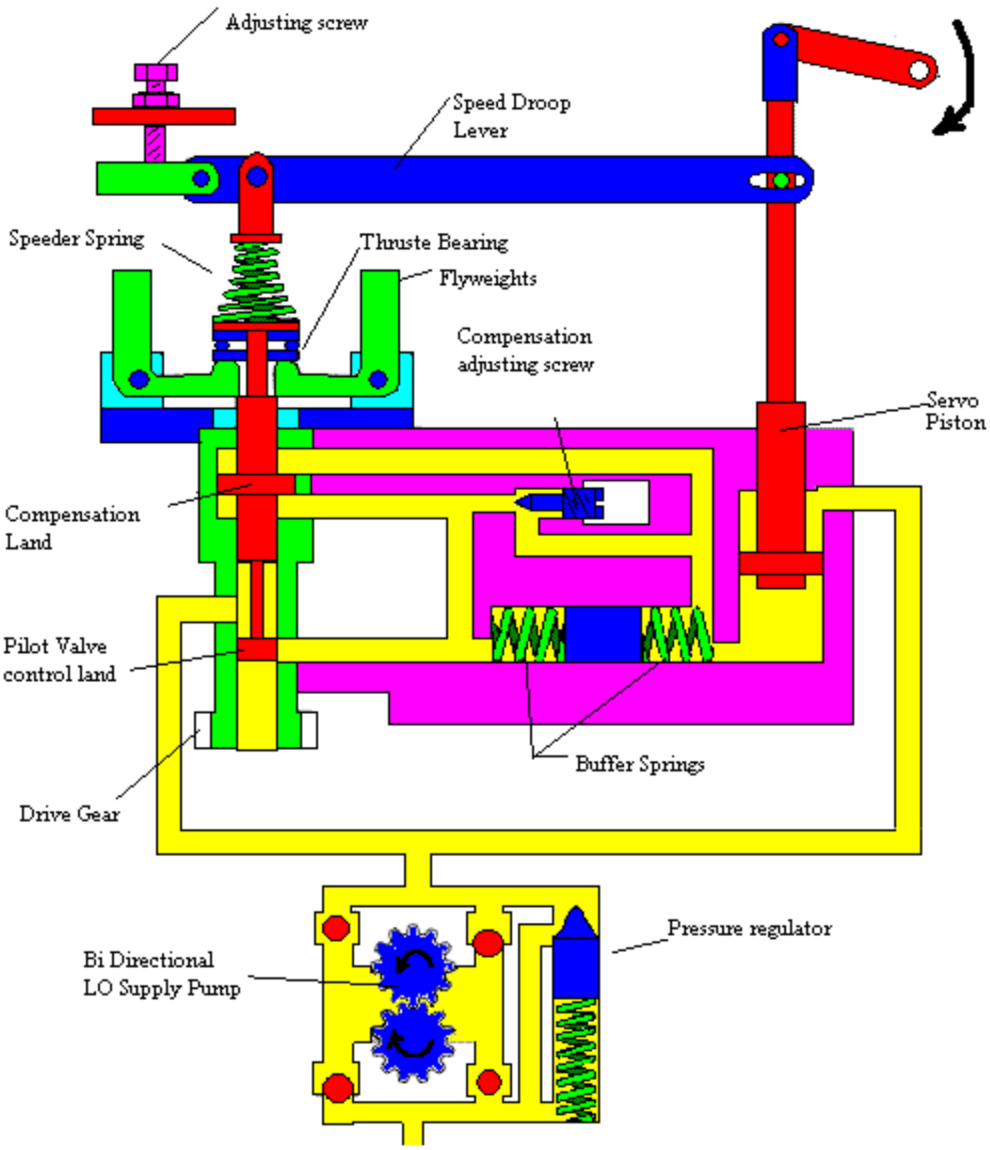
Should the engine speed fall due to the impact of increased load thecontrol land will fal allowing supply oil pressure to pass through. As well as forcing up the servo piston via the action on the buffer spring it also acts on the underside of the compensation land were it tends to push the pilot valve up against the force of the speeder spring. The pressure differential across the compenation land bleeds off via the compensation screw as the engine returns to normal speed This is known as **temporary droop**

Alternately



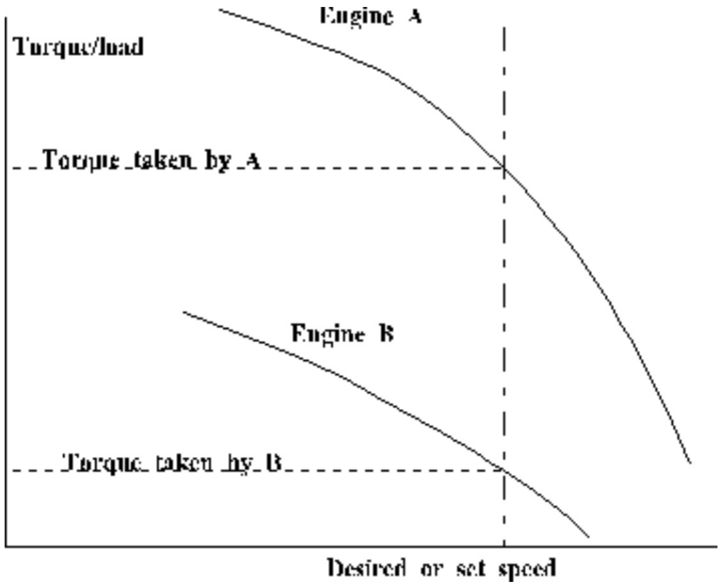
. Compensation takes place to provide a further slight fuel change to return the speed to normal. The centering spring forces the receiving piston downwards and oil escapes through the adjustable valve.. This lowers that end of the floating lever until both centering springs are equally loaded and that end of the floating lever is in its original position. The pilot valve is open slightly allowing oil to the servo which gives a further slight increase in fuel. The engine speeds up, the rotating weights move out and the pilot valve is lifted until it is closed. The engine now operates with increased load, increased fuel but at the same original speed. class="noindent">

Complete assembly



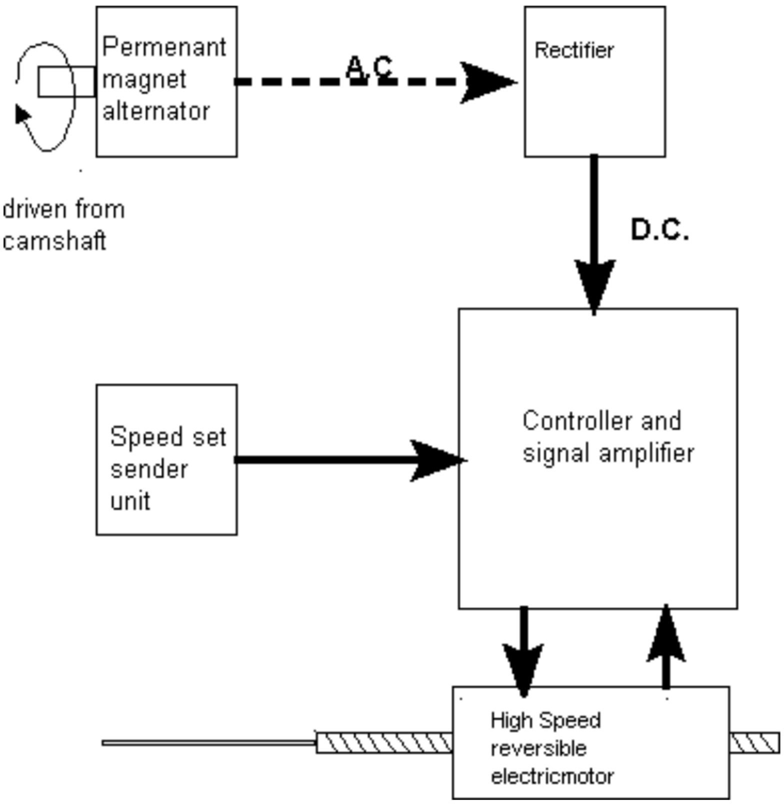
Load sharing

Engines share load increase in the inverse ratios of their speed droop. i.e. the lower the value of droop the greater the share of the load increase taken



PRADEEP@MSC SHIPPING

Electric Governors



Electric governors have become in favour due to their compact size, rapid response and high reliability allied to low maintenance costs.

The main part of the governor is the controller and signal amplifier. This receives a D.C. signal proportional to the engine speed and compares it to a speed set signal. The difference between the measured value (engine speed) and the set value is the offset, this offset value is passed to the output circuit which produces an appropriate output signal . In this case, a signal which raises or lowers the fuel rack by an amount dependent on the degree of offset. This system is inherently stable due to the feedback layout.

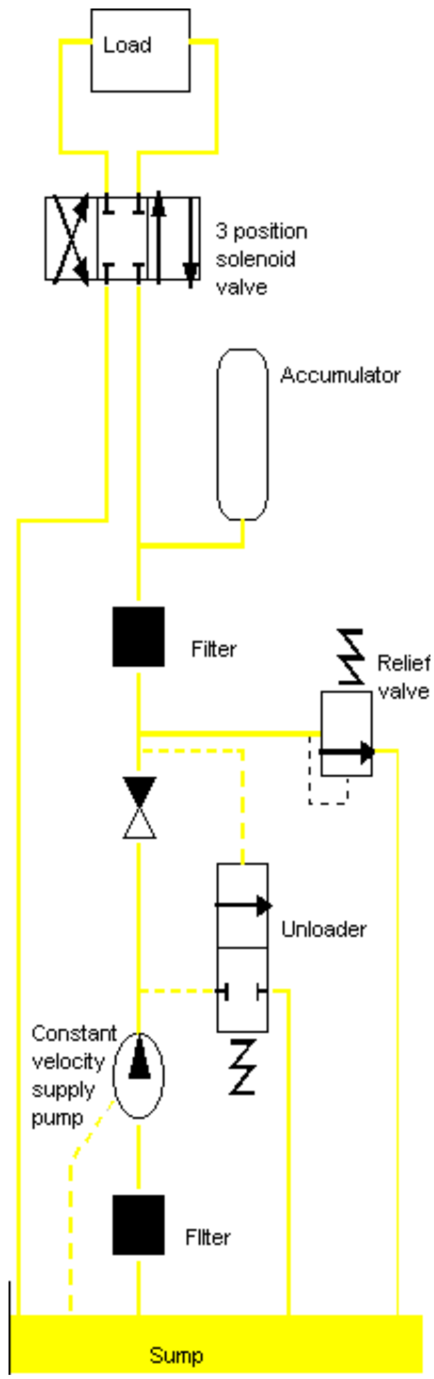
For this system the engine speed is measured using an alternator driven off the camshaft- this is a common arrangement. The speed set signal is typically supplied by the bridge control arrangement via the engine management system.

An arrangement for a generator set might replace the camshaft driven alternator with a tapping off the alternator output. The frequency of the alternator output is now the measured value. In addition a load sensing element can be introduced detecting changes in current flow. For increased current, that is an increased electrical load, the governor can act to supply increased fuel before the engine has began to slow.

Hydraulic systems

Although the hydraulic systems used aboard vary widely. They may, however, be grouped into the three basic set ups.

Constant flow



For a constant flow pump it is possible to vary the flow to a load by varying the outlet from the load.

The major components are the fixed delivery pump, unloading valve, and accumulator.

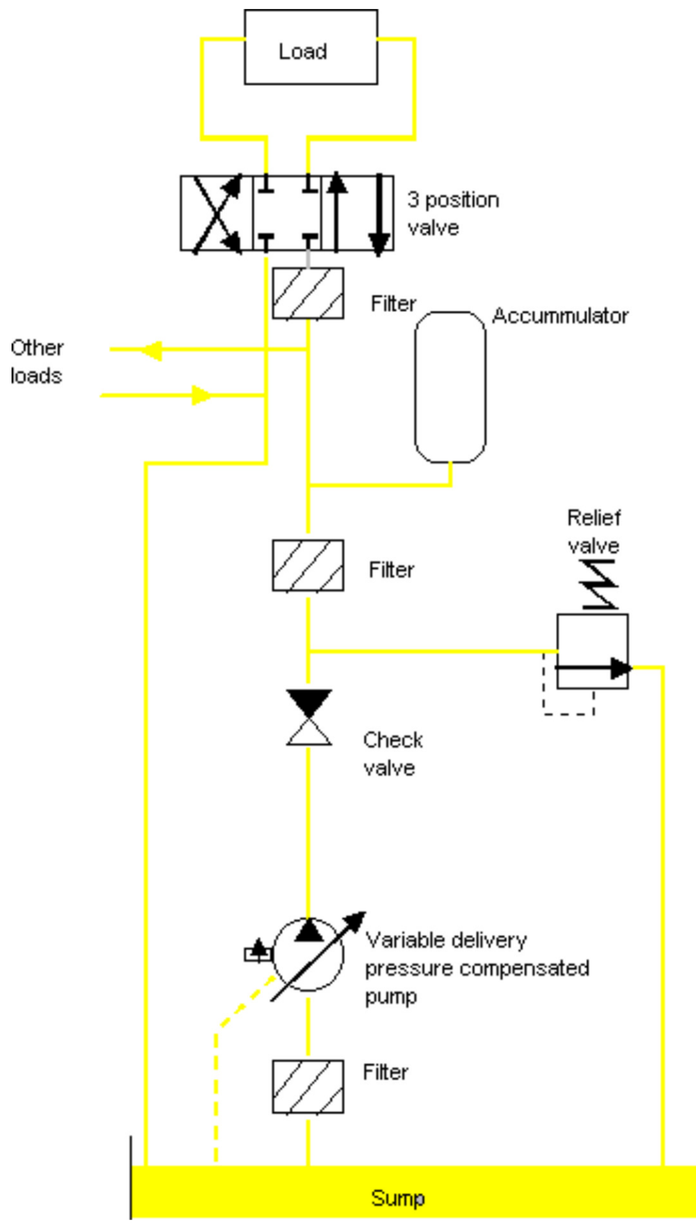
The accumulator consists of a steel pressure vessel within which is a rubber bag. The space between the bag and the steel walls is filled with nitrogen at a set pressure. When the constant delivery pump is started, oil is supplied to the accumulator inflating the bag with oil against the nitrogen pressure.

When the set system pressure is reached the unloader valve will open maintaining system pressure at a set amount. The check valve maintains the pressure in the accumulator giving a ready reserve on demand. An alternative to this is to have a pressure cut out switch for the pump with a suitable dead band to prevent cycling.

When a throttle or control valve is opened the accumulator supplies oil to the load, the pressure above the check valve drops, the valve opens, the unloading valve begins to close and oil is supplied through the check valve.

A common use for this system is for valve opening/closing.

Constant pressure

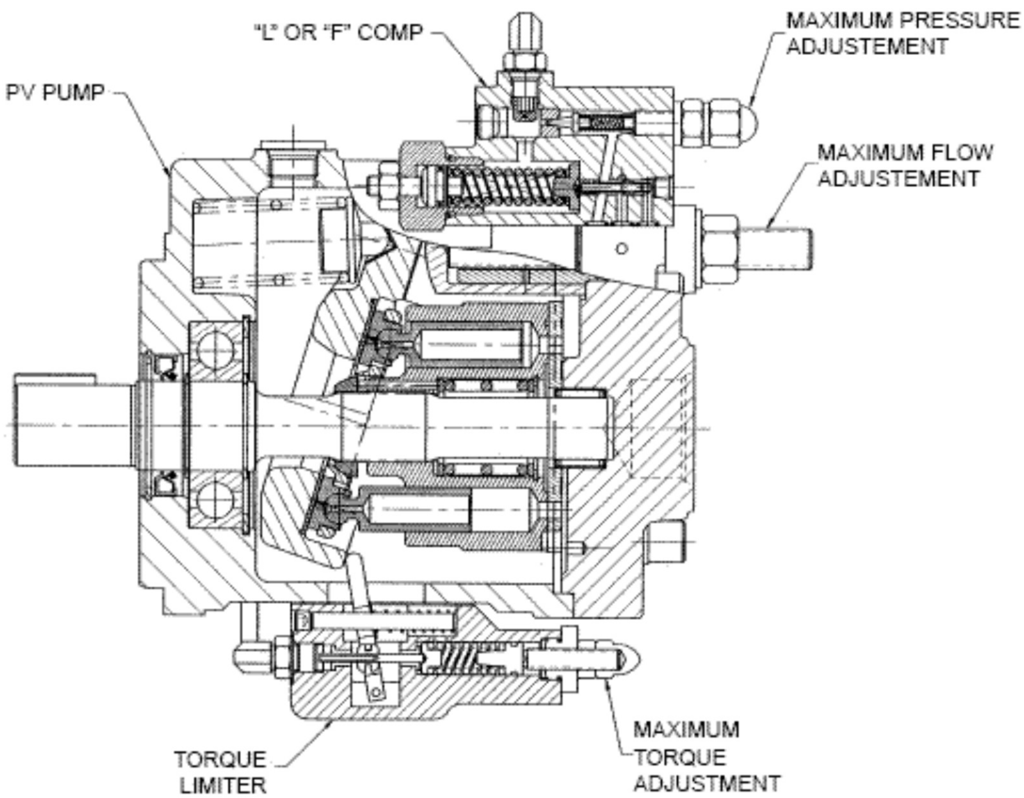


Uses one or more variable delivery pumps which supply oil at nearly constant pressure to either a system of multiple loads or a single load such as a hydraulic elevator hoist.

When the pumping capacity exceeds load requirements, the system pressure increases above a set value, at which point the pressure compensator acts to take the pump off stroke. A relief valve is fitted in case of malfunction of the compensator.

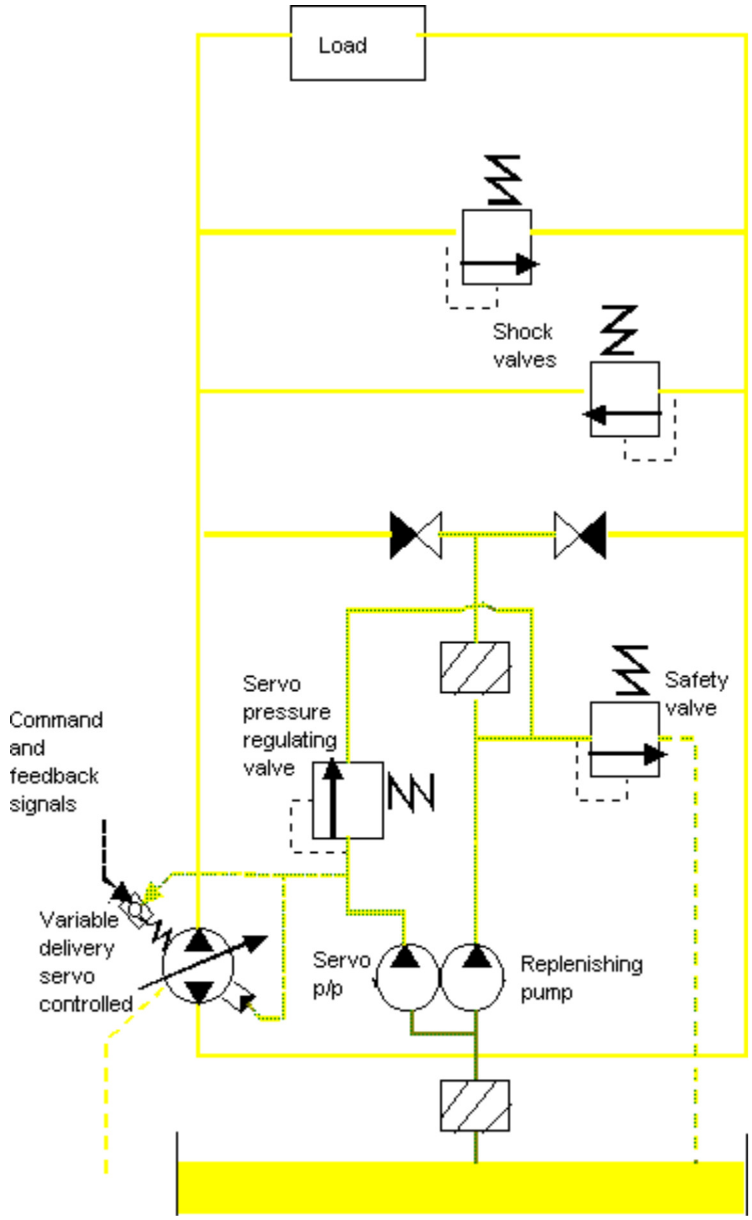
Fluid flow to the load may be controlled by a variety of methods one of which is the simple three position valve shown.

This system suits an installation containing several high demand units such as deck winch hydraulics



Shown is a pump typical of the service described. The Flow Limiter acts to restrict the maximum movement of the Swash plate.The maximum pressure adjustement acts on the set point spring for the swash plate positioning control. The Torque limiter takes both the Pressure and Flow (Swash Plate Position)signals in calculating torque

Demand system



The demand hydraulic system is a closed loop system particularly adapted to meet the precise demands of varying loads such as steering gear and automatic weapons handling equipment. The variable and reversible delivery pump does not take suction from a sump tank, as a loop of oil is maintained between the main pump and the load. The closed loop eliminates pressure drop which would exist if the load control were achieved by a servo valve located in the main hydraulic piping. A servo pump and replenishing pump are driven off the same shaft as the main pump, provide actuating fluid to stroke the main pump and to provide make up fluid to the closed loop, respectively. Control of the main pump is accomplished by command and feedback signals. The command and feedback signals may be composed of a combination of mechanical, electrical, or hydraulic devices.

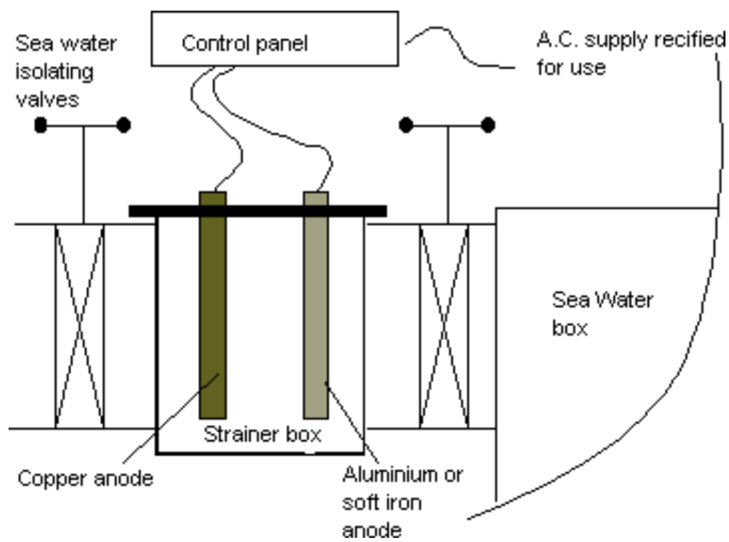
This system is able to deliver a reasonably precise flow of oil which makes it suitable for equipment where finite speed control is essential. An example other than those given above could be an anchor handling windlass.

Pipework Fouling Protection

Anti-fouling systems help avoid problems of blockages in water intakes. The main cause of the problem are barnacles and mussels which are drawn into the intake of vessels as larvae and then attach themselves to the surfaces of pipes where they grow and multiply.

There is also considerable evidence that marine growth accelerates corrosion. Previously the only remedy has been mechanical removal and the replacement of damaged parts. Preventive measures have been used such as chlorination, chemical dosage or an electrolytic system.

Electrolytic system



The **electrolytic system** consists of pairs of copper and aluminium or iron anodes which are mounted in the ship's sea chest or strainer, and a control panel, either an LED panel or an analogue digital meter showing the output of each anode.

In operation a dc current is applied to the copper anode which produces ions which are then carried throughout the pipework system by the seawater flow. Although the concentration of copper in solution are said to be extremely small- less than two parts per billion- they create an environment where marine organisms cannot settle or multiply. This also gives continuous protection to valves, condensers engine cooling systems and ancillary equipment.

A second anode is employed to combat corrosion. All metals have layers of protective oxide films which are prone to breakdown by natural means. Seawater which is carrying corrosive agents such as sulphur, can break down these protective films on all metal surfaces. Soft iron anodes are used for protection of alloyed pipework such as yorcalbro (an aluminium brass).

Chemical dosing

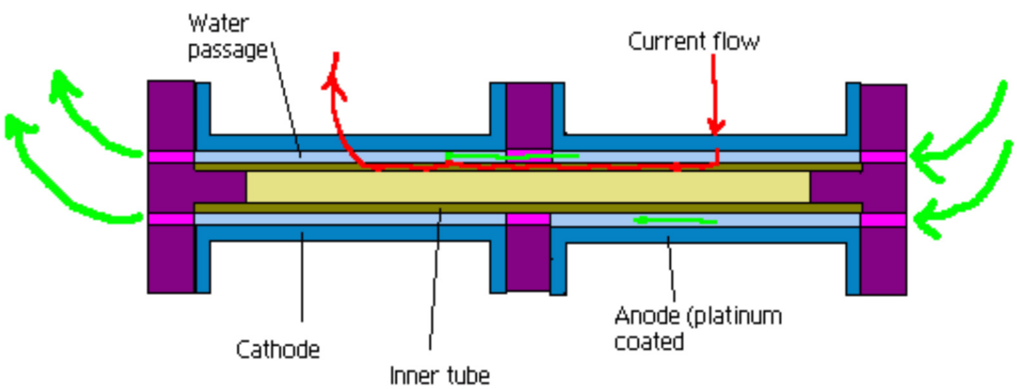
This involves metering in quantities of an anti- foulant into the sea water boxes. A typical chemical is Ferrous chloride which as a by product coats the pipework with a protective ferrous layer.

Ultrasonics

Ultrasonics are said to have a two fold effect on anti-fouling: a disturbance action, caused by the high frequency waves, which renders the habitat unacceptable and a mechanical action, which operates on organisms trying to deposit adhesive, by preventing it from solidifying and on already anchored organisms of 4-5mm. A reduction in fouling of as much as 80% is claimed.

A generator produces and then sends electrical impulses at high frequency via a coaxial cable to transducers mounted externally to the sea chests or strainers. Each transducer contains a piezoelectric ceramic crystals, which when excited by the electrical impulses generate the ultrasonic beam. Power levels are said to be low, with an input of around 300-600w for each generator, which can supply four transducers. The main advantages of this system is that it is non-invasive, no parts are in contact with sea water so require replacing, and that no toxic substances are produced.

Electro-Chlorination



Chlorine is used as an effective pollution control. However, its application raises difficulties in the form that it is used

Chlorine gas is highly toxic and attacks the mucous membranes in the repiratory tract

Anhydrous liquid chlorine has a very high thermal coefficient of expansion and places high hydrostatic loading on container. Also, it is a vigoorous oxidising agent and can cause instant auto-oxidation of metal surfaces when ignited by a spark. Water in trace amounts can lead to rapid corrosion of the container. The release of a 50 ton tank requires evacuation of a 5 mile radius.

Sodium Hypochlorite is available as a 15% high concentration liquid manufactureed by chemical industry
It is odourless and requires no special handling. However the economics of use is poor. A sewage plant requireing 6 ton of chlorine per day would require 83 tonnes of sodium hypochlorite (13-15% solution).

Bulk storage is impractical due to the 100 day half life. On site production removes the costs of transportation.

Method of operation

Titanium is used as the cathode material as it is Electrochemically inert at postive voltages less than 9volts. For the anode the titanium is coated with 100micro inches of platinum. This layer is consumed at a rate of 6 mg/ampere per year giving a life expectancy of 3 years.(Note this layer degrades much more rapidly if the unit voltages and currents are not set correctly)

The Anode/Cathode voltage is 7v

Chlorine is generated a the anode along with other elements to form NaOCl (sodium hyperchlorite). Large quantites of hydrogen are produced which must be safely evacuated.

10pp chlorine in sea water will kill all marine life quickly, 1 PPM will prevent fouling. This may be tested on board.

The total output of chlorine is a function of current rather than flow through the unit, adequate flow is required to ensure cooling and to prevent calcerous deposits.

A typical 1 Kg unit requires a minimum flow of 100 litres per minute. Less than this will mean regualr acide cleaning is required, less than 50Litres per minute will lead to overheating and heavy fouling. Cell damage occurrs at greater than 9v, high voltage alarm/shutdown occurrs at 8 v.

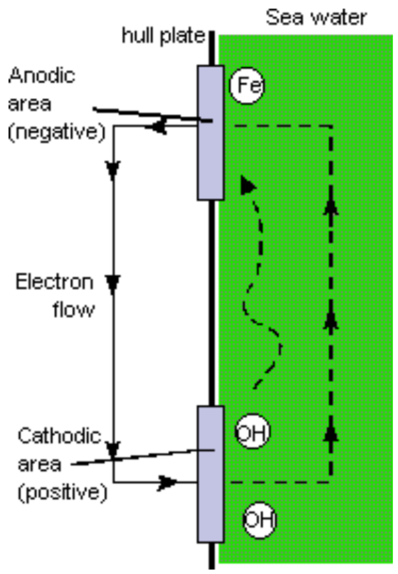
This system is designed to be used in sea water only and not in fresh water.

Troubleshoot:

I have sailed with all these methods and each has proved to be very effective in the control of fouling. The easiest to use by far was the electrolytical unit although the cost of replacement copper anodes (which are quite some size) is prohibitive.

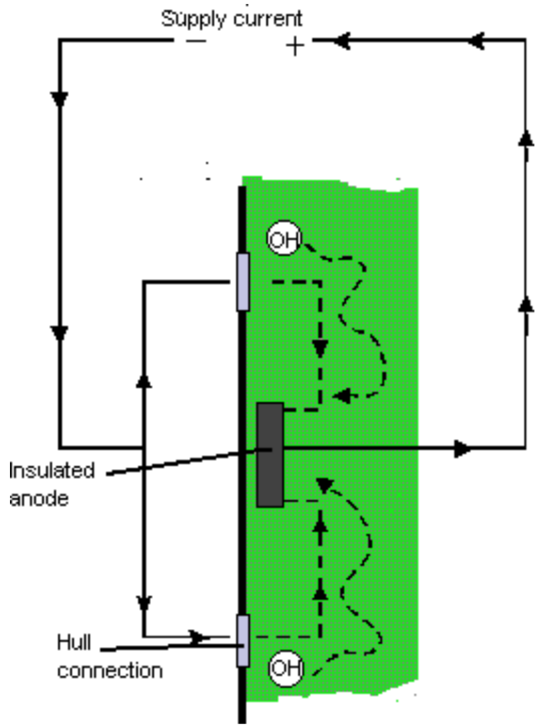
Like all equipment careful monitoring is essential. I joined one vessel and on walkround with my relief noted that the output from the Chlorinator unit was incorrect. After getting the unit operational, which involved the replacement of cells which has been damaged due to incorrect voltage being applied across them, there followed several weeks of cooler cleaning as the growth in the pipework died off.

Cathodic Protection



Different chemical structure, paint thickness', aeration etc. can lead to one area of the hull becoming more cathodic than another.

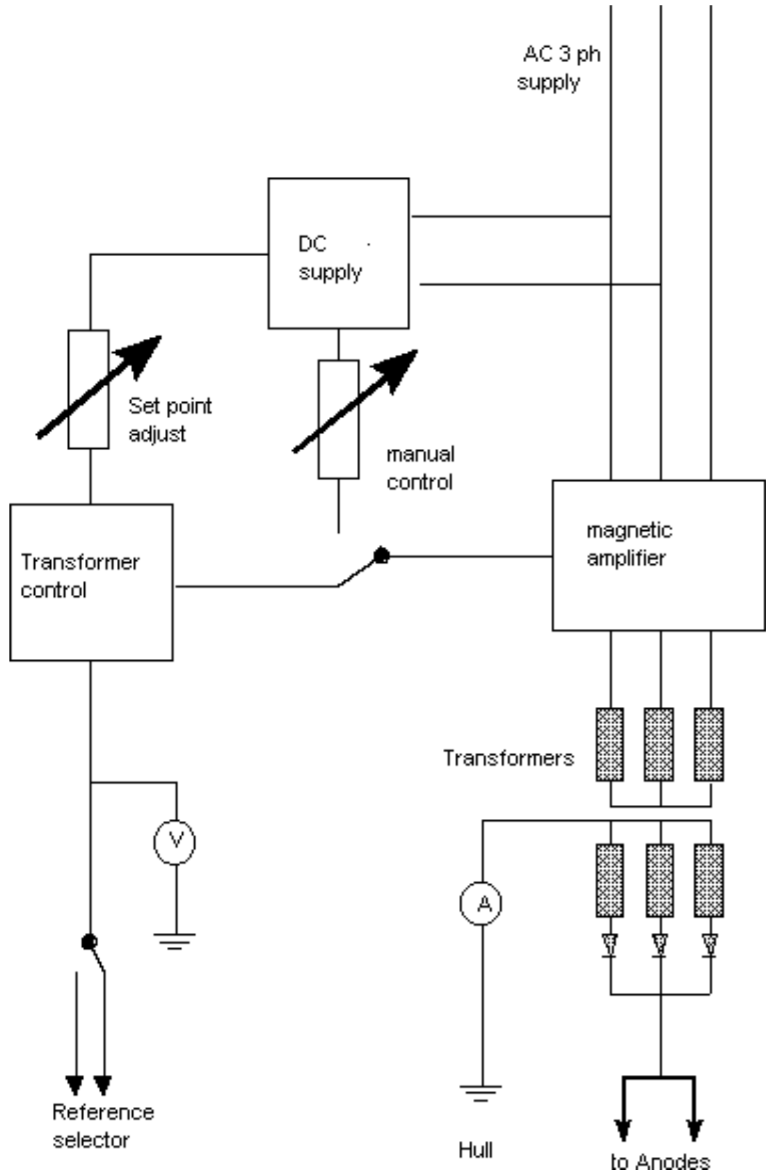
Electrons will flow from the anodic area through the hull to the cathodic area. By hydrolysis negatively charged hydroxyl ions will form. At the anode electron depletion leads to positively charged Iron ions. Hydroxyl ions migrated through the water to the anode, here combining with the iron ions to form $Fe(OH)_2$ which combines with dissolved oxygen to form $Fe(OH)_3$ or rust. In this way the anodic area will corrode. To prevent this it would be necessary to make the entire hull cathodic



The anode is insulated from the hull, electrical connection is via cable and ships side gland box. It may be made of lead or Platinised Titanium. With the lead anodes, the hydroxyl ions turn the surface of the lead a rich brown colour (PbO_2).

A D.C. voltage is applied to just overcome the natural galvanic voltage. If the current is allowed to become too great then the increased Hydroxyl release causes sponginess and flaking of the paint

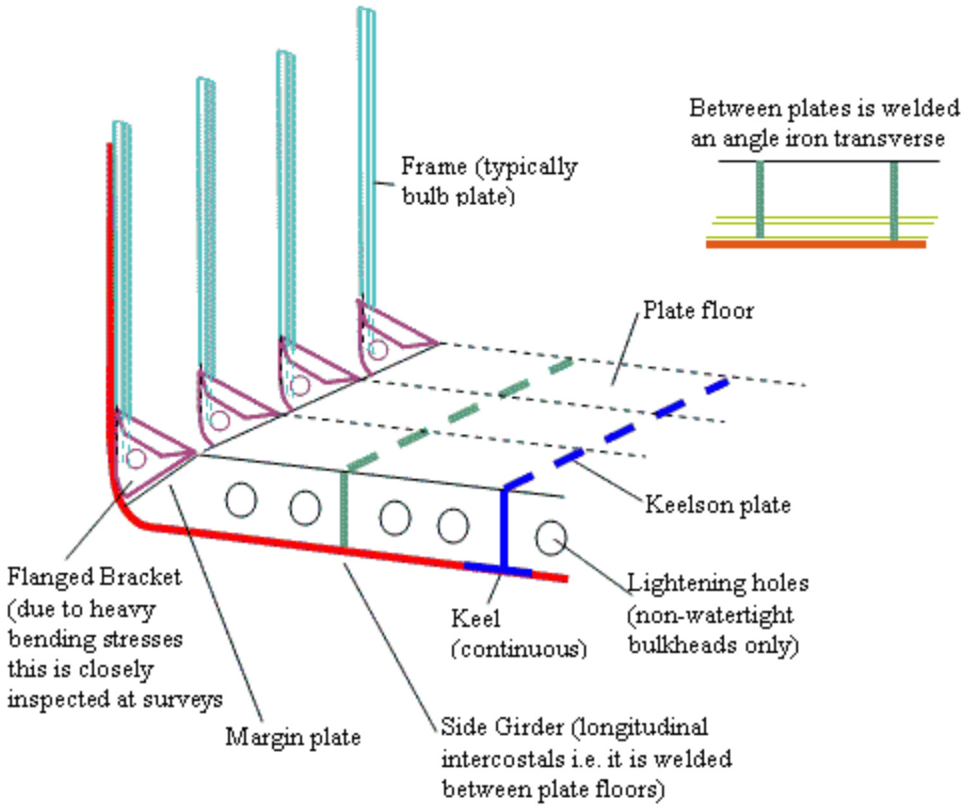
The cathodic system should make the hull 200mV more cathodic i.e. 2oomV negatively charged. The system measures this by checking the hull voltage against an insulated reference anode which has a known value of galvanic voltage with the hull material. Typically this may be Zinc which is normally at a voltage 450mV more negative than the hull, or Silver which is 600 mV more positive than the hull. The Cathodic protection system will try to make the potential difference between the hull and the zinc reference anode 250 mV (Zinc anode 250mV more negative than the hull), and the silver anode 600mV(Silver anode 800mV more positive than the hull).

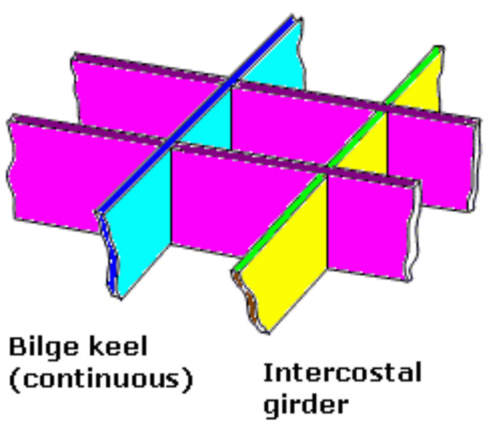


Hull Construction

Transversally stiffened

This structure is now virtually obsolete and may not be used on hulls greater than 120m in length



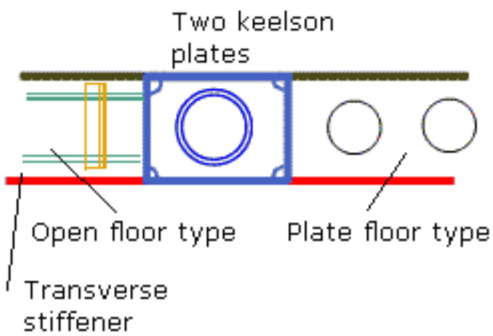


The hull requires a plate floor every 3.05m and a frame every 1m. Hence there are 3 frames for every plate floor. The two frames are attached to the floor angle iron transverse.

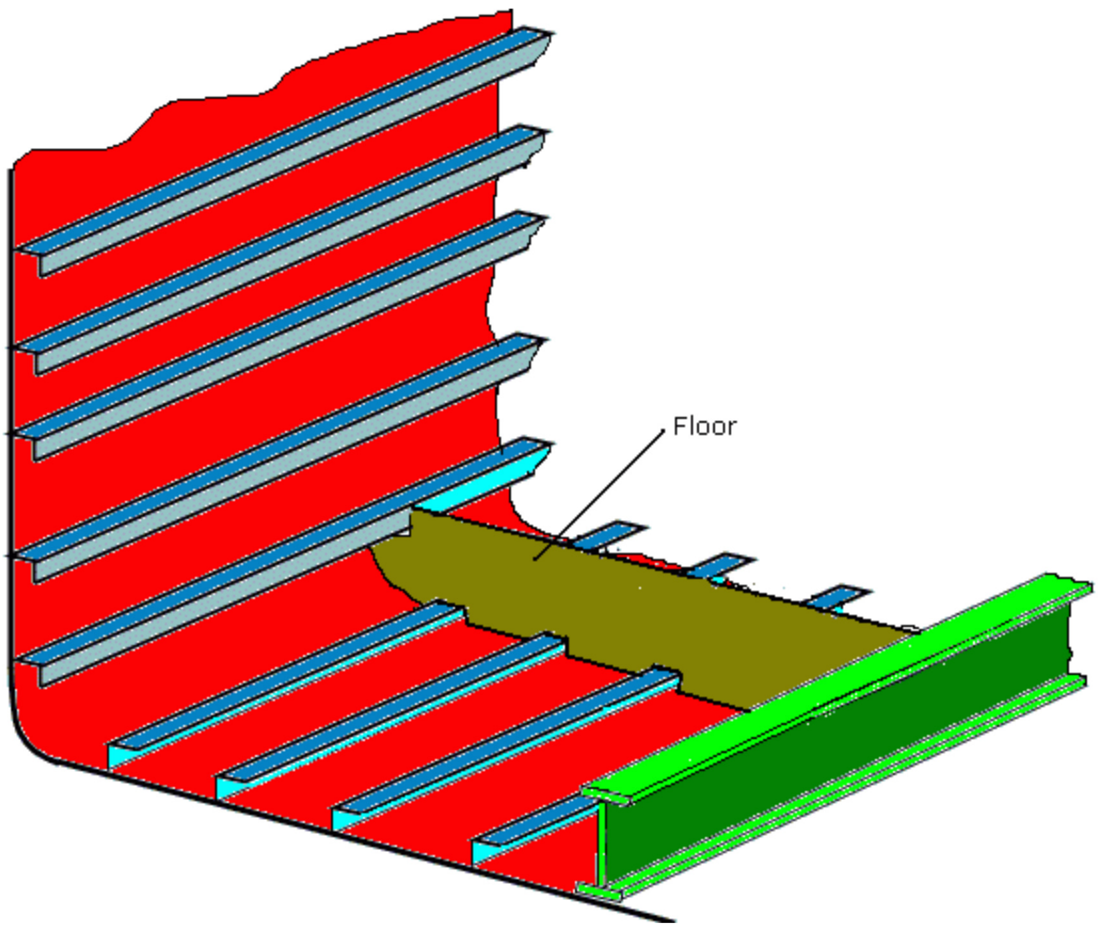
For the aft framing of the aft peak tank or the for'd framing of the for'd collision bulkhead the maximum framing pitch is 0.61m. Also for the for'd 0.2l of the ship the maximum spacing of the frame is 700mm (this helps to prevent damage due to slamming).

Underneath the engine seating a plate flooris required every frame.
The keelp plate is made from heavier section of plate and has its ends tapered to allow it to be welded onto the normal hull plating

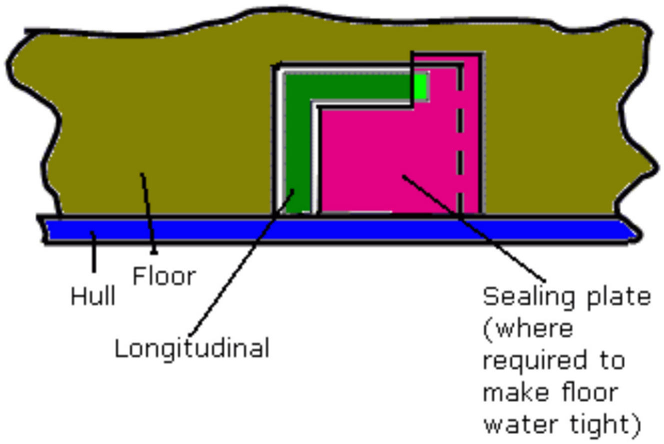
Duct keel construction for transversely framed hull

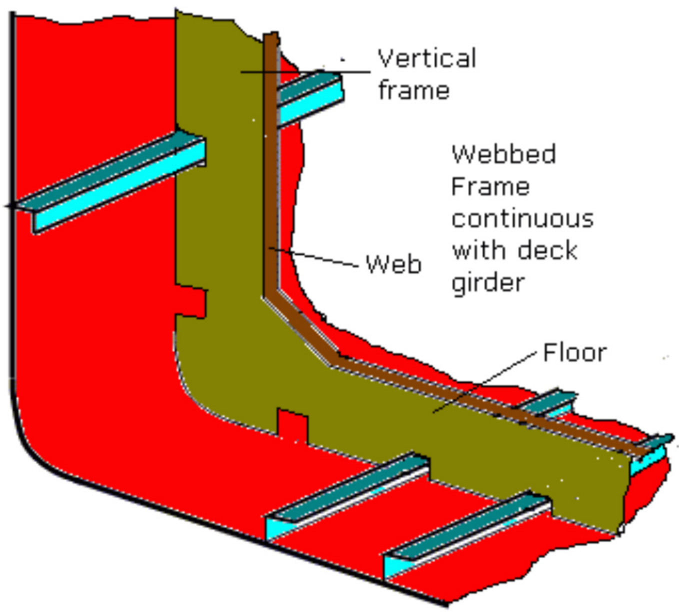


Longitudinally framed hull (tanker)

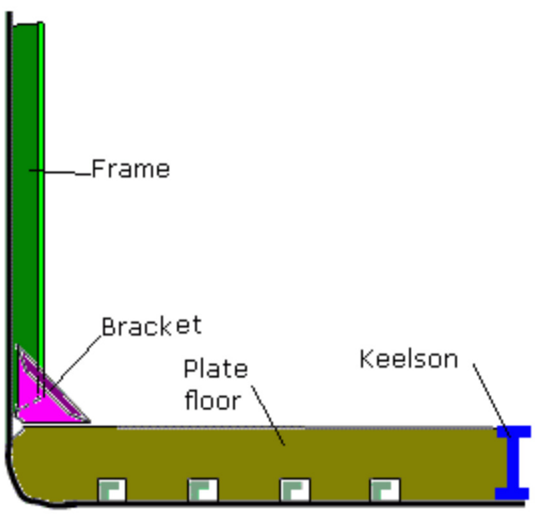


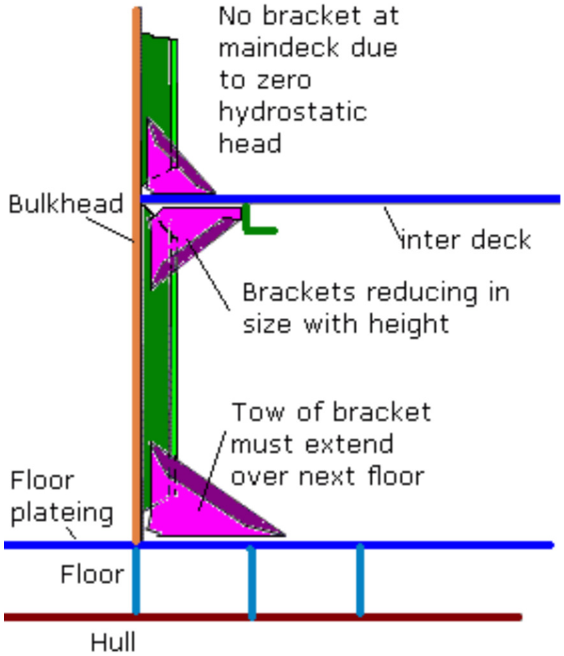
The longitudinal framing is much better able to resist buckling when the hull is hogging

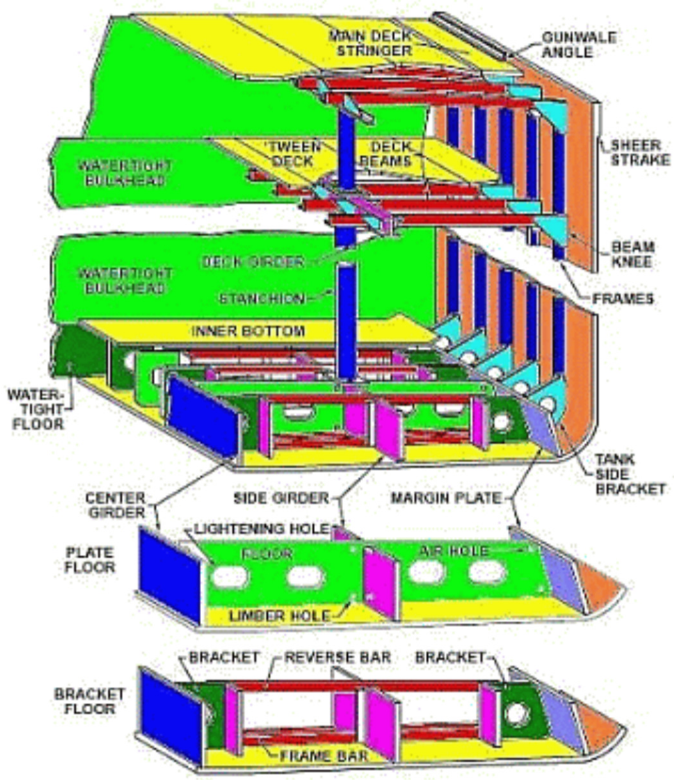


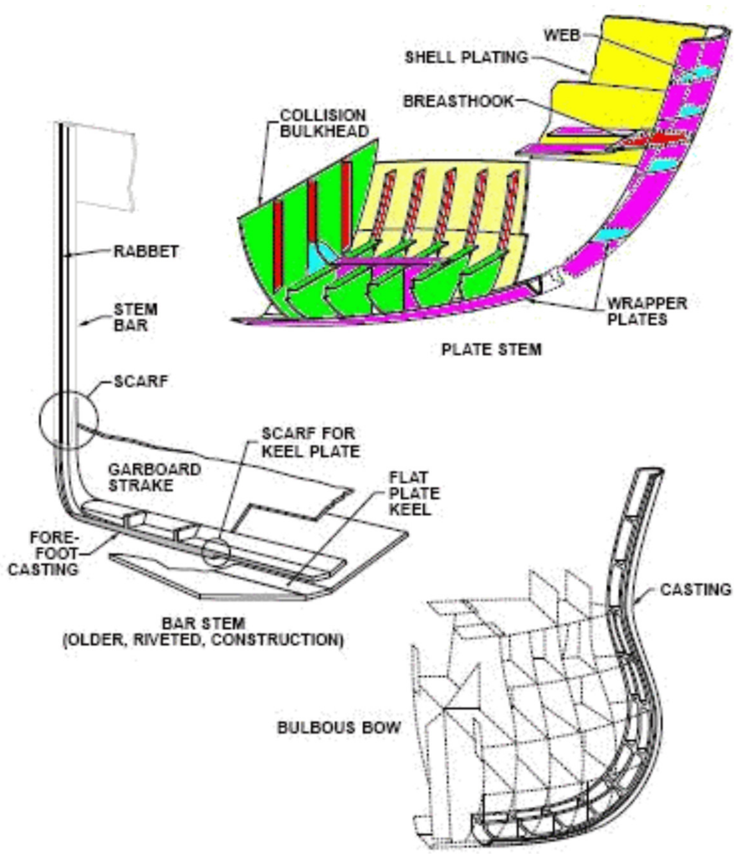


Longitudinal framing (Dry Cargo)




No bracket at maindeck due to zero hydrostatic head
Bulkhead
inter deck
Brackets reducing in size with height
Tow of bracket must extend over next floor
Floor plateing
Floor
Hull


MAIN DECK STRINGER
GUNWALE ANGLE
SHEER STRAKE
'TWEEN DECK
DECK BEAMS
WATERTIGHT BULKHEAD
BEAM KNEE
DECK GIRDER
WATERTIGHT BULKHEAD
STANCHION
FRAMES
INNER BOTTOM
WATER-TIGHT FLOOR
TANK SIDE BRACKET
CENTER GIRDER
SIDE GIRDER
MARGIN PLATE
LIGHTENING HOLE
PLATE FLOOR
FLOOR
AIR HOLE
LIMBER HOLE
BRACKET
REVERSE BAR
BRACKET
BRACKET FLOOR
FRAME BAR


WEB
SHELL PLATING
BREASTHOOK
COLLISION BULKHEAD
WRAPPER PLATES
PLATE STEM
RABBET
STEM BAR
SCARF
SCARF FOR KEEL PLATE
GARBOARD STRAKE
FLAT PLATE KEEL
FORE-FOOT CASTING
BAR STEM
(OLDER, RIVETED, CONSTRUCTION)
CASTING
BULBOUS BOW

Spectacle prop shaft supports

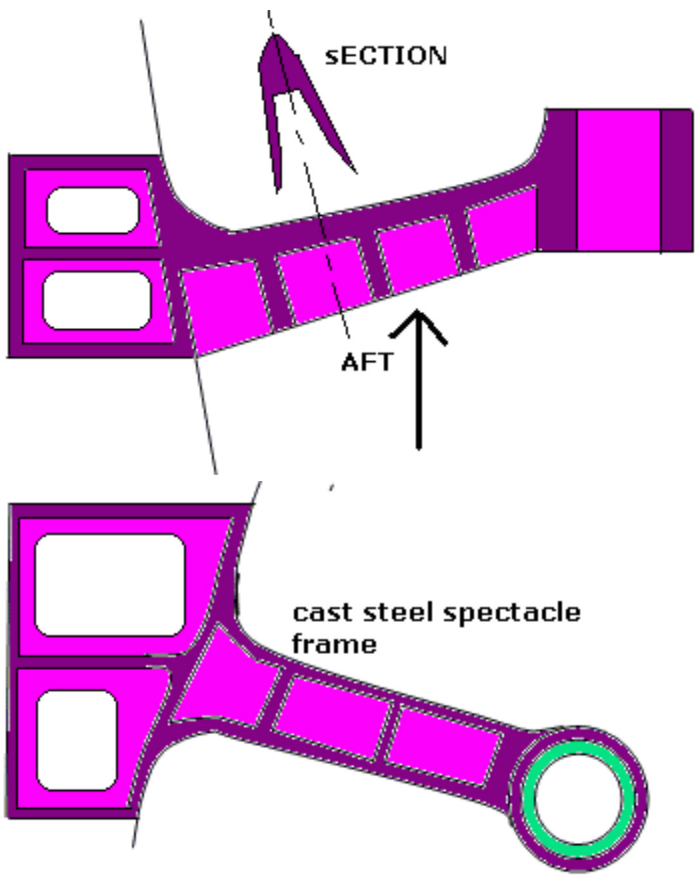
The advantages of mounting drive shafts externally are

- Reduced 'blade passing' hull vibration and noise
- Increase propeller effcicency as hull in clearer water
- Allows finer stern hull form increaseing hull efficiency and reducing material requirements
-

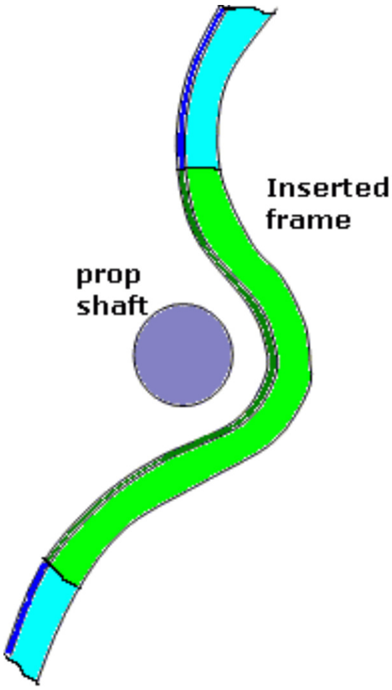
Some disadvantages are

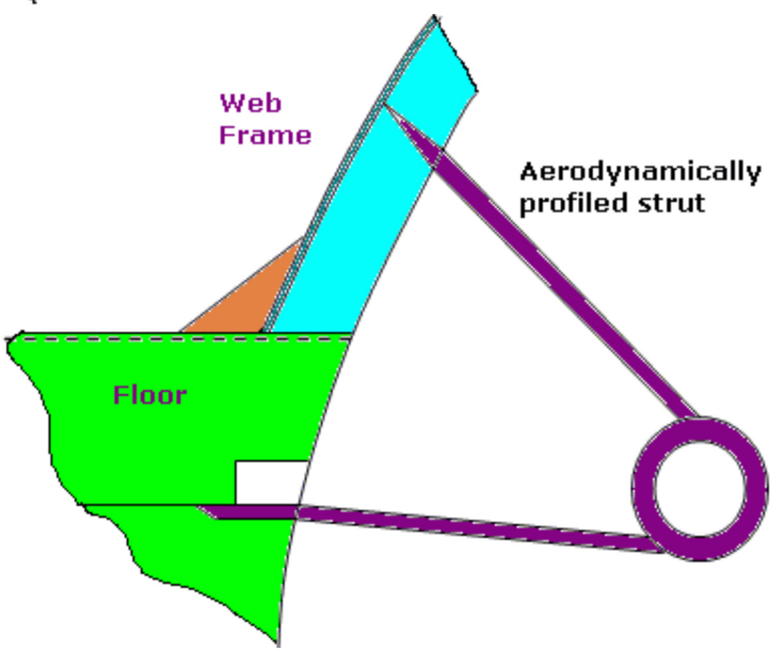
- Propshaft is more open to damage, erosion and corrosion, for some desgins the extended length of the shaft is shrouded.
- Increase hull drag

Cast construction



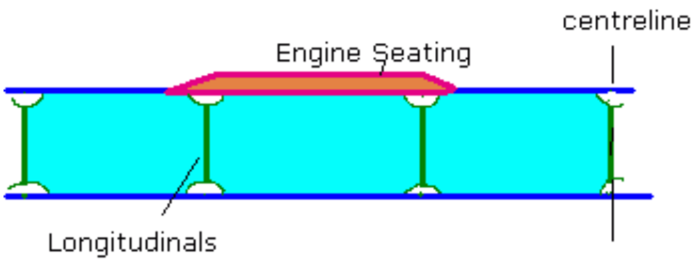
Welded construction


Inserted frame
prop shaft


Web Frame
Aerodynamically profiled strut
Floor

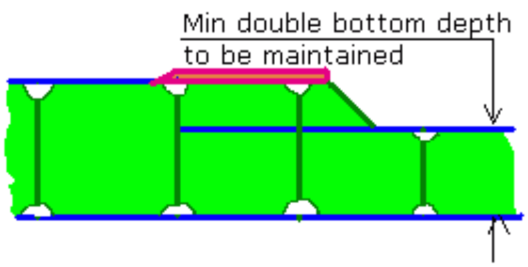
Engine Seating

Flat Bed Plate

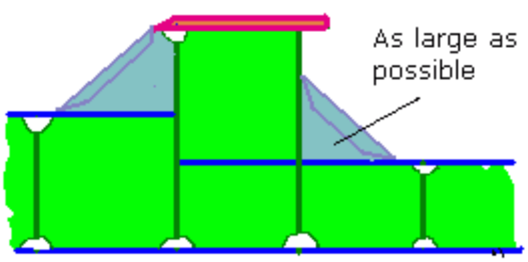


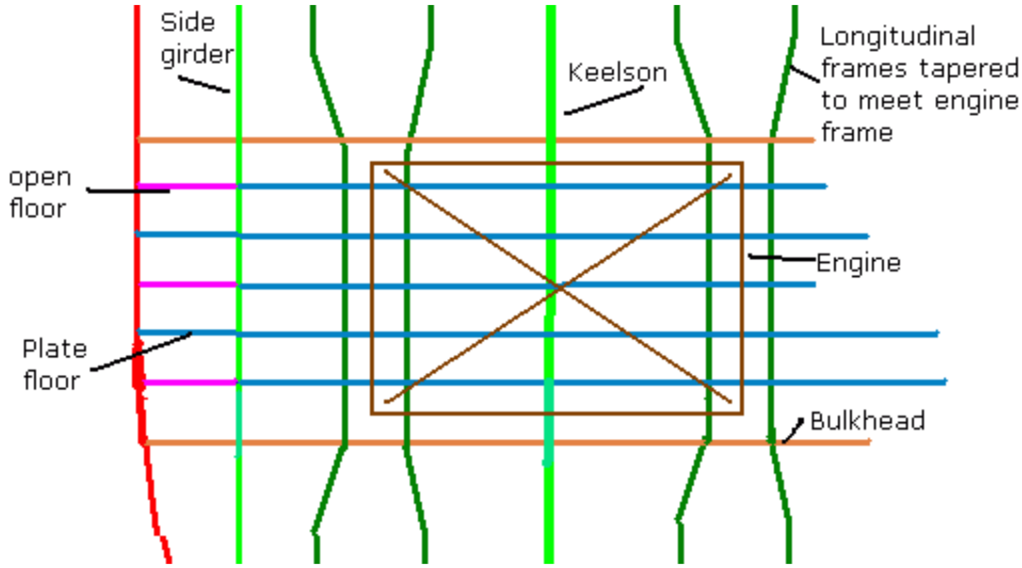
There are transverse plate floors at each frame. The thickness of the engine seating is governed by the power, weight,and length of th eunit

Small Drop-raised Seat



Large Drop-raised seat

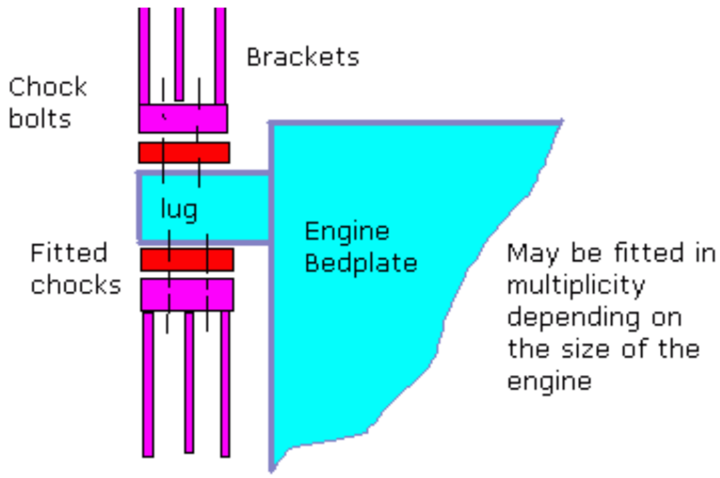


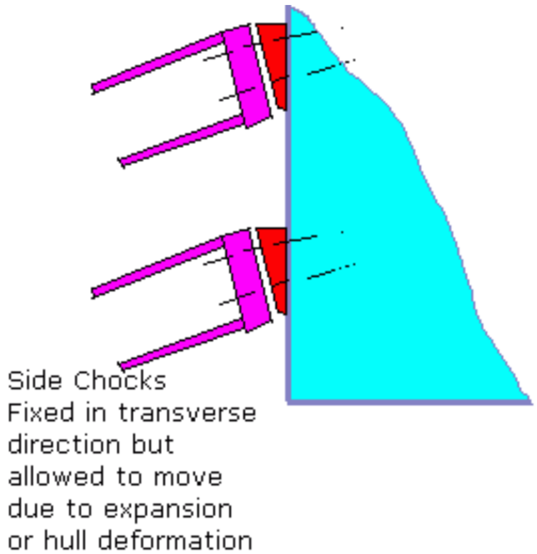


Historically the engine bolts at the after end of the engine were fitted bolts to take the shear of the thrust and the more for'd bolts were loose fit bolts allowing for expansion.

This method has proved unreliable and the more modern practice is to weld lugs on the bedplate and have brackets and fitted chocks

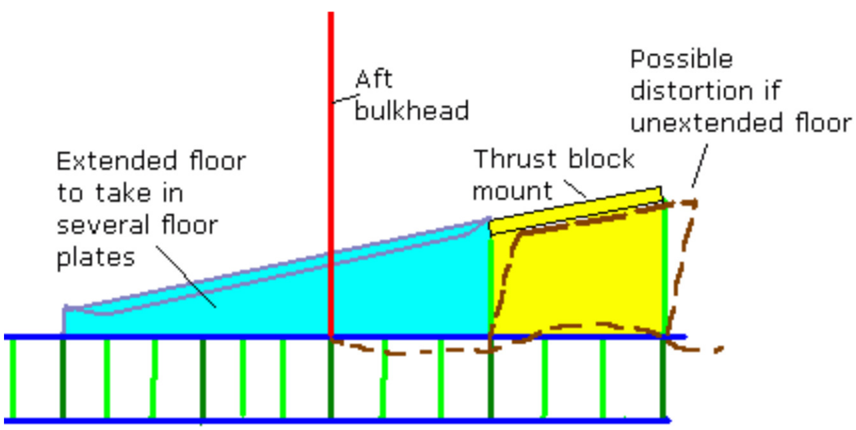
Bedplate location





The holding down arrangement should be arranged to be above any bilge water level to allow for easy access and inspection

Engine Mounting for seperate thrust block



Where the thrust is taken in the gearbox casing it is necessary then to have the mounts for the casing as close as possible to the centreline of the shaft so as to ensure little or no bending moment on the casing. The mountings should be suitably extended in a similar fashion to the thrust block arrangement shown above

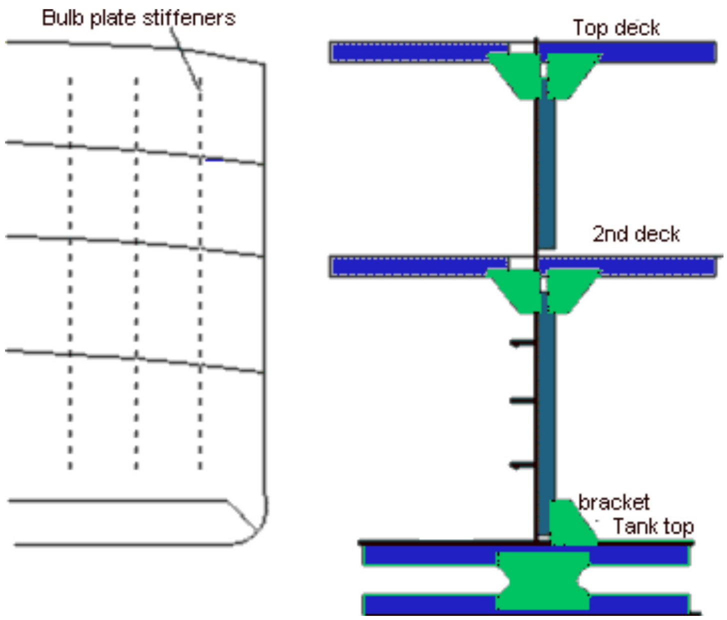
Bulkheads

There are three basic types of bulkhead, watertight, non watertight and tank.

Different types of bulkheads are designed to carry out different functions.

The watertight bulkhead several important ones;

i. *It divides the ship into watertight compartments giving a buoyancy reserve in the event of hull being breached. The number of compartments is governed by regulation and type of vessel*
ii. *cargo separation*
iii. *They restrict the passage of flame*
iv. *Increased transverse strength, in effect they act like ends of a box*
v. *Longitudinal deck girders and deck longitudinal are supported by transverse watertight bulkheads which act as pillars*



Number of bulkheads (cargo ship)

Length of ship (m)		Number of bulkheads	
Above	Not exceeding	Machinery midships	Machinery Aft
90	105	5	5
105	115	6	5
115	125	6	6
125	145	7	6
145	165	8	7
165	190	9	8
190	To be considered individually	To be considered individually	To be considered individually

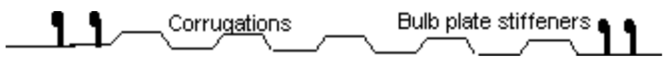
The number of bulkheads depends upon the lenght of the ship and the postion of the machinery. There must be a collision bulkhead positioned at least 1/20th of the distance from the forward perpendicular. This must be continuous to the uppermost continuous deck.

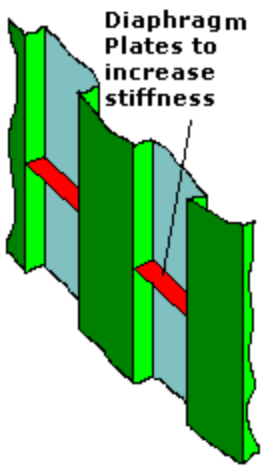
The stern tube must be enclosed in a watertight compartment formed by the stern frame and the after peak bulkhead which may terminate at the first continuous deck above the waterline.

The engineroom must be contained between two watertight bulkheads one of which may be the after peak bulkhead.

Each main hold watertight bulkhead must extend to the uppermost continuous deck unless the freeboard is measured from the second deck in which case the bulkhead can extend to the second deck.

A water tight bulkhead is formed from plates attached to the shell, deck and tank top by means of welding. The bulkheads are designed to withstand a full head water pressure and because of this the thickness of the plating at the bottom of the bulkhead may be greater than that at the top. Vertical stiffeners are positioned 760mm apart except were corrugated bulkheads are used.



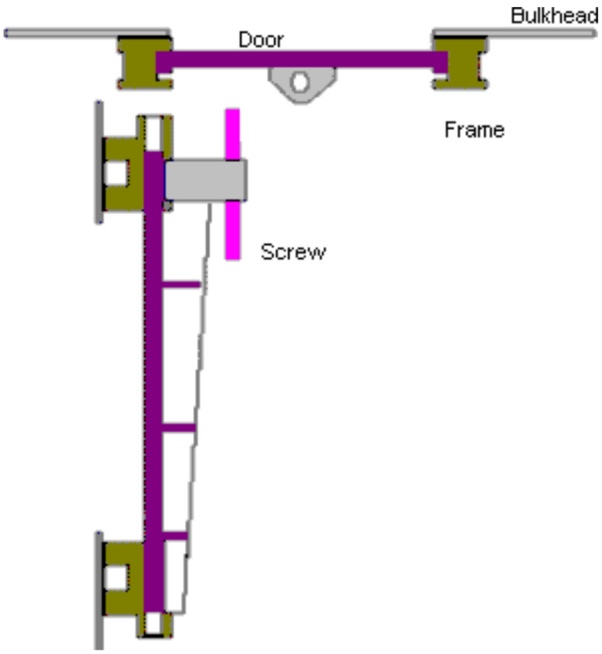


Watertight bulkheads must be tested with a hose at a pressure of 200 Kn/m2 . The test being carried out from the side on which the stiffeners are fitted and the bulkhead must remain watertight.

Water tight bulkheads which are penetrated by pipes, cables etc. must be provided with suitable glands which prevent the passage of water.

Water tight doors

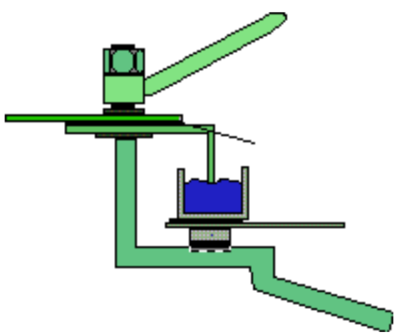
Vertically mounted watertight door



To allow the passage for personnel water tight doors are fitted , openings must be cut only were essential and they should be as small as possible. 1.4m high, 0.7m wide being the usual. Doors should be of mild steel or cast steel, and they may be arranged to close vertically or horizontally.

The closing action must be positive i.e. it must not rely on gravity. Hinged water tight doors may be allowed in passenger ships and in watertight bulkheads above decks which are placed 2.2m or more above the waterline. Similar doors may be fitted in weather decks openings in cargo ships.

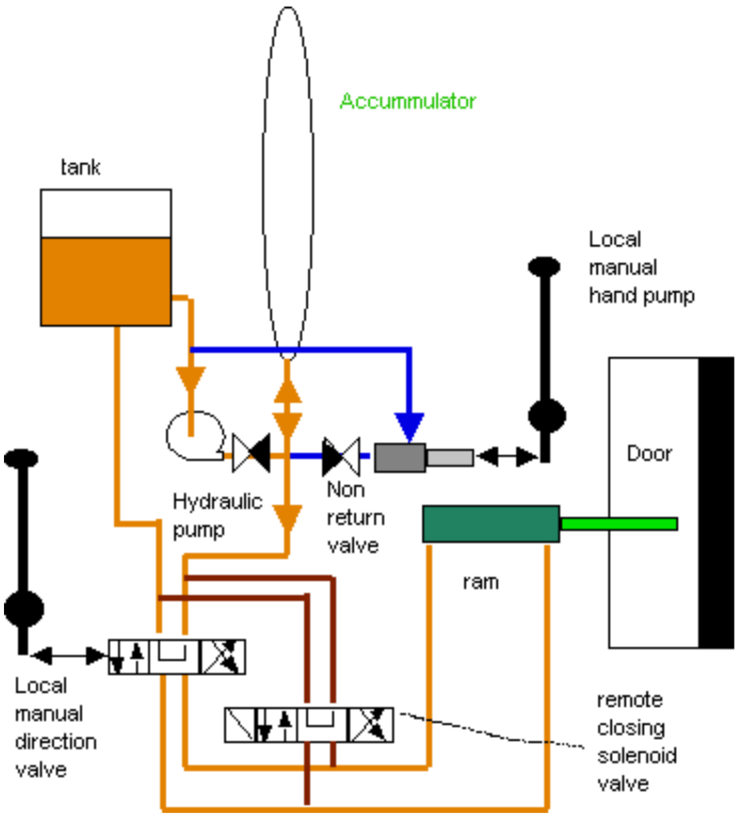
Hinged water tight door



Hinged water tight doors consist of a heavy section door which when closed seals on a resilient packing mounted in channel bar welded to the door frame.

The door is held firmly in the door frame when closed by the dogging arrangements shown which allow the doors to be opened from either side.Normally six of these dogs are spread equally around the periphery.

Automatic watertight operating gear



Automatic operating gear allows the remote operation of watertight doors. These are fitted on many vessels including passenger ships.

In the event of fire or flooding, operation of switches from bridge/fire control area sends a signal to an oil diverter valve. Oil from a pressurised hydraulic system is sent to a ram moving the door.

The door may also be operated locally by a manual diverter valve. In addition, in the event of loss of system pressure the door may be operated by a local manual hand pump

remote door position indicators are fitted as well as were appropriate alarms to indicate operation.

Bulkhead definitions

Class A

Are divisions forming bulkheads and decks that;

- Constructed of steel or equivalent
- suitably stiffened
- Prevent passage of smoke and flame to the end of one hour standard fire test
- Insulated using non-combustible material so that average temperature on exposed side does not rise above 140°C and point temperature above 180°C. The time the bulkhead complies with this governs its class
  A-60 60min
  A-30 30Min
  A-15 15Min
  A-0 0Min

Class B

These are divisions formed by bulkheads, decks, ceilings and lining

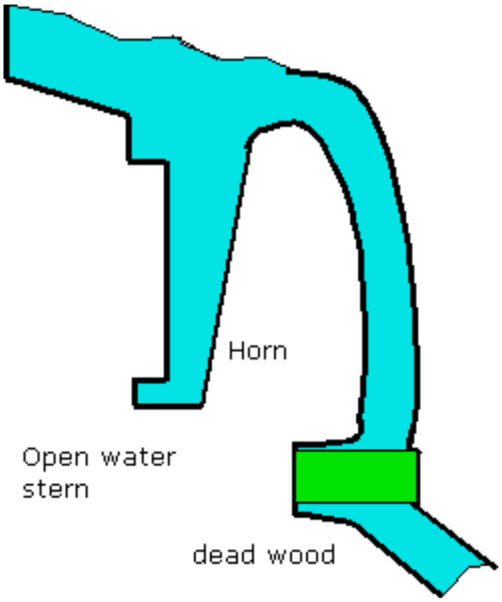
- Prevent passage of flame for first half hour of standard fire test
- Insulated so average exposed side temperature does not rise more than 139^{o}C above original and no single point rises more than 225^{o}C above originalThe time the bulkhead complies with this governs its class
  B-15 15Min
  B-0 0Min
- Constructed of non-combustible material and all materials entering the construction are similarly non-combustible except where permitted

Class C

These are divisions constructed of approved non-combustible materials. Combustible veneers are allowed were they meet other criteria

Main vertical zones Divided by Class A bulkheads and not exceeding 40m in length

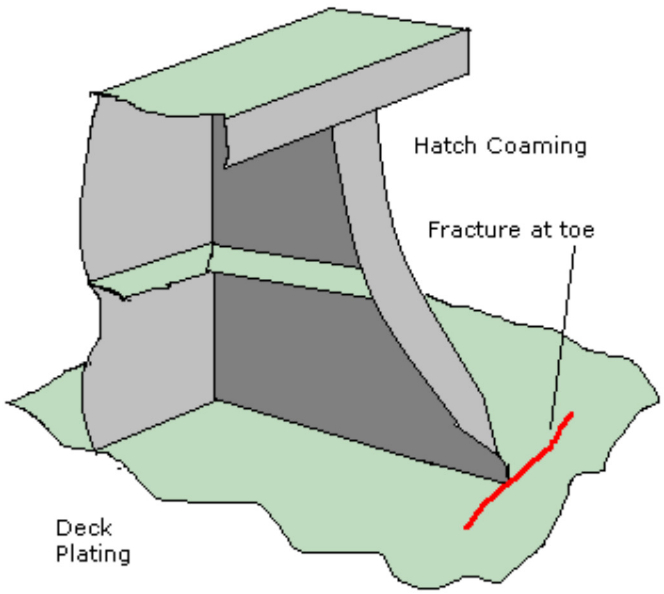
Stern Frame

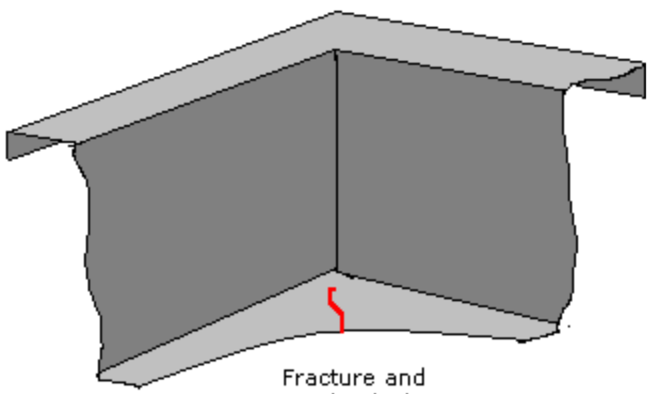


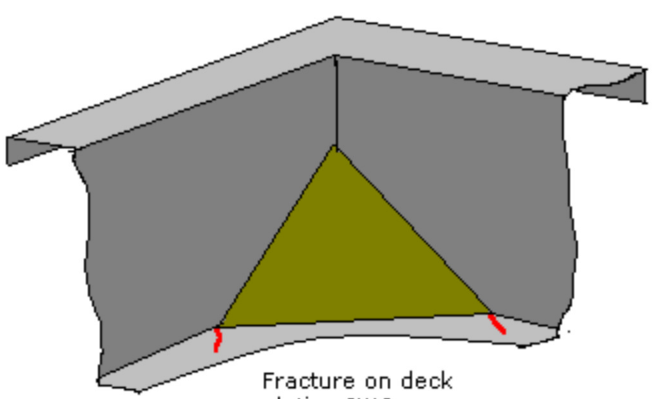
A stern frame may be cast or fabricated and its shape is influenced by the type of rudder being used and the profile of the stern. Sternframes also differ between twin and single screw ships, the single screw sternframe having a boss for the propeller shaft. Adequate clearance is essential between propeller blade tips and sternframe in order to minimise the risk of vibration. As blades rotate water immediately ahead of the blades is compressed and at the blade tips this compression can be transmitted to the hull in the form of a series of pulses which set up vibration. Adequate clearance is necessary or alternatively constant clearance, this being provided with ducted propellers such as the Kort nozzle. A rotating propeller exerts a varying force on the sternframe boss and this can result in the transmission of vibration. Rigid construction is necessary to avoid this. The stern post, of substantial section, is carried up inside the hull and opened into a palm end which connects to a floor plate, This stern post is often referred to as the vibration post as its aim is to impart rigidity and so minimise the risk of vibration. Side plating is generally provided with a Rabbet or recess in order that the plating may be fitted flush. The after most keel plate which connects with this region the structure od the ship serves no useful purpose and it is known as the 'deadwood'. This may be removed without ill effect on stability or performance and some sternframes are designed such that the deadwood is not present.

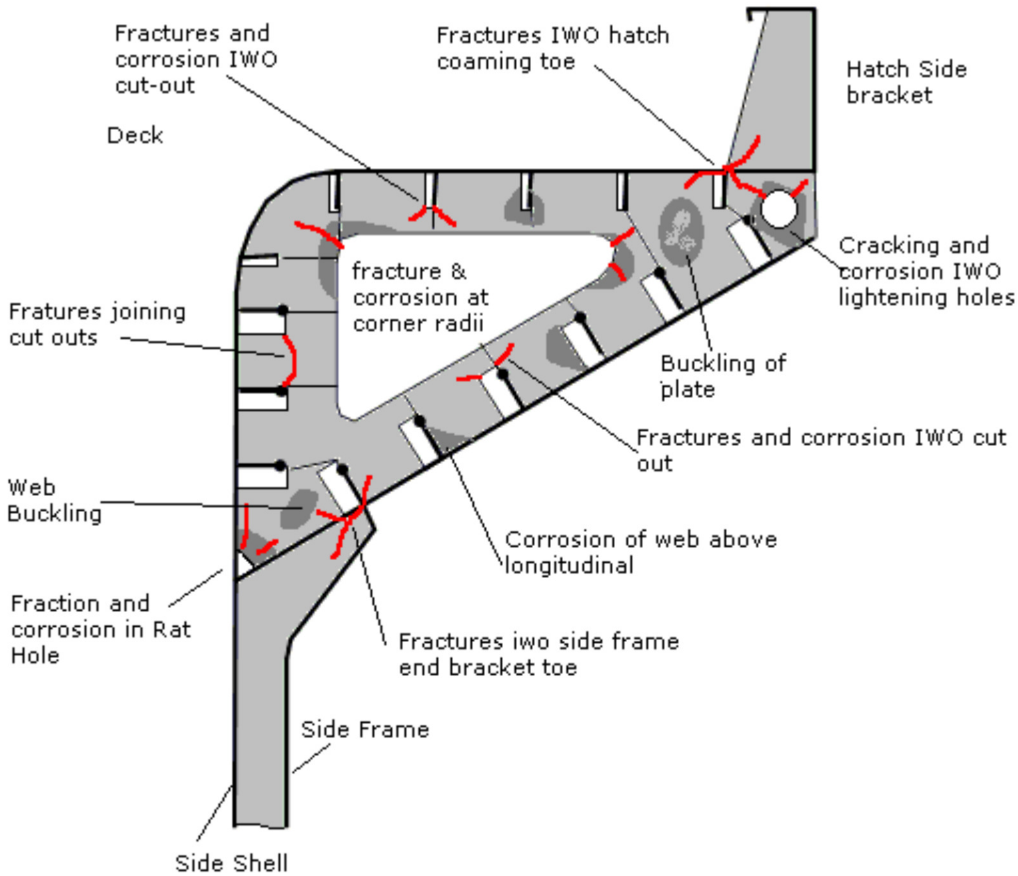
Tank Inspections

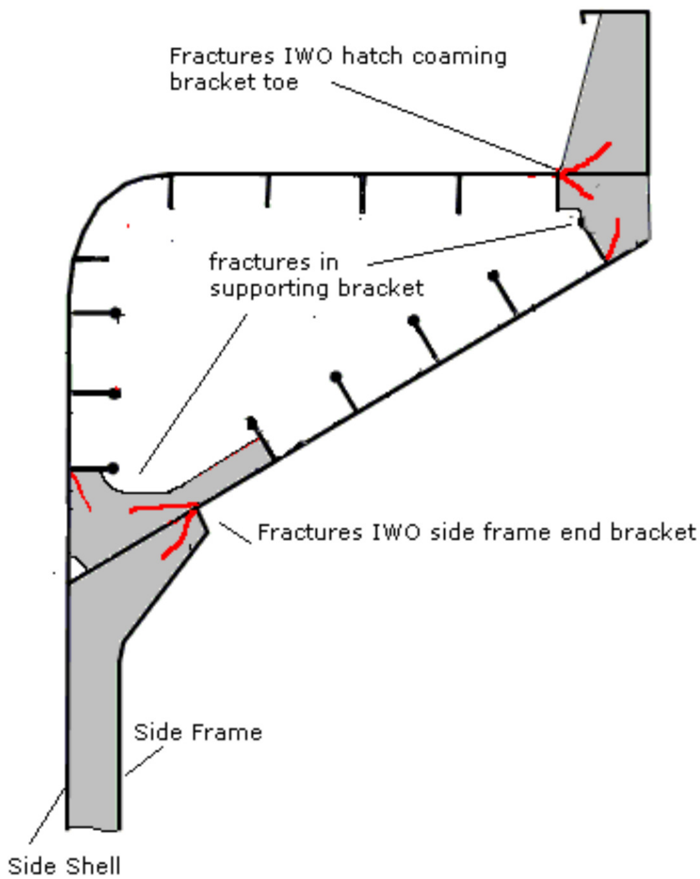
The following describes a few of the common defects found in various hull constructions;

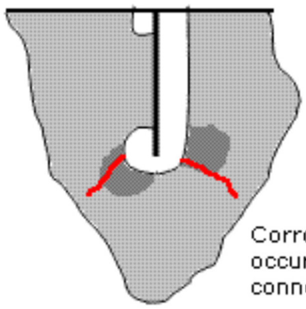




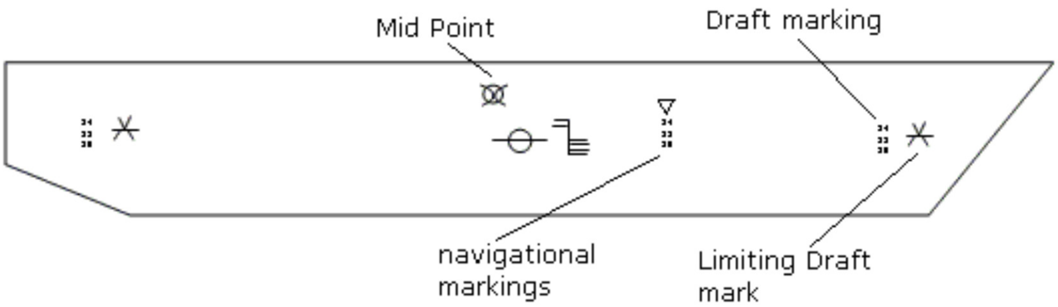


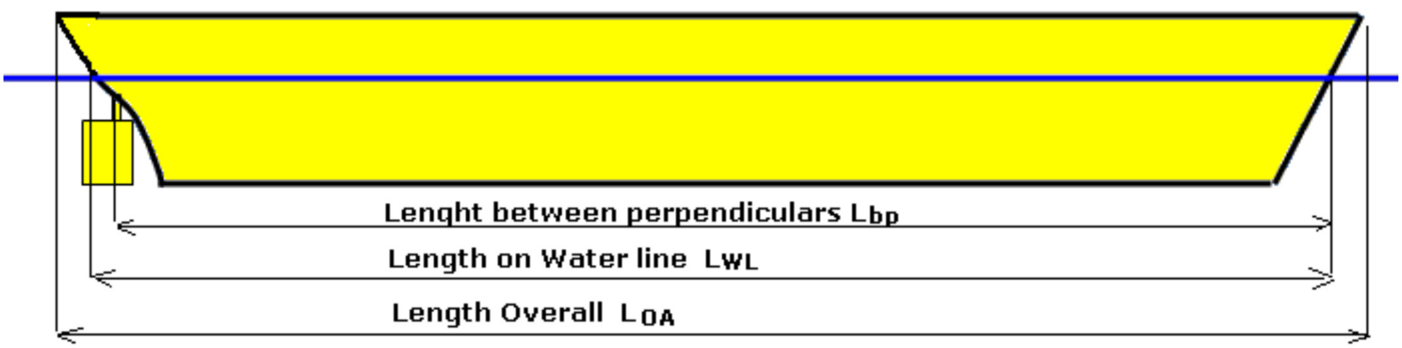

Fractures and
corrosion IWO
cut-out
Fractures IWO hatch
coaming toe
Hatch Side
bracket
Deck
Cracking and
corrosion IWO
lightening holes
fracture &
corrosion at
corner radii
Fratures joining
cut outs
Buckling of
plate
Fractures and corrosion IWO cut
out
Web
Buckling
Corrosion of web above
longitudinal
Fraction and
corrosion in Rat
Hole
Fractures iwo side frame
end bracket toe
Side Frame
Side Shell

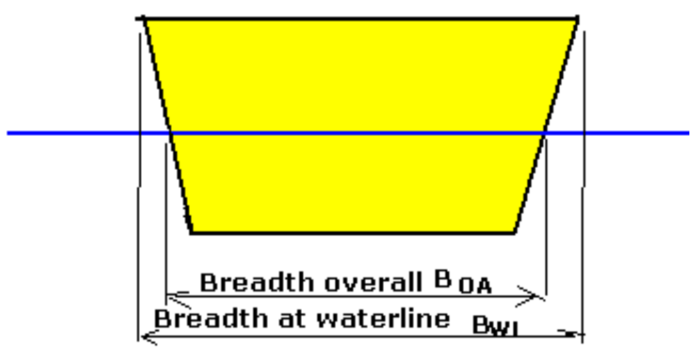

Fractures IWO hatch coaming
bracket toe
fractures in
supporting bracket
Fractures IWO side frame end bracket
Side Frame
Side Shell


Transverse
web plating
Corrosion and fractures
occur in longitudinal
connection cut outs

Ship Nomenclature







Load Line Length(m)- taken as 96 per cent of the total length on a waterline at 85 per cent of the least moulded depth measured from the top of the keel, or as the length from the fore side of the stern to the axis of the rudder stock on that waterline, if that is greater. In ships designed with a rake of keel, the waterline on which this length is measured is to be parallel to the designed waterline. The length is to be measured in metres.

LR Scantling Length-Rule length, is the distance, in metres, on the summer load waterline from the forward side of the stern to the after side of the rudder post or the centre of the rudder stock if there is no rudder post. L is to be not less than 96 per cent, and need not be greater than 97 per cent, of the extreme length on the summer load waterline.

The ships **Draught D** is the vertical distance from the waterline to that point of the hull which is deepest in the water The foremost draught D_F and aft most draught D_A are normally the same when the ship is in the loaded condition.

The **Scantling Draught** is the ships design draught and is equal to the Summer Load Line draught.

Breadth on waterline BWL-the largest breadth on the waterline B_{WL}

Displacement

This is the equivalent mass of sea water (sg = 1.025) displaced by the hull. It is therefore equal to the **Total** weight of the vessel

Deadweight

Deadweight is the difference in tonnes (1000Kg) between the displacement of a ship in water of specific gravity 1.025 at the load waterline corresponding to the assigned summer freeboard and the lightweight of the ship.
It includes bunkers and other supplies necessary for the vessel to proceed on passage as well as cargo.
The Deadweight may be quoted at the design draught although this would be specially denoted

Lightweight

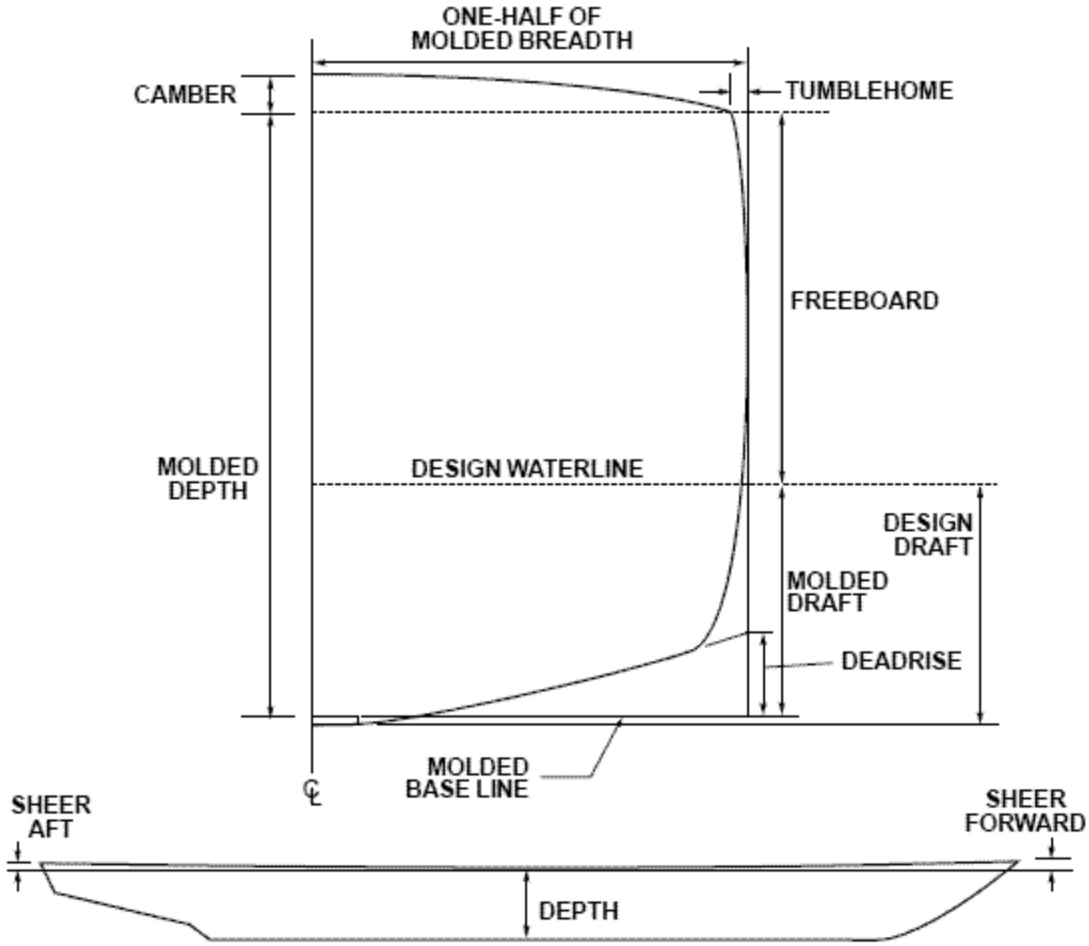
Lightweight is the displacement of a ship in tonnes without cargo, fuel, lubricating oil, ballast water, fresh water and feedwater in tanks, consumable stores, and passengers and crew and their effects.

Thus
DISPLACEMENT = DEADWEIGHT + LIGHTWEIGHT

Gross Register Tonnage, Net Register Tons

This is a volume measurement where one Register Ton is equivalent to 2.83 m^3 and express the total moulded internal size of the vessel and are used for the calculation of harbour and canal dues. It can be found on the International Tonnage Certificate each vessel must hold

Hull Form description



Parallel midbody In many modern ships, the form of the hulls transverse section in the midships region extends without change for some distance fore and aft. This is called parallel midbody and may be described as extensive or short, or expressed as a fraction of the ships length.

Forebody The portion of the hull forward of the midship section.

After body The portion of the hull abaft the midship section.

Entrance The immersed portion of the hull forward of the section of greatest immersed area (not necessarily amidships) or forward of the parallel midbody.

Run The immersed portion of the hull aft of the section of greatest immersed area or aft of the parallel midbody.

Deadrise The departure of the bottom from a transverse horizontal line measured from the baseline at the molded breadth line. Deadrise is also called **rise of floor** or **rise of bottom**. Deadrise is an indicator of the ships form; fullbodied ships, such as cargo ships and tankers, have little or no deadrise, while fine-lined ships have much greater deadrise along with a large bilge radius. Where there is rise of floor, the line of the bottom commonly intersects the baseline some distance from the centerline, producing a small horizontal portion of the bottom on each side of the keel. The horizontal region of the bottom is called **flat of keel,** or **flat of bottom**. While any section of the ship can have deadrise, tabulated deadrise is normally taken at the midships section.

Knuckle An abrupt change in the direction of plating or other structure.

Chine The line or knuckle formed by the intersection of two relatively flat hull surfaces, continuous over a significant length of the hull. In hard chines, the intersection forms a sharp angle; in soft chines, the connection is rounded.

Bilge radius The outline of the midships section of very full ships is very nearly a rectangle with its lower corners rounded. The lower corners are called the bilges and the shape is often circular. The radius of the circular arc is called the bilge radius or **turn of the bilge**. The turn of the bilge may be described as hard or easy depending on the radius of curvature. If the shape of the bilge follows some curve other than a circle, the radius of curvature of the bilge will increase as it approaches the straight plating of the side and bottom. Small, high-speed or planing hulls often do not have a rounded bilge. In these craft, the side and bottom are joined in a chine.

Tumblehome The inward fall of side plating from the vertical as it extends upward towards the deck edge. Tumblehome is measured horizontally from the molded breadth line at the deck edge. Tumblehome was a usual feature in sailing ships and many ships built before 1940. Because it is more expensive to construct a hull with tumblehome, this feature is not usually incorporated in modern merchant ship design, unless required by operating conditions or service (tugs and icebreaking vessels, for example). Destroyers and other high-speed combatants are often built with some tumblehome in their mid and after sections to save topside weight.

Flare The outward curvature of the hull surface above the waterline, i.e., the opposite of tumblehome. Flared sections cause a commensurately larger increase in local buoyancy than unflared sections when immersed. Flaring bows are often fitted to help keep the forward decks dry and to prevent "nose-diving" in head seas.

Camber The convex upwards curve of a deck. Also called round up, round down, or round of beam. In section, the camber shape may be parabolic or consist of several straight line segments. Camber is usually given as the height of the deck on the centerline amidships above a horizontal line connecting port and starboard deck edges. Standard camber is about one-fiftieth of the beam. Camber diminishes towards the ends of the ship as the beam decreases. The principal use of camber is to ensure good drainage in calm seas or in port, although camber does slightly increase righting arms at large angles of inclination (after the deck edge is immersed). Not all ships have cambered decks; ships with cambered weather decks and flat internal decks are not uncommon.

Sheer The rise of a deck above the horizontal measured as the height of the deck above a line parallel to the baseline tangent to the deck at its lowest point. In older ships, the deck side line often followed a parabolic profile and sheer was given as its value at the forward and after perpendiculars. Standard sheer was given by: where sheer is measured in inches and L is the length between perpendiculars in feet. Actual sheer often varied considerably from

sheer forward = 0.2L + 20

sheer aft = 0.1L + 10

these standard values; the deck side profile was not always parabolic, the lowest point of the upper deck was usually at about 0.6L, and the values of sheer forward and aft were varied to suit the particular design. Many modern ships are built without sheer; in some, the decks are flat for some distance fore and aft of midships and then rise in a straight line towards the ends. Sheer increases the height of the weather decks above water, particularly at the bow, and helps keep the vessel from shipping water as she moves through rough seas as well as improving sea keeping by adding bouyancy Ford and Aft.

Rake A departure from the vertical or horizontal of any conspicuous line in profile, defined by a rake angle or by the distance between the profile line and a reference line at a convenient point. **Rake of stem**, for example, can be expressed as the angle between the stem bar and a vertical line for ships with straight stems. For curved stems, a number of ordinates measured from the forward perpendicular are required to define the stem shape. Ships designed so that the keel is not parallel to the baseline and DWL when floating at their designed drafts are said to have raked keels, or to have drag by the keel.

Cut-up When a keel departs from a straight line at a sharp bend, or knuckle, the sloping portion is called a cut-up. This is seen on some high speed craft and on Ice breakers allowing them to ride up on to the ice

Deadwood Portions of the immersed hull with significant longitudinal and vertical dimensions, but without appreciable transverse dimensions. Deadwood is included in a hull design principally to increase lateral resistance or enhance directional stability without significantly increasing drag when moving ahead. Sailing craft require deadwood to be able to work to windward efficiently.
Skegs or fins are fitted on barges to give directional stability. Deadwood aft is detrimental to speed and quick maneuverability and is minimized by use of cut-up sterns and by arched keels or sluice keels (with athwartships apertures) in tugs and workboats.

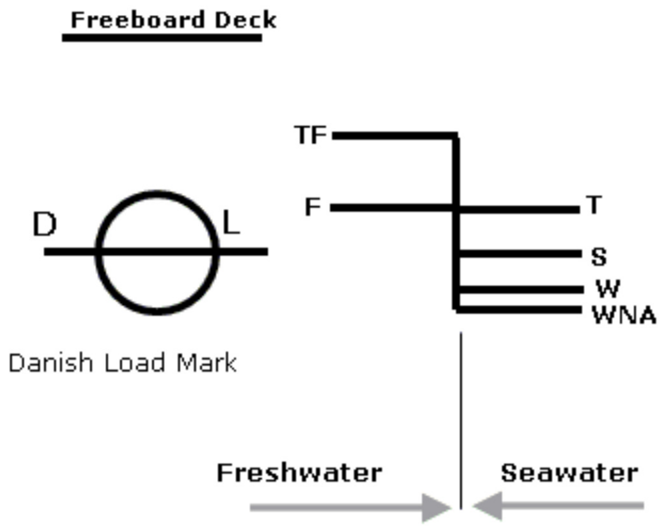
Appendages Portions of the vessel that extend beyond the main hull outline or molded surface. Positive appendages, such as rudders, shafts, bosses, bilge keels, sonar domes, etc., increase the underwater volume, while negative appendages, such as bow thruster tunnels and other recesses, decrease the underwater volume. Shell plating, lying outside the molded surface, is normally the largest single appendage, and often accounts for one-half to two-thirds of the total appendage volume. Appendages generally account for 0.2 to 2 percent of total immersed hull volume, depending on ship size, service, and configuration.

Hull Surfaces Hull surfaces are either warped, consisting of smoothly faired, complex three-dimensional curves, developed, consisting of portions of cylinders or cones, or flat. Hydroconic hulls are built up of connected flat plates rather than plates rolled to complex curves. Hydroconic construction lowers production costs and may simplify fitting patches to a casualty.
The part of the hull which effects the speed and fuel consumed is the area under the water. Thus Length Overall (L_{OA}) is not relevant. Instead the length between perpendiculars (L_{PP} and Length at waterline (L_{WL}) are used. For L_{PP} the aftermost perpendicular is usually taken as passing through the rudder stock. An accepted method of calculation is

$$L_{PP} = 0.97 \times L_{WL}$$

The draught is taken as the design draught. This draught depends on the trading of the vessel and may be between the summer loadline draught and ballast draught

Loadline (Plimsoll) Marking



Each vessel is required to hold a **Loadline Certificate**. Part of the requirements for this is the permanent marking of loadlines on either side of the hull arounf about midhsips. Permanent marking means that they have to be impressed or welded so that they cannot be removed by normal wear and tear. They should be white or yellow on a dark contrasting back ground. Regulations govern the number and size of these, the main ones are described below.

Danish Load mark

The Load Line Mark shall consist of a ring 300 millimeters (12 inches) in outside diameter and 25 millimeters (1 inch) wide which is intersected by a horizontal line 450 millimeters (18 inches) in length and 25 millimeters (1 inch) in breadth, the upper edge of which passes through the centre of the ring. The centre of the ring shall be placed amidships and at a distance equal to the assigned summer freeboard measured vertically below the upper edge of the deck line

Deck Mark

The deck line is a horizontal line 300 millimeters (12 inches) in length and 25 millimeters (1 inch) in breadth. It shall be marked amidships on each side of the ship, and its upper edge shall normally pass through the point where the continuation outwards of the upper surface of the freeboard deck intersects the outer surface of the shell. The location of the reference point and the identification of the freeboard deck is indicated on the International Load Line Certificate (1966). Lines to be used with the Load Line Mark

Loadline Mark

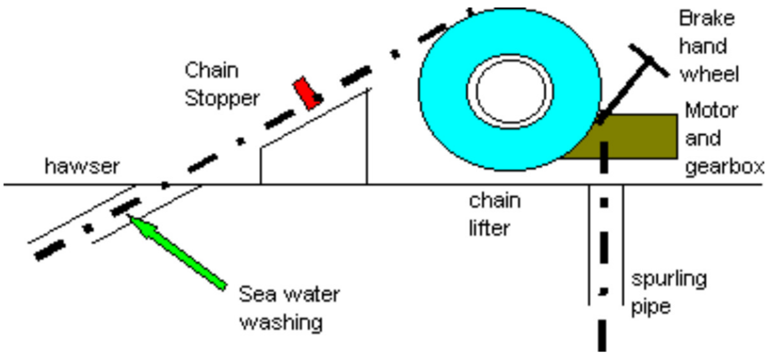
The lines which indicate the load line shall be horizontal lines 230 millimeters (9 inches) in length and 25 millimeters (1 inch) in breadth which extend forward of, unless expressly provided otherwise, and at right angles to, a vertical line 25 millimeters (1 inch) in breadth marked at a distance 540 millimeters (21 inches) forward of the centre of the ring . Aft of thevertical mark refers to loading in freshwater only. For'd refers to loading in sea water only

The loadline mark consists of the following marks

- The Summer Load Line indicated by the upper edge of the line which passes through the centre of the ring and also by a line marked **S**.

- The Winter Load Line indicated by the upper edge of a line marked **W**.
- The Winter North Atlantic Load Line indicated by the upper edge of a line marked **WNA**.
- The Tropical Load Line indicated by the upper edge of a line marked **T**.
- The Fresh Water Load Line in summer indicated by the upper edge of a line marked **F**.
- The Tropical Fresh Water Load Line indicated by the upper edge of a line marked **TF**

Anchoring equipment

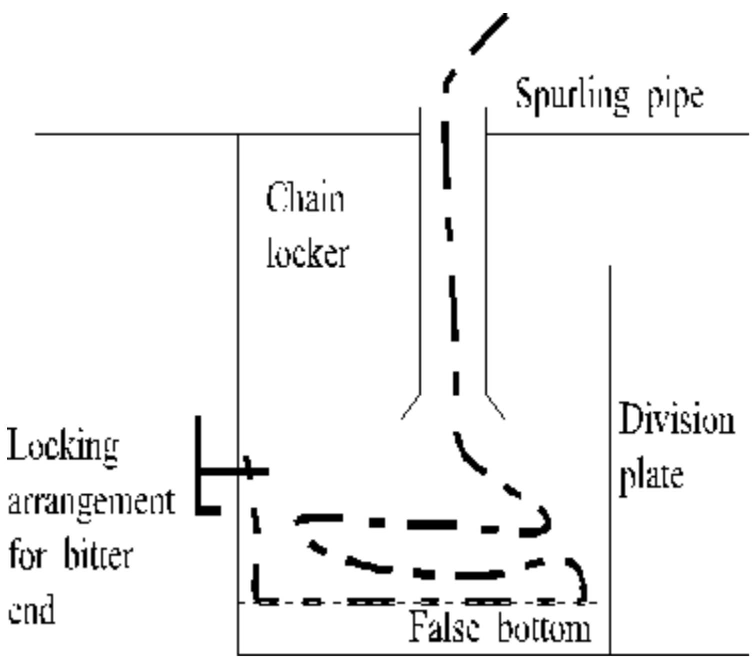


The anchoring equipment fitted to the majority of vessels consists of two matched units, offering a degree of redundancy.

These units consists of an anchor, chain (or for smaller vessels wire), a gypsum or chain lifter wheel, brake, lift motor and various chain stopper arrangements.

When not in he use the chain is stowed in a chain locker, systems fitted with wire are stowed on a drum in the same way as winches.

Chain locker



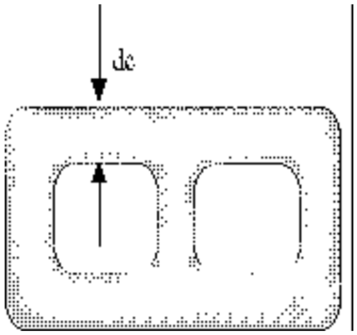
A false bottom is fitted to the chain locker consisting of a perforated plate. This allows water and mud to be removed from the space. The end of the chain is attached to the hull by a quick release mechanism known as the 'bitter end'.

The strength of the 'Bitter End' fixing arrangement for a moderately large vessel is in the region of 6 H tons, this will not be sufficient to prevent a run away unbraked chain. The arrangement must be easily accessible.

The proof load for the windlass (the load the windlass must withstand without being pulled from the deck) is given by;

$6.18\ dc^2\ (44 + 0.08dc)$ [kN]

Where dc is the diameter of the chain metal



This will prove that it is strong enough. It must also be as strong as the braking load on the cable.

The windlass must be capable of pulling the anchor from a depth of 25% of the total cable carried, i.e. 50% of the length of chain on one side

It should be capable of lifting the anchor from 82.5m to 27.5m at 9m/min.

Motive force

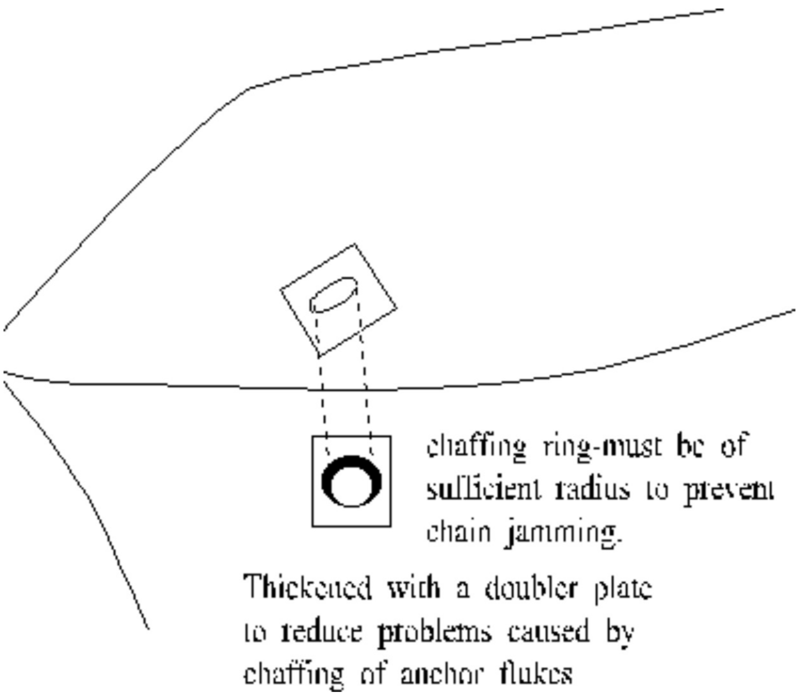
May be steam, electrical, hydraulic or even engine driven although the latter is rare. A gear box arrangement, heavy tooth pitch on final drive, are fitted

Brake

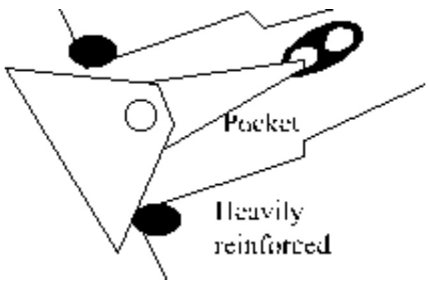
Generally consists of ferodo lined half cylinder steel bands which are joined by a pivot point at the rear. The bands are closed and opened by the action of a threaded brake wheel spindle acting on the fixings at the front of the band ends

Hawser

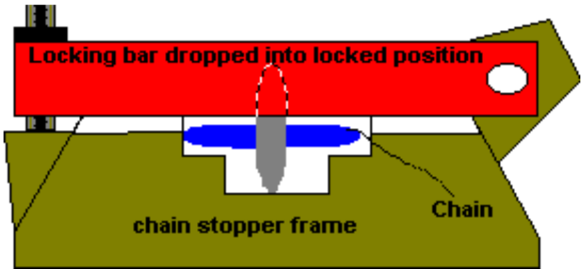
The chain is led overboard by a strengthened and reinforced pipe called a Hawser



One of the reasons for bow flare is to allow the anchor and chain to lie well clear of the hull when in use, preventing damage.



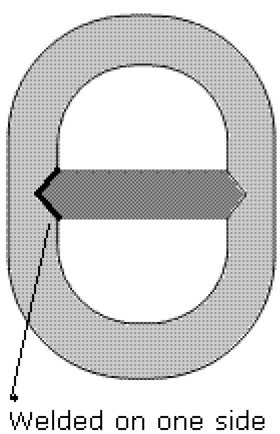
Chain stopper



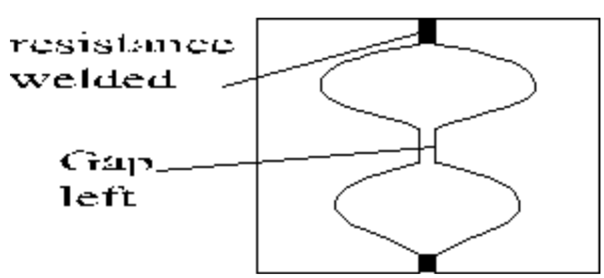
For anchoring operations the stopper bar is locked upright. When it is required to fix the position of the chain the stopper is lowered into the position shown. This allows the brake to be released and is typically used for stowing the anchor. chain stopper arrangements are not design to stop a runaway chain. Alternately an arrangement known as the 'devil's claw' may be used which has a forked locking piece. For smaller vessels, and where extra security is required bottle jacks with wire strops passed though the chain may be used.

Chain

End pull will cause the link to collapse in. This repeated many times will lead to fatigue failure. Hence, stud linked chain is insisted upon



Here a stud is welded on one side in the link to brace it against deformation. An alternative to this albeit in limited use is shown below.



Chain sizing

Each vessel is given an equipment number which is calculated with use of a formula and tkaens into account the vessels size, underwater area and sail area. From this a 'look-up' table may be used to give an appropriate size of cable. The diameter of the chain may be read from this table and differs depending on the grade of steel. This grade of steel varies from U1 (mild steel), U2 (Special Steel) to U3 (extra special steel).

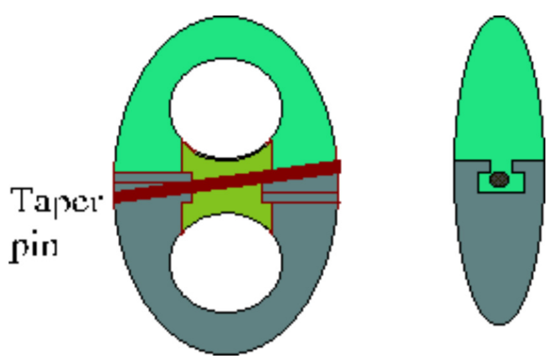
Equipment number		Equipment Letter	Stockless bower anchors		Stud link chain cables for bower anchors			
						Diameter, in mm		
Exceeding	Not exceeding		Number	Mass of anchor, in kg	Total length, in metres	Mild steel (Grade 1 or U1)	Special quality steel (Grade U2)	Extra special quality steel (Grade U3)
60	70	A	2	180	220	14	12,5	
70	90	B	2	240	220	16	14	–
90	110	C	2	300	247,5	17,5	16	–
110	130	D	2	360	247,5	19	17,5	–
130	150	E	2	420	275	20,5	17,5	–
150	175	F	2	480	275	22	19	–
175	205	G	2	570	302,5	24	20,5	–
205	240	H	2	660	302,5	26	22	20,5
240	280	I	2	780	330	28	24	22
280	320	J	2	900	357,5	30	26	24
320	360	K	2	1020	357,5	32	28	24
360	400	L	2	1140	385	34	30	26

The size of cable that is to be used is found by the use of a formula which is

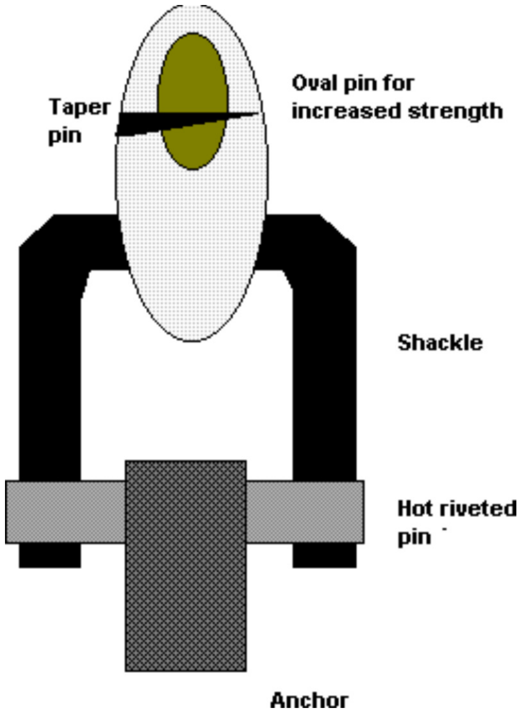
Equipment number = D2/3 + 2Bh +A

where
D = Displacement
B = beam
h = Freeboard + height of deckhouses over B/4 wide
A = Transverse area including deckhouses over B/4 wide

Connecting chain and components



To join two sections of chain a 'kenter' (don't quote me on the name) shackle is used. This consists of two half sections and removable bridge all held together by a tapered pin. This arrangement works remarkably well and can be found on all sizes of chain.



Ranging Anchor Chain

During docking the anchor chain is lowered from the chain locker to the dock bottom and laid out for inspection.

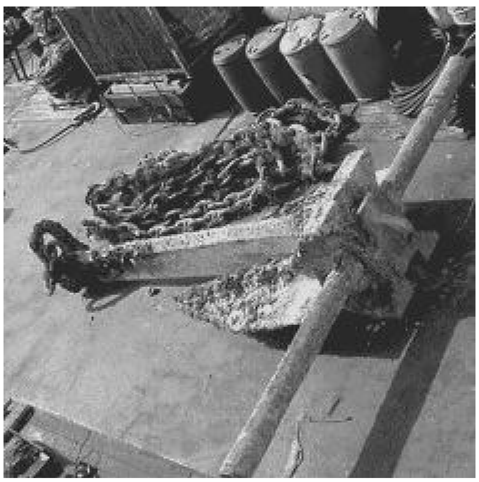
This allows the inspecion of the chain for broken or lost chain studs. A random set of links are measured from each shackle length (Shackle refers to a standard length- nominally 27.5m, of chain joined to other shackle lengths by a splitable link). There is an allowable wear limit allowed nominally 12%. The link showed below has wear in excess of this and the shackle length required replacement.

Anchor designs

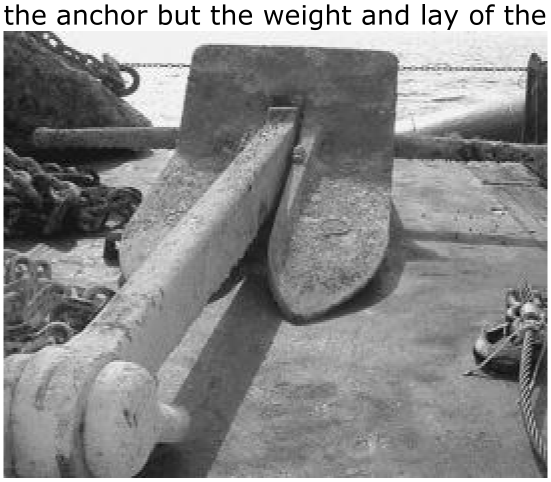
All of the anchors shown below are of the 'flipper' type. Regulations allows these to be smaller than standard types

Below is an anchor of typical design seen in many small to medium sized tankers

Below is a high grip anchor typical of that used for four mointing mooring of vessels required to fix their positions accurately



This anchor weighs about 20 tonnes without attachments. The chain link in comparison the anchor size probably indicates this came from a jack up barge. For vessels the holding comes not only from the anchor but the weight and lay of the anchor chain



Again the chain link in comparison the anchor size probably indicates this came from a jack up barge

Freeboard

Freeboard is the distance between the waterline and the freeboard deck at mid length. The freeboard deck is the uppermost continuous deck which has means of closing all openings. Rules allow different freeboards for different ships in relation to their construction and cargo they carry. There are two types of ship;

Type A -which covers vessels designed to carry only liquid cargoes.

Type B-Which covers all other types of ship,

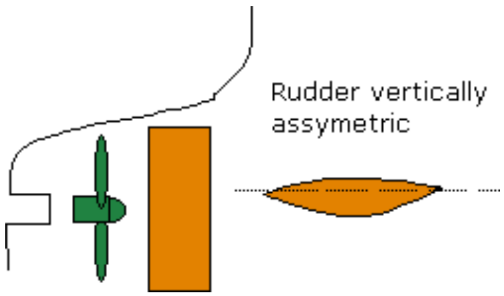
For type A ships cargo tanks must only have small openings which can be effectively sealed

Type B ships must have sufficient bulkheads and sealing arrangements for openings, but such openings e.g. hatches can be large

The freeboard allowed will be smaller for the type A ship compared to the type B ship of similar length because of the type of cargo carried and means of access for water. Type B ships classed as B-60 may have their freeboard reduced by 60% of that required for a normal B-100 ship provided that its method of construction approaches that of the type A ship. This type exists with OBO's.

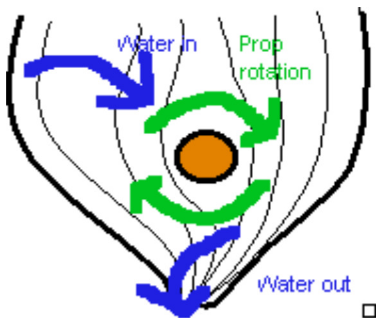
Designs to reduce propeller vibration and increase propulsive efficiency.

Shaped rudder



As the wash of the propeller does not enter at the same angle rudders (sometimes called 'slopped') with uneven inlet angles are sometimes fitted to even the flow from the propeller.

Asymmetric hull

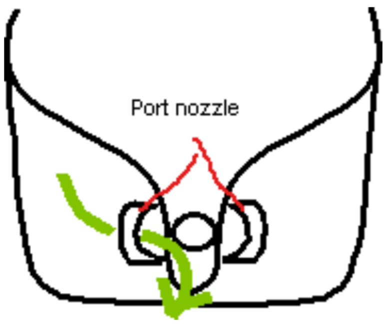


Another design involves the use of design. The water is directed in the same direction as the blade rotation and hence the shock loading occurring when the blade hits relatively still water is removed

Increasing number of blades and skewing

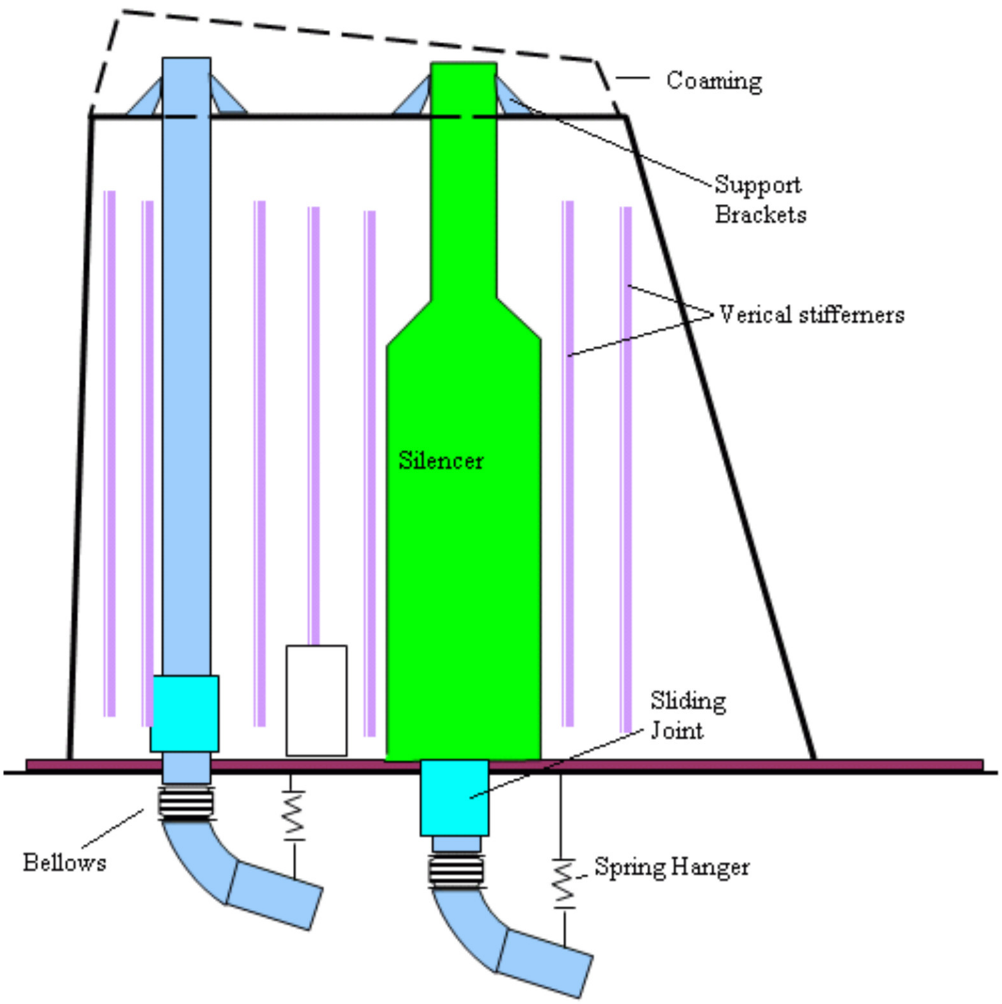
An overlap can be arranged to reduce the pressure fluctuations and change the forcing frequency

Half Kort (Port Nozzles)



Consists of two half loops mounted either side of the hull which smooths the flow of water into the propeller

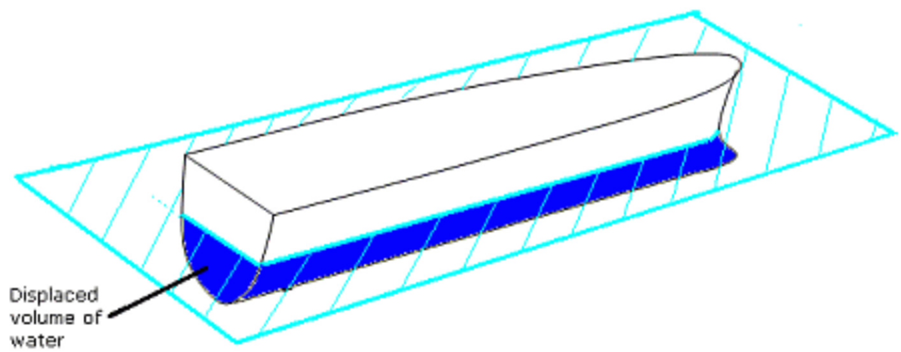
Funnel


Coaming
Support
Brackets
Verical stiffeners
Silencer
Sliding
Joint
Bellows
Spring Hanger

Stability

Fundamental of Buoyancy

- A Floating body displaces a volume of water equal to the weight of the body

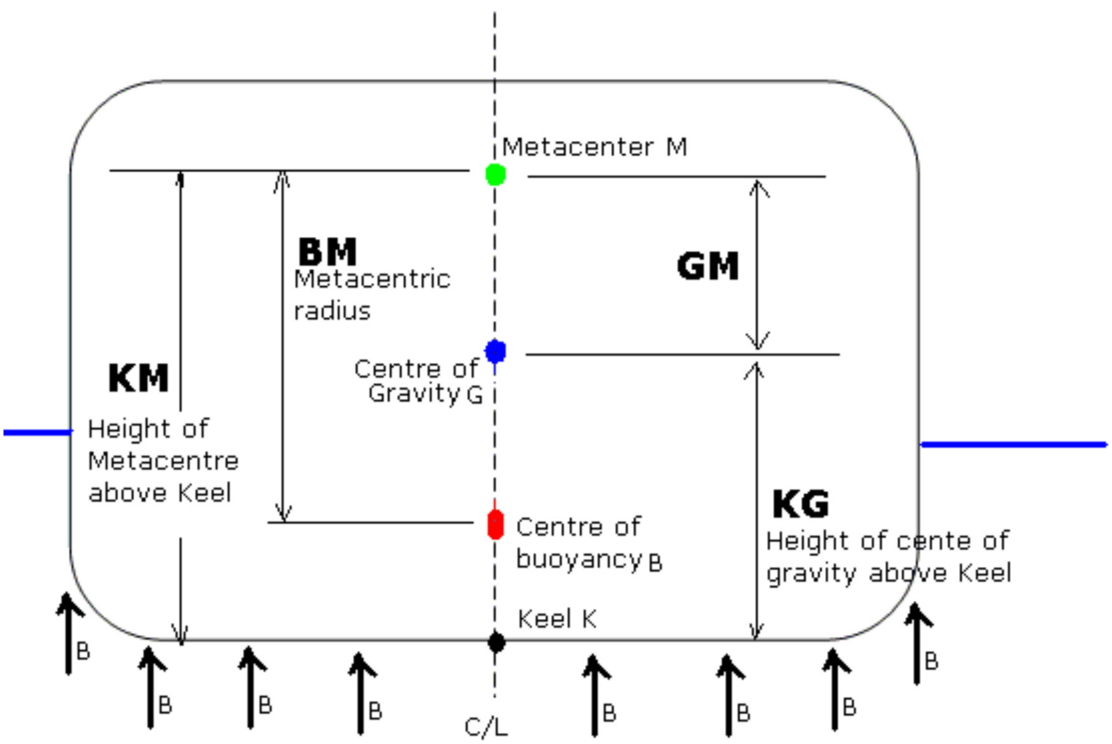


- A Floating body will be buoyed up by a force equal to the weight of the water displaced

Displacement

This is the equivalent mass of sea water (sg = 1.025) displaced by the hull. It is therefore equal to the **Total** weight of the vessel. The units are tons (long)

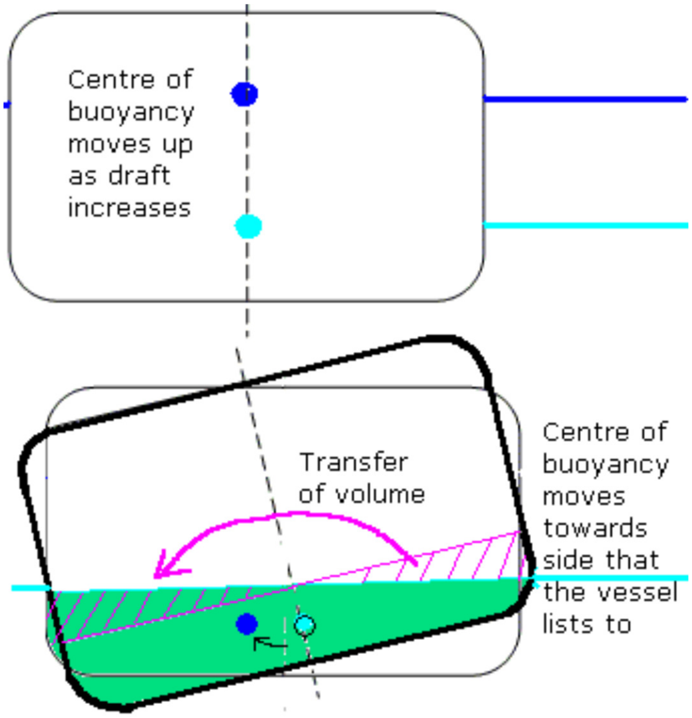
Small angle stability- Listing



The **center of Buoyancy B** is a theoretical point though which the buoyant forces acting on the wetted surface of the hull act through.

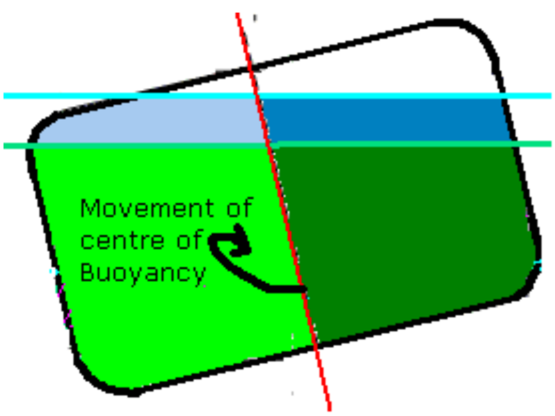
The **center of Gravity** is the theoretical point through which the summation of all the weights act through

Affects of listing

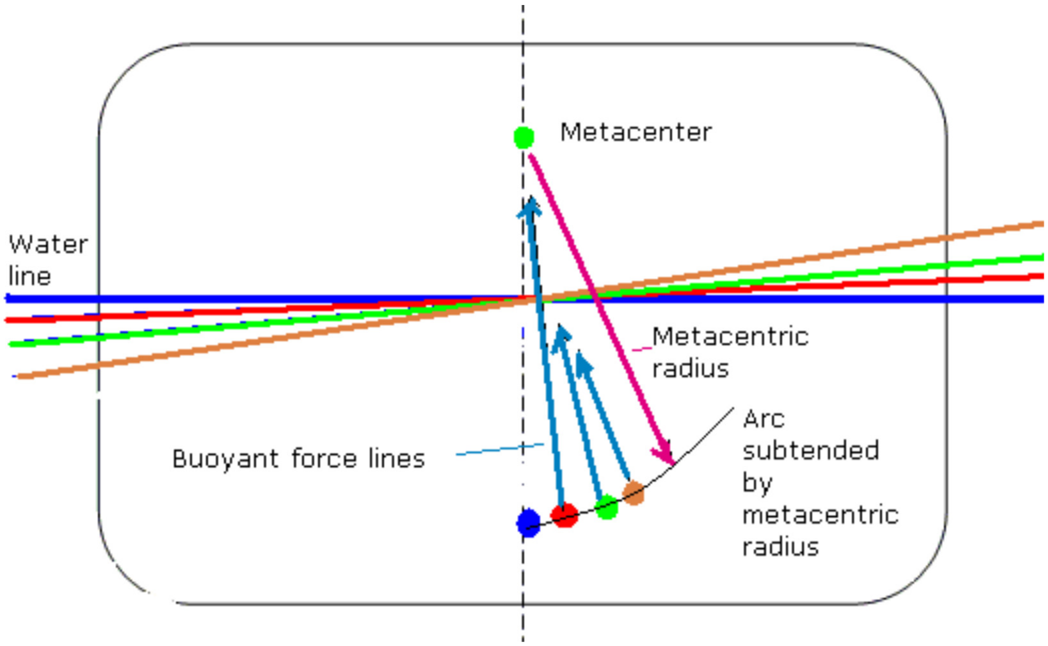


The position of the center of buoyancy changes depending on the attitude of the vessel in the water. As the vessel increases or reduces its draft so the center of buoyancy moves up or down respectively caused by increase in water displaced. As the vessel lists the center of buoyancy moves in a direction governed by the changing shape of the submerged part of the hull. For small angles the tendency is for the center of buoyancy to move towards the side of the ships which is becoming more submerged

Affects of listing to larger angles or low freeboard



Note this is true for consideration of small angle stability and for vessels with sufficient freeboard. In the example shown above when the water line reaches and moves above the main deck level a relatively smaller volume of the hull is submerged on the lower side for every centimeter movement as the water moves up the deck. The center buoyancy will now begin to move back towards centreline

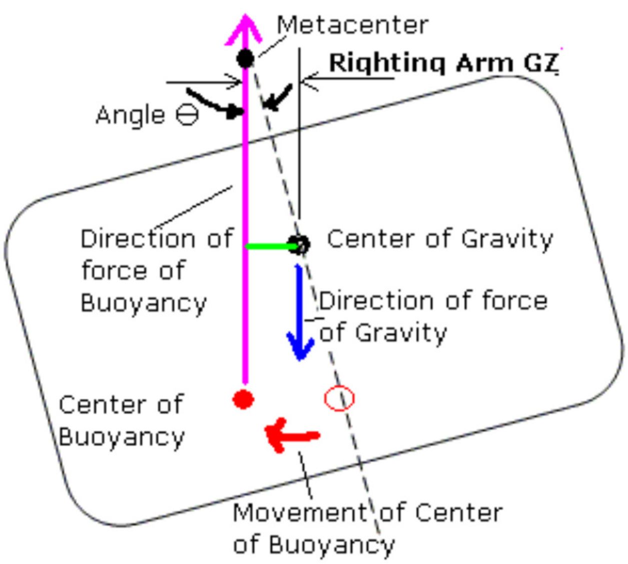


The **Metacenter M** is a theoretical point through which the buoyant forces act and small angles of list. At these small angles the center of buoyancy tends to follow an arc subtended by the **metacentric radius BM** which is the distance between the Metacenter and the center of buoyancy.

A the vessels draft changes so does the metacenter moving up with the center of buoyancy when the draft increases and vice versa when the draft decreases. For small angle stability it is assumed that the Metacenter does not move

Righting Moments

When a vessel lists there center of buoyancy moves off centreline. The center of gravity , however, remains on centerline



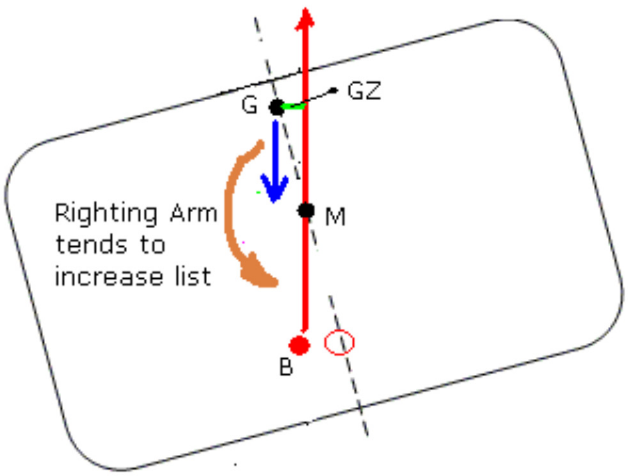
For small angles up to 10 degrees depending on hull form the righting Arm GZ can be found by

GZ = GM (Metacentric Height) x SinØ It can be seen that the greater the metacentric height the greater the righting arm is and therefore the greater the force recovering the vessel (**Righting Moment RM**)to the upright position.

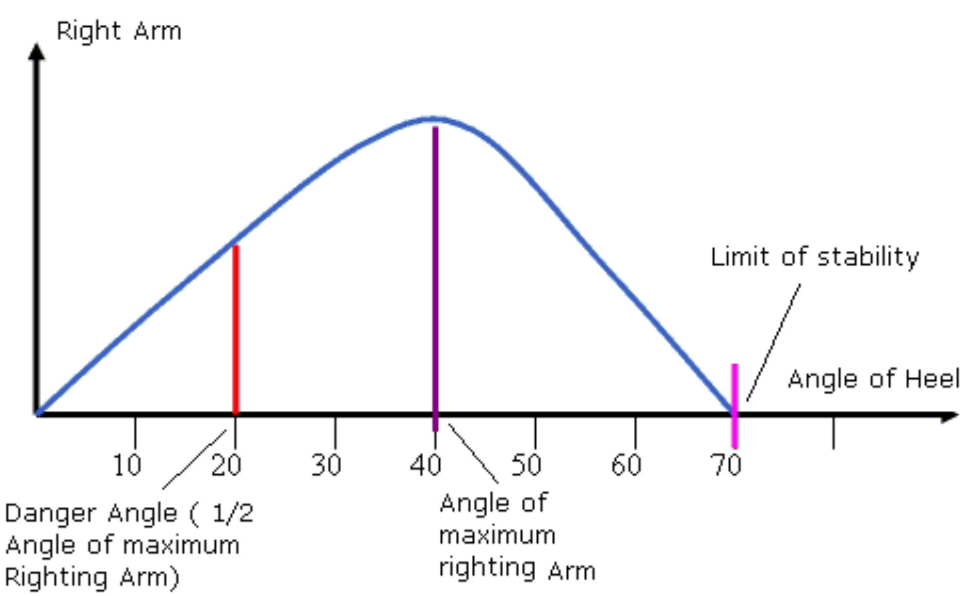
Negative Stability

The above examples all show the metacentre above the centre of gravity. This creates a righting arm at small angles always returning the vessel to the upright position. Where the metacentre is at or very near the centre of gravity then it is possible for the vessel to have a permanent list due to the lack of an adequate righting arm. Note that this may occur during loading operations and it is often the case that once the small angle restrictions are passed the metacentric height increases and a righting arm prevents further listing.

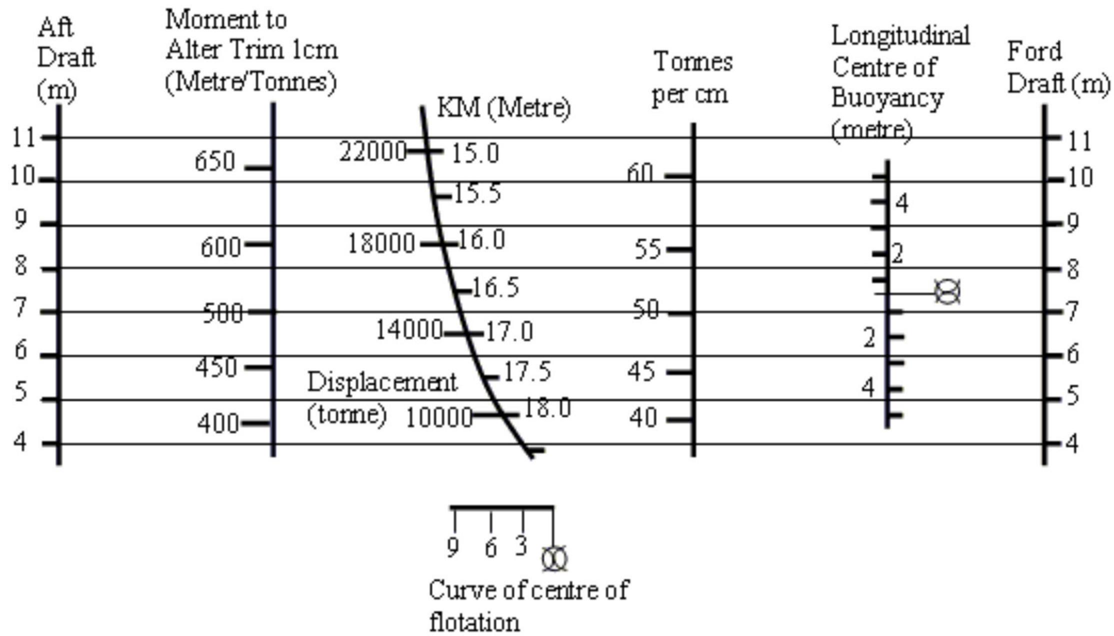
In a worst case the metacentre may be substantially below the center of Gravity.



Stability Curve



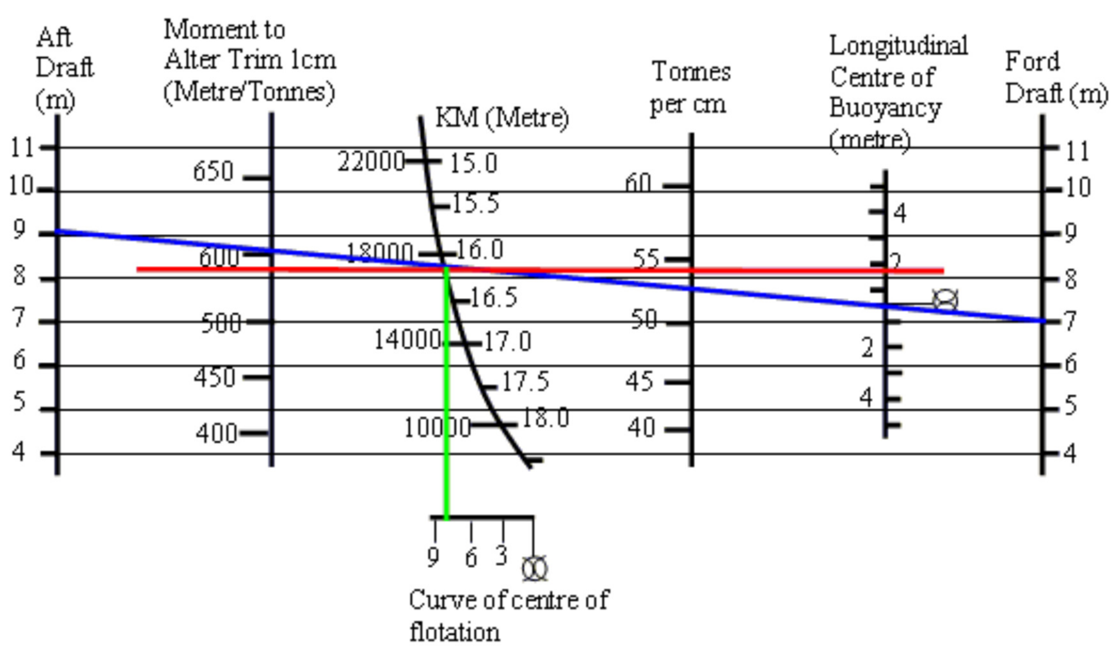
Draft Diagram



The Draft diagram is a simple and quick method of determining the following

- Moment to Trim per cm (MTC)
- Tonnes per Centimetre Immersion (TPC)
- Height of Metacenter (KM)
- Longitudinal Center of Flotation (LCF)
- Longitudinal Center of Buoyancy (LCB)

Worked example.

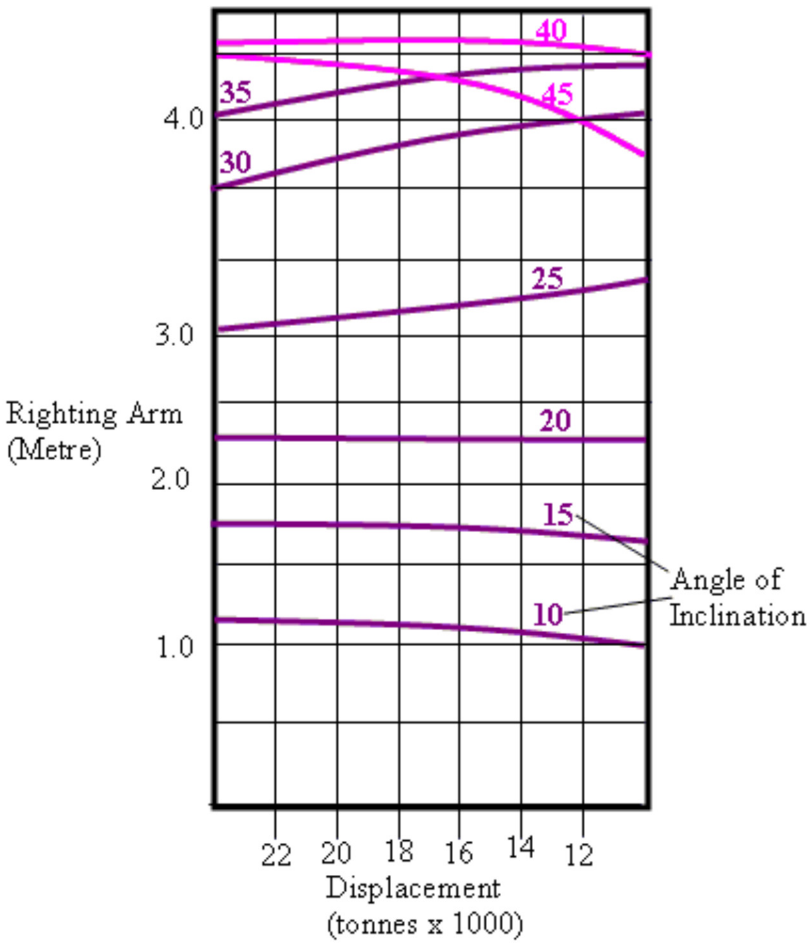


A line is drawn joining the ford and aft draft marks. (Blue Line). The Displacement can be read directly off

A horizontal line is drawn passing through the intersection of the blue line onto the displacement curve (Red Line). MTC, TPC, KM & LCB are read where the redline intersects their respective scales.

A vertical line (green) is dropped from the intersection of the blue line with the displacement curve from which can be read the LCF off the respective scale

Cross Curves of Stability

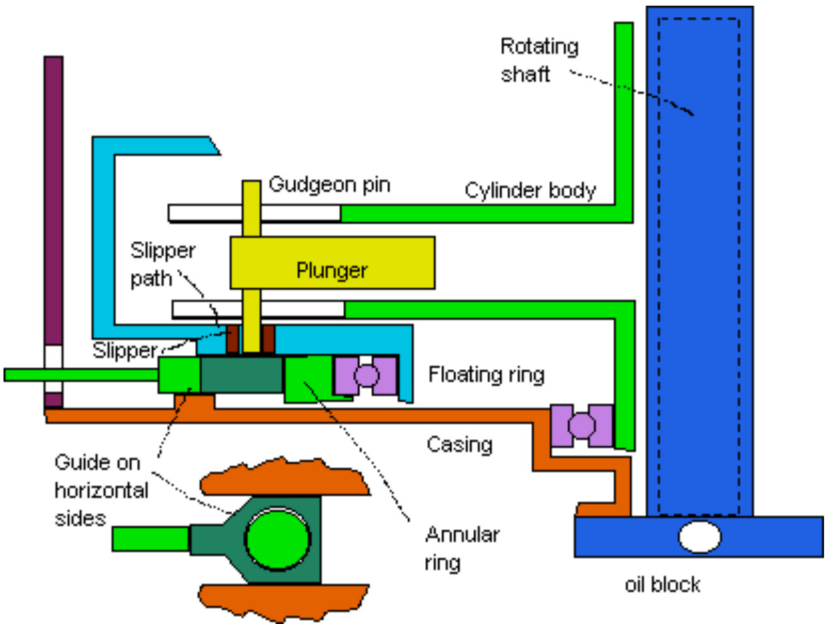


This may be used to determine the righting arms at different displacements and different angles of inclination

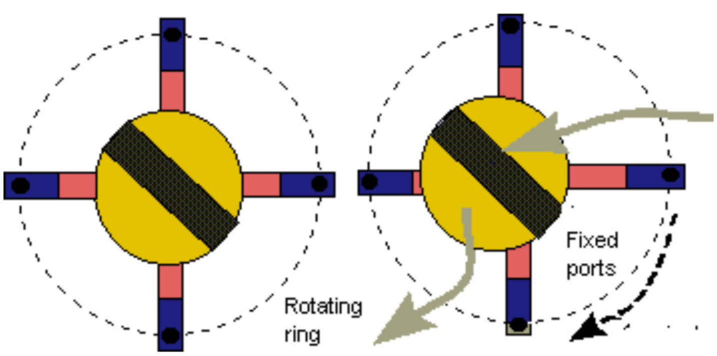
Pumps suitable for steering gear systems

Pumps used for supplying the working fluid to the main steering gear can be of either the variable capacity reversible delivery type or the fixed delivery non-reversible type. For large capacity outputs with high rates of change in demand, the variable capacity pumps are normally fitted. These are of two main types, the Hele-Shaw variable stroke pump having radial cylinders and the swash plate variable stroke pump having axial cylinders.

Hele-Shaw Pump



Left shows the construction and operation of this type of pump which is normally driven by a constant speed electric motor. The pistons are fitted in a row of radial cylinders and through the outer end of each piston is a gudgeon pin , which attaches the slippers to the piston. The slippers are free to oscillate on their gudgeon pins and fit into circular grooves in the circular floating ring . This ring is free to rotate being mounted on ball bearings , which are housed in guide blocks , this reduces oil churning and friction losses. The latter bear on tracks are controlled by the actuating spindles, which passes through the pump casing. The movement of the floating ring by the actuating control spindle (operated by, say, the telemotor receiver) from the central position causes pistons to reciprocate in the radial cylinders so that a pumping action takes place. The direction of the pumping depends upon whether the movement is to the left or right of the central or neutral position.

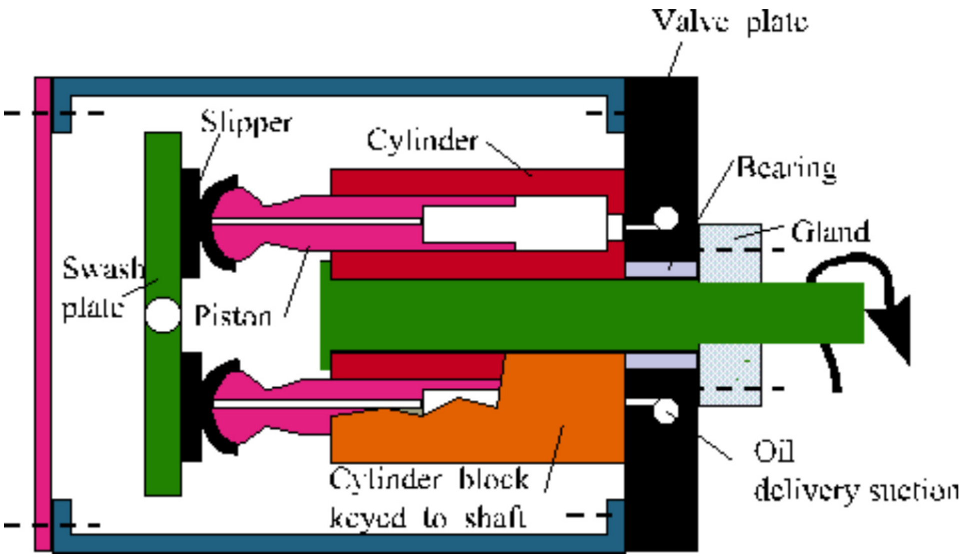


The action of the pump is shown above.

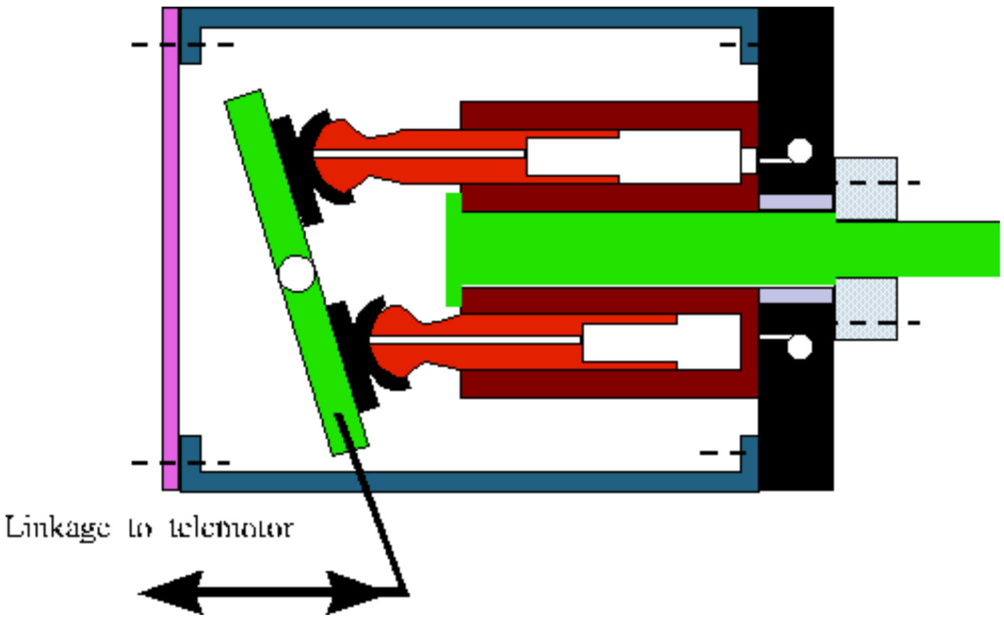
It should be noted that an advantage with this system is that in reversing the direction of the flow of fluid, the pump moves from maximum delivery in one direction across to zero delivery then through zero delivery to maximum delivery in the opposite direction. The build up in fluid pressure taking place without shock loading of pipe lines supplying fluid to the main steering unit.

The pump is usually provided with an odd number of cylinders, usually seven or nine, which produces more even hydraulic flow and a better balanced pump.

Variable Stroke Reversible Swashplate Pump



This pump is sometimes called the variable stroke gear pump (V.S.G), it runs in the flooded condition, the make up tank being above the level of the pump so that all the working parts are immersed in oil. It is driven by a constant speed electric motor the volume and direction of the oil flow being controlled by means of a stroke control lever.



The VSG pump is stated to have some advantages over the Hele-Shaw , this is due to the fact that the c of g of the Hele Shaw plungers is a relatively large distance from the centre of rotation operating relatively large centrifugal forces . The VSG plunges have a c of g close to the centre of rotation creating relatively small centrifugal forces, this means that the VSG system can be run at much higher speeds and therefore can be much smaller whilst doing the same work as the Hele-Shaw. Due to centrifugal forces acting, the wear on the V.S.G. pump pistons can be greater than that for the radial type pistons There is a small clearance between the valve and cylinder blocks when running off load. When the unit comes on stroke the hydraulic pressure forces the two faces together.

External pipes connect ports to steering gear.

VSG pumps and Hele-Shaw pumps have an odd number of cylinders since calculation shows that this gives better hydrodynamic balancing (and a better starting torque when used in a pump driving hydraulic motor).

Auxiliary Pump

Some manufacturers supply an auxiliary pump driven from the main pump shaft, which draws oil from the replenishment tank, delivering through non return valves to each side of the main hydraulic system. A low pressure relief valve opens to return the auxiliary pump delivery back to the replenishment tank if the main system is full, at the same time keeping equivalent initial pressure on the whole system. This ensures the lubrication of the main pumps when at no stroke and resists the ingress of air into the system. Pressure from this pump can also be used to power the automatic helmsman control, to operate change over valves, or to power servo control units which in large installations may be used to operate pump stroke mechanisms and so reduce the force required from the telemotor.

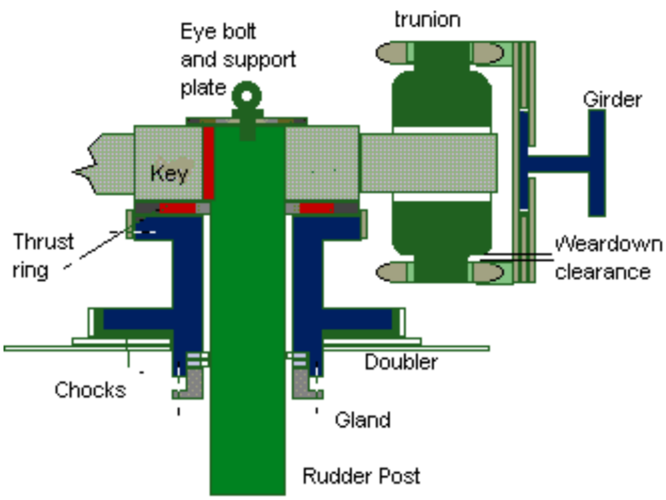
Constant Pressure Pumps

The constant pressure delivery pump is a standard production line , cheap pump; it runs constantly delivering a set volume of liquid whose pressure must be regulated .Recirculating v/v's allow oil to by-pass rams when stationary, an oil cooler may have to be incorporated.

Valves must be incorporated to divert the flow of oil to one side or the other. These normally take the form of electrically operated solenoid valves which are subject to wear, as well as damage to seats and solenoid coils.

Shock loading to rams and pipework causing noise and vibration as well as damage.

Rudder Carrier bearings



The rudder carrier bearing takes the weight of the rudder on a grease lubricated thrust face. The rudder stock is located by the journal, also grease lubricated. Support for the bearing is provided by a doubler plate and steel chock. The base of the carrier bearing is located by wsdge type side chocks, welded to the deck stiffening. The carrier is of meehanite with a gunmetal thrust ring and bush. Carrier bearing components are split as necessary for removal or replacement. Screw down lubricators are fitted, and the grease used for lubrication is of a water resistant type (calcium soap based with graphite).

Weardown

A small allowance is made for weardown, which must be periodically checked. This may be measured either between pads welded on top of the rudder and onto the rudder horn, or between the top of the rudder stock and a fixed mark on the inner structure of the steering gear flat. The latter generally involves the use of a 'Trammel gauge' which takes the form of a 'L' shaped rod ade to fit the new condition of the gear. As wear down occurs it can easily be checked with this gauge.

The rudder is prevented from jumping by rudder stops welded onto the stern frame.

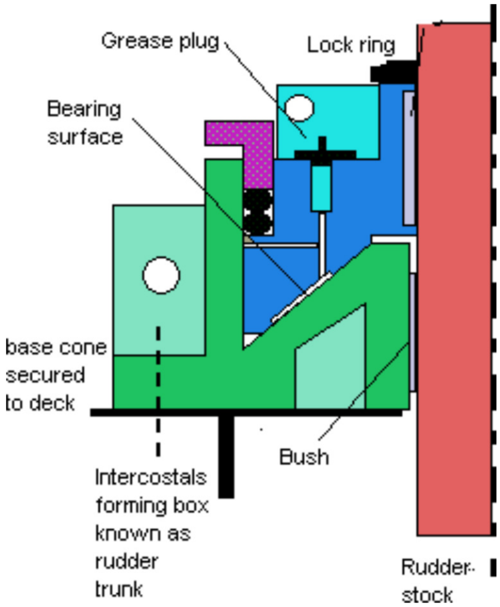
Rudder movement stops

Rudder stops are arranged as follows;

Angle from centreline	Position of stop	Note
35^o	On telemotor system	Normal limit
37^o	On steering gear	Prevents rudder striking external stops
39^o	External, on stern frame	emergency stop to protect propeller

These limits refer to rudders of traditional design and is governed by both the physical layout of the rudder and actuator but also due to the stall angles of the rudder. i.e. the angle at which lift (turning moment) is reduced or lost with increasing angle of attack. There are designs of rudder such as becker flap which have increased stall angles up to 45^o

Critical profiling of carrier bearing



Reasons for critical contouring of thrust face;

i. *for lubrication*
ii. *conical in order to prevent side slip and centralise rudder*
iii. *projected area gives greater bearing area allowing smaller diameter bearing*

Steering gear

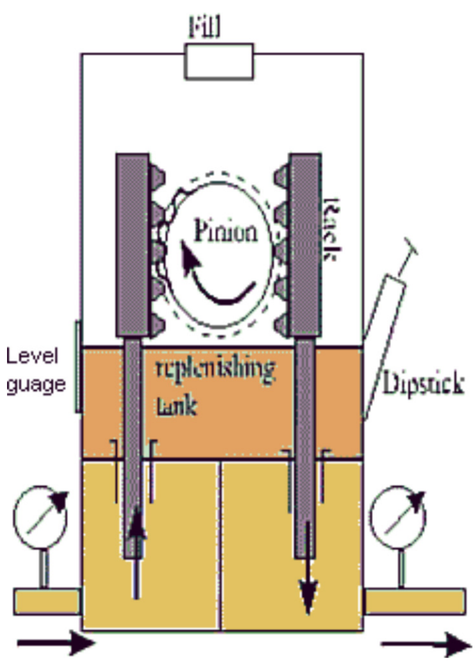
A hydraulic steering gear consists of a bridge control which applies helm, an engine control which is operated jointly by the helm and hunting gear (when fitted) and a power pump and rudder actuator which constitutes the steering engine.

Telemotor systems

The telemotor system consists of a transmitter on the bridge and a receiver fitted on the steering gear forming a part of the hunting gear. The system may be electrical or hydraulic or a combination of the two.

Most modern vessels are fitted with electric or electro-hydraulic systems. Due to the increasing size of vessels pipe runs have lengthen causing lags in the operation of the receiver in hydraulic systems. In addition hydraulic only systems generally require more maintenance.

Hydraulic transmitter



Shown above is a typical hydraulic transmitter unit. The pinion driving the pistons is turned by the bridge wheel.

The casing is usually gun metal, with bronze rams, and copper pipes are led in by frilled leads on the casting.

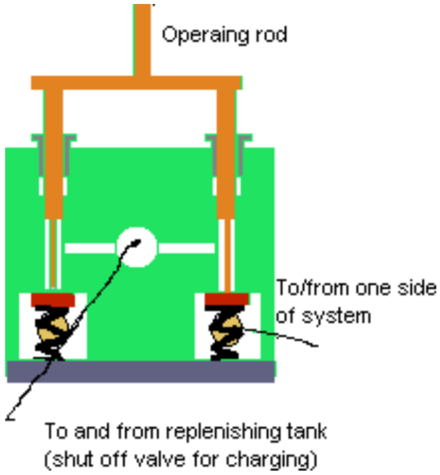
To test the system, with the steering gear actuating pumps stopped, the wheel may be lashed at hard over and the pressure recorded. It should maintain this pressure for some time

To allow for expansion in the system and to allow topping up a 'by-pass valve' is fitted. It will also act as a safety valve.

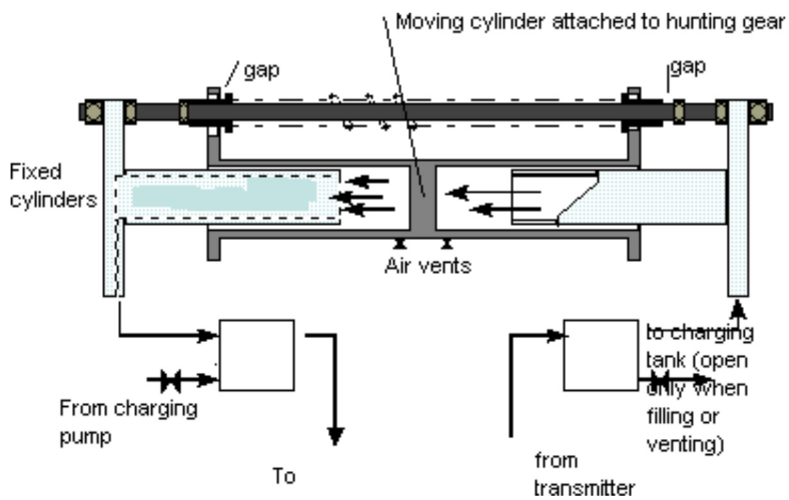
Author note:
The main problem appears to be the effect of air entrained within it. Thus

regular venting of the system is required.

By-pass valve



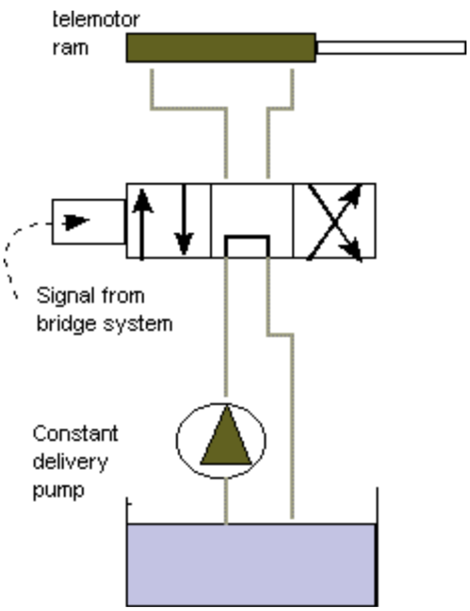
The operating rod is pushed down making both line common whenever the wheel is at midships, generally by a cam fitted to the pinion. This ensures they system is always balanced.



The charging valves are opened only when filling or flushing.

The moving cylinder is attached to the hunting gear. When the bridge wheel is turned hydraulic pressure acts on the cylinder causing it to move. This in turn moves the hunting gear. The steering gear is then moved to compensate until the hunting gear is moved back to the neutral position. The total movement of the receiver is limited by stops.

Electro-hydraulic type telemotor system



Shown is a very simple system capable of operating a steering hunting gear. A pressure relief valve would normally be fitted after the valve and across the pump to prevent over pressurisation of the system.

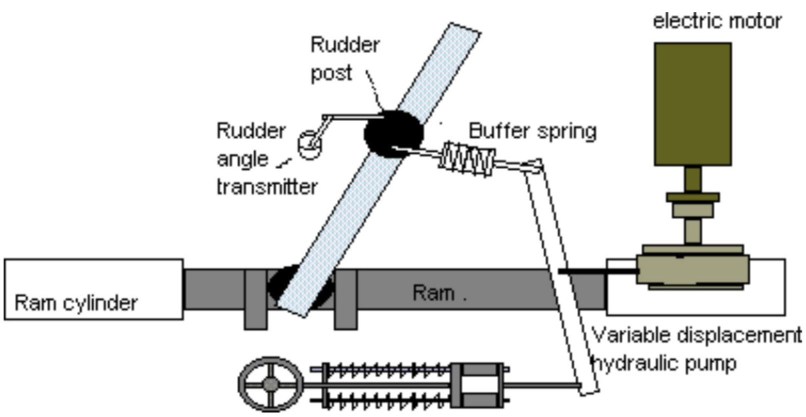
The signal is derived from the action on the steering wheel, created by the autopilot or directly from the non-follow up control levers.

Telemotor fluid

should be a good quality mineral oil with the following properties;

i. *low pour point*
ii. *non sludge forming*
iii. *non corrosive*
iv. *good lubricating properties*
v. *high flash point*
vi. *low viscosity*

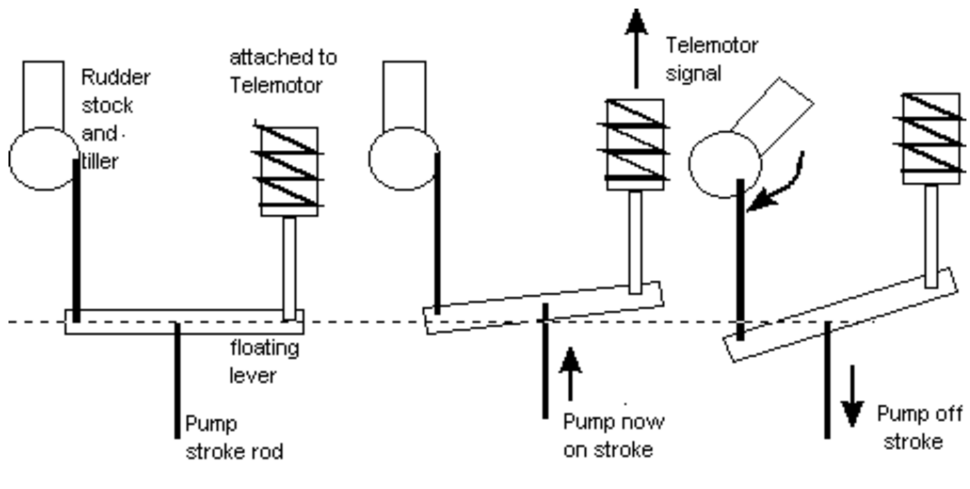
Hunting Gear



The steering gear system above consists of the telemotor which receives a signal from the bridge wheel. This acts on the hunting gear.

The hunting gear moves displacing a control rod, this rod acts on the pump displacement control gear to alter the delivery from the pump. The delivery from the pump causes the ram to move rotating the rudder stock and hence the rudder. The other end of the hunting gear is mounted on the rudder stock.

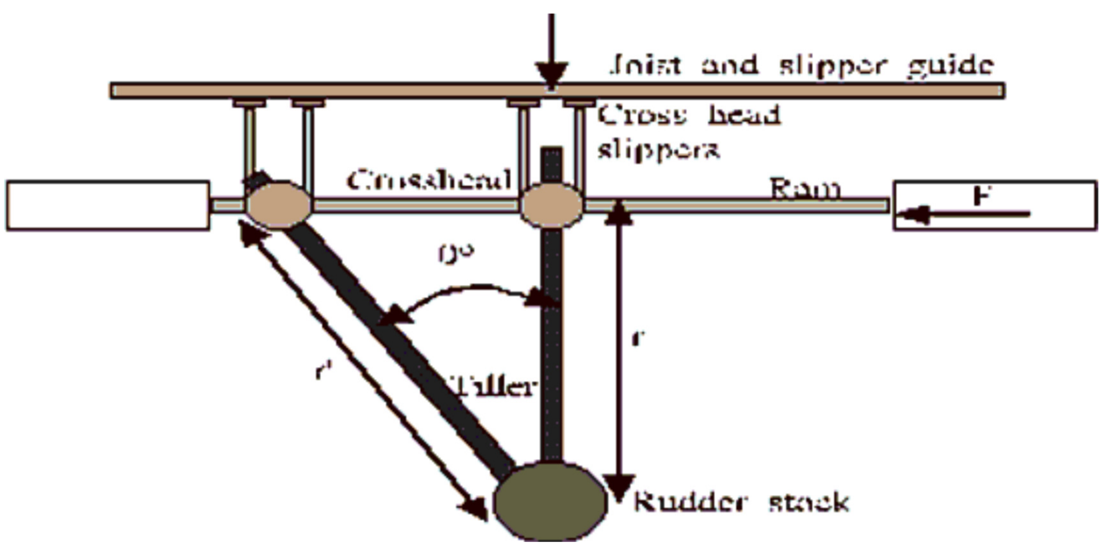
The rotation of the rudder stock moves the hunting gear returning the operating rod for the pump to the neutral position once the rudder has reached the correct angle.



Rudder Actuators

There are many different mechanisms by means of which hydraulic power can be converted into torque at the rudder stock some of which are as follows;

Rapson Slide Actuators - Ram type



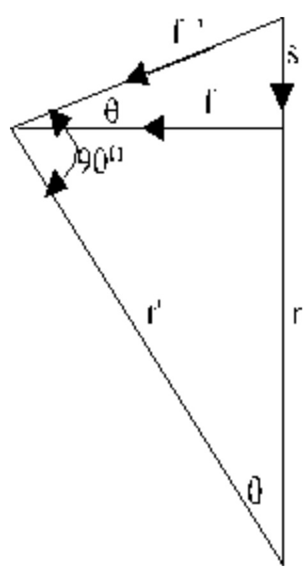
Steering gear incorporating the rapson slide principle are the most common in use on heavy duty applications.

The rapson slide acting on either a fork tiller or the more common round arm. The tiller drives the rudder stock by means of a key or keys. The crosshead is free to slide along the circular arm of the tiller so that the straight line effort of the rams is applied to the angular moving tiller. Each set of two cylinders in line are connected by a strong steel girder usually called a "Joist" which stiffens the system and forms a "guide bar" for the crosshead guide slippers to slide along. The joist is often designed to incorporate the steering engine stops.

An important consideration in all steering gears is the "wear down" of the rudder carrying bearing, this bearing takes all the weight of the rudder. Therefore there must be adequate clearance between the bottom of the tiller and the crosshead bearing, so as the rudder bearing wears down in service the tiller and crosshead bearing do not touch, clearance when new can be 22 mm at bottom and 12 mm at top; the top clearance is a precaution to stop the tiller bumping up the steering rams in the unlikely event of the rudder lifting in heavy weather. Should the bottom of the tiller and the crosshead bearing touch, then the weight of the rudder will be transferred from the rudder bearing to the steering rams with disastrous results such as leaking of working fluid from the cylinders and shearing of the rams.

In the case of forked tiller design, the thrust from the rams is transmitted to the tiller through swivel blocks. One advantage of this arrangement is that the overall length of pairs of rams is reduced compared to the round arm tiller design and this can be an important consideration in some cases. A disadvantage is that where as any slight misalignment in the case of the round arm tiller is not vitally important, it could lead to uneven loading of the swivel blocks in the forked tiller design and it is essential that the line of the rams be exactly at right angles to the rudder stock centre line if this is to be avoided.

With the Rapson Slide the torque reaction from the rudder is taken on the tiller by a force which is balanced by an equal and opposite force having two components one of which is produced by the ram and acts in the line of the ram, whilst the other is at right angles to the line of the ram and is produced by the guide reaction.



Where guides are not fitted as is sometimes the case with smaller steering gears then the guide reaction force must be carried by bearings or the glands of the cylinders.

a = actuator area
p = Working fluid pressure
n = Number of effective rams (1 for 2 ram, 2 for 4 ram)
q = rudder angle
r = tiller radius at amidships
r' = tiller radius at q^{o} of tiller helm
s = guide reaction force
f = force on ram with tiller amidships (= p x a)
f' = effective force acting at 90^{o} to tiller

r' = r / cos.q also f' = f / cos.q = p x a / cos.q
t = torque available = f' x r' x n
= ((p x a) / cosq). (r / cos.q) . n
t = (p x a x n x r) . (1 / cos.2q)

Showing that the rapson slide effect which gives increase of available torque with increases of rudder angle

The torque demanded from the steering gear increases and is at a maximum at maximum rudder angle when the mechanical advantage of the Rapson Slide gear is at a maximum. Ram type gears are also well adapted to take advantage of the high pressures which are currently available, since ram diameters and casing are relatively small and leakage paths are small or non-existent.

Oscillating Cylinder Actuators

The use of oscillating cylinders or pinned actuators is a recent development. They can be used as single cylinder units for hand only steering or two cylinder units for hand and power steering. While four double acting cylinders can cope with larger torque demands. These units are double acting because pistons work in the cylinders and pressure can be applied to either side as compared with ram gears which are single acting.

In these cases, the torque T applied to the rudder stock varies with the rudder deflection angle and on the location of the actuator. In general the torque developed will be less at the maximum rudder angle than the maximum possible from the actuator.

Maximum torque from actuator = p.a.n.r.
Torque at 35^o = p.a.n.r. cos (35 = o)
where o = angle traced out by the actuator
between o = 0^o and o = 35^o
Mechanical advantage at 35^o = Cos 35^o = 0.82
since the actuators are pivoting about their pin centre, they usually have their working fluid tank and pump mounted on the actuator cylinder, or they are connected to tank and pump by a flexible pipeline.

Rams Connected To Crossheads By Links

This type of gear is used if the athwartships space is limited, or the head room at the rudder head is restricted, as for example, in the case of a vehicle ferry having a slip way aft. The design enables the steering gear to be moved forward where there is reasonable head room for access.

As in the case of the oscillating cylinder design the Mechanical Advantage of the Rapson Slide gear is lost in the links and the torque output of the gear is at a minimum at hard over when the torque demand created by the rudder hydrodynamic forces is at a maximum.

Rotary Vane Gear

These consist of two elements:

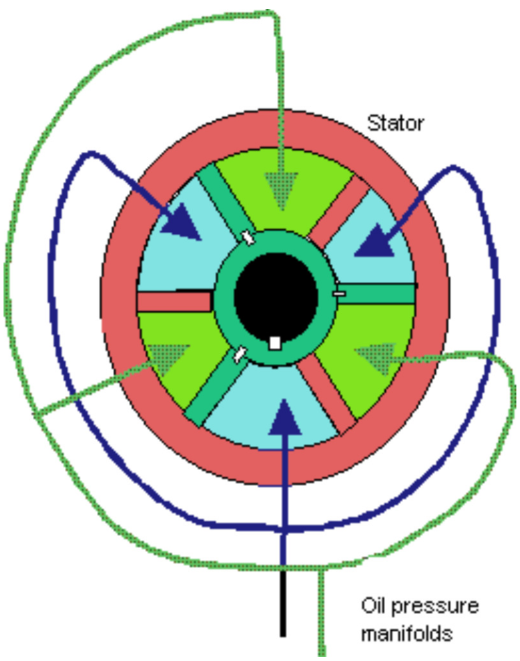
1. *a cylindrical static casing (stator) with usually three internal vanes which project radially inwards*
2. *a rotor keyed to and concentric with the rudder stock, the rotor has rotor vanes which project radially outwards into the spaces formed by the stator vanes.*

The spaces formed between the stator and rotor vanes are used as high and low pressure chambers. The main advantage of the system is that it is compact, occupying about 1 / 10 the space of a ram system. The disadvantages are ;

1. *it has a long oil sealing path*
2. *it is a constant torque machine at all angles of helm compared to the ram system where due to the Rapson slide effect, the torque available increases with increasing helm.*

Where 100% redundancy is required two rotary vanes in piggy back are used.

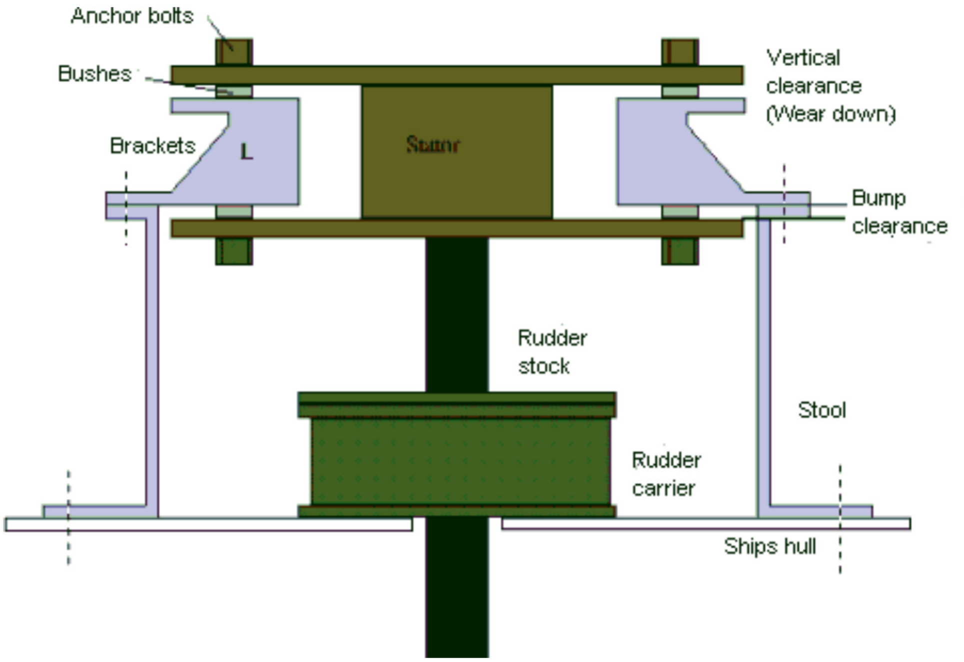
All vanes are spheroidal graphite cast iron secured to the cast iron rotor and stator by high tensile steel dowel pins and cap screws. Rotor strength is maintained by keys fitted full length of the rotary vane. Steel sealing strips are fitted along the working faces, backed by synthetic rubber in grooves along the working faces which are elastically loaded, so as to ensure that contact with the mating surfaces is maintained in order to hold the hydraulic pressures.

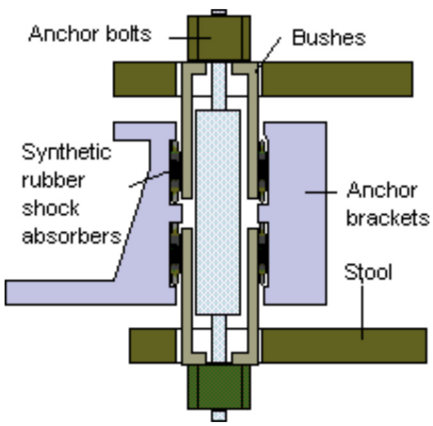


The chambers are alternately connected to the suction and delivery from the hydraulic pump so that they can be used to produce the rudder actuating torque. Because the distribution of the pressure chambers is balanced around the rudder stock, only pure torque is transmitted to the stock and no side loading are imposed by the gear.

There are two main types of rotary vane steering gear in use today. One has its stator firmly fixed to the steering flat deck and the stator housing and cover are provided with suitable bearings to enable the unit to act as a combined rudder carrier and rudder stock bearing support. The other type of vane gear is supported where the stator is only anchored to the ships structure to resist torque but is free to move vertically within the constraints of the separate rudder head bearing and carrier which is similar to the bearing provided for ram type steering gears.

The rudder carrier ring bearing (Pallister Bearing) is taking the weight of the rotary vane steering gear and the rudder and stock.





Rotation of the stator is prevented by means of two anchor brackets and two anchor bolts . The anchor brackets are securely bolted to the stool and vertical clearance is arranged between the inside of the Stator flanges and the top and bottom of the anchor brackets to allow for vertical movement of the rudder stock. This clearance varies with each size of rotary unit but could be about 40 mm total . It is essential that the rudder carrier should be capable of restricting the vertical movements of the rudder stock to less than this amount.

The anchor bolts are fitted with special bushes in halves, shaped externally in order to pre-load the synthetic rubber shock absorbers , which are fitted between them and the anchor brackets. The maximum deflection of the shock absorbers under full load is approximately 1 mm.

The working angle of the gear is governed by the number of vanes and their thickness. Vanes act as rudder stops when a moving vane contacts a fixed vane. Valves at inlet to the chambers may be shut causing a hydraulic lock. In the rotary vane units the Mechanical Advantage is unity at all angles and hence torque is constant

Torque = p.a.n.r.
where n = number of rotating vanes

Tendfjord Rotary Piston Gear Actuator

This gear consists of a casing around the rudder stock which contains pistons of rectangular section sliding in angular compartments concentric with the rudder stock. The tiller projects into a gap between the cylinder, the piston ends abutting onto the tiller but not being attached to it so that axial movements of the rudder cannot be transmitted to the pistons. Steering gears of this type operate at hydraulic pressures up to 41 bar (600 lbf/in2) and are in general restricted to low power application.

As with the rotary vane steering gears the Mechanical Advantage is unity at all angles and hence the torque is constant.

Torque = p.a.n.r.
where n in this case is unity.

Components

Relief Isolating And Bypass Valves

Hydraulic actuators are provided with relief and bypass valves between complementary pairs of cylinders or chambers of vane gears. The relief valves are set to lift at pressures above the normal maximum.

The bypass valves are normally closed but can be opened on a two cylinder gear to enable emergency steering to be used. On a four cylinder gear one pair of cylinders can be bypassed while the other pair provide emergency steering at a reduced torque, an instruction plate is fitted over the controls valve block giving a combination of failures and which valves have to be open or shut to cope with the emergency etc. It should be noted that if one ram or cylinder in a four ram system breaks down, then never isolate the cylinder diagonally opposite the damaged unit, since the steering gear will not operate due to the fact that the remaining two cylinders will be either on all pressure or on all suction at the same time.

Isolating valves are provided at each cylinder or rotary vane chamber which when closed will hold the rudder by trapping the oil in the chambers. Isolating valves are also fitted to pumps so that a pump can be completely shut off from the circuit and removed for servicing while steering is continued with the other pump.

In the case of gears with duplicated variable stroke pumps, in order to be able to bring a standby unit quickly into operation, the pump stroke mechanisms are permanently coupled together and both pumps are left open to the hydraulic circuit. Thus it is only necessary to start up a motor for the stand by pump to be operative. It is usual to run both pumps in restricted navigation waters. As a variable stroke pump can operate as a motor if pressure oil is applied to one side while it is on stroke, it is necessary to prevent wind milling or rotation of the pump which is on stand by duty.

Otherwise, the output of the operation pump, instead of moving the steering gear would be used up in rotating the stand by pump.

One method to prevent this,is using a fixed ratchet is provided concentric with the pump driving shaft. Pawls that can engage this ratchet are carried in the drive coupling. When the pump is on stand-by the pawls engage with the ratchet and prevent rotation when oil on the delivery side of the operating pump is on pressure. In this condition the tendency to motor the stand by pump will always be against its normal direction of rotation. As soon as the pump is started, rotation being in the opposite direction, the pawls disengage and by centrifugal action fling out against the inner flange of the coupling completely clear of the ratchet. When a pump is on stand-by and the rudder is being driven by water pressure in the direction in which it is being moved so as to generate pressure on what is normally the suction side of the operating pump, this will cause the stand by pump to rotate in its normal running direction. This means that the pawls will disengage and the pump will be motored round, allowing the rudder to move more quickly to a new steering position than the single operating pump will allow.

Another method of protection against rotation of the stand by pump is to fit Servo pressure operated automatic change over valves in the pipelines; these ensure that the pump can only be started in the unloaded condition (neutral) and in addition prevents the stand by pump from being motored by the pump in service.

On some ships it has been discovered that the ball bearing races on the stand-by pump have been failing due to brinelling of the ball bearings, caused by ship vibrations, and in these cases it is usual to fit devices which allows the stand by pump to be motored slowly.

When fixed delivery pumps are duplicated in supplying oil to a common hydraulically operated control valve, an automatic change over valve can be fitted which will isolate the stand by pump when it is at rest, but will connect it to the actuator when the pump is started up.

Stops And Limit Switches

External or stern posts stops are set at the absolute limit to hard over movement of the rudder , protects propeller and ship stern in the event of metal or other failure which allows rudder to swing in an uncontrolled manner. Mechanical stops on the rudder actuator operate before the external stop are reached .these take the form of travel limits. Stops on the bridge control operate before mechanical stops. local controls are set midway. auto pilot controls are set first. It should be noted that the vanes act as stops on rotary vane gears.

Drive Back Due To Heavy Sea's

Heavy seas acting on the rudder can force the actuator against the hydraulics sufficient to lift the relief v/v, in which case the rudder will move. Hunting gear will tend to return the gear to its correct position.

Hand And Power Hydraulic Steering Gears

For small ships during navigational course keeping hand steering can be used, whist during manoeuvring power steering can be used. These may take the form of chains or simple hydraulics operated by a fixed delivery pump attached to the steering gears.

"Follow Up" Steering

This is the normal method of steering and involves the feedback of steering angle to the helm. This is suited to both manual and automatic operation.

The ships heading may be set into the autopilot which can then compare the actual to desired heading and adjust the rudder angle to suit

"Non-follow Up" Steering

Normally used for back up purposes only. Consists of a single lever per steering gear unit, by moving the lever in on direction the rudder will begin to turn, the rudder will continue to turn until the lever is released or it reaches the limit of its operation

Charging A System With Fluid

. In all cases high quality hydraulic oil should be used , containing inhibitors against oxidation , foaming, rust and wear and emulsification.

In order to keep the transmission load as low as possible when hand steering , hand power systems must have oil of low viscosity.

The condition of the oil should be monitored and ensured at least clean and free of moisture.

Steering gear failure

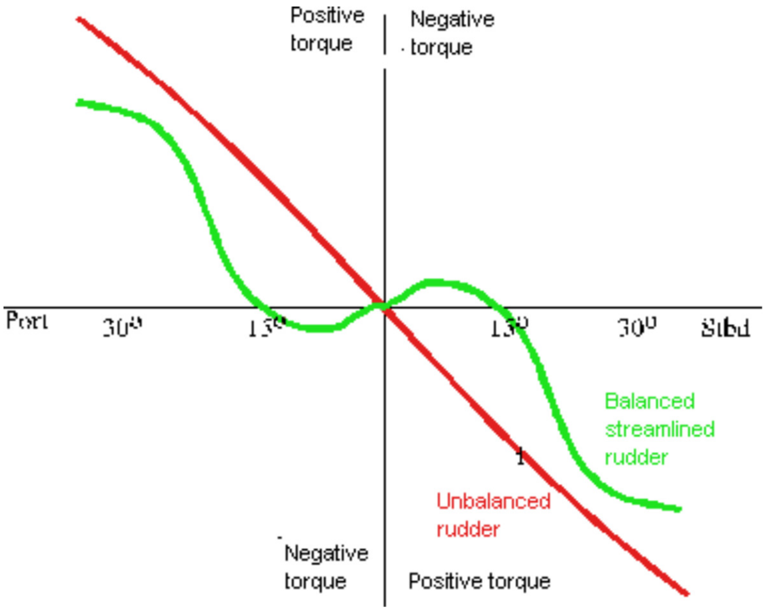
A study of steering gear defects demonstrates that the most common are related to vibration and the working loose of components.

The most common source of failure are the pump and the hydraulic system associated with it.

Rudder torque calculations

Formulae for assessing rudder torque's are based upon the expression Ta ACpV^2 Sin q where:-
T = rudder torque
C = rudder area
Cp = centre of pressure distance from centre line of rudder stock
V = velocity of ship
q = rudder angle measured from mid-ship position

In practice different constants obtained empirically are used with this expression and take into account such factors as propeller slip and wake speed as appropriate depending upon the relation of the rudder and propeller positions. The position of the centre of pressure has a significant effect upon rudder torque and hence the size of the steering gear required; the greater the distance of the C of P from the centre line of the rudder stock, the larger the torque required; therefore designers attempt to bring the C of P as near to the centre line as possible. With the simple "barn door" type rudder on some single screw ships, no adjustment can be made, but the semi-balanced and balanced-type rudders can be designed to reduce the torque required; for instance, with the spade type rudder such as fitted to twin screw ferries, the position can be adjusted by the designer to give optimum position. This lies between 30 and 32 per cent abaft the leading edge of the mean chord of the rudder. Such a rudder would have its C of P forward of the stock position at low angles of helm, would balance around 10^o to 15^o and drift aft of the stock at higher rudder angles.



In graph above is shown a typical torque characteristics for a spade type balanced rudder and a "barn door" or unbalanced plate rudder. The astern torque's should also be calculated since this is sometimes higher than the ahead torque, this is true for spade rudders.

POWER

The peak power that a steering gear must develop is the product of the maximum torque (T) usually at hard over with the ship travelling at full speed, and the maximum speed (S) of rudder movement i.e. Power (max) a T x S.

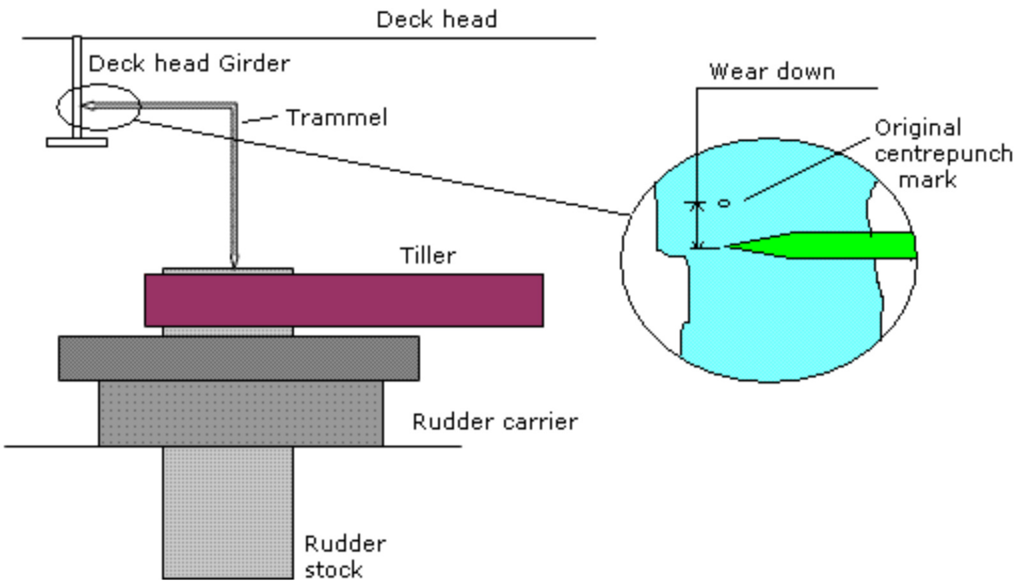
The combination of maximum power and speed only exists for 2 or 3 seconds during each manoeuvre; so clearly the average power required to operate the steering gear is considerably below the peak. Because the steering gear must have sufficient power to overcome friction and still have ample reserve of power, the value for used in the foregoing expression is significantly higher than that used in the expression for rudder torque. When considering the diameter of the rudder stock, bending and shear stresses must be taken into account.

Rudder Wear Down

This refers to the measurements taken generally during a docking period to indicate excessive wear in the steering gear system particularly the rudder carrier. The significance of this is that for ram systems excessive wear can lead to bending moments on the rams. For rotary vane systems it can lead to vane edge loading.The readings taken are offered for recording by the classification society.

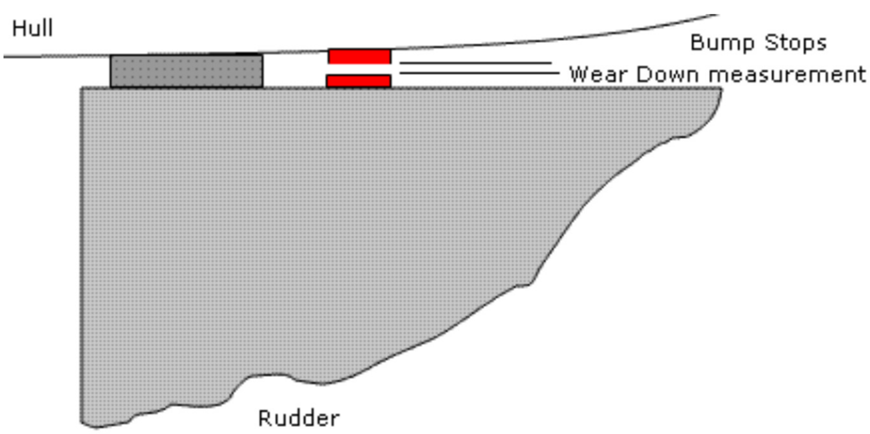
Trammel

This takes the form of an 'L' shape bar of suitable construction. When the vessel is built a distinct centrepunch mark is placed onto the ruder stock and onto a suitable location on the vessels structure, here given as a girder which is typical. The trammel is manufactured to suit these marks As the carrier wears the upper pointer will fall below the centrepunch mark by an amount equal to the wear down.



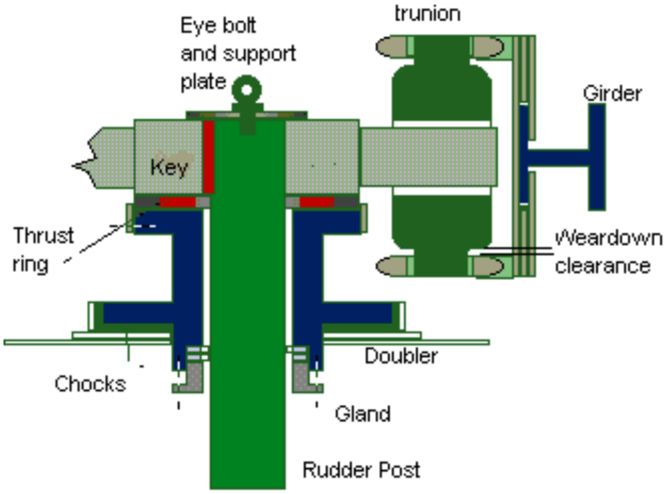
Rudder Clearance

Pads are welded to the hull and rudder. A clearance is given (sometimes refered to as the jumping clearance). As the carrier wears this clearance will increase



Steering gear Clearance

Direct measurement can be taken from the steering gear assembly. Shown below is one example, here the clearance will be seen to reduce as the carier wears and impact his has on the system can be directly judged



Rules

Design of steering gears have been influenced over the years by the rules and regulations of national authorities and classification subjects. Any changes of real substance tend nowadays to originate from the international

Maritime Organisations(I.M.O.) conventions and regulations. Classification society requirements are as follows;

1. *All ships to have power operated main gear capable of displacing the rudder from 35^o port to 35^o starboard at the deepest draught and at maximum service speed. Must also be capable of displacing the rudder from 35^o port to 30^o starboard in 28 seconds and vice versa.*
2. *The auxiliary gear must be power operated and capable of being brought rapidly into action. The auxiliary gear is only required to steer the ship at either 7 knots or half service speed*
3. *If the main gear comprises two or more identical power units, then a single failure of either power unit or piping must not impair the integrity of the remaining part of the steering gear*
4. *Each power unit must be served by at least two electrical circuits from the main switchboard. One circuit may pass through the emergency switchboard. All circuits to be separated as widely as possible throughout their length.*
5. *All power operated gears to be fitted with shock relieving arrangements to protect against the action of heavy seas.*
6. *An efficient brake or locking arrangement to be fitted to enable the rudder to be maintained stationary*
7. *the maximum power developed by the gear is proportional to T x S*
   where T = rudder torque
   S = Speed of rudder movement

   also T = A x P x sinq x V2
   where A = rudder area
   P = centre of pressure
   q = rudder angle
   V = velocity of the ship

Special requirements

Owners may specify additional requirements such as faster hard-over to hard-over time, strength of components above that required by the Rules, additional control points and additional duplication,

New tankers of 100 000dwt and above-shall comply with the following

The main steering gear shall comprise of either

- two independent and separate power actuating systems each capable of meeting the hard over port to 30^o starboard in 28 sec requirements,

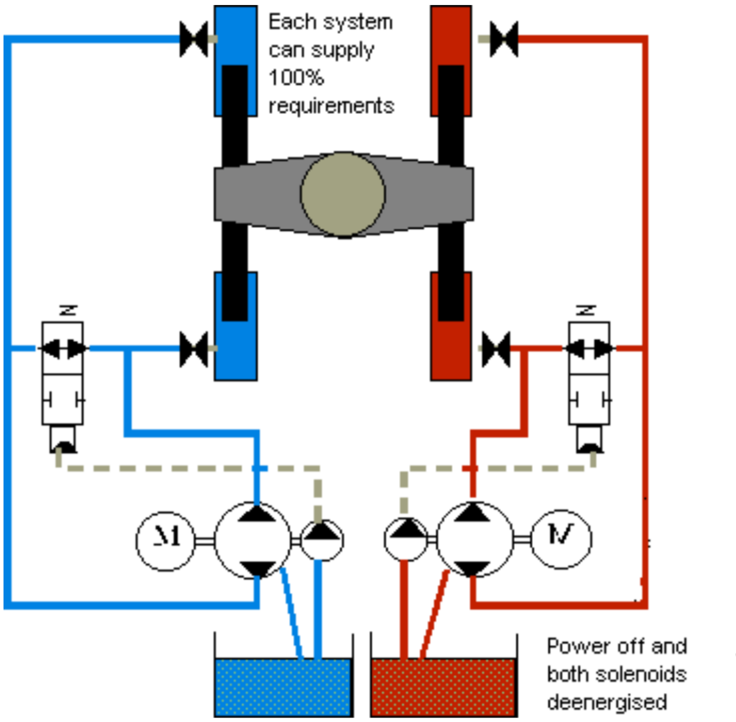
  or

- at least two identical power actuating systems which acting simultaneously in normal operation, shall be capable of meeting the hard over requirements. Where necessary to comply with this requirement inter connection of hydraulic power systems shall be provided. Loss of hydraulic fluid from one system shall be capable of being detected and the defective system isolated so that the other system shall remain fully operational

In the event of loss of steering capability due to a single failure other than the tiller, quadrant or components serving the same purpose (these are excluded from single failure concepts), or seizure of the rudder actuators. The steering capability shall be regained in not less than 45 seconds after the loss of one power actuating system.

Steering gear other than hydraulic should meet the same standards.

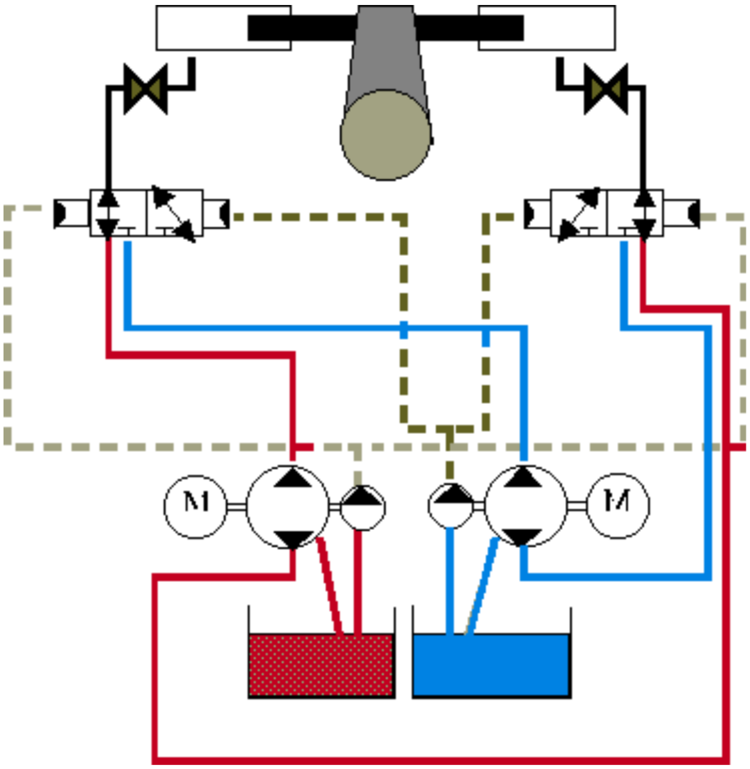
Example of suitable system permissible for all ships



The system shown consists of two sets of rams but could equally be two rotary vane units. With no power on the solenoids are in by-pass mode with oil being allowed to pass freely from one side to the other. When an electric motor is started the control pump supplies oil to the solenoid shutting it. High pressure oil from the main unit is now fed to the rams as required. The other unit remains in by-pass until the electric motor is started.

Low level alarms are fitted to the tanks. Low low changeovers may also be fitted so that in the event of oil loss from one system, the other system is started.

New tankers between 10 000gt upwards to 100 000tdwt



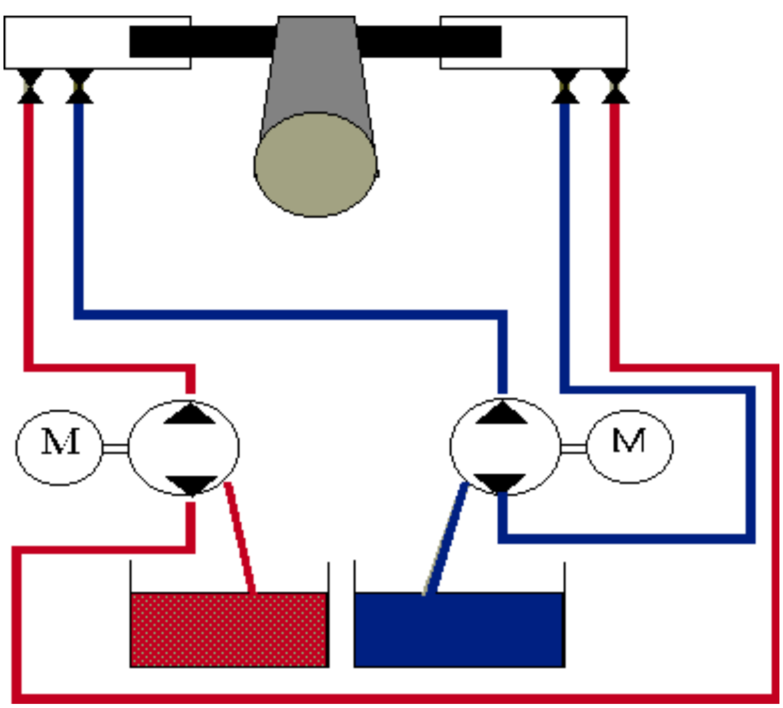
For these tankers the single failure criterion need not apply to the rudder actuator or actuators subject to certain requirements being fulfilled. These include a requirement that steering be regained within 45 seconds following failure of any part of the piping system or power units and a special stress analysis of non-duplicated rudder actuators.

The left hand unit is shown in operation.

For this basic arrangement the power units must be identical

New ships 70 000gt and upwards

system suitable for all ships except tankers of 10 000 gt and above

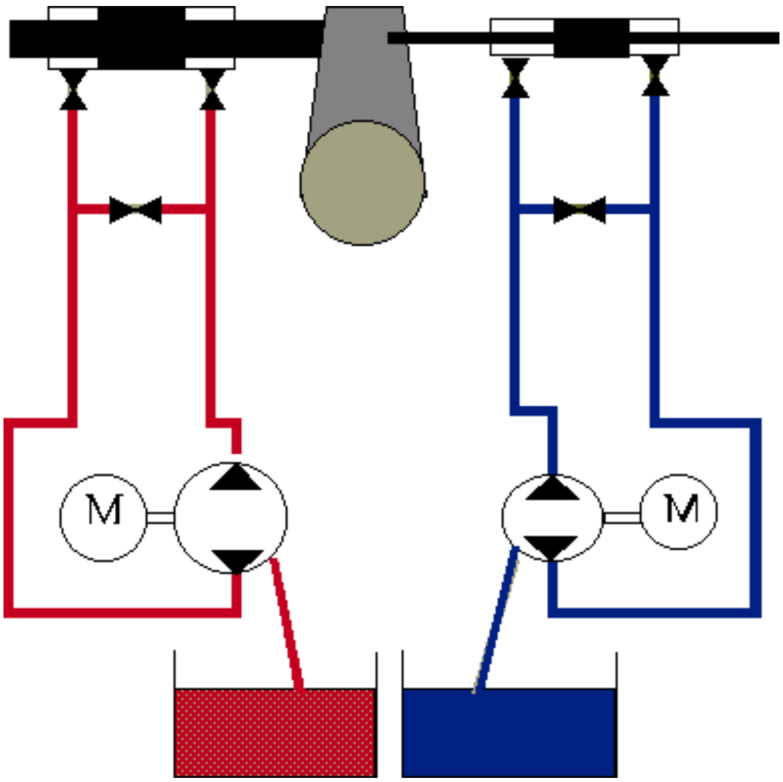


The main steering shall comprise two or more power units and that the main steering gear is so arranged that, after a single failure in its piping system or in one of the power units the defect can be isolated so that steering can be speedily regained.

'Speedily' is intended to mean the provision of duplicate hydraulic circuits or , for example, a conventional four ram steering gear with a common hydraulic circuit with appropriate isolating valves

New ships of less than 70 000 gt and tankers less than 10 000 gt

suitable system



Single failure is not applicable as a rule, however, attention is drawn to the requirement that auxiliary steering gear be independent of any part of the main gear except the tiller. There is no requirement that main and auxiliary power units be identical.

The auxiliary steering gear must be capable of putting the rudder over from 15^{o} from one side to the other in not more than 60 seconds with the ship at its deepest draught and running ahead at half maximum speed or 7 knots.

Existing tankers of 40 000gt and upwards

The steering gear shall be arranges so that in the event of single failure of the piping or one of the power units, steering capability can be maintained or the rudder movement can be limited so that steering capability can be speedily regained by

- An independent means of restraining the rudder

  or

- fast acting valves to isolate the actuator or actuators from the external hydraulic piping together with a means of directly refilling the actuators by a fixed independent power pump and piping system

  or

- An arrangement so that, where hydraulic power systems are interconnected any loss of hydraulic fluid from one system shall be detected and the defective system shut off either automatically or remotely from the bridge so that the other system remains intact

Requirements for all new ships

- Administrations must be satisfied in respect to the main and auxiliary steering gear provided for every ship that all components and the rudder stock are of sound construction
- Every component, where appropriate, utilise anti-friction bearings which will be permanently lubricated or provided with lubricant fittings
- Parts subjected to hydraulic pressures should be designed to cope with 1.25 maximum working pressure when the rudder is hard over at maximum draught and service speed
- special requirements for fatigue resistance(due to pulsating hydraulic pressure), relief valves and oil cleanliness
- Low level alarm to be fitted to each hydraulic reservoir.
- Fixed storage capacity sufficient to recharge on system

Auxiliary steering gear

The other set of steering (auxiliary) may be an arrangements of blocks and tackles or some other approved alternative method.

The auxiliary steering gear need only be capable of steering the ship at navigable speed, but it must be capable of being brought speedily in to action in an emergency. Navigable speed is one half of maximum service speed ahead or 7 knots whichever is the greater.

The auxiliary steering gear must be a power operated type if the rudder stock exceeds 230mm for passenger ships and 250mm for cargo vessels. No additional means of steering is required when electric or electro-hydraulic steering gear is fitted having two independent motors or two sets of pumps and motors.

Electrical Supply

Short circuit protection and overload alarm are to be provided in steering gear circuits. Indicators for running indication of steering gear motors are to be installed on the navigation bridge and at a suitable machinery control position. Each electric or electro-hydraulic steering gear shall be served by at least two independent circuits fed from the main switchboard. Cables for each circuit led through a separate route as far apart as possible so that damage to one cable does not involve damage to the other. A change over switch is fitted in an approved position to enable power supplies to be interchanged. One circuit may pass through an emergency switchboard.

Rudders

In passenger ships where the rudder stock exceeds 230mm, an alternative steering position remote from the main position is to be provided. Failure of one system must not render the other system inoperable. Provision made to transmit orders from bridge to alternative position. The exact position of the rudder must be indicated at principal steering positions. An efficient braking or locking device must be fitted to the steering gear to enable the rudder to be held stationary if necessary. Spring or hydraulic buffer relief valves fitted in steering gear system to protect the rudder and steering gear against shock loading due to heavy seas striking the rudder. Suitable stopping arrangements are to be provided so as to restrict the total travel of the rudder. Stops or cut outs on the steering gear are arranged so that it operates on a smaller angle of helm than the rudder stops.

Rudder restraint

Since failure of a single hydraulic circuit can lead to unrestricted movement of the rudder, tiller and rams, repair and recharging may not be possible. Difficulty arises with which the speed a restraint whether in the form of a mechanical or hydraulic brake can be brought in to use.

Due to the possibility of considerable damage occurring before it could, regulations have concentrated on continuity of steering rather than a shut down and repair solution

Testing and drills

a. Within 12 h before departure, the ship's steering gear shall be checked and tested by the ship's crew. The test procedure shall include, where applicable, the operation of the following:
    i. *the main steering gear;*
    ii. *the auxiliary steering gear;*
    iii. *the remote steering gear control systems;*
    iv. *the steering positions located on the navigation bridge;*
    v. *the emergency power supply;*
    vi. *the rudder angle indicators in relation to the actual position of the rudder;*
    vii. *the remote steering gear control system power failure alarms;*
    viii. *the steering gear power unit failure alarms; and*
    ix. *automatic isolating arrangements and other automatic equipment.*

b. The checks and tests shall include:
    i. *the full movement of the rudder according to the required capabilities of the steering gear;*
    ii. *a visual inspection of the steering gear and its connecting linkage; and*
    iii. *the operation of the means of communication between the navigation bridge and steering gear compartment.*

c.
    i. *Simple operating instructions with a block diagram showing the change-over procedures for remote steering gear control systems and steering gear power units shall be permanently displayed on the navigation bridge and in the steering gear compartment.*
    ii. *All ships' officers concerned with the operation or maintenance of steering gear shall be familiar with the operation of the steering systems fitted on the ship and with the procedures for changing from one system to another.*

d. In addition to the routine checks and tests prescribed in paragraphs (a) and (b), emergency steering drills shall take place at least once every three months in order to practise emergency steering procedures. These drills shall include direct control from within the steering gear compartment, the communications procedure with the navigation bridge and, where applicable, the operation of alternative power supplies.

e. The Administration may waive the requirement to carry out the checks and tests prescribed in paragraphs (a) and (b) for ships which regularly engage on voyages of short duration. Such ships shall carry out these checks and tests at least once every week.

f. The date upon which the checks and tests prescribed in paragraphs (a) and (b) are carried out and the date and details of emergency steering drills carried out under paragraph (d), shall be recorded in the log-book as may be prescribed by the Administration.

Steering gear regulations

As listed by lloyds

General

1.1 Application

1.1.1 The requirements of this Chapter apply to the design and construction of steering gear.

1.1.2 Whilst the requirements satisfy the relevant regulations of the International Convention for the Safety of Life at Sea 1974, as amended, and the IMO Protocol of 1978, attention should be given to any relevant statutory requirements of the National Authority of the country in which the ship is to be registered.

1.1.3 Consideration will be given to other cases, or to arrangements which are equivalent to those required by the Rules.

1.2 Definitions

1.2.1 Steering gear control system means the equipment by which orders are transmitted from the navigating bridge to the steering gear power units. Steering gear control systems comprise transmitters, receivers, hydraulic control pumps and their associated motors, motor controllers, piping and cables.

1.2.2 Main steering gear means the machinery, rudder actuator(s), the steering gear power units, if any, and ancillary equipment and the means of applying torque to the rudder stock (e.g. tiller or quadrant) necessary for effecting movement of the rudder for the purpose of steering the ship under normal service conditions.

1.2.3 Steering gear power unit means:

(a) in case of electric steering gear, and electric motor and its associated electrical equipment;

(b) in the case of electrohydraulic steering gear, an electric motor and its associated electrical equipment and connected pump;

(c) in the case of other hydraulic steering gear, a driving engine and connected pump.

1.2.4 Auxiliary steering gear means the equipment other than any part of the main steering gear necessary to steer the ship in the event of failure of the main steering gear but not including the tiller, quadrant or components serving the same purpose.

1.2.5 Power actuating system means the hydraulic equipment provided for supplying power to turn the rudder stock, comprising a steering gear power unit or units, together with the associated pipes and fittings, and a rudder actuator. The power actuating systems may share common mechanical components, i.e. tiller quadrant and rudder stock, or components serving the same purpose.

1.2.6 Maximum ahead service speed means the maximum service speed which the ship is designed to maintain, at the summer load waterline at maximum propeller RPM and corresponding engine MCR.

1.2.7 Rudder actuator means the components which converts directly hydraulic pressure into mechanical action to move the rudder.

1.2.8 Maximum working pressure means the maximum expected pressure in the system when the steering gear is operated to comply with 2.1.2(b).

1.3 General

1.3.1 The steering gear is to be secured to the seating by fitted bolts, and suitable chocking arrangements are to be provided. The seating is to be of substantial construction.

1.3.2 The steering gear compartment is to be:

(a) readily accessible and, as far as practicable, separated from machinery spaces; and

(b) Provided with suitable arrangements to ensure working access to steering gear machinery and controls. These arrangements are to include handrails and gratings or other non-slip surfaces to ensure suitable working conditions in the event of hydraulic fluid leakage.

1.4 Plans

1.4.1 Before starting construction, the steering gear machinery plans, specifications and calculations are to be submitted. The plans are to give:

(a) Details of scantlings and materials of all load bearing and torque transmitting components and hydraulic pressure retaining parts together with proposed rated torque and all relief valve settings.

(b) Schematic of the hydraulic system(s), together with pipe material, relief valves and working pressures.

(c) Details of control and electrical aspects.

1.4.2 These plans should give details of scantlings and materials of the steering gear together with proposed rated torque and all relief valve settings.

1.5 Materials

1.5.1 All the steering gear components and the rudder stock are to be of sound reliable construction to the Surveyor's satisfaction.

1.5.2 All components transmitting mechanical forces to the rudder stock are to be tested according to the requirements of Part 2.

1.5.3 Ram cylinders; pressure housings of rotary vane type actuators, hydraulic power piping, valves, flanges and fittings; and all steering gear components transmitting mechanical forces to the rudder stock (such as tillers, quadrants, or similar components) are to be of steel or other approved ductile material, duly tested in accordance with the requirements of Part 2. In general, such material is to have an elongation of not less than 12 per cent nor a tensile strength in excess of 650 N/mm2. Special consideration will be given to the acceptance of grey cast iron for valve bodies and redundant parts with low stress levels.

1.5.4 Where appropriate, consideration will be given to the acceptance of non-ferrous material.

1.6 Rudder, rudder stock, tiller and quadrant

1.6.1 For the requirements of rudder and rudder stock, see Pt 3, Ch 13,2.

1.6.2 For the requirements of tillers

Performance

General

2.1.1 Unless the main steering gear comprises two or more identical power units, in accordance with 2.1.4 or 8.1.1, every ship is to be provided with a main steering gear and an auxiliary steering gear in accordance with the requirements of the Rules. The main steering gear and the auxiliary steering gear is to be so arranged that the failure of one of them will not render the other one inoperative.

2.1.2 The main steering gear and rudder stock is to be:

(a) Of adequate strength and capable of steering the ship at maximum ahead service speed which shall be demonstrated in accordance with 7.2;

(b) Capable of putting the rudder over from 35 A on one side to 35A on the other side with the ship at its deepest seagoing draught and running ahead at maximum ahead service speed and under the same conditions, from 35A on either side to 30A on the other side in not more than 28 seconds.

(c) Operated by power where necessary to meet the requirements of (b) and in any case when the Rules excluding strengthening for navigation in ice, require a rudder stock over 120 mm diameter in way of the tiller; and

(d) So designed that they will not be damaged at maximum astern speed; however, this design requirement need not be proved by trials at maximum astern speed and maximum rudder angle.

2.1.3 The auxiliary steering gear is to be: (a) Of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency;

(b) Capable of putting the rudder over from 15 A on one side to 15A on the other side in not more than 60 seconds with the ship at its deepest seagoing draught and running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater; and

(c) Operated by power where necessary to meet the requirements of (b) and in any case when the Rules, excluding strengthening for navigation in ice, require a rudder stock over 230 mm diameter in way of the tiller.

2.1.4 Where the main steering gear comprises two or more identical power units, an auxiliary steering gear need not be fitted, provided that:

(a) In a passenger ship, the main steering gear is capable of operating the rudder as required by 2.1.2(b) while any one of the power units is out of operation;

(b) In a cargo ship, the main steering gear is capable of operating the rudder as required by 2.1.2(b) while operating with all power units;

(c) The main steering gear is arranged so that after a single failure in its piping system or in one of the power units the defect can be isolated so that steering capability can be maintained or speedily regained.

2.1.5 Main and auxiliary steering gear power units are to be:

(a) Arranged to re-start automatically when power is restored after power failure;

(b) Capable of being brought into operation from a position on the navigating bridge. In the event of a power failure to any one of the steering gear power units, an audible and visual alarm is to be given on the navigating bridge;

(c) Arranged so that transfer between units can be readily effected.

2.1.6 Where the steering gear is so arranged that more than one power or control system can be simultaneously operated, the risk of hydraulic locking caused by a single failure is to be considered.

2.1.7 A means of communication is to be provided between the navigating bridge and the steering gear compartment.

2.1.8 Steering gear, other than of the hydraulic type, will be accepted provided the standards are considered equivalent to the requirements of this Section.

2.1.9 Manually operated gears are only acceptable when the operation does not require an effort exceeding 16 kg under normal conditions.

2.2 Rudder angle limiters

2.2.1 Power-operated steering gears are to be provided with positive arrangements, such as limit switches, for stopping the gear before the rudder stops are reached. These arrangements are to be synchronized with the gear itself and not with the steering gear control.

Construction and design

General

3.1.1 Rudder actuators other than those covered by 8.3 and the `Guidelines' are to be designed in accordance with the relevant requirements of Chapter 11 for Class I pressure vessels (notwithstanding any exemptions for hydraulic cylinders).

3.1.2 Accumulators, if fitted, are to comply with the relevant requirements of Chapter 11.

3.1.3 The welding details and welding procedures are to be approved. All welded joints within the pressure boundary of a rudder actuator or connecting parts transmitting mechanical loads are to be full penetration type or of equivalent strength.

3.1.4 The construction is to be such as to minimize local concentrations of stress.

3.1.5 The design pressure for calculations to determine the scantlings of piping and other steering gear components subjected to internal hydraulic pressure shall be at least 1,25 times the maximum working pressure to be expected under the operational conditions specified in 2.1.2(b) taking into account any pressure which may exist in the low pressure side of the system. Fatigue criteria may be applied for the design of piping and components, taking into account pulsating pressures due to dynamic loads, see Section 9.

3.1.6 For the rudder actuator, the permissible primary general membrane stress is not to exceed the lower of the values determined by calculation for the material:

(

3.2 Components

3.2.1 Special consideration is to be given to the suitability of any essential component which is not duplicated. Any such essential component shall, where appropriate, utilize anti-friction bearings such as ball bearings, roller bearings or sleeve bearings which shall be permanently lubricated or provided with lubrication fittings.

3.2.2 All steering gear components transmitting mechanical forces to the rudder stock, which are not protected against overload by structural rudder stops or mechanical buffers, are to have a strength at least equivalent to that of the rudder stock in way of the tiller.

3.2.3 Actuator oil seals between non-moving parts, forming part of the external pressure boundary, are to be of the metal upon metal type or of an equivalent type.

3.2.4 Actuator oil seals between moving parts, forming part of the external pressure boundary, are to be duplicated, so that the failure of one seal does not render the actuator inoperative. Alternative arrangements providing equivalent protection against leakage may be accepted.

3.2.5 Piping, joints, valves, flanges and other fittings are to comply within the requirements of Chapter 12 for Class I piping systems components. The design pressure is to be in accordance with 3.1.5.

3.2.6 Hydraulic power operated steering gear are to be provided with the following :

(a) Arrangements to maintain the cleanliness of the hydraulic fluid taking into consideration the type and design of the hydraulic system;

(b) A fixed storage tank having sufficient capacity to recharge at least one power actuating system including the reservoir, where the main steering gear is required to be power operated. The storage tank is to be permanently connected by piping in such a manner that the hydraulic systems can be readily recharged from a position within the steering gear compartment and provided with a contents gauge.

3.3 Valve and relief valve arrangements

3.3.1 For vessels with non-duplicated actuators, isolating valves are to be fitted at the connection of pipes to the actuator, and are to be directly fitted on the actuator.

3.3.2 Arrangements for bleeding air from the hydraulic system are to be provided, where necessary.

3.3.3 Relief valves are to be fitted to any part of the hydraulic system which can be isolated and in which pressure can be generated from the power source or from external forces. The settings of the relief valves is not to exceed the design pressure. The valves are to be of adequate size and so arranged as to avoid an undue rise in pressure above the design pressure.

3.3.4 Relief valves for protecting any part of the hydraulic system which can be isolated, as required by 3.3.3 are to comply with the following:

(a) The setting pressure is not to be less than 1,25 times the maximum working pressure.

(b) the minimum discharge capacity of the relief valve(s) is not to be less than 110 per cent of the total capacity of the pumps which can deliver through it (them). Under such conditions the rise in pressure. is not to exceed 10 per cent of the setting pressure. In this regard, due consideration is to be given to extreme foreseen ambient conditions in respect of oil viscosity.

3.4 Flexible hoses

3.4.1 Hose assemblies approved by LR may be installed between two points where flexibility is required but are not to be subjected to torsional deflection (twisting) under normal operating conditions. In general, the hose should be limited to the length necessary to provide for flexibility and for proper operation of machinery, see also Ch 12,7.

3.4.2 Hoses should be high pressure hydraulic hoses according to recognized standards and suitable for the fluids, pressures, temperatures and ambient conditions in question.

3.4.3 Burst pressure of hoses is to be not less than four times the design pressure.

Steering control systems

4.1 General

4.1.1 Steering gear control is to be provided:

(a) For the main steering gear, both on the navigating bridge and in the steering gear compartment;

(b) Where the main steering gear is arranged according to 2.1.4, by two independent control systems, both operable from the navigating bridge. This does not require duplication of the steering wheel or steering lever. Where the control system consists of a hydraulic telemotor, a second independent system need not be fitted, except in a tanker, chemical tanker or gas carrier of 10 000 gross tonnage and upwards;

(c) For the auxiliary steering gear, in the steering gear compartment and, if power operated, it shall also be operable from the navigating bridge and is to be independent of the control system for the main steering gear.

(d) Where the steering gear is so arranged that more than one control system can be simultaneously operated, the risk of hydraulic locking caused by single failure is to be considered.

4.1.2 Any main and auxiliary steering gear control system operable from the navigating bridge is to comply with the following:

(a) Means are to be provided in the steering gear compartment for disconnecting any control system operable from the navigating bridge from the steering gear it serves;

(b) The system is to be capable of being brought into operation from a position on the navigating bridge.

4.1.3 The angular position of the rudder shall:

(a) If the main steering gear is power operated, be indicated on the navigating bridge. The rudder angle indication is to be independent of the steering gear control system;

(b) Be recognizable in the steering gear compartment.

4.1.4 Appropriate operating instructions with a block diagram showing the change-over procedures for steering gear control systems and steering gear actuating systems are to be permanently displayed in the wheelhouse and in the steering gear compartment.

4.1.5 Where the system failure alarms for hydraulic lock (see Table 19.5.1) are provided, appropriate instructions shall be placed on the navigating bridge to shutdown the system at fault.

Section 5 Electric power circuits, electric control circuits, monitoring and alarms

5.1 Electric power circuits

5.1.1 Short circuit protection, an overload alarm and, in the case of polyphase circuits, an alarm to indicate single phasing is to be provided for each main and auxiliary motor circuit. Protective devices are to operate at not less than twice the full load current of the motor or circuit protected and are to allow excess current to pass during the normal accelerating period of the motors.

5.1.2 Indicators for running indication of each main and auxiliary motor are to be installed on the navigating bridge and at a suitable main machinery control position.

5.1.3 Two exclusive circuits are to be provided for each electric or electrohydraulic steering gear arrangement consisting of one or more electric motors.

5.1.4 Each of these circuits is to be fed from the main switchboard. One of these circuits may pass through the emergency switchboard.

5.1.5 One of these circuits may be connected to the motor of an associated auxiliary electric or electrohydraulic power unit.

5.1.6 Each of these circuits is to have adequate capacity to supply all the motors which can be connected to it and which can operate simultaneously. 5.1.7 These circuits are to be separated throughout their length as widely as is practicable.

5.1.8 In ships of less than 1600 gross tonnage, if an auxiliary steering gear is not electrically powered or is powered by an electric motor primarily intended for other services, the main steering gear may be fed by one circuit from the main switchboard. Consideration would be given to other protective arrangements than described in 5.1.1, for such a motor primarily intended for other services.

5.2 Electric control circuits

5.2.1 Electric control systems are to be independent and separated as far as is practicable throughout their length.

5.2.2 Each main and auxiliary electric control system which is to be operated from the navigating bridge is to comply with the following:

(a) It is to be served with electric power by a separate circuit supplied from the associated steering gear power circuit, from a point within the steering gear compartment, or directly from the same section of switchboard busbars, main or emergency, to which the associated steering gear power circuit is connected.

(b) Each separate circuit is to be provided with short circuit protection only.

5.3 Monitoring and alarms

5.3.1 Alarms and monitoring requirements are indicated in 5.3.2 and Table 19.5.1.

5.3.2 All alarms associated with steering gear faults are to be indicated on the navigating bridge and in accordance with the alarm system specified by Pt 6, Ch 1,2.3.

Section 6 Emergency power

6.1 General

6.1.1 Where the rudder stock is required to be over 230 mm diameter in way of the tiller, excluding strengthening for navigation in ice, an alternative power supply, sufficient at least to supply the steering gear power unit which complies with the requirements of 2.1.3 and also its associated control system and the rudder angle indicator, shall be provided automatically, within 45 seconds, either from the emergency source of electrical power or from an independent source of power located in the steering gear compartment. This independent source of power shall be used only for this purpose.

6.1.2 In every ship of 10000 gross tonnage and upwards, the alternative power supply shall have a capacity for at least 30 minutes of continuous operation and in any other ship for at least 10 minutes.

6.1.3 Where the alternative power source is a generator, or an engine driven pump, starting arrangements are to comply with the requirements relating to the starting arrangements of emergency generators.

Section 7 Testing and trials

7.1 Testing

7.1.1 The requirements of the Rules relating to the testing of Class 1 pressure vessels, piping, and related fittings including hydraulic testing apply.

7.1.2 After installation on board the vessel the steering gear is to be subjected to the required hydrostatic and running tests.

7.1.3 Each type of power unit pump is to be subjected to a type test. The type test shall be for a duration of not less than 100 hours, the test arrangements are to be such that the pump may run in idling conditions, and at maximum delivery capacity at maximum working pressure. During the test, idling periods are to be alternated with periods at maximum delivery capacity at maximum working pressure. The passage from one condition to another should occur at least as quickly as on board. During the whole test no abnormal heating, excessive vibration or other irregularities are permitted. After the test, the pump is to be opened out and inspected. Type tests may be waived for a power unit which has been proven to be reliable in marine service.

7.2 Trials

7.2.1 The steering gear is to be tried out on the trial trip in order to demonstrate to the Surveyor's satisfaction that the requirements of the Rules have been met. The trial is to include the operation of the following:

(a) The steering gear, including demonstration of the performances required by 2.1.2(b) and 2.1.3(b). For the main steering gear trial, the propeller pitch of controllable pitch propellers is to be at the maximum design pitch approved for the maximum continuous ahead RPM. If the vessel cannot be tested at the deepest draught, alternative trial conditions may be specially considered. In this case, for the main steering gear trial, the speed of the ship corresponding to the maximum continuous revolutions of the main engine should apply;

(b) The steering gear power units, including transfer between steering gear power units;

(c) The isolation of one power actuating system, checking the time for regaining steering capability;

(d) The hydraulic fluid recharging system;

(e) The emergency power supply required by 6.1.1;

(f) The steering gear controls, including transfer of control and local control;

(g) The means of communication between the steering gear compartment and the wheelhouse, also the engine room, if applicable;

(h) The alarms and indicators.

(j) Where the steering gear is designed to avoid hydraulic locking this feature shall be demonstrated.

Test items (d), (g), (h) and (j) may be effected at the dockside.

Section 8 Additional requirements

8.1 For tankers, chemical tankers, or gas carriers of 10 000 tons gross and upwards and every other ship of 70 000 tons gross and upwards

8.1.1 The main steering gear is to comprise two or more identical power units complying with provisions of 2.1.4.

8.2 For tankers, chemical tankers or gas carriers of 10 000 tons gross and upwards

8.2.1 Subject to 8.3 the following are to be complied with:

(a) The main steering gear is to be so arranged that in the event of loss of steering capability due to a single failure in any part of one of the power actuating systems of the main steering gear, excluding the tiller, quadrant or components serving the same purpose, or seizure of the rudder actuators, steering capability is to be regained in not more than 45 seconds after the loss of one power actuating system.

(b) The main steering gear is to comprise either:

(i) two independent and separate power actuating systems, each capable of meeting the requirements of 2.1.2(b); or

(ii) at least two identical power actuating systems which, acting simultaneously in normal operation, are capable of meeting the requirements of 2.1.2(b). Where necessary to comply with these requirements, inter-connection of hydraulic power actuating systems is to be provided. Loss of hydraulic fluid from one system is to be capable of being detected and the defective system automatically isolated so that the other actuating system or systems remain fully operational.

(c) Steering gears other than of the hydraulic type are to achieve equivalent standards.

8.3 For tankers, chemical tankers or gas carriers of 10 000 tons gross and upwards but of less than 100 000 tons deadweight

8.3.1 Solutions other than those set out in 8.2.1 which need not apply the single failure criterion to the rudder actuator or actuators, may be permitted provided that an equivalent safety standard is achieved and that:

(a) Following loss of steering capability due to a single failure of any part of the piping system or in one of the power units, steering capability is regained within 45 seconds; and

(b) Where the steering gear includes only a single rudder actuator special consideration is given to stress analysis for the design including fatigue analysis and fracture mechanics analysis, as appropriate, the material used, the installation of sealing arrangements and the testing and inspection and provision of effective maintenance. In consideration of the foregoing, regard will be given to the `Guidelines' in Section 9.

8.3.2 Manufacturers of steering gear who intend their product to comply with the requirements of the `Guidelines' are to submit full details when plans are forwarded for approval.

Section 9 `Guidelines' for the acceptance of non-duplicated rudder actuators for tankers, chemical tankers and gas carriers of 10 000 tons gross and upwards but of less than 100 000 tons deadweight

9.1 Materials

9.1.1 Parts subject to internal hydraulic pressure or transmitting mechanical forces to the rudder-stock are to be made of duly tested ductile materials complying with recognized standards. Materials for pressure retaining components are to be in accordance with recognized pressure vessel standards. These materials are not to have an elongation less than 12 per cent nor a tensile strength in excess of 650 N/mm2.

9.2 Design

9.2.1 Design pressure. The design pressure should be assumed to be at least equal to the greater of the following:

(a) 1,25 times the maximum working pressure to be expected under the operating conditions required in 2.1.2(b).

(b) The relief valve(s) setting.

9.2.2 Analysis. In order to analyse the design the following are required:

(a) The manufacturers of rudder actuators should submit detailed calculations showing the suitability of the design for the intended service.

(b) A detailed stress analysis of pressure retaining parts of the actuator should be carried out to determine the stresses at the design pressure.

(c) Where considered necessary because of the design complexity or manufacturing procedures, a fatigue analysis and fracture mechanics analysis may be required. In connection with these analyses, all foreseen dynamic loads should be taken into account. Experimental stress analysis may be required in addition to, or in lieu of, theoretical calculations depending upon the complexity of the design.

9.2.3 Dynamic loads for fatigue and fracture mechanics analysis. The assumption for dynamic loading for fatigue and fracture mechanics analysis where required by 3.1.5, 8.3 and 9.2.2 are to be submitted for appraisal. Both the case of high cycle and cumulative fatigue are to be considered.

9.2.4 Allowable stresses. For the purpose of determining the general scantlings of parts of rudder actuators subject to internal hydraulic pressure the allowable stresses should not exceed limits calculated using the materials to be used

9.2.5 Burst test. Pressure retaining parts not requiring fatigue analysis and fracture mechanics analysis may be accepted on the basis of a certified burst test and the detailed stress analysis required by 9.2.2 need not be provided. The minimum bursting pressure should be calculated using set formulae:

9.3 Construction details

9.3.1 General. The construction should be such as to minimize local concentrations of stress.

9.3.2 Welds.

(a) The welding details and welding procedures should be approved.

(b) All welded joints within the pressure boundary of a rudder actuator or connection parts transmitting mechanical loads should be full penetration type or of equivalent strength.

9.3.3 Oil seals. Oil seals forming part of the external pressure boundary are to comply with 3.2.3 and 3.2.4.

9.3.4 Isolating valves are to be fitted at the connection of pipes to the actuator, and should be directly mounted on the actuator.

9.3.5 Relief valves for protecting the rudder actuator against over-pressure as required in 3.3.3 are to comply with the following:

(a) The setting pressure is not to be less than 1,25 times the maximum working pressure expected under operating conditions required by 2.1.2(b).

(b) The minimum discharge capacity of the relief valve(s) is to be not less than 110 per cent of the total capacity of all pumps which provided power for the actuator. Under such conditions the rise in pressure should not exceed 10 per cent of the setting pressure. In this regard due consideration should be given to extreme foreseen ambient conditions in respect of oil viscosity.

9.4 Non-destructive testing

9.4.1 The rudder actuator should be subjected to suitable and complete non-destructive testing to detect both surface flaws and volumetric flaws. The procedure and acceptance criteria for non-destructive testing should be in accordance with requirements of recognized standards. If found necessary, fracture mechanics analysis may be used for determining maximum allowable flaw size.

9.5 Testing

9.5.1 Tests, including hydrostatic tests, of all pressure parts at 1,5 times the design pressure should be carried out.

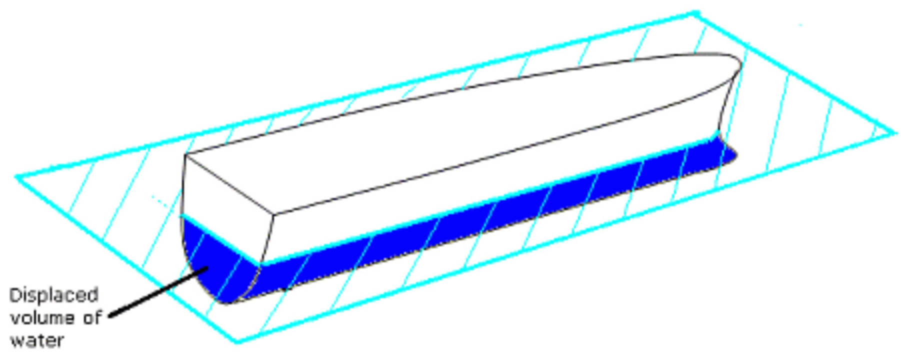
9.5.2 When installed on board the ship, the rudder actuator should be subjected to a hydrostatic test and a running test.

9.6 Additional requirements for steering gear fitted to ships with Ice Class notations

Stability

Fundamental of Buoyancy

- A Floating body displaces a volume of water equal to the weight of the body

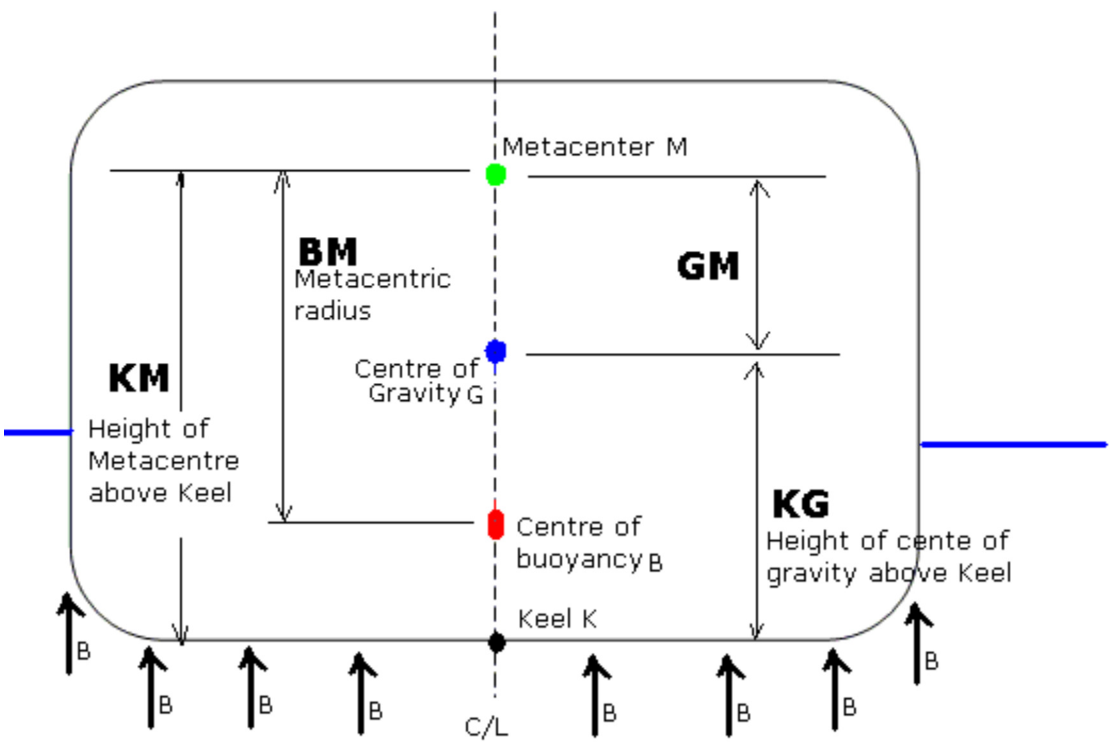


- A Floating body will be buoyed up by a force equal to the weight of the water displaced

Displacement

This is the equivalent mass of sea water (sg = 1.025) displaced by the hull. It is therefore equal to the **Total** weight of the vessel. The units are tons (long)

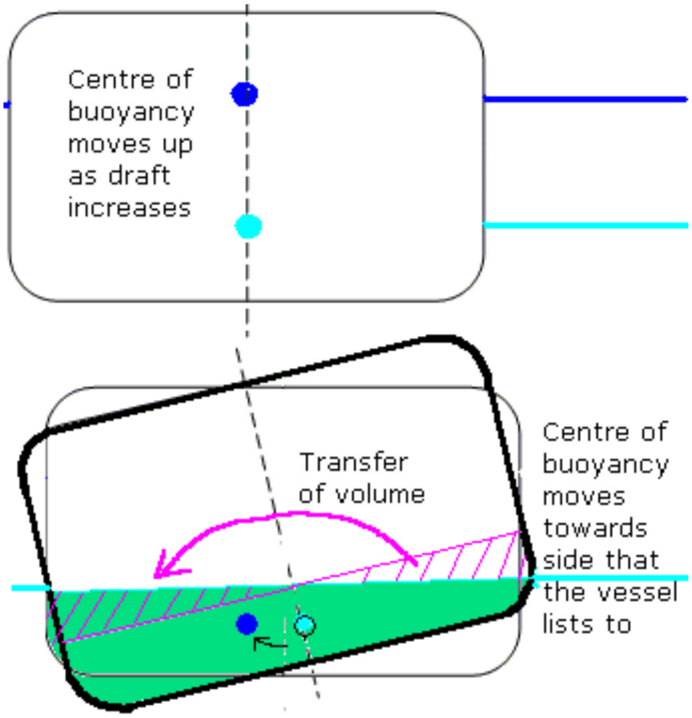
Small angle stability- Listing



The **center of Buoyancy B** is a theoretical point though which the buoyant forces acting on the wetted surface of the hull act through.

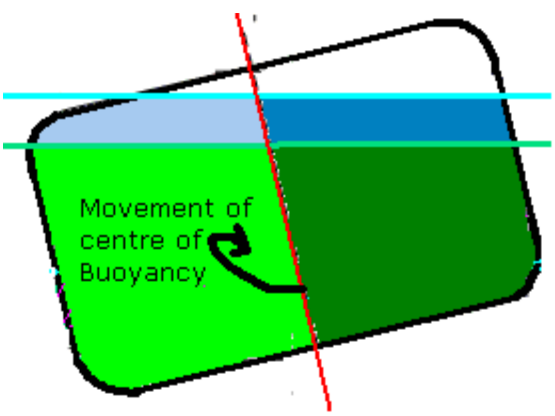
The **center of Gravity** is the theoretical point through which the summation of all the weights act through

Affects of listing

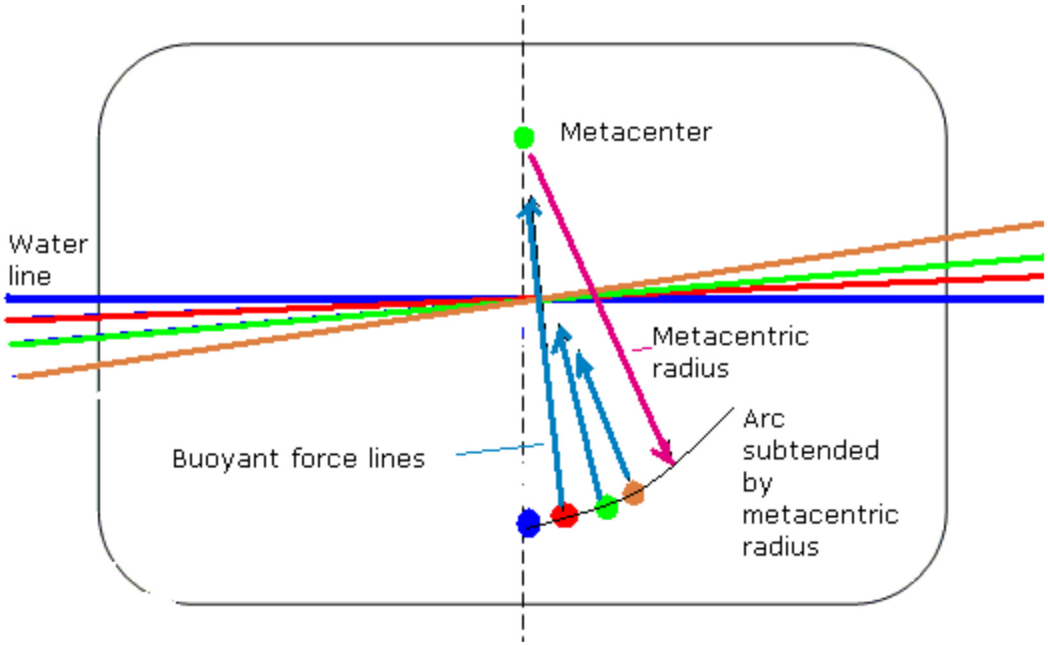


The position of the center of buoyancy changes depending on the attitude of the vessel in the water. As the vessel increases or reduces its draft so the center of buoyancy moves up or down respectively caused by increase in water displaced. As the vessel lists the center of buoyancy moves in a direction governed by the changing shape of the submerged part of the hull. For small angles the tendency is for the center of buoyancy to move towards the side of the ships which is becoming more submerged

Affects of listing to larger angles or low freeboard



Note this is true for consideration of small angle stability and for vessels with sufficient freeboard. In the example shown above when the water line reaches and moves above the main deck level a relatively smaller volume of the hull is submerged on the lower side for every centimeter movement as the water moves up the deck. The center buoyancy will now begin to move back towards centreline

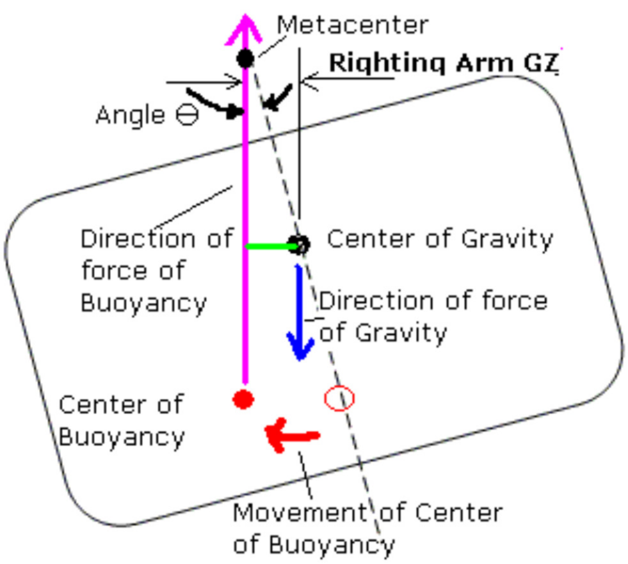


The **Metacenter M** is a theoretical point through which the buoyant forces act and small angles of list. At these small angles the center of buoyancy tends to follow an arc subtended by the **metacentric radius BM** which is the distance between the Metacenter and the center of buoyancy.

A the vessels draft changes so does the metacenter moving up with the center of buoyancy when the draft increases and vice versa when the draft decreases. For small angle stability it is assumed that the Metacenter does not move

Righting Moments

When a vessel lists there center of buoyancy moves off centreline. The center of gravity , however, remains on centerline



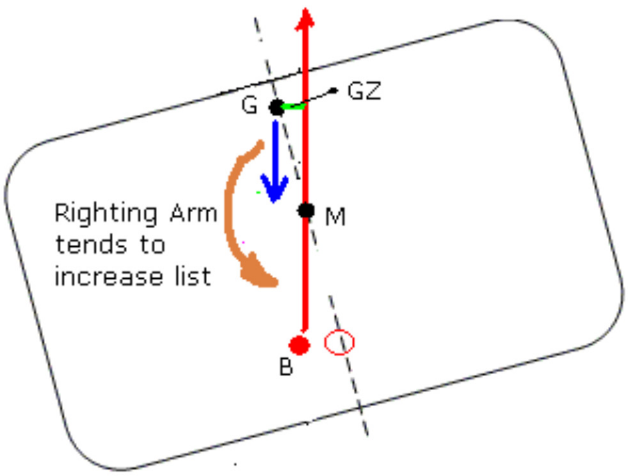
For small angles up to 10 degrees depending on hull form the righting Arm GZ can be found by

GZ = GM (Metacentric Height) x SinØ It can be seen that the greater the metacentric height the greater the righting arm is and therefore the greater the force recovering the vessel (**Righting Moment RM**)to the upright position.

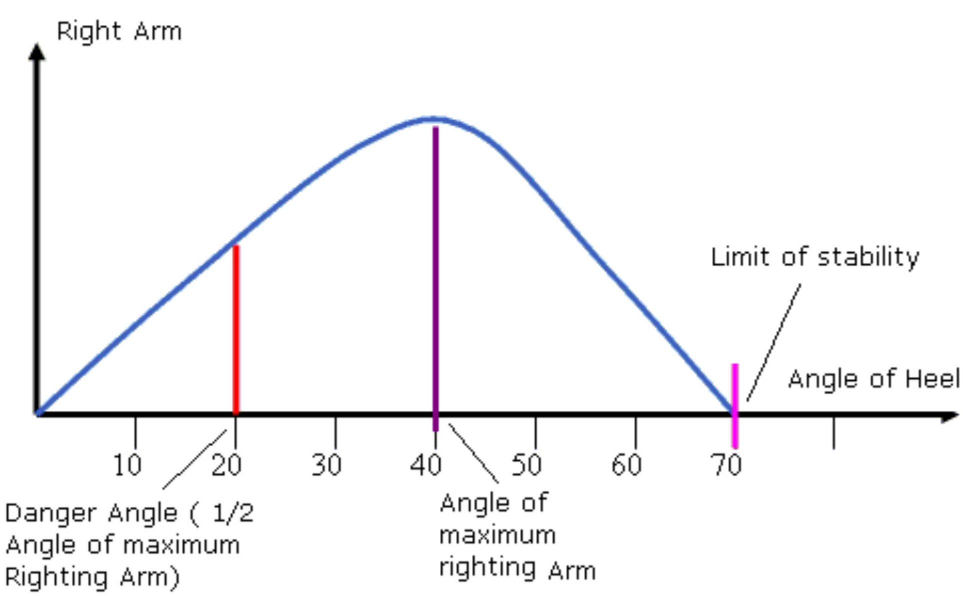
Negative Stability

The above examples all show the metacentre above the centre of gravity. This creates a righting arm at small angles always returning the vessel to the upright position. Where the metacentre is at or very near the centre of gravity then it is possible for the vessel to have a permanent list due to the lack of an adequate righting arm. Note that this may occur during loading operations and it is often the case that once the small angle restrictions are passed the metacentric height increases and a righting arm prevents further listing.

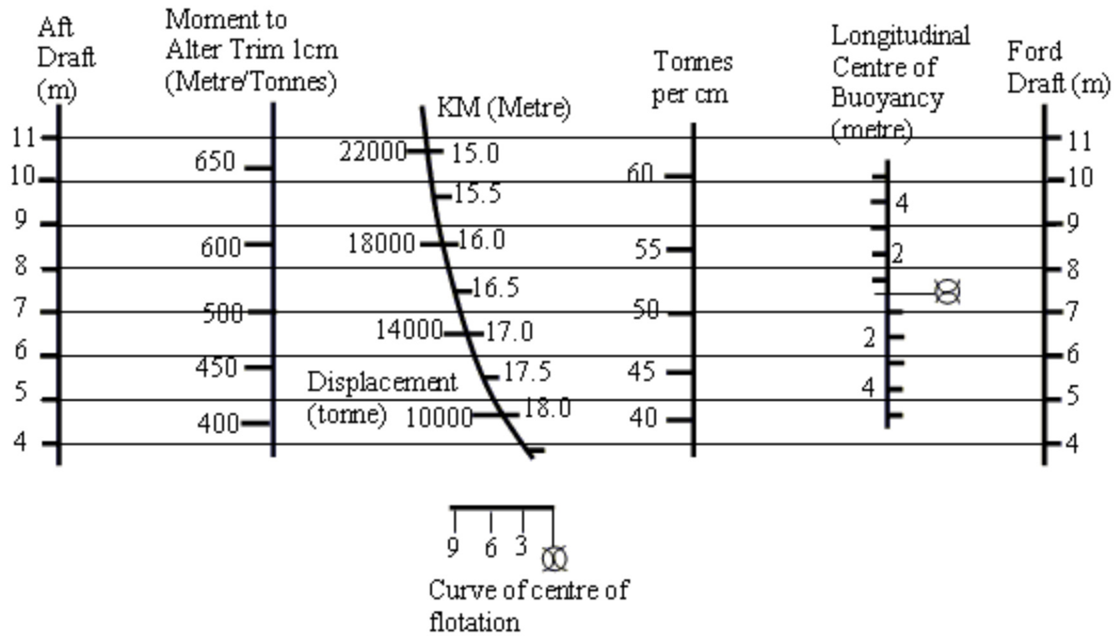
In a worst case the metacentre may be substantially below the center of Gravity.



Stability Curve



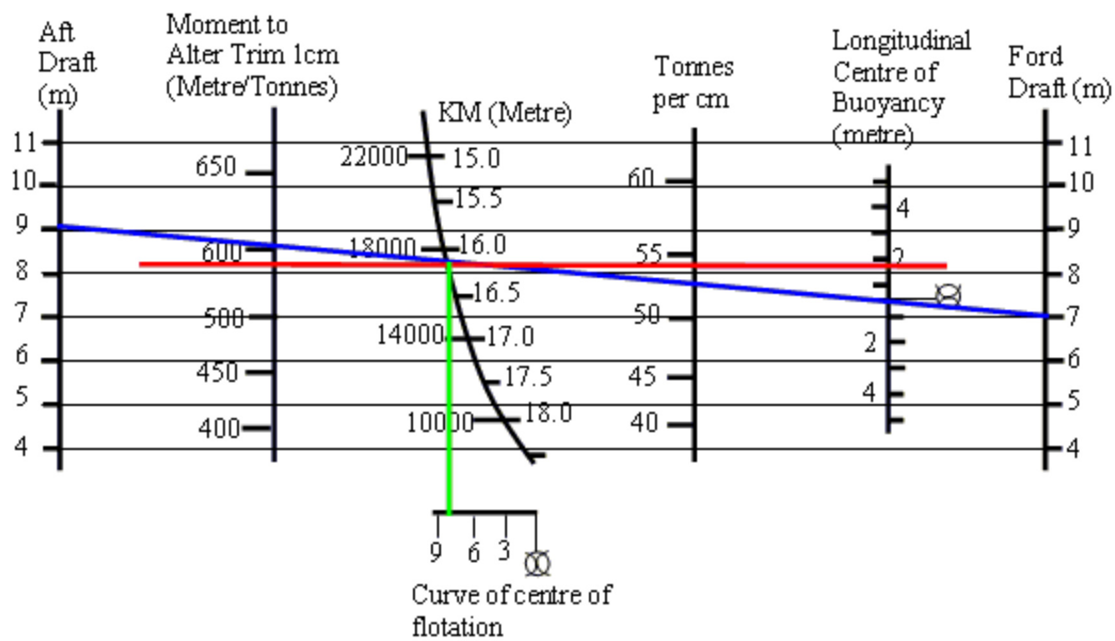
Draft Diagram



The Draft diagram is a simple and quick method of determining the following

- Moment to Trim per cm (MTC)
- Tonnes per Centimetre Immersion (TPC)
- Height of Metacenter (KM)
- Longitudinal Center of Flotation (LCF)
- Longitudinal Center of Buoyancy (LCB)

Worked example.

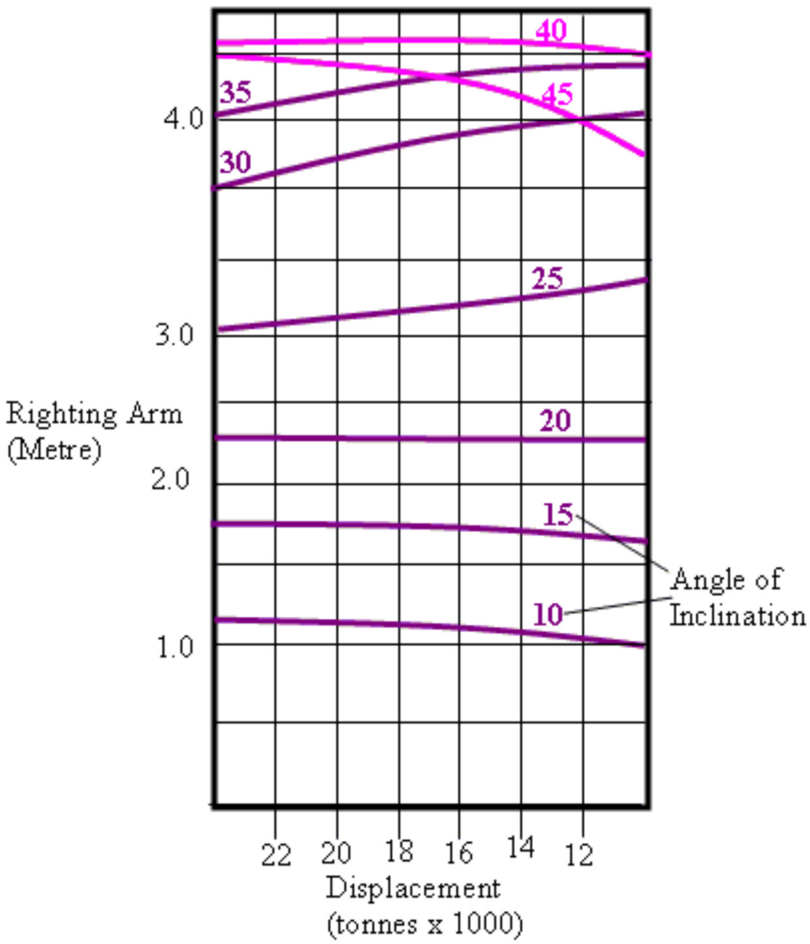


A line is drawn joining the ford and aft draft marks. (Blue Line). The Displacement can be read directly off

A horizontal line is drawn passing through the intersection of the blue line onto the displacement curve (Red Line). MTC, TPC, KM & LCB are read where the redline intersects their respective scales.

A vertical line (green) is dropped from the intersection of the blue line with the displacement curve from which can be read the LCF off the respective scale

Cross Curves of Stability



This may be used to determine the righting arms at different displacements and different angles of inclination

Stabilising systems

A vessel will roll due to the force of the waves .The actual effect of a wave system is dependent upon wave period , magnitude, ships metacentric height and displacement and others. All ships have a natural roll period depending upon; metacentric height, and the radius of gyration about the longitudinal polar axis. A large metacentric height will produce a short roll period which can be very uncomfortable whilst a small metacentric height produces slow roll periods with large amplitude .Both conditions can cause problems and reducing the roll amplitude is seen as advantageous.

Rolling causes severe racking stresses in the hull and additional loads due to gravity on the superstructure. It is unpleasant for passengers and crew and can lead to damage of cargo. The fitting of roll reduction systems reduces the effects without a supposed increase in racking stresses, due to the ship rising with the wave reducing its effect.

Bilge keels

These form the simplest method of controlling roll they consist of narrow steel strips extending along a portion of the length of the hull.

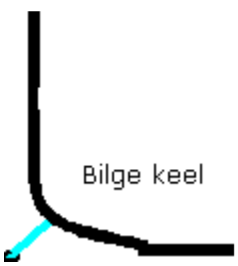
The are mounted at the turn of the keel and project no further than the breadth and depth of the ship thereby preventing contact damage.

They are attached to the hull by a relatively weak joint, say by riveting to a second fixing which is welded to the hull, or by stitch welding allowing the keel to be torn off without further hull damage.

Size of bilge keels depend upon the ship , but two conditions should be satisfied;

1. *The web must be long enough to penetrate the boundary layer of water travelling with the hull.*
2. *The web should not be so deep so as to sustain damage due to force of water during rolling.*

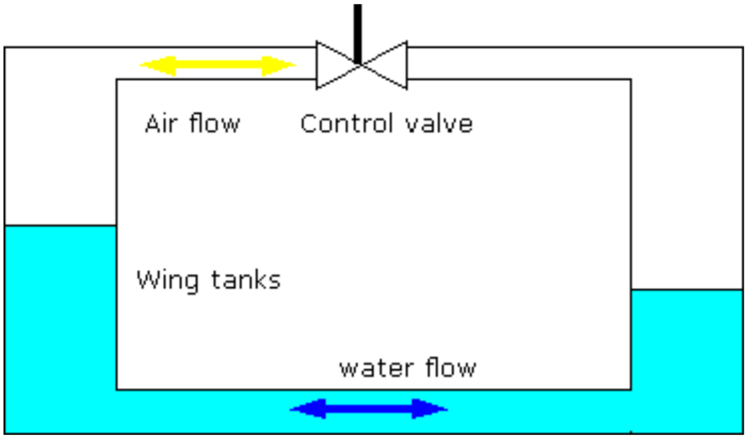
In addition the ends of the keel should be tapered or well rounded so that they blend smoothly with the lines of the hull,this reduces eddies which could lead to vibration and/or erosion damage.



Stabilising tanks

Two forms have been in general use but the passive tank system is the most common .

Passive system



In basic terms the system consists of a "U" shaped tank positioned across the ship with the main body of water being contained in the two side tanks .These are connected at he top by means of an air channel which contains one or more valves. This controls the rate of air flow and hence the rate of water flow between the tanks, baffle plates prevent surge.

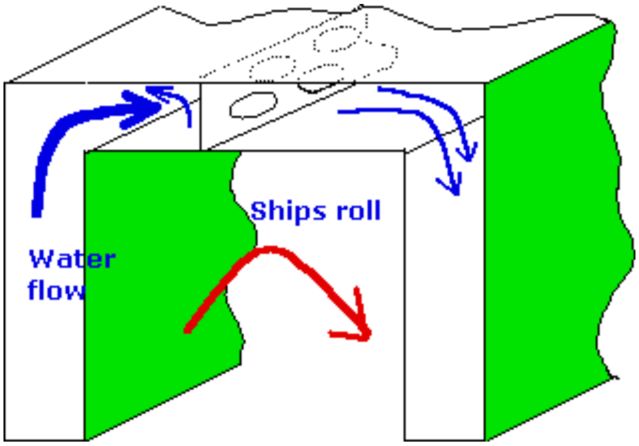
Maximum rolling occurs when the time interval between wave crests is the same as the time taken for a complete roll and that time depends upon a particular ship. Under these conditions the roll of the ship lags behind the wave crests by exactly one quarter time period. The ship will be vertical midway between crest and trough , reaching maximum roll angle at trough or crest.Anti rolling tanks employ a third oscillating system, namely water held in the "U" tube;t he First and second being the waves and the ship.

Careful design of the tank in terms of its shape , water capacity and vertical positioning in the ship allows control to be exercised with respect to rolling. With correct design of tank the water oscillating period will equal the roll period of the ship but its motion will lag behind that of the ship by one quarter of the roll period and behind the wave by half of the roll period. Water in the tank thus opposes the wave action producing the roll. Water movement between the tanks is regulated to some extent by the air valves. With the valves closed the system is put out of action. With this arrangement, known as the controlled passive system, the mass of water to about 2 to 2.5% of the ships displacement.

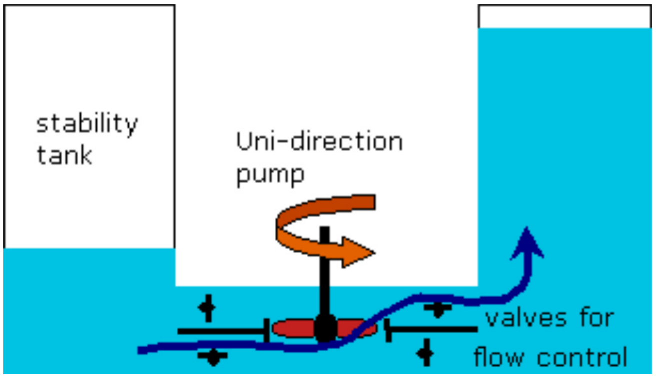
Care must be taken when retrofitting this system not to place the tanks to high or a critical loss of GM results .In an emergency it must be possible to dump the water very quickly thus large dump v/v's must be fitted.

Flume tank

This is a passive system which whilst simple in design remains very effective in its action. A restriction in the form of a perforated plate reduces the flow of water from on side to another during ships roll. In this way a righting moment is given automatically to the vessel. The amount of righting moment is dependent on the ship roll angle and speed.



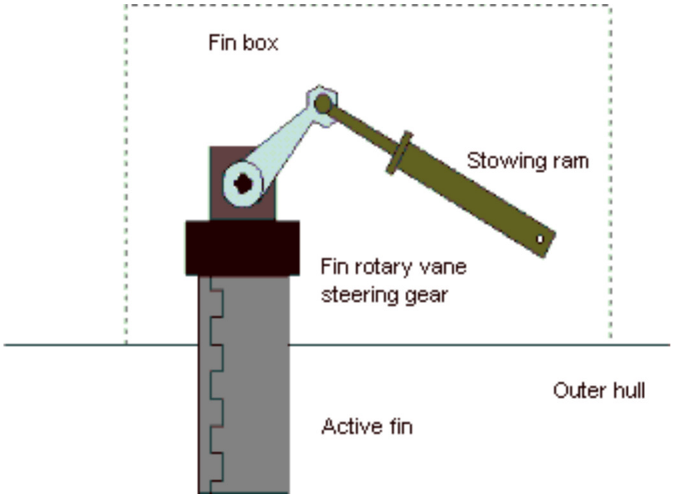
Active system



Active tanks employ the same basic principle of water counteracting the wave induced rolling but water flow is produced by means of a pump. In order to ensure rapid water flow in the desired direction the unidirectional pump impeller is kept running at all times and valves are actuated in order to direct the flow to and from particular tanks. Valves activation is by means of a control system employing gyroscopes.

In the neutral position all the flaps are open

Fin stabilisers

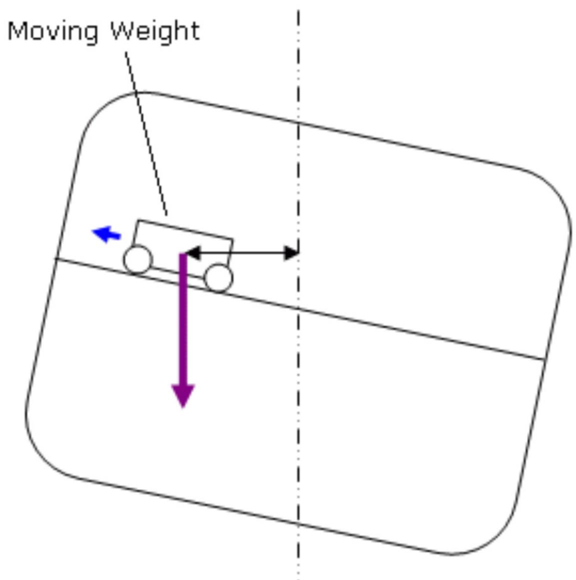


These work very much like aircraft wing in that they provide lift, positive or negative depending upon their aspect relative to water flow. Fins are of aerofoil cross section and are provided with tail flaps which can be moved relative to the main fin .This is accomplished automatically as the main fin is rotated . Main fins usually have a maximum movement of 20 degrees up or down whilst the tail can move a further 30 degrees relative to the main flap.

The magnitude determined by means of a control system employing gyroscopes .One of the gyro's reacts to change in position from vertical and is mounted vertically, whilst the other mounted horizontally reacts to rate of roll. Rapid acting control systems , rotate the fins by electro hydraulic systems similar to that used on the steering gear .Early arrangements were made to slide into fin boxes but recent systems employ hinged arrangement .The latter requires less space within the hull.

Very careful design of the fins and control systems is required in order to achieve optimum effect. The size of fin area and length of arm to ships center line must be taken into account as must the normal operating speed. At reduced speeds the fin may not operate effectively and in certain sea conditions even increase roll. Fin stabilisers require power to operate and increase drag slightly .Some larger vessels are fitted with twin sets operating independently giving total roll control.

Moving Weight

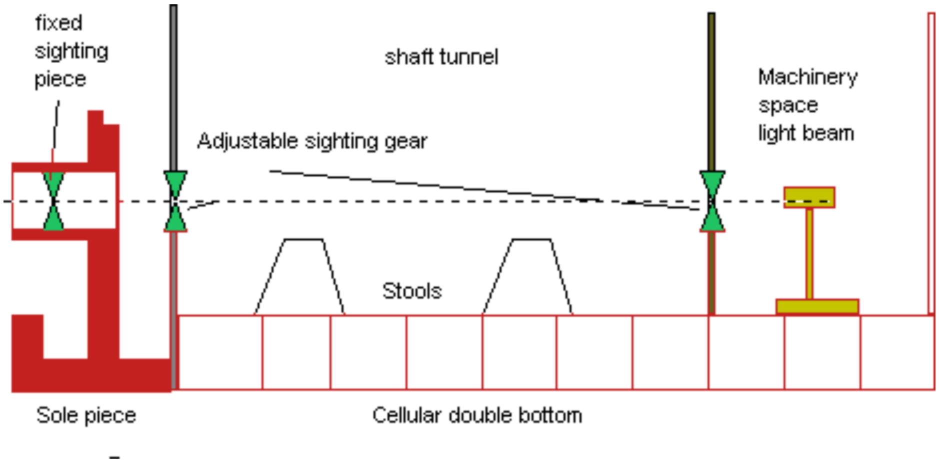


This system consists of a large mass (1% of ships displacement) which is able to be driven athwartships by electric motors to provide a righting moment

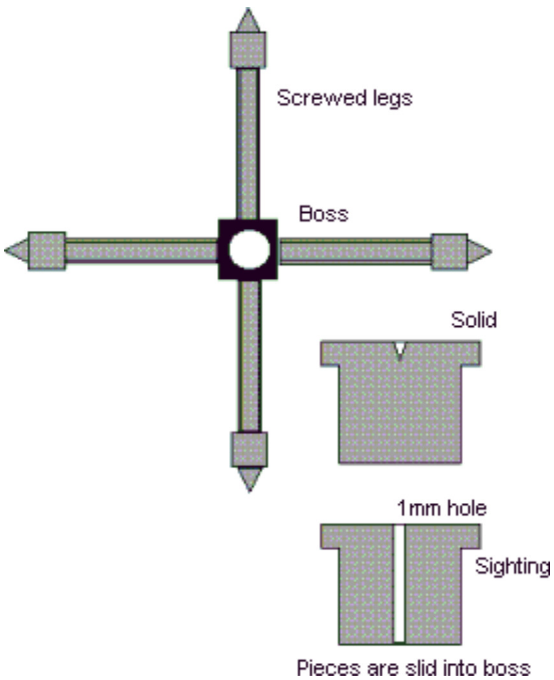
Thje advantage of this system is that it is able to cope with variations in roll period and is active even with the ship stopped

Shaft alignment

Optical alignment



At the for'd end of the engine room a light box emitting light through a pin hole is fixed from the design height of the crankshaft.



Using the sighting gear in stern frame boss with solid piece fitted. The stern frame boss is marked off for boring . The solid piece is then exchanged for a sighting piece.

A second sighting gear with sighting piece is fitted to the bore hole in the aft peak bulkhead. This is adjusted until the light source can be seen through the boss and aft peak bulkhead sighting pieces. The sighting piece is replaced by the fixed piece and the bulkhead may be machined. The stern tube is scribed out and the p.c.d. of the bolts which will support the stern tube flange marked off. A similar procedure us repeated for other bulkheads. When boring out is completed the stern tube is hauled into position, wood packing being fitted under the flange before bolting up at the aft peak bulkhead, the external stern tube nut is screwed up hard making a rigid connection at the after end. The tail end shaft is now fitted into the stern tube, the flange of the tail end shaft is now the standard by which the remaining line shafting will be aligned.

The trailing block (or towing block), of fitted, sometimes an ordinary plummer block is fitted (bearing material all round) is mow fitted around tail end shaft using feelers and wedging, chocked and bolted sown. The bearing acts also as an auxiliary thrust with a large clearance so that there is no possibility of it taking over from the main thrust under normal conditions other wise the towing block would shear.

This takes the form of a split brass ring fitted to the for'd end of the towing block which allows the tail end shaft to be disconnected from the intermediate shaft and hence rotate freely whilst the ship is under extended towing . The after face of the connecting flange then rides against this brass ring.

Coupling relationship method

The rest of the intermediate shafting is dropped into position on lower half bearings and using tail end flange as a standard they are lined up . This is done by using feelers between the faces of adjoining flanges, wedging the lower half bearings until faces are parallel with a 1/10mm gap between.

A parallel block is used around the periphery of the flanges. The intermediate bearings are chocked up by cast iron chocks about 50mm thick and bolted down. Couplings are continually rechecked. The thrust block is now aligned coupling to coupling and secured.

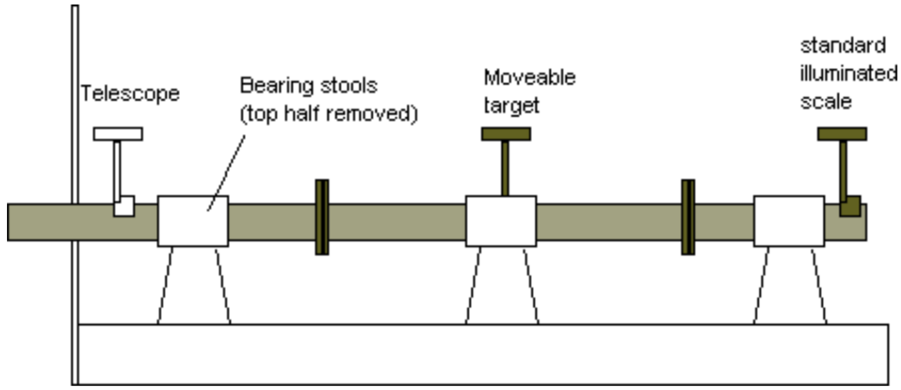
Main engine alignment

Bedplate and crankshaft now landed on hardwood blocks in approximately the position, slightly lower than true. It is now raised and jacked into position by lining the mating couplings on thrust and crankshaft. Cast iron chock thickness now measured, a small allowance being made to allow for individual fitting after machining. As each chock fitted its corresponding stud bolt is screwed through to engine seating and secured top to bottom. Checks made to ensure that shaft alignment is maintained, interference fit coupling bolts fitted and nuts screwed up.

It should be understood that the lining up of the shaft will only be true for one set of conditions such as on the building stocks or floating in a light condition. During service with variable loading some hogging and sagging takes place but there is sufficient flexibility in the shaft system to take care of this variation. Any bearing which runs chronically hot is almost certainly due to bad initial alignment.

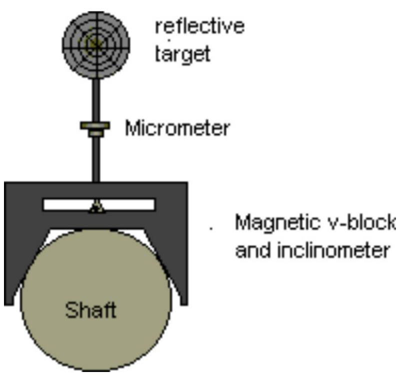
Optical sight line method

This method uses a micro alignment telescope which generates a sight line between an illuminated reflective target at one end of the shafting and the telescope mounted at the other end. The sight line is generated at a uniform height above the shaft vertically above the centreline of the shaft. A movable scale or target is employed on the intermediate shaft at bearing support points to measure distance from shaft to the sight line. The reflective target and movable scale consists of a magnetic 'v'-block fitted with transverse inclinometer and vertical stand with micrometer and scale.



Laser system

Similar to optical arrangement except that a laser housing generates a collimated red laser beam above the shaft which is detected by a centring detector at the other end of the shafting. A moving scale detector is used at intermediate bearing position.

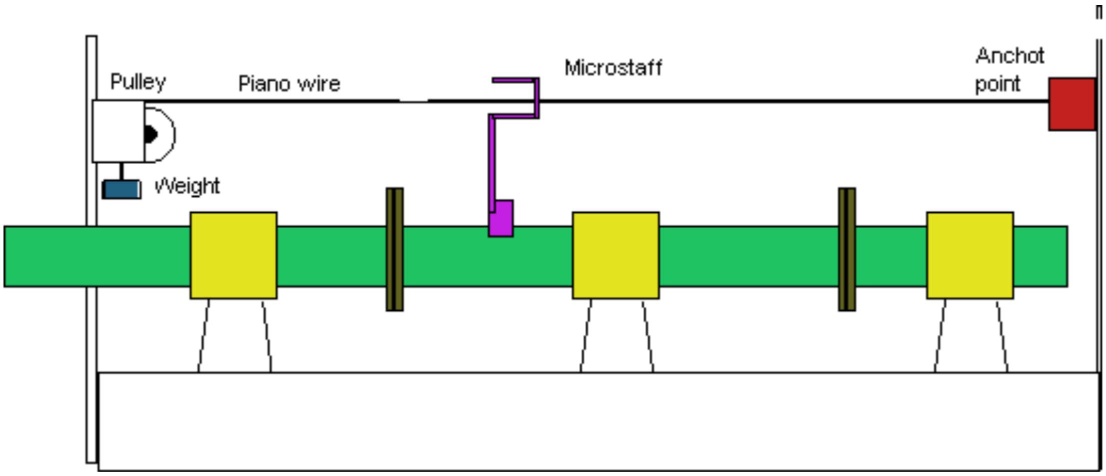


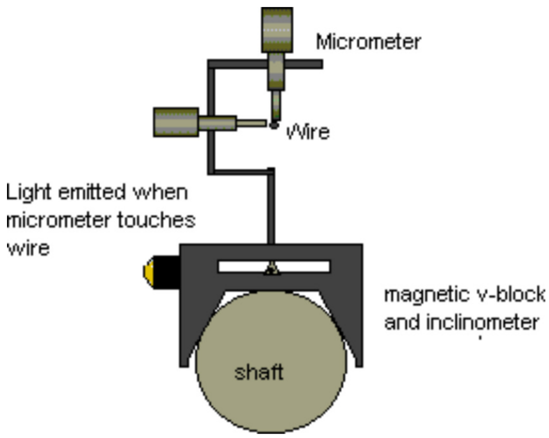
Taut wire method (Pilgrims wire)

Consists of steel wire anchored above shaft at one end of system and led over a pulley with suspended weight at the other end.

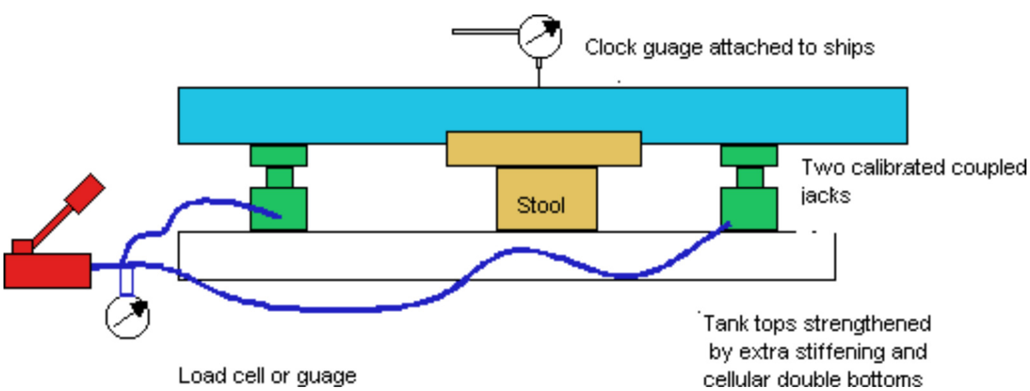
The height of the pulley and fixed anchorage are adjusted so that they are the same distance above the shaft and are positioned vertically over the shaft centre line. A microstaff is employed to measure the differences in height at bearing support points between shafts and wire, an allowance being made for wire sag.

A master inclinometer is employed to monitor ships movement during the aligning process.



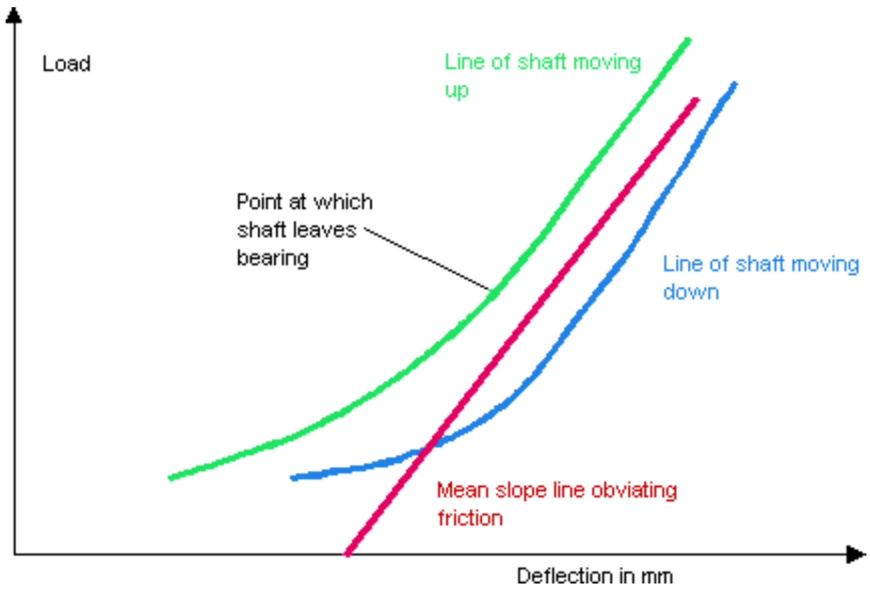


Bearing load method



Top cover off and horizontal alignment checked by measuring the side clearances of the shaft within the bearings. By using the system shown the shaft is carefully jacked up and a graph plotted. Initially a curve will be plotted as the ships structure stress relieves itself from the weight of the shafting, shaft still sitting on bearing material.

When curve assumes a straight line shaft has left bearing and in order to avoid damaging the shaft only sufficient plots will be taken to establish the slope of the straight line. The slope of the line for each bearing is put into a computer program which establishes the shaft system characteristic.


Load
Line of shaft moving up
Point at which shaft leaves bearing
Line of shaft moving down
Mean slope line obviating friction
Deflection in mm

Coupling bolts

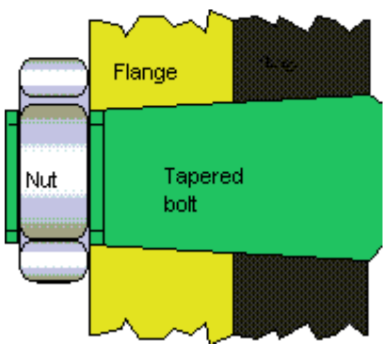
Elongation of a bar produces a related reduction in cross sectional area.

A bar with the same elastic properties in all directions will have a constant relationship between axial strain and lateral strain. This is termed the Poissons Ratio and given by the symbol n.

A bolt when tightened similarly causes a loss in area and diameter. In a clearance hole this is not a problem. With a fitted bolt however, the positive contact or 'fit' between the accurately machined bolt and reamed hole would be affected.

Shaft coupling bolts are tightened to force the faces of the flange together so the friction between the faces will provide some proportion of the drive. However, fitted bolt shanks are also designed to take a proportion of the drive. A clearance bolt could provide the first requirement but not the second. A fitted bolt when tightened and subject to reduction in cross section would also fail on the second count and probably be damaged by fretting. A tapered bolt may be used instead of a conventional coupling bolt to obtain a good fit and required tightening.

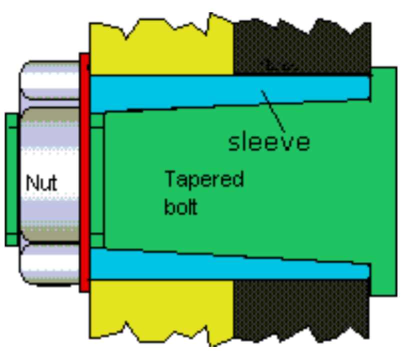
Taper fit bolt



Parallel shank fitted bolts

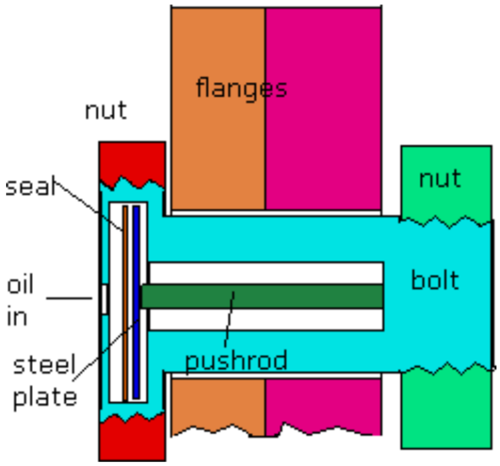
have Interference fit in holes so that in the event of loss of frictional grip between flanges then each bolt will take on equal share of the shear stress due to torque transmission.

Parallel bolts become slack after one or two refits. Therefore taper shank bolts have been used. An alternative is the sleeved coupling bolts.



The fit of the bolt is achieved by the tensioning of the taper shank bolt. Should wear occur in the sleeve then this can be renewed, reusing the rest of the assembly.

Hydraulically fitted bolts.



The pilgrim or margrip hydraulic bolt uses the principal embodied by poissons ratio to provide a calculated and definite fitting force between bolt and hole.

Center load rod fitted into hollow coupling bolt and hydraulic head fitted. High pressure oil pumped into head pushing down, seal, piston and rod .This action stretches the bolt (within its elastic limit) and reduces its diameter sufficiently for a sliding fit into the hole. Fluid pressure is released allowing bolt to expand and tightly grip within the hole with a radial grip of about 2.36 Kg/mm2 . Simultaneously longitudinal contraction of the bolt having already fitted the nut hand tight, exerts considerable compressive force which is about 2 1/2 x greater than that which can be achieved by normal torque tightening.

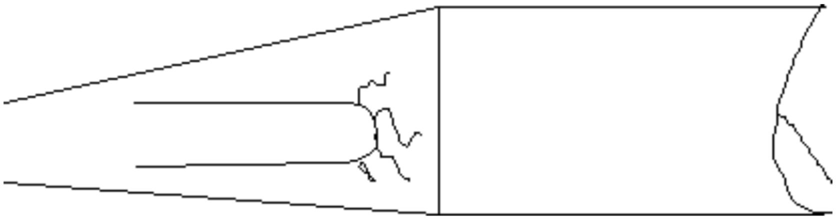
Hydraulic head and loading rod now removed and a protective cap and seal screwed back on

Advantages

Reduction in fitting and dismantling time, bolts can be used repeatedly, no replacements required , known loads applied

Tailshaft keys and keyways

KEYS AND KEYWAYS There are approximately 100 reported cases per year of partial or total tail shaft failure and 200 reported cases of lost props. Causes of this are quoted as inadequate force fit between prop and tailshaft causing loss of peripheral grip which allows prop to move and make contact with key. This causes excessive dynamic load to fall on key and shaft adjacent to keyway. This causes incipient cracks (small and superficial) which usually begin at high stress concentration areas i.e. around the leading edge of the keyway

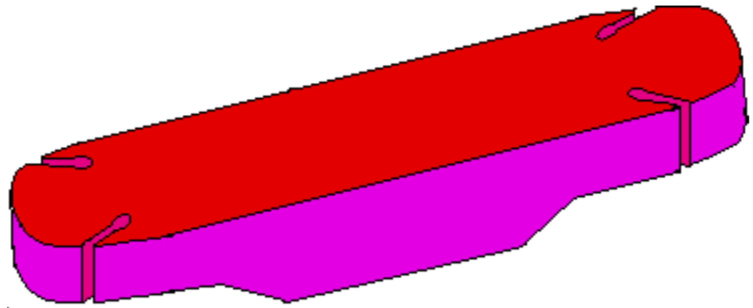


These fatigue failures may be corrosion N.B. Temperature variations in sea water can alter the force fits

Keys and Keyways

Abrupt changes of shape of section cause stress concentrations to build up due to interruption of the stress flow lines.

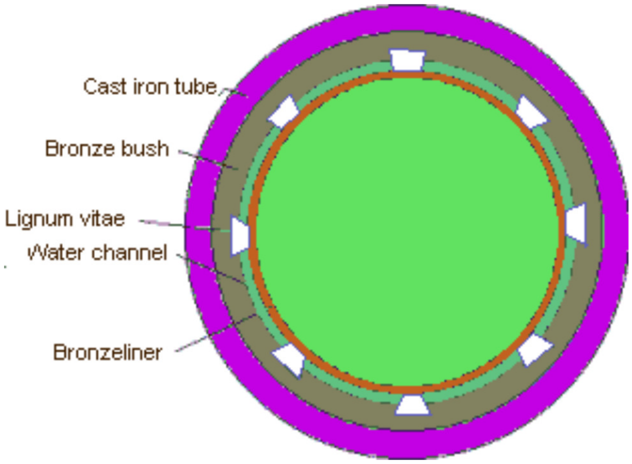
This build up in stress causes cracks to develop and supports crack propagation. With this in mind it can be seen that shapes or sections which may be subject to great stresses; should be well rounded or gradually tapered off to give smooth stress flow.



Round end keys used and the keyway in prop boss and cone of the tailshaft are to be provided with a smooth fillet at bottom of keyways, fillet radius at least 0.0125 of shaft diameter at top of cone. Sharp edges at top of keyway to be removed. Two screw pins secure key in keyway and the for'd pin should be at least 1/3 of key length from for'd end. Pin holes should have a depth not exceeding pin diameter. Hole edges bevelled.

Stern tubes

Water lubricated bearings



- The stern tube is normally constructed of cast iron slightly larger at the forward end to ease removal. The forward end is flanged and bolted to a doubler plate stiffened aft peak bulkhead. The forward end is supplied with a stuffing box and gland, the after end with a bearing comprising lignum vitae or similar, the wood is dove tailed into a brass bush, the wood is machined and cut on end grain. Can be lined with Lignum Vitae , rubber composition (cutlass rubber) or an approved plastic material (Certain plastics possess good bearing properties being inert and very tolerant of slow speed boundary lubrication conditions. Cresylic resin bonded asbestos such as Railco WA80H give good results in condition of heavy water contamination in the lubricating oil of almost 100%)

For water lubricated bearing not less than 4 x the diameter of the steel shaft. If the bearing is over 380mm diameter forced water lubrication must be used, a circulating pump or other source with a water flow indicator.

The shaft is withdrawn for examination every 3 years.

Modern Water tolerant oil lubricated stern Tube

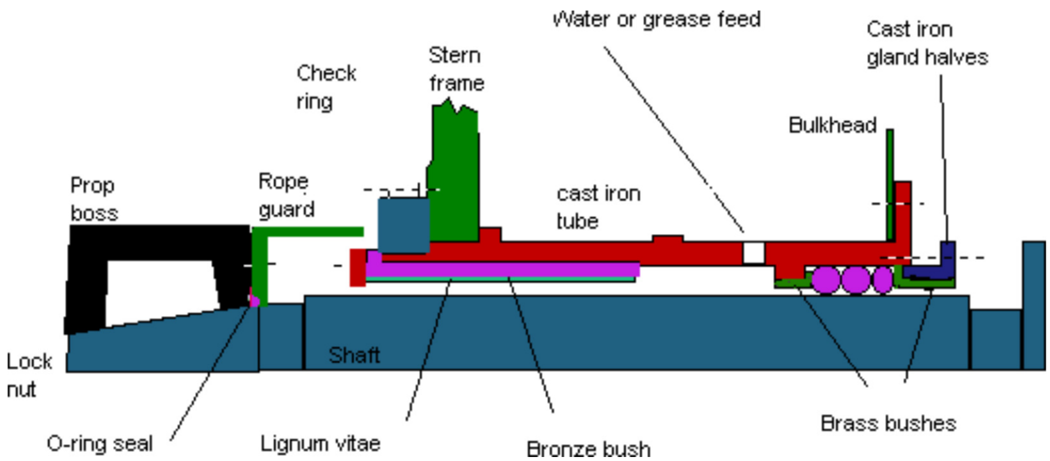
With the increase in size of VLCC's shipping companies required a stern tube bearing capable of operating with high degrees of water comtamination. The alloys in white metal tend to oxidise and the clearance is removed leading to seizure. In addition as shaft revs reduced in search of improved propeller efficiency the hydrodynamic forces available become limitedfor oil film generation.

For this reason Railco WA80H bearings where developed.These contained a phenolic resin impregnated asbestos yarn. The next generation contained non-asbestos material. This material tended to be tainted due a series of overheating problems. (later found due to the combination of stiff high power transfer shafts and flexible hull design).

The modern material is called SternSafe and comprises an inner bearing surface with an overwound outerlayer. This has greater tolerance to overheating and reduced swell in the event of water contamination. The latter allows for reduced running clearance and thereby greater control of the shaft position reducing oil loss, seal damage and water ingress.

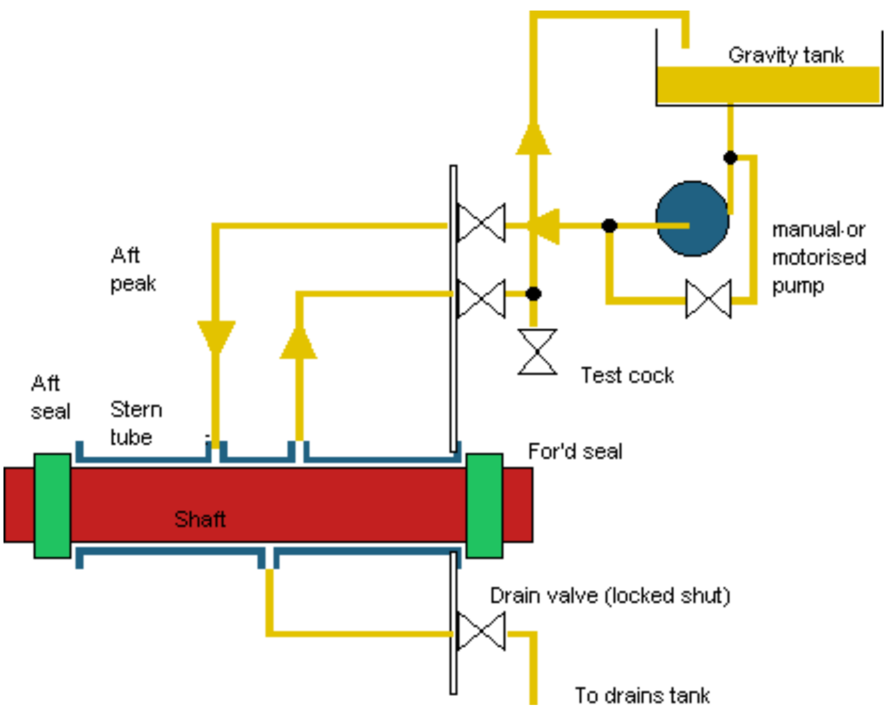
A wear gauge is incorporated into the bearing as our temperature sensors.

Oil lubricated bearings



Unlike for the water lubricated stern tube a shaft liner is unnecessary. Generally a small one is fitted in way of the aft seal bolted on to the propeller boss. In this way it excludes sea water contact with the main shaft and provides an easily replaceable rubbing surface for the seal. Lined with white metal are to have a bearing length so as not to exceed a bearing pressure from the weight of the shaft and propeller of 5 kg/cm2. The limitations of a bearing are the load it can withstand without metal cracking or squeezing out and the temperature it can withstand without melting. Length of bearing not less than 2 H D in any case. Cast iron and bronze bearings must have a bearing length not less than 4D. Lubrication system must be capable of maintaining oil tightness despite varying temperature. Gravity tanks fitted with low level alarms, Usual for aft peak to be filled with water to provide cooling low suction valve to be fitted to be locked shut.

Wear down for the white metal should not exceed 2mm to avoid hammering out and the period for inspection is 6 years. A highly resilient reinforced plastic may be used in place of the white metal. It is claimed to have greater load carrying capacity, high resistance to fatigue and shock loading, with good lubrication properties. Ceramic liners can also be used.



This system depends upon Hydrostatic lubrication stern tube oil charge remaining in stern tube until pressure test is carried put to ensure that oil supply line is not blocked. This is done by manipulation of valves at header tank and operation of pump which slightly over pressurises stern tube. Oil returning to tank indicating clear oil lines. Top half of white metal bearing is usually machined to give a left hand and right hand helix, this gives a small pumping pressure forward to aft to provide lubrication and to assist in maintaining oil tightness of the oil seals.

If outboard seal leaks, the following steps are to be taken

i. *Fresh water in gravity tank to emulsify and coagulate it, oil pumped around system to seal and lubricated.*
ii. *Recharge with high viscosity oil*
iii. *disconnect oil supply line and reconnect to 45 gallon drum which is supported by block and tackle in order to give a variable head. By raising and lowering the drum the oil pressure in the system can be made to match the water pressure from outside (taking into account the difference in gravities.*

When large propellers are fitted the heavy overhanging weight greatly increases the load at the after end of the stern tube breaking down the hydrostatic lubrication causing metal to metal contact and seizure towards the aft end of bearing. To obviate this it is usual to angle the shaft downwards for about 8mm over 100m length thus attempting to ensure than the weight of the bearing is taken on the full length of the bearing. It is good practice to leave the oil tank open to the stern tube when in port with machinery stopped, this prevents sea water leaking into the system. However, water has been known to contaminate lubricating oil systems causing rusting of tail shaft particularly when shaft is stopped for periods long enough for water to settle in bottom of bearing. Fit only water seperator I,e, a coalescer or cyclonic or osmosis system.

In ships with large changes in draught it is usual to fit two gravity tanks. The upper tank is used when fully loaded or there is water leaking in.

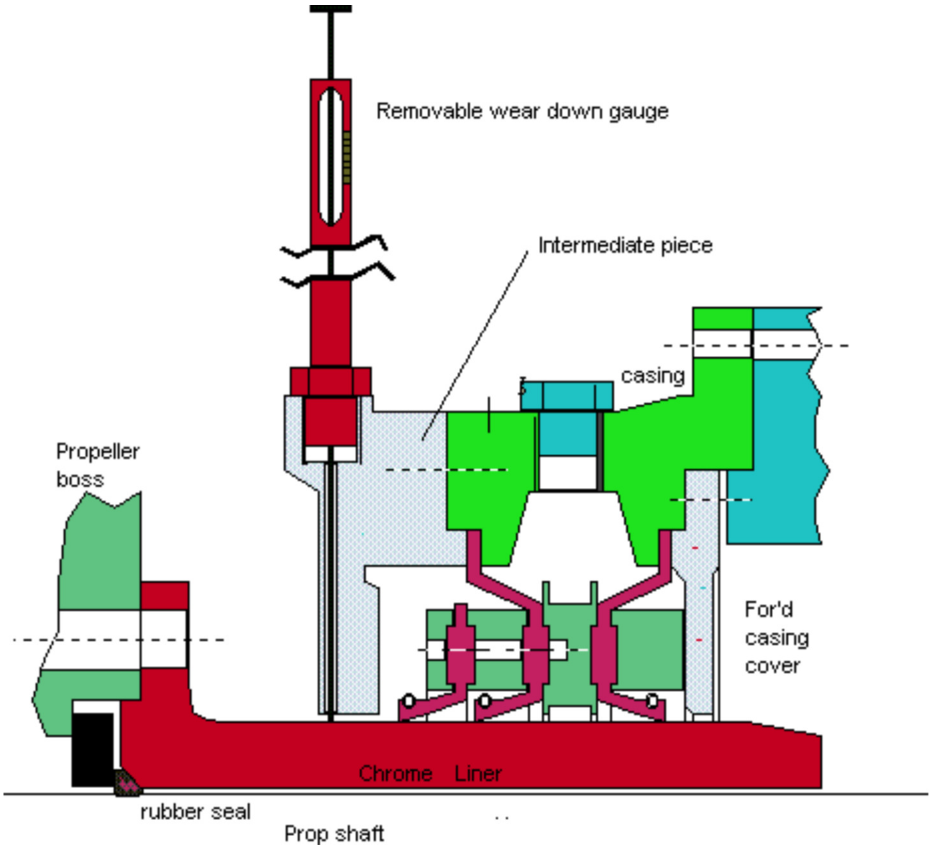
Water based oil replacements

Available are water based sterntube lubricants having the advantages of oil but with a more eco-friendly face. These lubricants must have an adequate viscosity, resistance to sea water contamination as well as biodegradability.

They typically have a water content greater than 90% and are highly soluble. Friction is reduced in comparison to equivalent mineral oil/white metal bearing.

Other benefits include increased heat transfer rates and better protection against galvanic corrosion of dissimilar metals found in the shaft/prop arrangement.The fluid has no measurable flash point.

Simplex shaft seal



A very common arrangement for oil lubricated stern tube bearings. A simplex seal arrangement is fitted to both inner and outer ends.

The replaceable chrome liner prevents damage to the prop shaft which would be expensive to repair.

Not show is a rope guard bolt to the hull which prevents material from being 'wound' into the gap and damaging the seal. Rope cutters may be fitted with a fixed blade attached to the hull and a moving blade to the propeller.

Oil pressure is fed to the area between the two opposite facing seals. This pressure is governed by the draught of the vessel and is often supplied via tanks situated at set heights. This pressure balances the sea water pressure on the seal and prevents sea water ingress, by opening the correct tank the pressure exerted by the oil is insufficient to cause oil to leakage out.

Stern tube seals with oil lubrication have tended to use rubber rings increasingly. Fluoric rubber (Viton) with additives has been shown to be more effective than nitrile butadiene rubber for seal rings

Fitting Shaft seals in service.

It is possible to replace lip seals without removal of the tailshaft by vulcanising split seals on the shaft.

The old seal is removed and the shaft and housing carefully cleaned

A pre cut seal is assembled into the vulcanising machine

The vulcanising machine is then set up off the shaft and the position of the seal checked.

The vulcanising agent is mixed and applied to the seal ends.

The vulcanising machine is then fitted to the shaft and connected to an electrical supply. A heater within the machine heats the seal to a predetermined temperature for a set time determined by ambient temperature, material type etc.

Split type stern tube (Ross-turnbull)

Main advantage of this system is that tail end shaft, stern tube bearing and tapped bolts can be inspected without dry docking. System allows stern tube to be drawn into the vessel for inspection

The bottom half bearing is supported on chocks which in turn rest on two ford and aft machined surfaces within stern tube boss, these chocks govern the height of shafting. A detachable arch is attached to the lower bearing and carries the outboard oil seal, the face of which comes into contact with a seal seat which is fastened to and rotates with tail shaft flange.

The top half of the bearing module makes a seal on the face of the arch and a seal along the horizontal joint on the bearing. The bearing is held in place vertically by 4 x 50 tonne pilgrim type jacks, these jacks also hold the two half bearings together. Lateral positioning is by 4 x 30tonne pilgrim type jacks, two each side.

A running track is arranged above the bearing for easy removal of top half . A rolled race skid is provided so that the bottom half can be transported.

Removal-The hydro mechanical seal is actuated making a seal on the ford face of the propeller and locked mechanically in position. The space is then drained of water.

Top half of bearing can then be removed by taking out the top vertical jacks and using the lifting jack to allow the top half to be brought inboard on the running track. These jacks are now fitted under the lower half bearing to raise bearing and shaft sufficient to allow the chocks to be removed.

The jacks are then lowered until the propeller rest on the propeller rest built into the stern frame. Further lowering allows the bearing to move away from the shaft until bearing is resting on roller skids. The lower half bearing complete with oil seal can then be removed into the vessel for examination.

Reversing the procedure enables the bearing to be replaced

Odd facts-Anti vibration locking gear fitted to jack nuts. As with a CPP it is usual to fit a flange mounted propeller eliminating taper and keyway with there associated problems. The tap bolts securing propeller to tail shaft flange can be removed one at a time, crack detected and returned to their working position.

Stresses in tail shafts

Due to the considerable weight of the propeller, the tail shaft is subject to a bending stress. There are however other stresses which are likely to be encountered. There is a torsional stress due to the propeller resistance and the engine turning moment, and a compressive stress due to the prop thrust. All these stresses coupled with the fact that the shaft may be in contact with highly corrosive sea water makes the likelihood of corrosion attack highly probable.

Examining a tail shaft and stern tube

- Before the periodic inspection the bearing weardown should be measured.
- After shaft removed given thorough examination.
- On water lubricated shafts the integrity of the fit of the bronze liner should be checked by tapping with a hammer along its length listening for hollow noise indicating a seperation.
- Measure wear of shaft.
- Examine key way for cracks especially the nut thread area.
- replace rubber rings

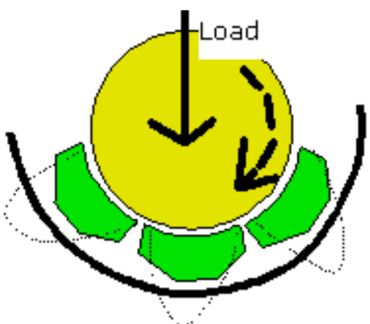
Shaft Bearings

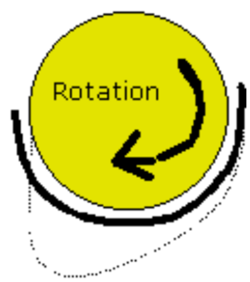
The intermediate shafting if supported in plain or tilting pad bearings, has an after most bearing which is lined top and bottom. Roller bearings are installed in many vessels.

Plain and tilting pad bearings

The shaft supported in a plain journal bearing, will as it rotates, carry oil to its underside and develop a film of pressure. The pressure build up is related to speed of rotation. Thus oil delivered as the shaft turns at normal speed, will separate shaft and bearing, so preventing metal to metal contact. Pressure generated in the oil film, is effective over about one third of the bearing area because of oil loss at the bearing ends and peripherally. Load is supported and transmitted to the journal, by the area where the film is generated. The remaining two thirds area does not carry load

Replacement of the ineffective side portions of the journal by pads capable of carrying load will considerably increase its capacity. Tilting pads based on those developed by Mitchell for thrust blocks are used for the purpose. Each pad tilts as oil is delivered to it so that a wedge or oil is formed. The three pressure wedges give a larger total support area than that obtained with a plain bearing. The tilt of the pads automatically adjusts to suit load, speed and oil viscosity. The wedge of oil gives a greater separation between shaft and bearing than does the oil film in a plain journal. The enhanced load capacity of a tilting pad design permits the use of shorter length or less bearings.





Any bearing instability, regardless of its nature is called 'oil whip'.

Bearing instability falls into two types

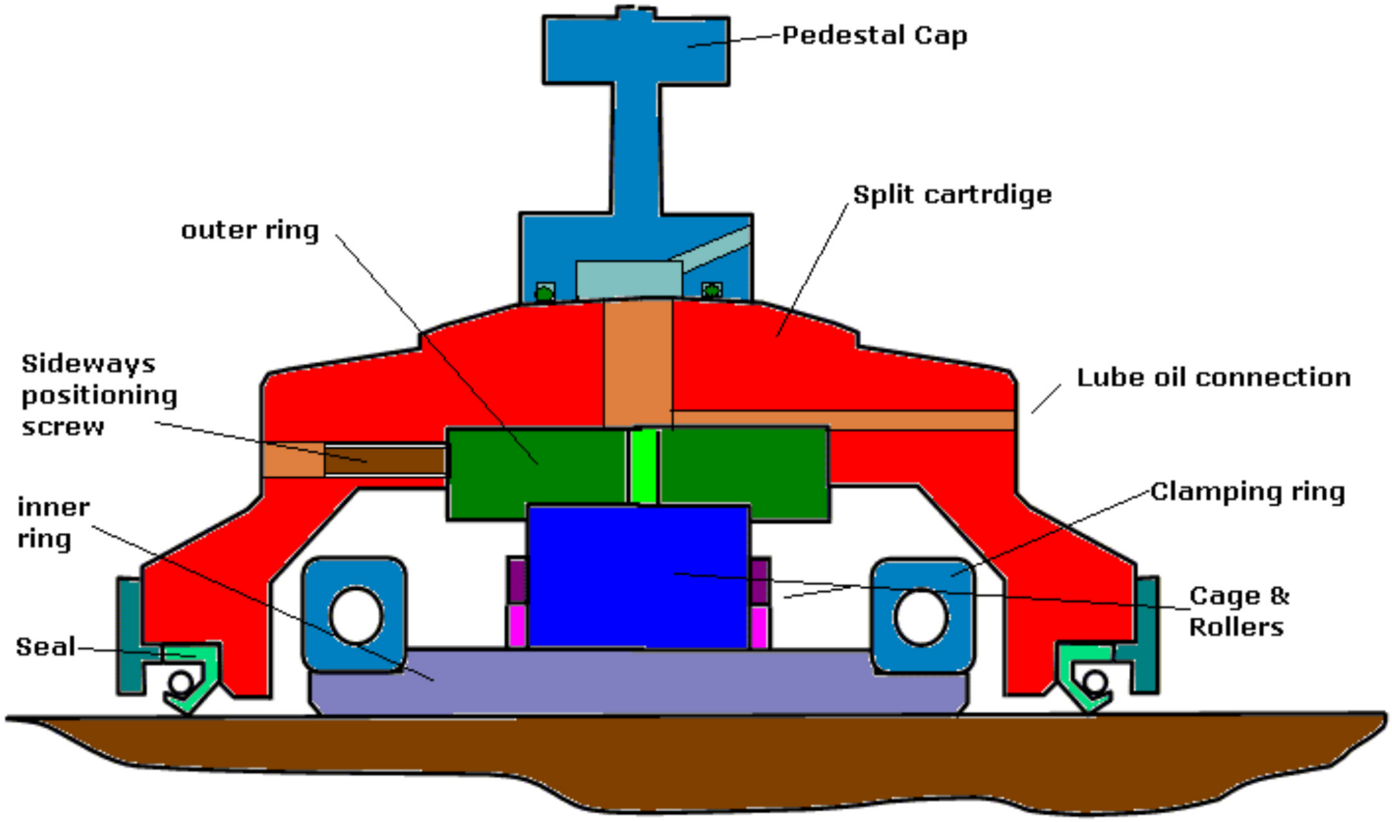
i. *Half frequency whirl*
ii. *Resonant whip*

The most effective bearing to prevent oil whip and dampen shaft vibration is the tilting and multiple shoe bearing.

Oil film operates at a lower temperature than a comparable full sleeved bearing.

Tilting pad bearings are in common use on steam turbines, high speed reduction gears, centrifugal compressors and line shafting.

Split Shaft bearings

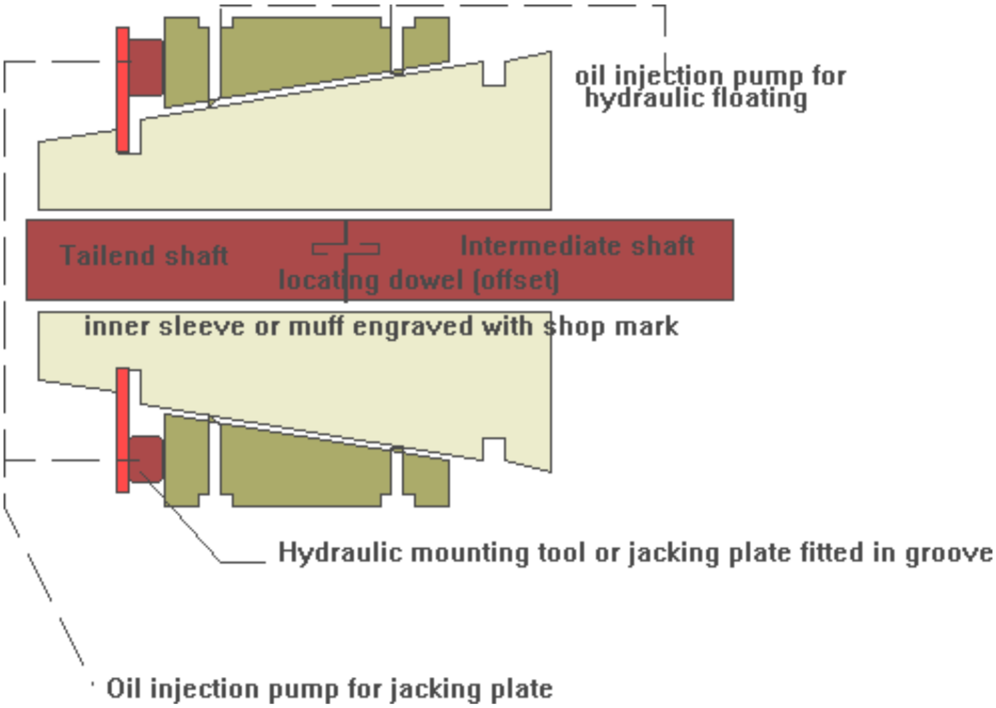


Inner Ring	Rotating inner ring is in two halves with a scarf or diagonal joint so that the tendency of the joint to open due to the weight of the shaft is reduced when the joint is at bottom centre. The scarf also allows more progressive transition of the roller over the joint reducing noise and vibration
Cage And rollers	The cage and rollers are in a matched pair with a diagonal split
Pedestal Cap	Clamps the splt cartridge. The joint is spherical allowing upto 2 1/2' of swivel without effect.
Split cartrdige	Is located by dowels and holds the outer ring in position. radial socket screw attach the outer ring securely to the split cartridge
Clamping ring	This rotating ring secures the split inner ring assembly and is joined by socket head screws

Clearance exists between the inner ring and thesplit cartridge. This allows movement of the shaft between thrust pads during ahead and astern movements. This also allows for thermal expansion of the shaft.

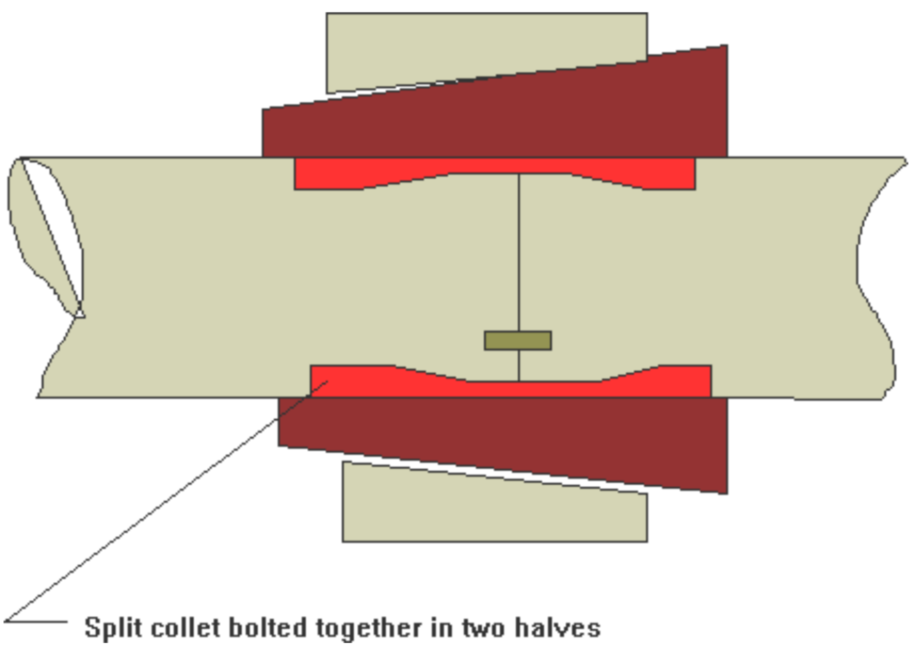
Plane white metal bearings offer a relatively high frictional resistance to rolling but are cheap and not subject to brinelling or corrosion.
Roller bearings are expensive but offer little resistance to rolling. However, they are susceptible to brinelling when stationary.
The above design removes the major disadvantage of assembling the bearing onto the shaft which would normally require shaft removal.

SKF (Muff) coupling



Outside dia's at end of outer muff measured before fitting
After fitted, dia's should be approx. 0.5mm greater Restraining devices must be fitted to prevent the muffs separating too quickly

Emergency astern arrangement



This is fitted to ships, the purpose of which is to prevent the shaft from slipping out of the stern tube if the muff coupling should fail. Its purpose is not to transmit torque.

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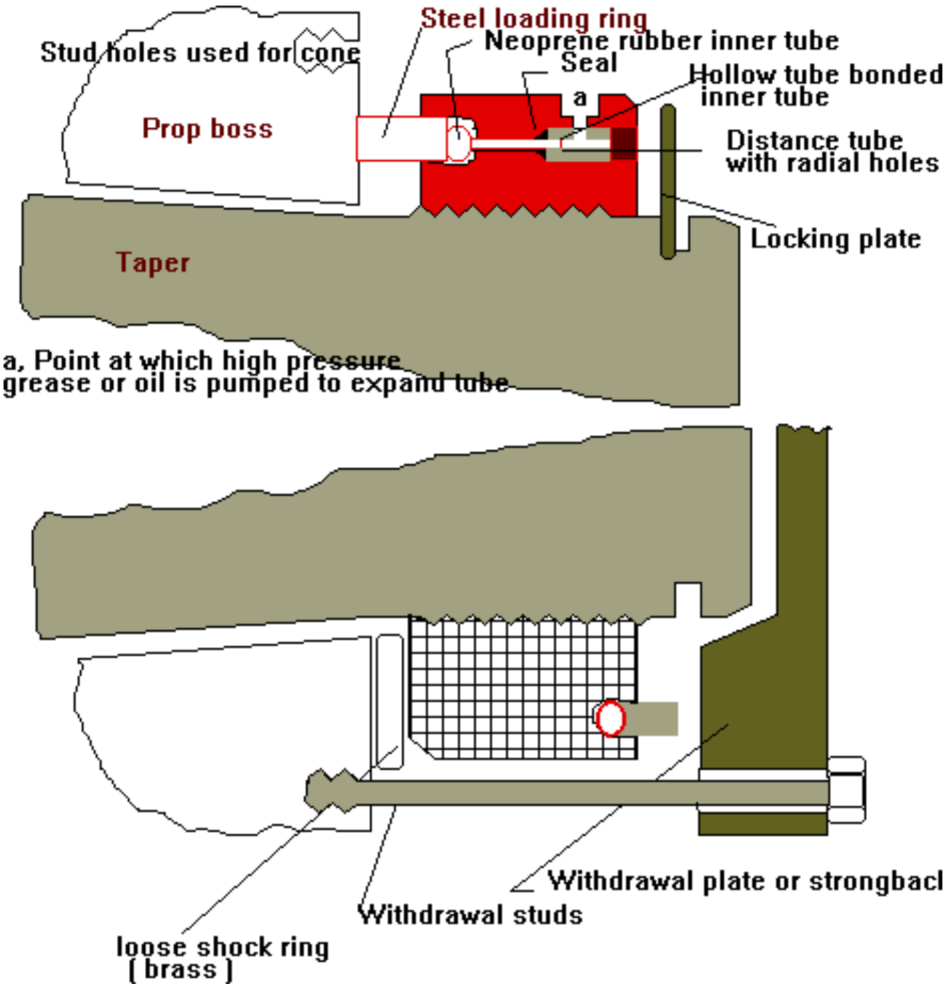
PILGRIM NUT



Assembly

Propeller bedded to tailshaft and jacked up to usual shop mark. The Pilgrim nut is then screwed on the shaft with the loading ring against the prop boss. With the lever operated, high pressure grease gun, grease is pumped into the inner tube inside the nut at around 600 bar, (w.p. stamped on nut, not to be exceeded), the prop will be pushed sufficiently up the taper to give the required frictional grip. The pressure is then released and the nut is rotated until it is hard up against the aft face of the prop hub and locked, fair water cone then fitted.

Removal

After removal of fair water cone and the locking plate, the pilgrim nut is removed, reversed and together with a loose shock ring is screwed back onto the shaft. A strong back is fitted and secured with studs to the prop boss. Grease is now inserted to the system expanding the inner tube forcing the loading ring, strongback, withdrawal studs and prop aft.

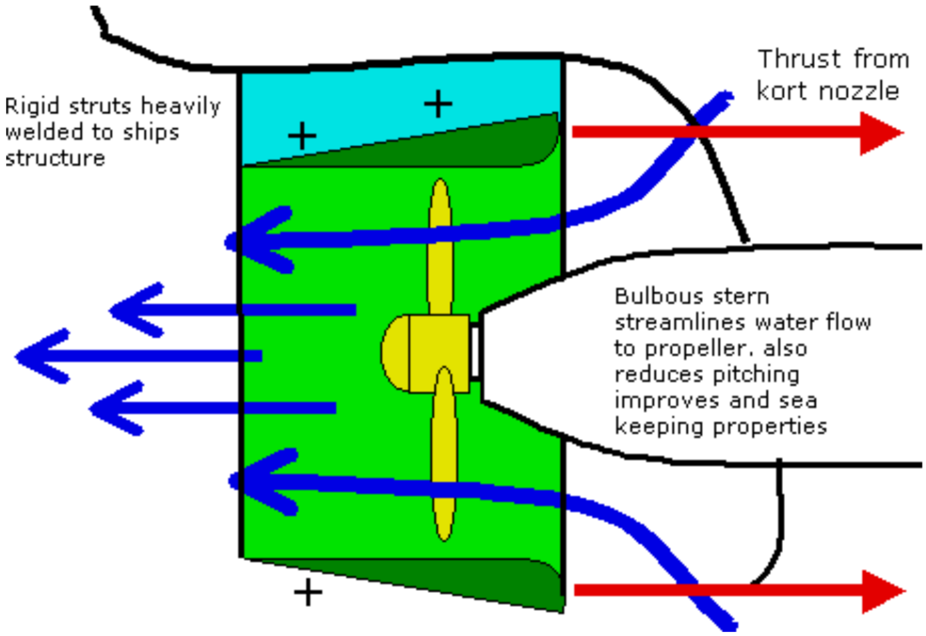
Advantages

- Precise tightening working on a measured applied load

- Adequate interference fit
- no heat used
- Simple and safe to operate
- No shock loads applied
- Considerable saving in man power and time

Increasing propulsive efficiency

Kort nozzle

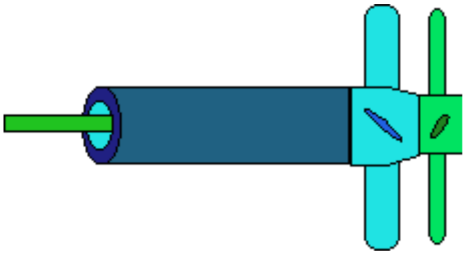


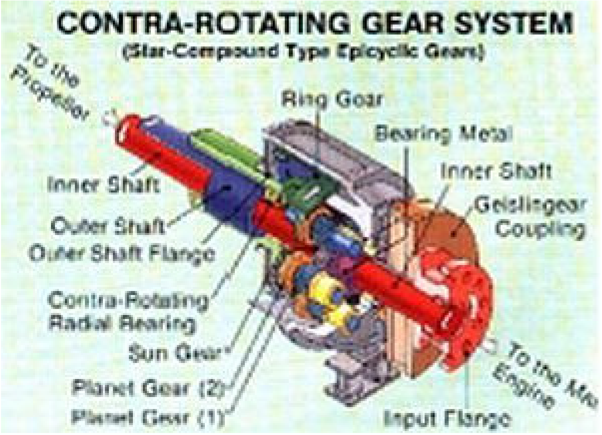
The action of the screw within a nozzle with a small clearance between the tips of the prop blade and the walls of the nozzle (clearance about 1/100 of prop diameter) is to eliminate or reduce trailing vortices which cause loss of efficiency and cavitation at the blade tips

The propeller increases efficiency by about 0.4% and their is additional reduction in vibration, cavitation and erosion. It is particularly effective for tugs where they provide an initial thrust although they can cause problems with manoeuvring

From an operational point of view there are problems with cavitation around the inner section of the nozzles although from what I have seen this is not particularly severe. It is important to ensure contant clearance betwen the blades and nozzle inner circumference. this is particularly important say when fitting a new blade to a CPP. Failure to do so can lead to increased vibration, noise and cavitation

Contra-rotating propellers

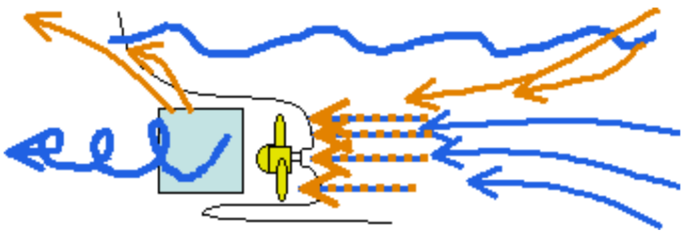




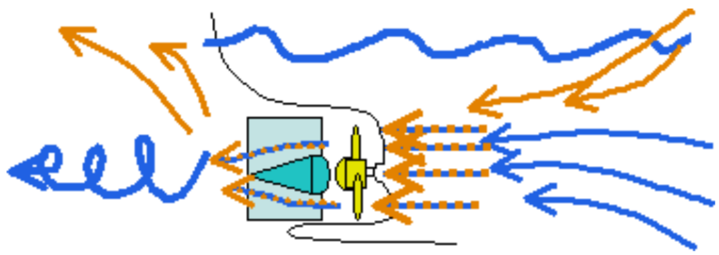
Whenever a propeller turns it exerts a thrust but it also rotates the water and this gives a loss of energy. If a second propeller os fitted immediately down stream but rotating in the opposite direction the second propeller exerts a rotating force on the water which opposes that of the upstream propeller.

water flow is axial and the drive more efficient the costs involved are high due to complicated shafting and gearing that is required to drive the two shafts from a single source. In order to minimise problems of vibration the downstream propeller usually has more blades than the upstream blade but the thrust from each is designed to be the same.

Costa bulb (Propulsion bulb)



Limited to single screw vessels (usually) the bulb is a simple but effective device for recovering energy from losses aft of the propeller. It consists of a fabricated stream lined steel shell, manufactured in two halves and welded onto the rudder immediately aft of the propeller boss with its centre line continuous with the tail shaft.

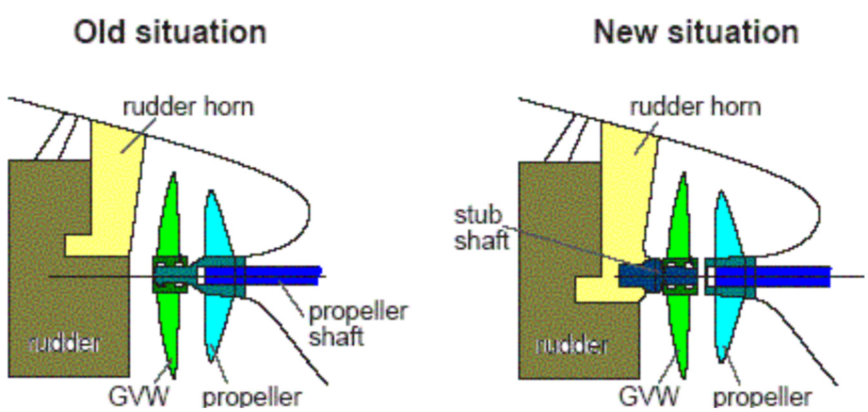


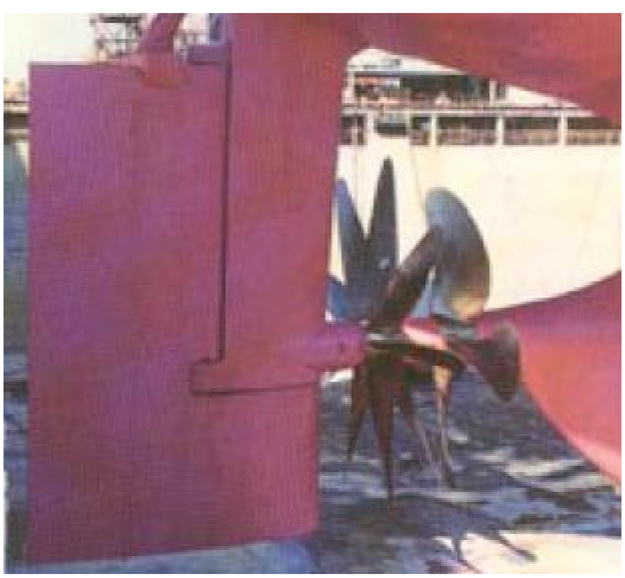
The bulb eliminates vortici created due to turbulent flow and sudden contraction of the water which trails from the boss. Thsi contraction is caused by the suden release of the very large volumes of air released under normal operational conditions when the water passes through the prop

It has a tranquillising effect on the flow of water behind a propeller. Reduces prop vibration, stiffens rudder, increases buoyancy and improves steering.

Increase in propulsive efficiency is about 0.5%

Grim wheel



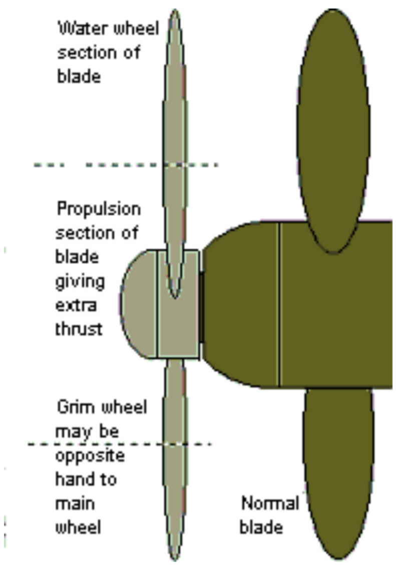


The grim wheel is a free turning propeller mounted after the main propeller. It use the rotational energy of the main prop wash that would otherwise be lost to provide increased propulsive force. The inner section up to the diameter of the main propeller acts as the turbine section. The area outside this is the propulsive section, thus the grim wheel must be larger than the diameter of the main wheel

Initial design had the grim wheel mounted on the main propeller boss. Severe problems including entire loss occurred. The more modern approach is to mount the wheel on the rudder horn. This having the added advantage of allowing a dedicated lube oil supply and reducing main prop shaft and stern tube bearing loading

Alternate design

Shown below is a design of unknown origin but has appeared for some time in this site so the source is lost. I am unsure as to its correctness. It is unusual that the propulsive section should be fitted in the vortex produced by the main prop hub.



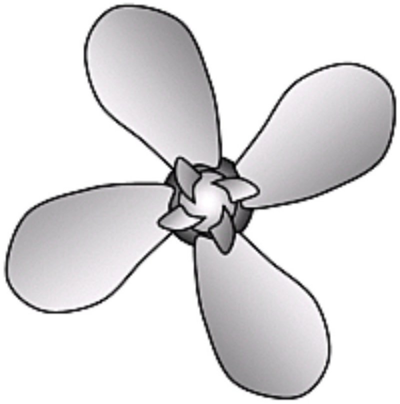
The Grim wheel is mounted on roller bearing and is therefore free to windmill on the end of the propeller boss. The Grim wheel is of two parts. The outer section acts as a turbine driven by the wake of the main propeller blading. This turns the inner section which is the propulsion section and provides extra thrust.

Increases efficiency by 5%

Highly skewed blades

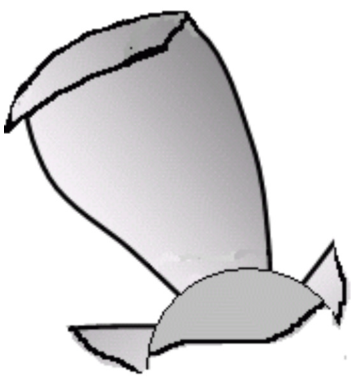
- are used to lower vibration

Prop Boss Cap Fins



 Fins of opposite hand to the main blades are mounted on the prop coss cap. These correct the prop hub vortex and recover rotational energy that would otherwise be lost. Fuel savings up to 5% are claimed

Contracted Loaded Tip

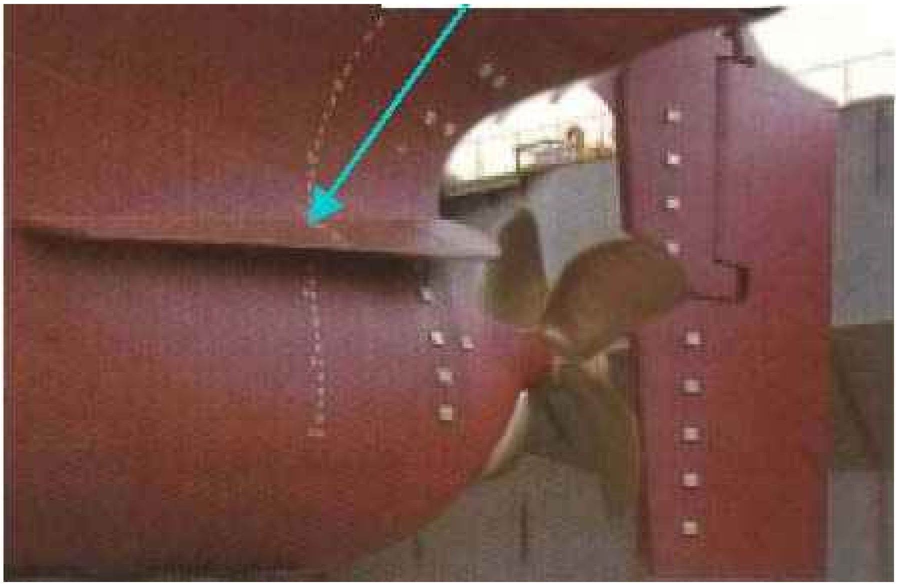


This is a modern design trend under heavy investigation adn yielding good results. They are screw propellers fitted with end plates at the blade tips. The plates are deigned to give minimum resitance to flow.

Half duct

Sometimes refered to as half kort

One or two nozzles may be fitted just ford of the propeller. There purpose is to steer the flow of water to enter the propeller with minimum shock. Efficiemcy claims are up to 3%. The advantage of this system over the full duct or kort nozzle is that it does not suffer from the same cavitation damage on the inner surface. A simplified version of this is two fins welded to the hull at a slight angle to the shaft centre line



Securing propellers

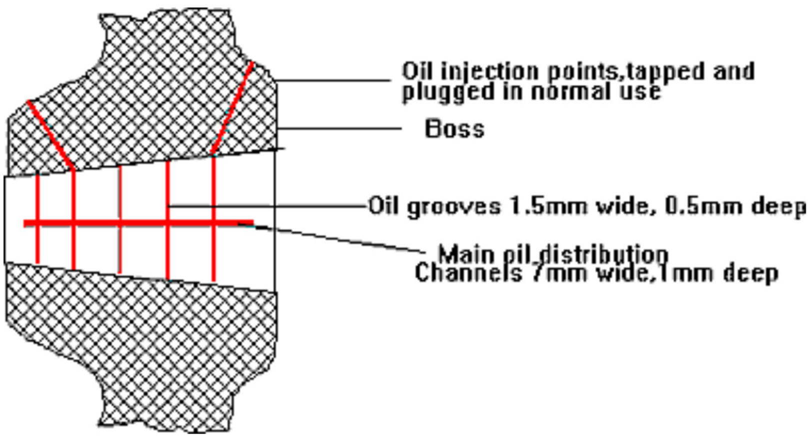
HYDRAULIC FLOATING OF PROPELLERS

Used for keyless propellers, ensures the correct interference fit using measured oil pressures for expanding the boss and hydraulic jacks or a Pilgrim nut for pushing it up or down the tailshaft taper. No heavy slogging required and low shock loads are applied, quick and safe.

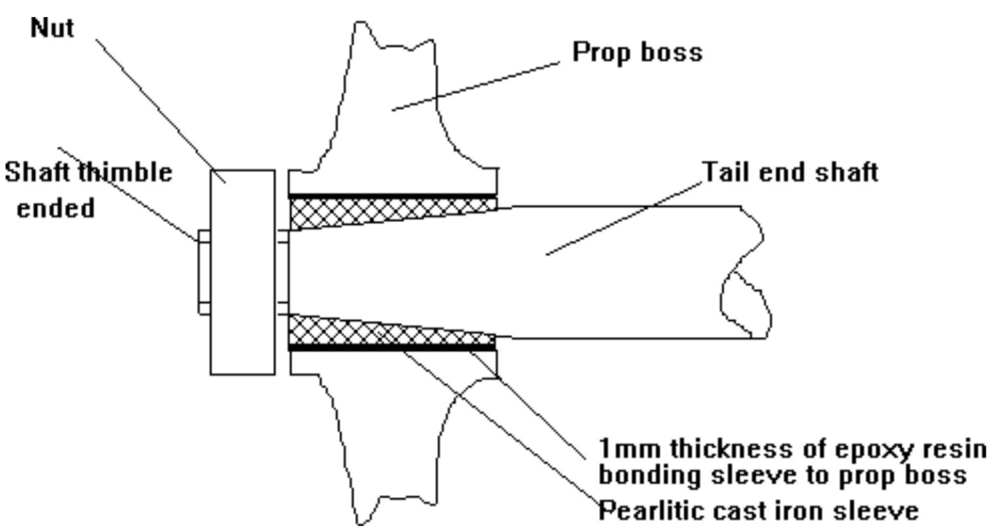
A disadvantage is loss of bearing area due to oil grooves which means that propeller must be longer or greater in Dia to give sufficient area to transmit the torque.

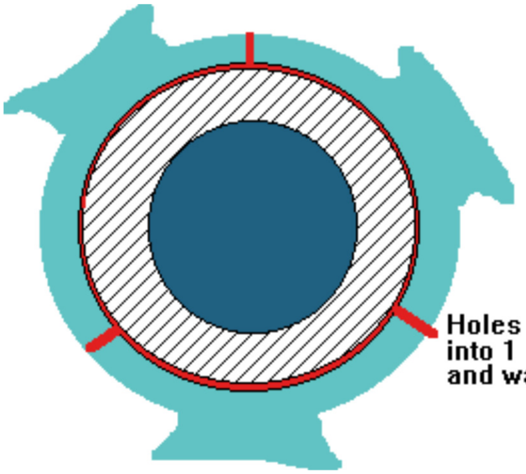
To remove, nut just slackened back. Oil injection applied to expand the boss which allows propeller to move off the taper.

Another disadvantage of wet fitting over dry fitting is that wet boss expansion stress is 30% greater than dry fitted which means that boss must be thicker.



Sleeved propeller





Usually fitted on large diameter shafting. Usually hydraulically floated and keyless. Difficult to bed large props to taper, easier to bed sleeve. Also each time a prop is refitted, prop bore becomes larger, this is accentuated in large bore dia props. Hence, after a few refits the prop moves to far up the shaft, more economical to replace the sleeve than the whole prop.

Pearlitic cast iron used to mate with forged mild steel shaft because this combination offers the greatest resistance to fretting which can be caused by prop excited vibration

Molecular fretting can occur internally, generally from the center outward due to molecular rubbing together. Surface fretting occurs at the surface due to two items moving over each other due to vibration.When fitting or removing, heat not to be used since it may effect the mechanical properties of the resin. Wedging or withdrawal systems should not be used since this would cause shearing of the araldite.

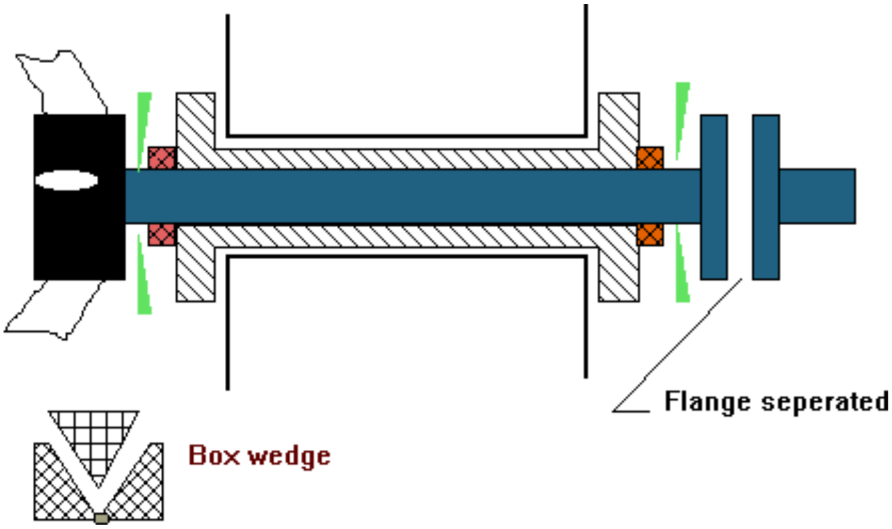
Traditional method

Shaft turned to top centre, i.e. when key is on top, convenient for key way inspection and prop slinging. Shaft locked, and prop nut just slacked.

Coupling bolts at tail end flange removed, if lignum vitae bearing- stuffing bearing removed and tailed flange shored up against aft peak bulkhead.

Secured lifting gear to propeller, then wedge off prop using box wedges between stern tube nut and ford face of prop.

If tail end and bronze liner are to be inspected then it must be brought inboard which requires the removal of one or two lengths of intermediate shafting.



Bolted

Controllable pitch propellers require a hollow prop shaft for the oil and feed back tubes to pass through. non of the above methods are suited to this.

Instead the propeller is bolted to a flange, the other end of the propshaft must therefore be parallel to allow removal from the stern bearing.

The prop shaft is attached to the intermediate shaft by a 'muff' coupling. Once the bolts have been tightened they are secured by tack welding locking bars across the heads.

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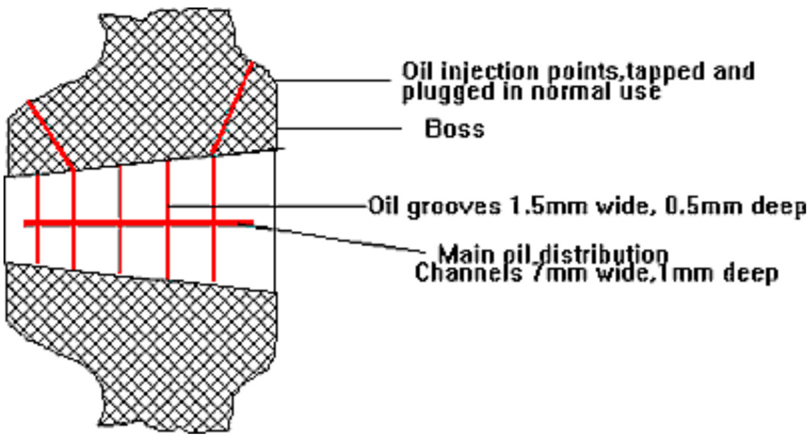

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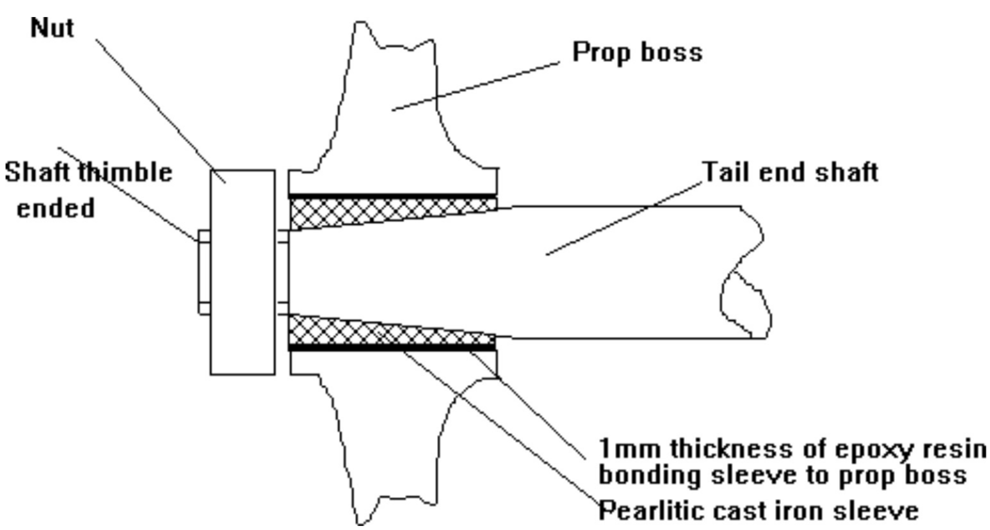

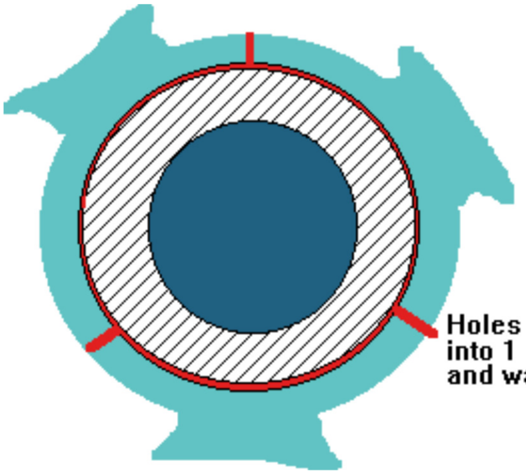

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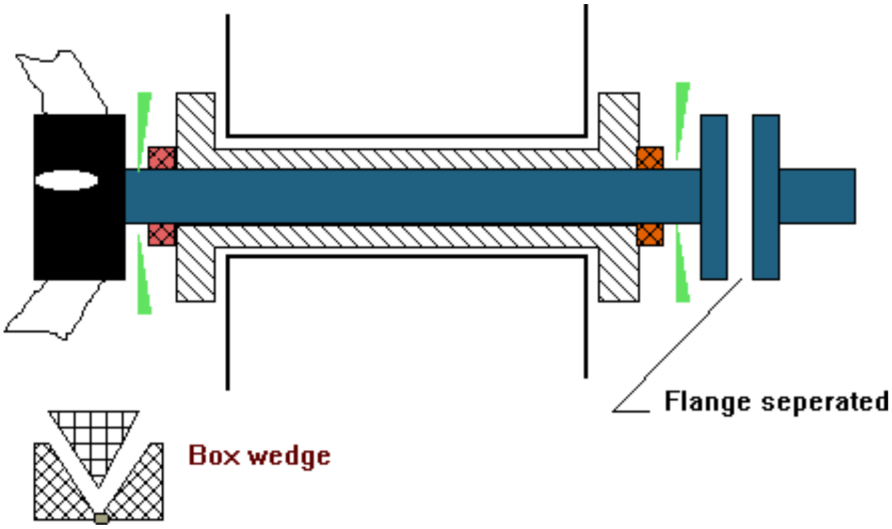

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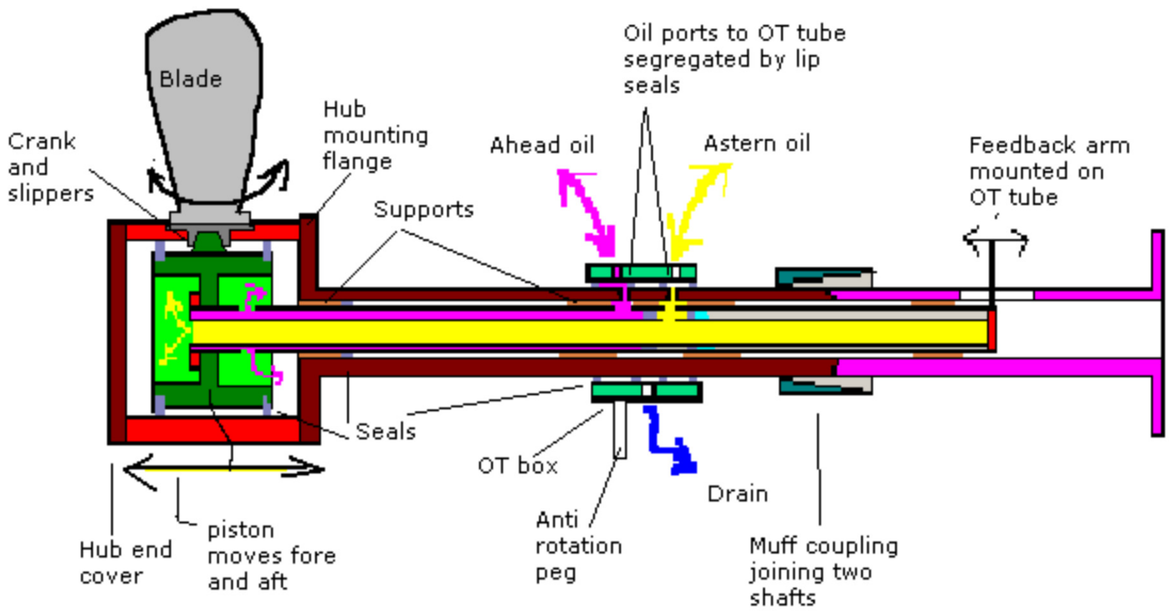
Controllable Pitch Propellers



Advantages

- Allow greater manoevrability
- Allow engines to operate at optimum revs
- Allow use of PTO alternators
- Removes need for reversing engines
- Reduced size of Air Start Compressors and receivers
- Improves propulsion efficiency at lower loads

Disadvantages

- Greater initial cost
- Increased complexity and maintenance requirements
- Increase stern tube loading due to increase weight of assembly, the stern tube bearing diameter is larger to accept the larger diameter shaft required to allow room for OT tube
- Lower propulsive efficiency at maximum continuous rating
- Prop shaft must be removed outboard requiring rudder to be removed for all prop maintenance.
- Increased risk of pollution due to leak seals

The CPP consists of a flange mounted hub inside which a piston arrangement is moved fore and aft to rotate the blades by a crank arrangement.The piston is moved by hydraulic oil applied at high pressure (typically 140 bar) via an Oil transfer tube (OT tube) This tube has and inner and outer pipe through which Ahead and astern oil passes. The tube is ported at either end to allow oil flow and segregated by seals.

Oil is transfered to the tube via ports on the shaft circumference over which is mounted the OT box. This sits on the shaft on bearings and is prevented from rotation my a peg. The inner bore of the box is seperated into three sections. The ahead and astern and also an oil drain which is also attached to the hydraulic oil header to ensure that positive pressure exists in the hub and prevents oil or air ingress

The OT tube is rigidly attached to the piston, as the piston moves fore and aft so the entire length of the tube is moved in the same way. A feedback mechanism is attached to the tube, this also allows for checking of blade pitch position from within the engineroom.

Operation Modes

There are two main methods of operation of a veseel with a CPP.

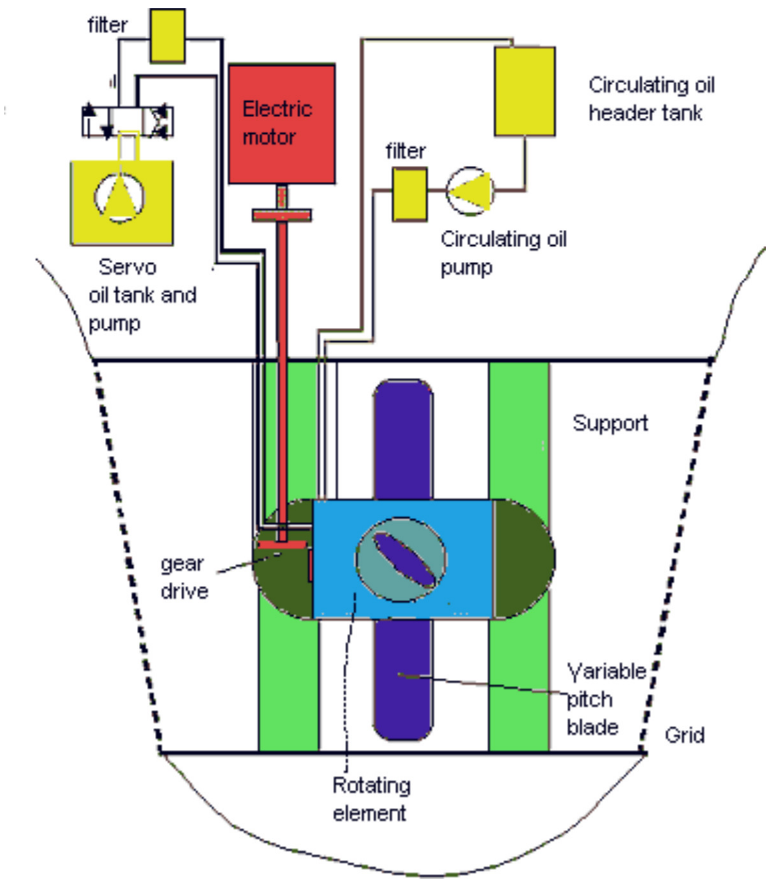
Combinator-For varying demand signals both the engine revs and the pitch are adjusted to give optimum performance both in terms of manouevrability and response, and also economy and emissions.
Constant speed- The engine operates at continuous revs (normally design normal max working revs), demand signals vary CPP pitch only. This is particularly seen in engines operating PTO generator systems

Emergency running

In the event of CPP system hydraulic failure an arrangement is fitted to allow for mechanical locking of the CPP into a fixed ahead pitch position. This generally takes the form of a mechanical lock which secures the OT tube. Either hand or small auxiliary electric hydraulic pump is available for moving the pitch to the correct position

Thrusters

Tunnel thruster



Thrusters are designed to increase the manoeuvring ability of a ship and may make the use of tugs unnecessary. They also be used to impart side thrust to a ship at a berth in order to counteract wind effect thus minimising stress on mooring wires. At slow speeds the effectiveness of a rudder is reduced and so thruster units are very useful, at higher speeds thruster become less and less effective.

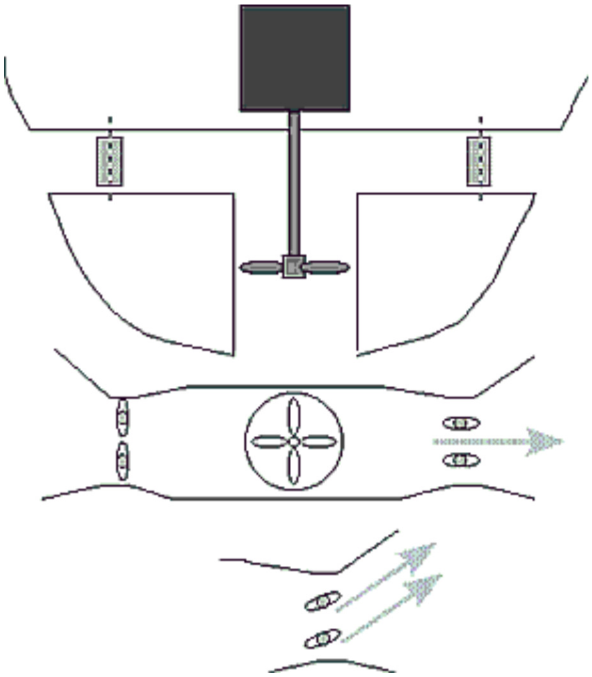
Multiple thruster units are fitted when the fitting of a single large unit is impractical. It is necessary to penetrate the hull on order to provide ducting for bow and stern thruster units and arrangements must be made to ensure the integrity of the hull remains. There is a small increase in hull drag and therefore a slight increase in fuel consumption. Grids protect the propeller from debris.

The thruster is mounted as low in the hull as practical to ensure a reasonable head of water. If this is insufficient it is possible that air from the surface might be drawn into the ducting thus reducing the thrust effect and causing cavitation of the blades

Shown above is one arrangement called a tunnel thruster. A prime mover, normally a constant speed electric motor a drive via a bevel gear a rotating element carrying the blade. The pitch of the blades is variable to allow thrust to be controlled in both direction. An alternative to this is to have fixed blades with a variable speed motor. In some cases with gill jet azimuth thrusters a diesel engine is used allowing it to act as emergency propulsion.

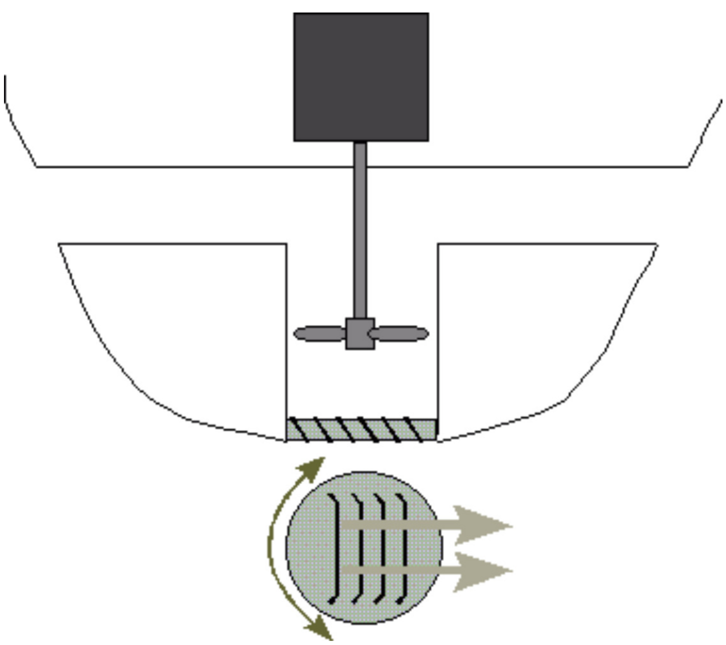
An alternative to the tunnel thruster is the gill jet which can take two forms

Gill jet-bottom suction



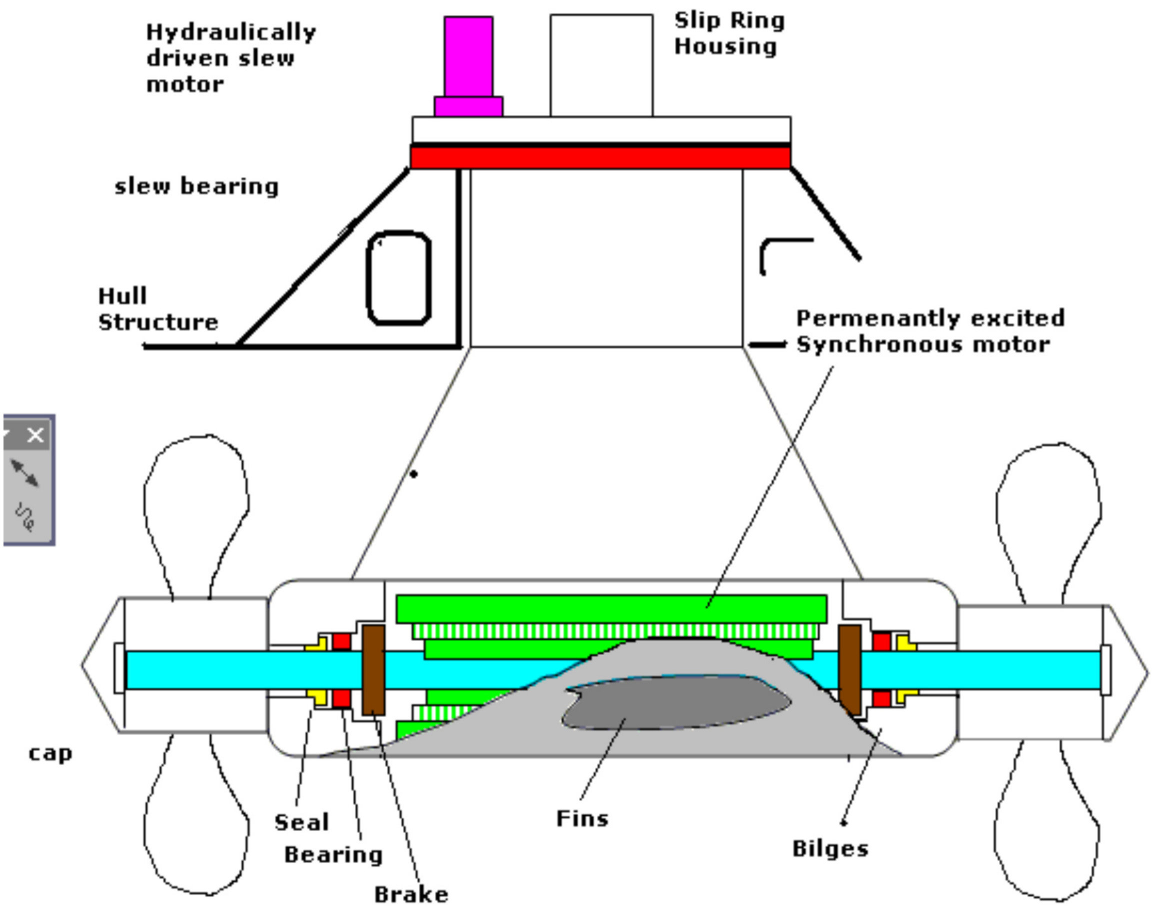
Water is drawn from the bottom of the ship and directed to either side by means of hydraulically actuated vanes. The angle of the vanes may be varied thereby allowing the water to be directed forward or aft thus providing forward and aft movement as well as sideways. A unidirectional constant speed motor provides the drive. As with the other system described the motor is vertically mounted and so a form of thrust bearing must be incorporated. This will usually be of the roller type and wear down must be checked periodically.

Gill jet-side suction



Thrust is directed via a circular slotted plate on the bottom of the hull. This allows equal thrust in all directions. Power is provided by a variable speed drive either d.c. or a.c. Where the thruster is used as an emergency propulsion unit then it is diesel engine driven

Podded Drives



Introduced relatively recently podded drive systems have become more and more common especially in the passenger ship market
They offer combined propulsive and steering ability thereby simplifying the stern arrangement. In addition they may be fitted relatively late is the ship build and remove the need for shaft alignment.

The plant layout may be optimised for the vessel type.

Construction

The pod is allowed to rotate on a rolling element slew bearing driven by either an electric or more commonly hydraulic motor via a gear ring. Electric power si supplied via slip rings to an electric motor mounted in the pod. This electric motor drives one or two fixed pitch propellers.
manouevring is a achieved by modulation of the power supply.

More recent developments have seen the use of single propellers arranged so that in normal running they are in pulling mode sitting ahead of the pod. This has been shown to increase propulsion efficiency.

Operational Difficulties

The removal of gearing from these units allows for increased operational reliability. They are air cooled and therefore require large volumes of air to cool. This can introduce sea water and salt laden air into the windings and lead to overheating and corrosion.

Slip rings must be properly maintained otherwise can be a potential source of failure.

The units are relatively exposed and may be susceptible to impact damage

Gas Carriers

Gas carriers take liquid which occupies about 1/600 of the volume it would occupy as a gas.

Two different forms are carried; Liquid Petroleum Gas which is mainly propane and butane, and Liquid Natural Gas which is mainly methane. Critical factors in the carriage of gas in liquid form are the boiling point tempo at atmospheric pressure and the critical tempo (this is the temperature above which the gas cannot be liquified no matter what the pressure.

The type of containment vessel used for the cargo will differ depending upon the desired tempo and pressure (the tempo must always be below the critical).

In general low pressures may be used if the tempo is kept low, alternately higher temperature may be used but higher pressures are required. LNG

LNG has a boiling point of -162°C at atmospheric pressure and a critical tempo at 47 bar of -82°C, suitable containment conditions allow the carriage of LNG at different tempo and pressure.

LPG

LPG comprises many different gases which have different boiling points and critical temperature, carriage requirements vary between atmospheric pressure and 18 bar and -100°C to -5°C

For smaller ships carrying LPG, pressurised systems are generally used, these employ spherical or cylindrical tanks. However, there is a considerable loss of space. With higher pressures (up to 18 bar) no reliquifacation plant is fitted and no insulation is required. Relief valves are used to protect the system.

Recompression of boil off gas may be employed.

Systems employing pressurised tanks may be partly or fully refrigerated thus requiring less strength in the cargo tanks. This reduces weight and cost. Insulation and reliquification plant is required. Partly refrigerated systems have a maximum pressure of about 8 bar and a temperature of about -10°C. Fully refrigerated have a maximum pressure of about 8 bar but the temperature may be down to -45°C thus increasing the range of petroleum gas cargoes that may be carried. These systems employ cylindrical or spherical tanks which must be self supporting.

Most shipments of LPG are carried at atmospheric pressure at theire respective boiling point. Some typical examples are ethylene -103°C, propane -42°C, ammonia -33°C and butane 0°C to- 5°C

Lloyds register require that in cases other than for pressurised tanks, for carriage of cargoes below 10 °C the hold spaces should be segregated from the sea by a double bottom. For below 50°C the ship should also have longitudinal bulkheads forming the tank sides.

Most gas tanks incorporate a method of detecting leakage. When the primary barrier is breached the secondary barrier should capable of confining the leakage for a minimum of 15 days.

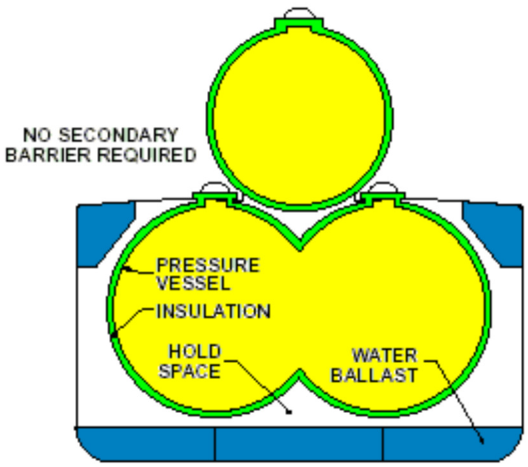
In addition, especially for LNG carriers, the inert gas contained in the barrier space is sampled and temperature probes fitted. Regular 'cold spot' inspections are carried out on the secondary barrier.

Before designing a gas tank certain criteria set down in the IMO code for ships carrying bulk gas must be met. These, by giving a set of figures determining a damage to the ship, ensure the ships survivability in a collision, grounding etc. The position of the tanks, determined by the type of cargo to be carried, are laid down to prevent the escape of cargo under similar conditions.

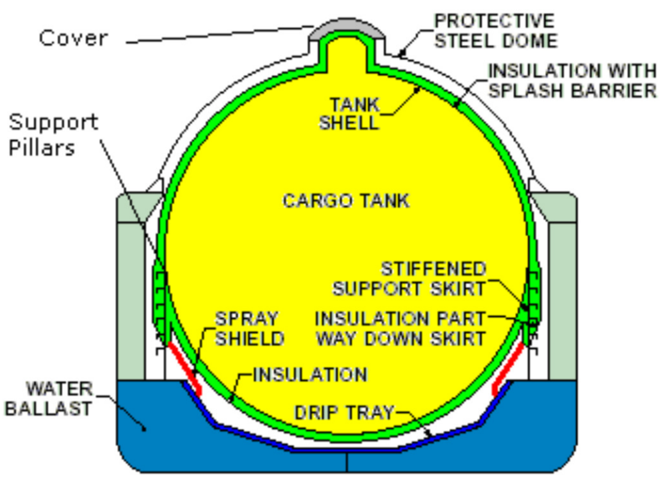
For systems other than fully pressurised a method of dealing with 'boil off' must be fitted. For LPG carriers this takes the form of an on board

Fully pressurised

The tanks are internally stiffened and constructed of ordinary grade steels as the cargo is carried at atmospheric temperatures.

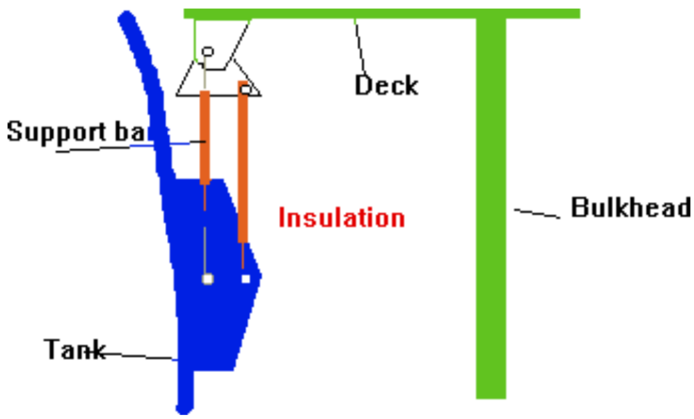


TYPE C TANKS (SEMI-PRESSURIZED
FULLY REFRIGERATED GAS CARRIERS)



SELF-SUPPORTING SPHERICAL TYPE B TANK

Alternative tank support arrangements



Tanks are in the form of pressure vessels, cylindrical or spherical.

Maximum pressure is about 18 bar and no reliquification plant is provided.

Apart from certain areas around the supports insulation is not usually fitted. Relief v/v's are required to safe guard against pressure build up due to boil off. A compressor is provided to keep the tank system pressurised.

Tanks are classed as self supporting, because of the loss of space the system is not popular and is usually applied to smaller ships

Semi-pressurised, partly refrigerated

These reduce the cost and weight; tanks are insulated and reliquifaction plant is fitted, max pressure is 8 bar and minimum tempo about $-5^{o}C$. Tank arrangement is similar to the fully pressurised and so there is still the loss of space.

Semi-pressurised, fully refrigerated

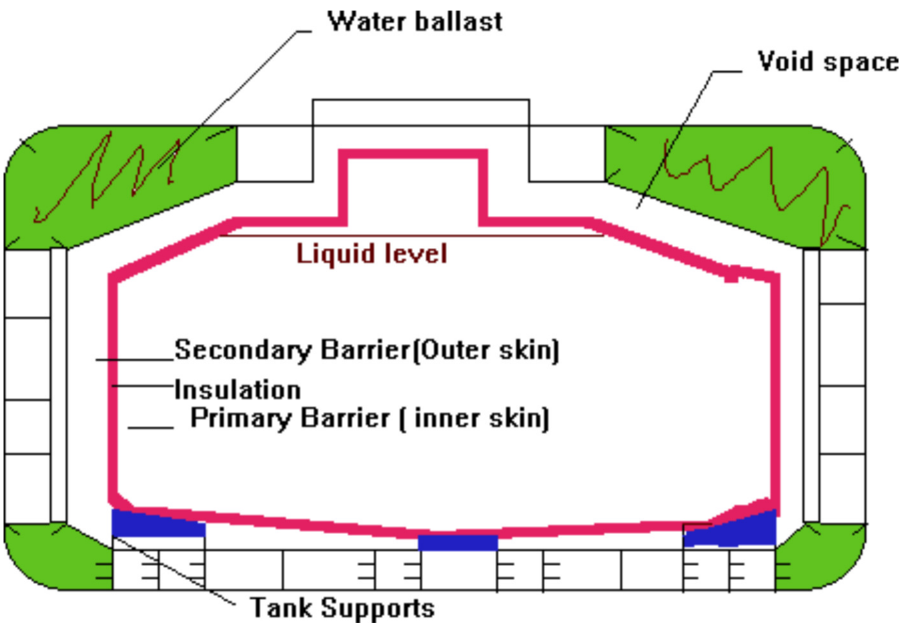
Pressure about 8 bar, and temperatures down to $-45^{o}C$. Tanks well insulated and reliquification plant essential. Tank pressurised but it is possible to carry a range to cargoes at different pressures and temperatures.

Fully refrigerated

Cargoes are carried at atmospheric pressure but at a temperature below the atmospheric boiling point. Very suitable for LNG, but can also be used for LPG and ammonia (LNG carriers do not generally have a reliquification plant but LPG carriers may)

Prismatic tanks or membrane wall systems may be used. Prismatic tanks are self supporting but they must be tied to the main hull structure.

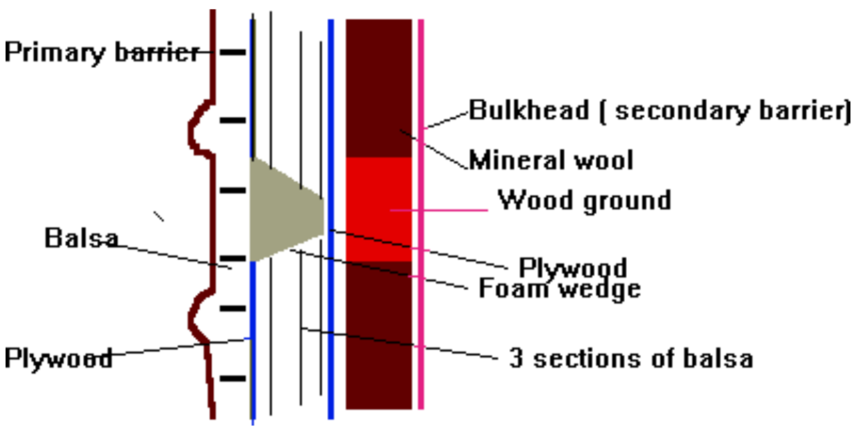
Prismatic tank



Membrane tanks

Membrane tanks are rectangular and rely on the main hull of the ship for strength.

The primary barrier may be corrugated in order to impart additional strength and to account for movement due to change of temperature. Systems vary but the arrangement shown is typical.



Primary barrier material must have the ability to maintain its integrity at the low temperatures. 36% Nickel steel(invar), stainless steel and aluminium are satisfactory at normal LNG temperatures.

Secondary barriers may be fitted depending upon the arrangements but it is not normally required as the ships hull may be used as the secondary barrier if the temperature of the barrier is higher than - 50 ^{O}C and construction is of arctic D steel or equivalent.

An independent secondary barrier of nickel steel, aluminium or plywood may be used provided it will perform a secondary function correctly.

Insulation materials may be Balsa, mineral wool, glass wool, polyurethane or pearlite. It is possible to construct a primary barrier of polyurethane's as this will contain and insulate the cargo.

Usually, secondary barriers are of low temperature steel or aluminium, neither of which becomes brittle at low temperatures.

Gas detection equipment needs to be fitted in the inner barrier and void spaces in cargo pump rooms and in control rooms.

The type of equipment depends upon the cargo being carried and the type of space involved measurement of inflammable gas vapours and toxic vapours as well as oxygen content should be monitored.

Visual and available warnings must be given when high levels are approached. Toxic gasses must be measured every four hours except when personnel are in the spaces when the interval is 30 mins.

Membranes are very thin (less than 2mm) and are therefore susceptible to damage, tanks are never partially loaded.

Boil off

With LNG reliquifaction is not economically viable. It is a requirement by class that a suitable method be installed for the handling of this gas

One common method is to utilise the gas as fuel for the propulsion plant. A suitable method of disposing with excess energy should be fitted. Typically for a steam powered vessel this would take the form of a steam dumping arrangement.

Alternately , the gas may be vented although port restrictions mean it may not always be possible.

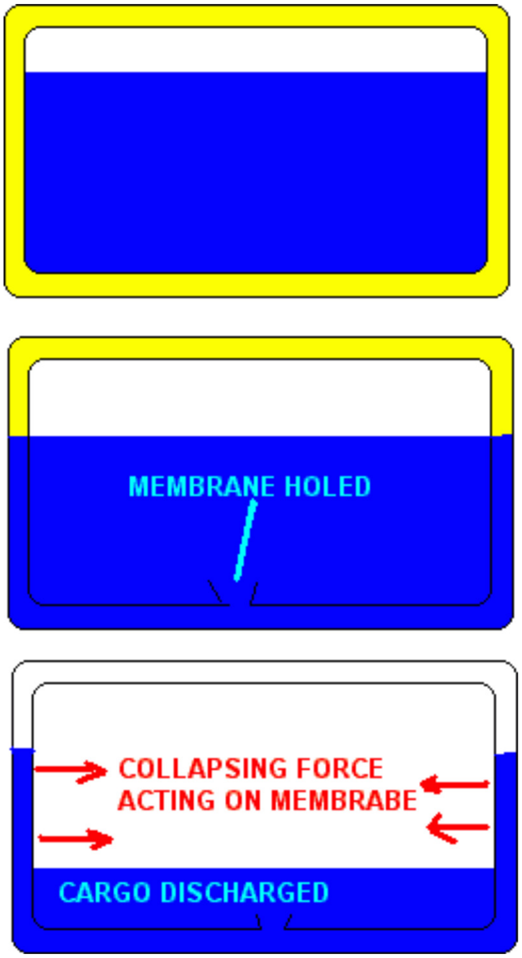
For LPG boil off can be reliquified or a suitable venting system clear of the ship may be used. Burning in the main engine can be very problematic, not least with the ensuring safe gas tightness on the engine. Combustion problems and the probable production of noxious gasses are also areas of concern.

Safety

During transit gas will boil off and venting may be employed to release pressure but methane is a green house gas and pollution regulations may restrict such venting. Any venting of gas must be vertical and away from the ship.

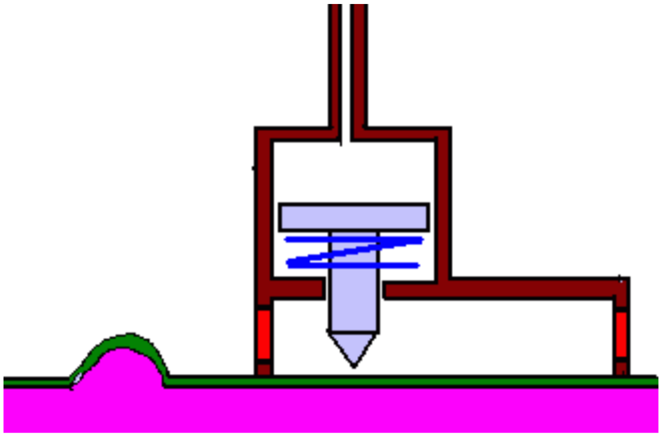
Spaces between the tank barriers or between the barrier and the ships side must be constantly inerted or there must be sufficient inert gas available to fill spaces. Tanks must be fitted with indicators for level, pressure and temperature. There must also be a high level alarm with visual and audible warning together with automatic flow cut off. Pressure alarms and gas monitoring points for detection equipment must also be provided in inter barrier spaces. Detection equipment is also required in void spaces, cargo pump rooms and control rooms. Measurements must be taken of flammable vapours, toxic vapours and oxygen content. For fire protection, the fire pump must be capable of supplying at least two jets or sprays which can reach all parts of the deck over the cargo tanks fixed dry chemical systems may also be required.

Automatic tank piecing (lng)



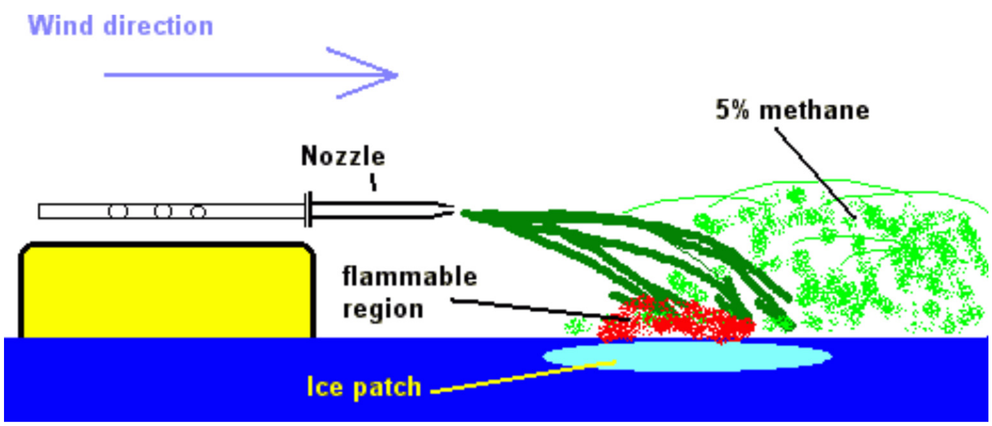
Should a leak be detected from the tank into the interbarrier space by either temperature probes or gas detectors during the loaded voyage the inter barrier space will fill to the level of the liquid in the tank. On discharge it is possible that the level in the tank will fall more rapidly than the liquid can drain from the inter barrier. The primary barrier, which has little mechanical strength will thus collapse.

To prevent this a nitrogen powered punch assembly is fitted to a low point in the tank, before start of discharge this punch may be operated to allow proper drainage. Once the cargo has been discharged both the original leak and the hole caused by the punch are repaired.



Jettison the cargo

Should a problem occur of such severity that it is required to jettison the cargo then a special nozzle arrangement is fitted to the manifold and the main cargo pumps started. The liquid is ejected down wind of the vessel forming a large gaseous ball. By carefull design and flow considerations the flammable region is kept to a minimum.



The author has witnessed videos of tests carried out on this system and can vouch for its effectiveness.

LNG vessel propulsion systems.

Although the amount of boil off from a modern LNG carrier represents a small percentage of the cargo it still is significant in terms of cost.

The traditional method of dealing with this boil off is to specify steam propulsion for the vessel and utilise the boil off as fuel in the boiler. The disadvantage of this is that initial cost is high and efficiency is low in comparison to reciprocating engines. The advantage is the proven design, low maintenance and high reliability

The growth in carrier size up to and above 200000m^3 has led to twin screw designs. This has favoured the use of slow speed and duel fuel burning engine designs There are alternatives available to this some of which are

Two stroke diesel electric propulsion plant- the boil off is burnt in a boiler which powers a turbo-alternator which supplies electricity for propulsion.- reached design stage but the proven track record of the steam turbine as held it at bay.

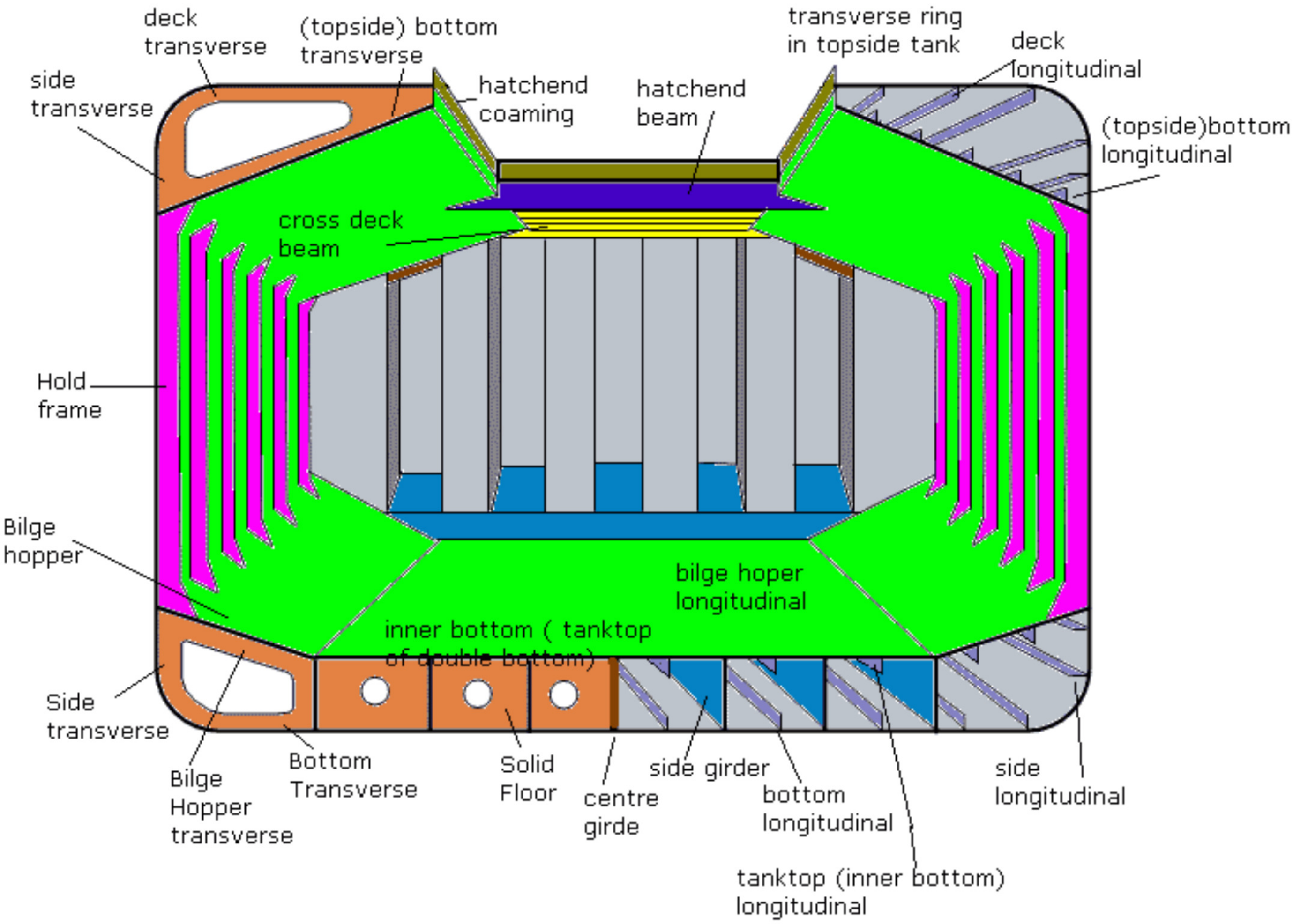
Slow speed engine and reliquificationconcerns over the initial cost, unproven reliability in the marine environment and high electrical power consumption has meant this is only a recent introduction

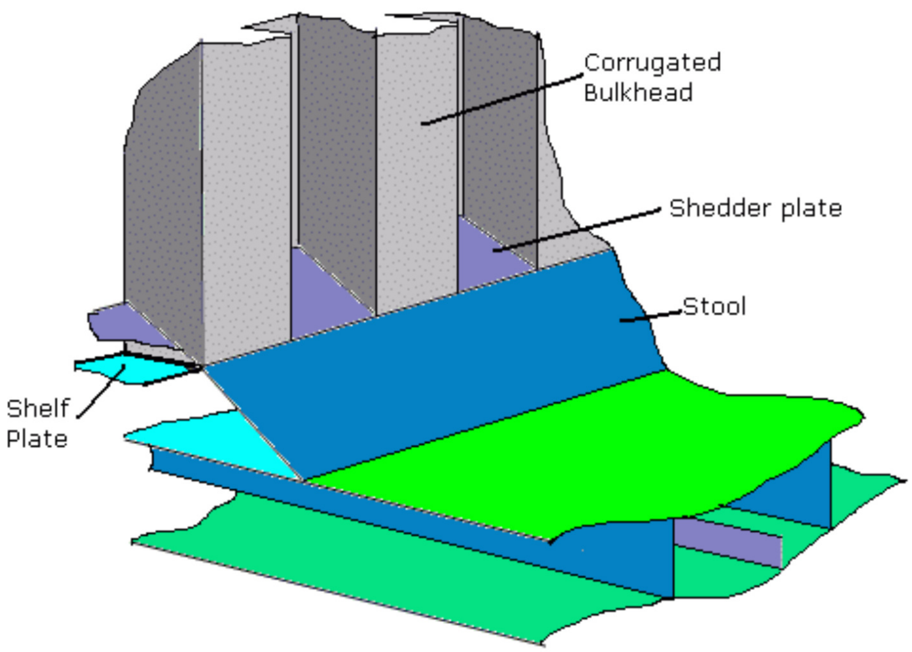
Duel burning diesel engines- question mark over reliability and effect on the near perfect safety record of the worlds LNG fleet. In this design gas is introduced either at low presure during the air suction stroke into the air inlet ducting. Alternately the gas may be injected at high pressure directly into the cylinder. In both designs a pilot fuel oil injector is used. The engine retains the ability to run on fuel oil only. Low NOx and CO_2 emissions at least equalt to steam plants are claimed

Gas Turbine

- in a turbolectric set up

Bulkers





The bulk carrier is designed for the carriage of dry caro such as grain , iron ore etc. Upper ballast water hoppers aid stability to revent cargo shit and the bottom hoppers aid the collection of the cargo for discharge.

Relatively low density caros such as grain and coal would be carried in each hold. Heavy cargos such as iron ore may be carried in alternate holds. The internal tank design for bulkers is a clean one. The floor is absent of framing allowing ease of cargo discharge and cleaning.

Classification

Bulk carriers are generally classed into three catagories according to size.

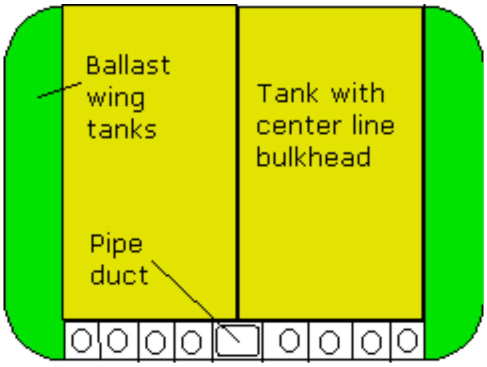
Handy type 30,000 to 45000 dwt, 5 holds

Panamax type breadth 32.2m and are the largest able to transit the panama canal. 50-60000 dwt and 7 holds

Capesize type- 100000 dwt, 9 or more holds

Vessels with there own carog handling gear , typically those carrying food products are termed **geared**

Chemical carriers



Chemical carriers are basically tanker type structures which are arranged to carry certain types of noxious substances. The structure will generally consist of central cargo tanks with the wing tanks and double bottoms used for dirty ballast. Restrictions will apply if the cargo being carried reacts with water and in these cases void spaces are required. Materials used for construction will depend upon the type of cargo being carried and these are grouped depending upon their properties.

Chemical carriers must be designed for the safe carriage of particular types of cargo and these are classed into 3 groups according to the potential hazard of that group.

In general a class A, ship could theoretically carry any class A, cargo, but particular cargoes react with certain materials used for tank pipe and pump construction. The carriage of such cargoes is therefore limited to those which will not react with the materials of construction. A ship designed for class A cargoes may also carry class Band C provided they will not react with the materials of construction. Similarly, class B vessels may carry class C cargoes.

Liquid sulphur must be maintained within a temperature range of 127-138^{o}C , and not exceeding 155^{o}C. Tanks should be insulated and the internal construction at the top of the tanks should not allow vapour pockets to form.

Hydrochloric acid presents difficulties (it reacts with most common metals) and special arrangements are required to line steel tanks with a material which will not react with the acid but is flexible enough to distort with the tank. A suitable material is rubber. Tanks must be separated from the main hull so that the stresses in the hull are not transmitted to the tank

Cargo classes

<table>
<tr><th>Class</th><th>Hazards</th><th>Examples</th></tr>
<tr><td rowspan="2">A,</td><td>Low flash point
toxic
Skin hazard
Reactive with water</td><td>acetic acid
Sulphuric acid
Liquid sulphur
Reactive with water
Phenol</td></tr>
<tr><td colspan="2">These are listed and have a high rate of reaction with moisture or water. Tanks must be segregated from the ships side and pumps must be located in the tanks or on deck. Cargo tank vent outlets are not to be closer than 15m to inlets to the accommodation. In general these cargos are unsuitable for carriage in mild steel tanks (generally acids and</td></tr>
</table>

	petrochemical substances)	
B	Low flash point e.g. Carbon tetrachloride Toxic Skin hazard	Formaldehyde Benzene
	Are not as restrictive as the type A although they are toxic and many have a low flash point their problems with relation to water are not as great. Mild steel is suitable for tanks but aluminium and copper are not.	
C	Low flash point	acetone Asphalt Caustic soda
	Are less dangerous and most are not toxic in general. Most engineering materials are suitable for tank construction. There is some risk of contamination through water but it is not great	

DP Systems

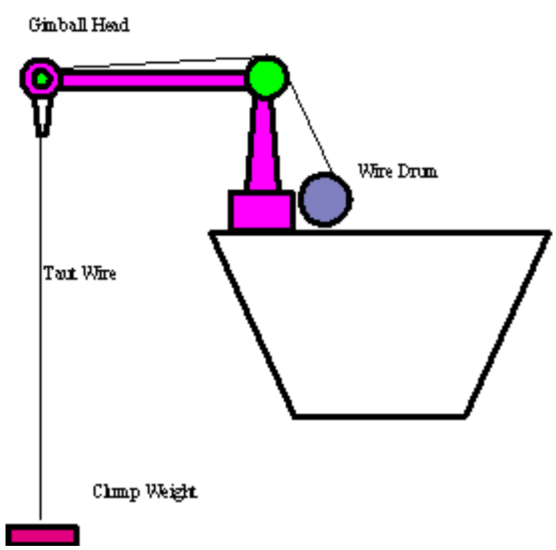
Dynamic Positionning systems allow a vessel to remain at a fixed point independent of the influences of the environment. This is achieved by a system of reference points, sensors and propulsive power units.
The reference points determine the vessels position relative to a datum, they do not necessarily determine the vessels exact location on the earths surface- only DGPS attempts to do this.
Sensors monitor the environmental effects on the vessel, such as the effects of swell and wind and use this to error compensate the reference systems.
Propulsive power units take the form of the main propulsion unit, thrusters and steeering gear system (in conjunction with propulsive unit). These units are mounted for and aft and may be either fixed or steerable.
The number of reference systems, sensors and propulsion units is determined by the required duties of the vessel

Types of reference systems

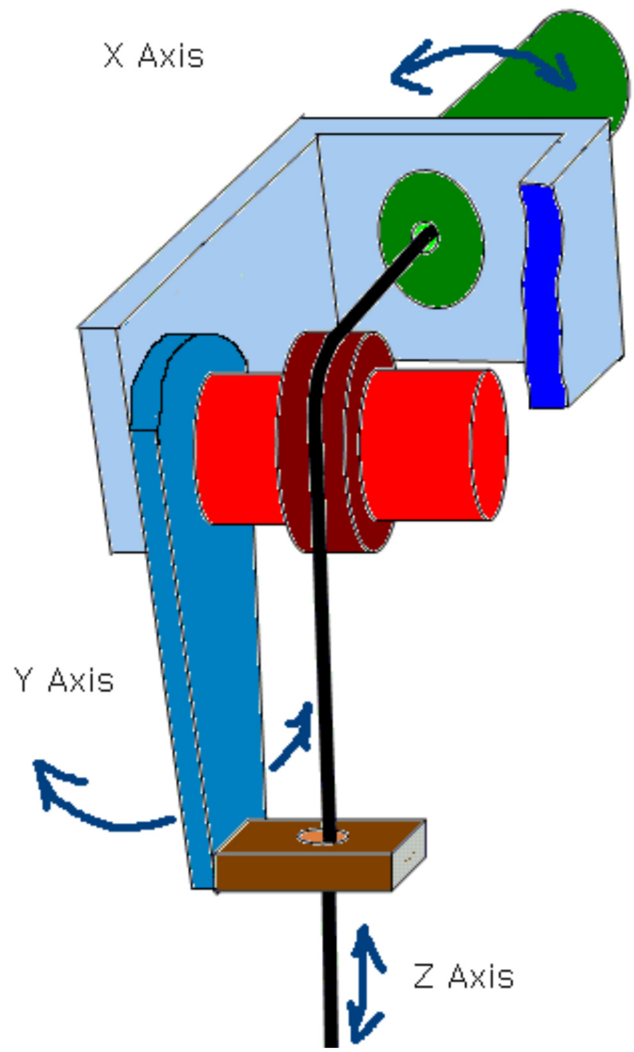
This is a non exhaustive list of the types of reference systems available;

- Differential GPS- The reliability of this system is very much dependent on the location and can range from good to very poor
- Microwave (Artemis)- Is limited in that it is a line of site only system, the advantage is that a communication link is available and emergency shut down systems are sometimes built in
- Laser (Fanbeam)- This cheap reference can be initially very reliable reducing as the target becomes dirty or due to atmospherics. It is a line of site reference
- Acoustic (HPR)-Can be reliable but is reliant on batteries in portable transponders (no limitation exists with fixed transponders)
- Taut Wire- Very reliable simple system. Can introduce movement restrictions when in use.

Taut Wire



A substantial weight is lowered to the sea bed attached by a high tensile steel wire or minimum diameter (reduces effect of current).



The wire passes through a Gimball head which is free to move in X and Y axis up to the mechanical limitations of the assembly. The angle the head is at relative to the vertical for the X axis and horizontal for the Y axis is measured by potentiometers and sent to the DP computer. The wire length is measured by a line out counter and sent to the DP computer. With the weight on the bottom contant tension is placed on the wire keeping it taut, this is achieved by having a constant rpm electric motor coupled to the wire drum via an electric clutch. The field current on the clutch determines the degree of coupling and thereby the degree of torque (note that this torque if far to small to lift the weight and a seperate hydraulic motor is provided).

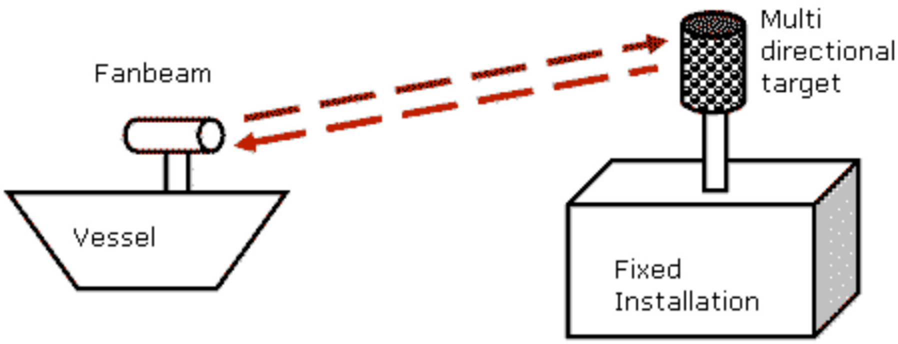
As the vessel moves the angle between the head and weight as well as the wire length will alter. A calculation is made by the DP computer which gives the vessels relative position to the weight. Vessel movement through wave action is measured by the accelerometers and factored in.

Shown is a system which is deployed from the ships side, a limitation is placed on the vessels movement towards the weight when the vessel is 'walked' (say moving into position or following an ROV). A second system would be mounted on the opposite side. Alternately a single system may be fitted operateing through a moonpool in the centre of the vessel.

The size of the weight (and corresponding wire diameter) is determined by the depth that the vessel operates and the operating conditions the vessel works in. Typically they would be not less than 350Kg

Described is a vertical taut wire system. Also avaible are horizontal taut wires which give the same degree of reliability without the need for the clump weight. The disadvantage is that they must be manually tethered.

Laser (fanbeam)

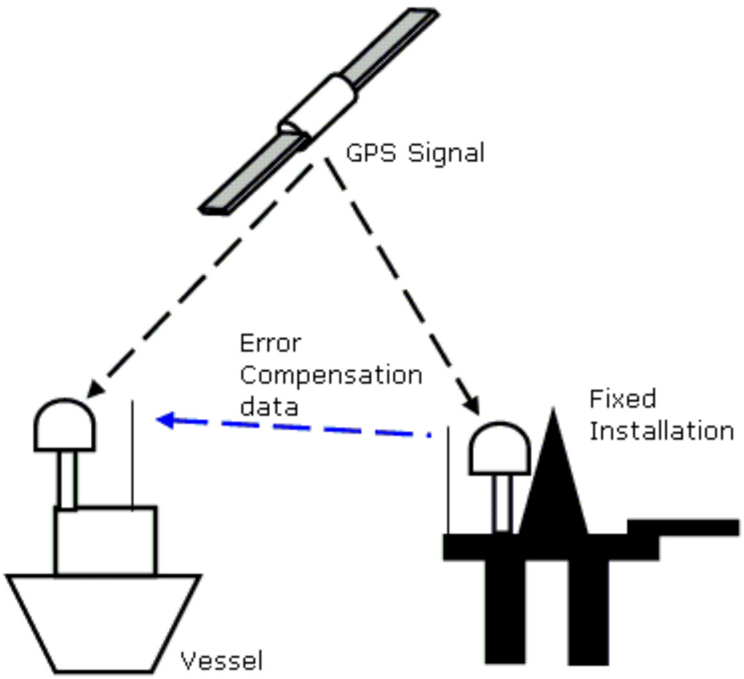


This is an auto tracking system whereby a scanning head fires a laser beam through one lens and receives a reflecion of it through a second

The targets must be equiped with reflectors, reflective white tpae may be used but the range is very limited. Greater distance is achieved prisms. 360' coverage is achieved by mounting these prisms on a tube.

Position reference is by the laser (this is a class one low power unit similar to that found in CD players) scanning for the target. The bearing and range of the target is found and by calculation using error correction from the vertical reference units the movement between the two points is known. **Differential GPS**

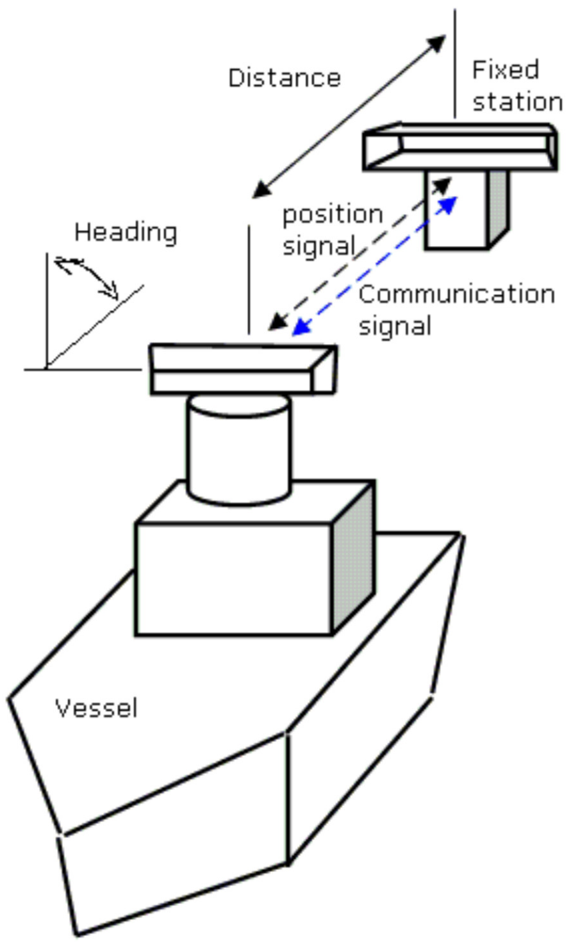
The GPS signal from a satellite does not give the degree of accuracy required for a vessel positioning system. To improve accuracy differential GPS is used



A satellite signal is received by both the vessel and by an installation whose position is precisely known. Any error in the signal from the satelite is converted into and error correction signal which is then broadcast. This signal is received by the vessel, a calculation is made and a more precise position now known.

This system is inherently risky for vessels working in critical postions and it is often required that GPS be not used as both of the minimum two sources required. The gps signal is sometimes intermittent as is the error compenstion signal, they are effected by relection from nearby installations and by ionospheric variation. Multiple stations are used to improve accuracy

Microwave (Artemis)



This consists of two stations. One unit mounted on a fixed installation, a second unit mounted on the vessel. These units consist of a rotateing antenna. When initialised both units rotate untill they point at each other. Manual control is available to speed this up. Once they have acquired each other the antenna horns point continuously at each other
The fixed unit now knows the relative postion of the vessel to itself by measurement of the angle of the 'antenna relative to north. The microwave connection gives the relative distance of the vessel. This information is given to the vessel. As the vessel moves there will be alterations in the distance and the bearing between the units. An error correction is made for changes in the ships heading measured by the GYRO.

Hydro Acoustic (HPR)
This system consists of an acoustic transponder and a sensor mounted on the vessel. The transponder may be fixed to the sea bed or installation required , be lowered to the sea bed as required from the vessel or be attached to a moving unit such as a diver or ROV to allow the vessel to 'watch' the know their location.

The sensor may be fixed so that it looks in one direction only, or tracking where it can move to locate several targets. To prevent interference from the vessels hull the sensors are normally mounted on a long pole which may be lowered through an isolation valve . The installation allows access to the sensor head for maintenance

The system is subject to variations in water temperature and salinity which effects the sound velocity. At water stratification layers a degree of refraction occurs to the wave.

Sensors

Wind- This measures both the wind speed and wind direction. A calculation based on parameters such as vessel topside area is made on the effect of the vessel. This signal is fed forward to the DP Computer so that action may be taken before the vessel moves off station

Gyro-Measures the vessels heading giving error correction for such reference systesm as artemis.

Vertical reference Unit-used to measure the vessels pitch and roll and used as error corrections on such reference systesm as taut wire, artemis etc.

Draught-Used on vessels sucha s heavy lift where ships operations may significantly effect the draught of the vessel

Draghead Force-Used on dredges where the vessels forward spped is governed by the loading of=n the draghead

There is generally no current measurement, instead the current is calculated by the DP computer which looks for a permenant off set in the thrust required to keep the vessel in position. Depending on the class of vessels all sensors may be duplicated

Functions of the DP system

Modes

Manual control- The vessel is operated by joystick but in built protection such as for black out are still available

Auto Position Control- The operator enters a position and the dp system moves the vessel

Auto track control -The vessel moves at slow speed between several waypoints

Auto sail Control-The vessel moves at high speed between several waypoints

Autopilot Control- The vessel follows a dtermined course using the functions of the DP system compensating for enviromental effects

Follow Target- The vessel follows a moving target such as an ROV or Diver.

Reliability and weighting

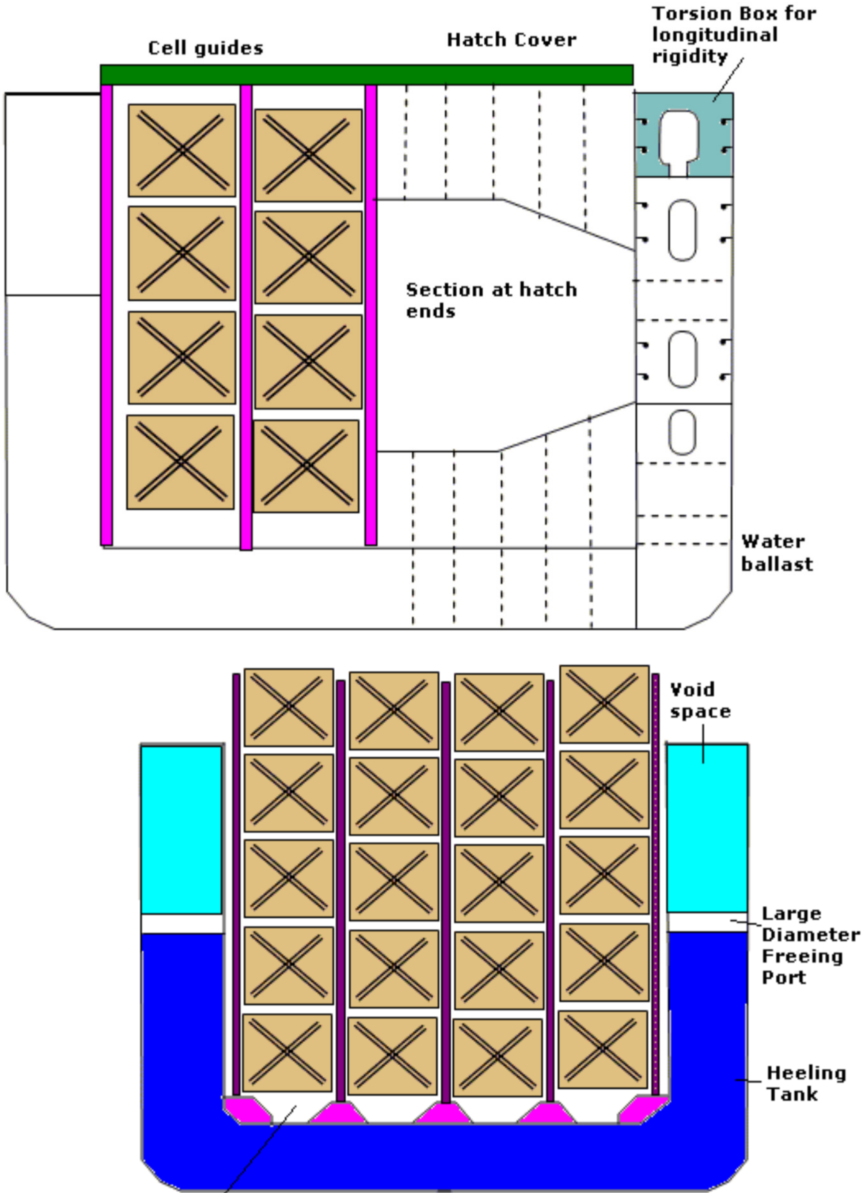
A minimum of three reference points is required for a diving operation. For example tautwire, DGPS and HPR.
Each of these systesm have a known reliability record. The DP computer 'weights' the measured position depending on the known reliability , say 60% for the taut wire, and 20% each for the other two. The position of the vessel determined by each system are unlikely to coincide exactly, the computers measured value position it uses in a combination of the determined positions suitably weighted. In this case it would hace the postion closer to where the taut wire believed it was.
Should a fault occur with the taut wire (say one of the potentiometers on the gimball heads begins tracking giving a noisy output signal), then this will be detected and the amount of weighting for that system reduced, below a certain value and the reference system will be automatically disconnected and a warning alarm sounded. A continuous read out of the positions from all three systems, the computer determined postion and the degree of weighting are all permenantly displayed.

Black out protection

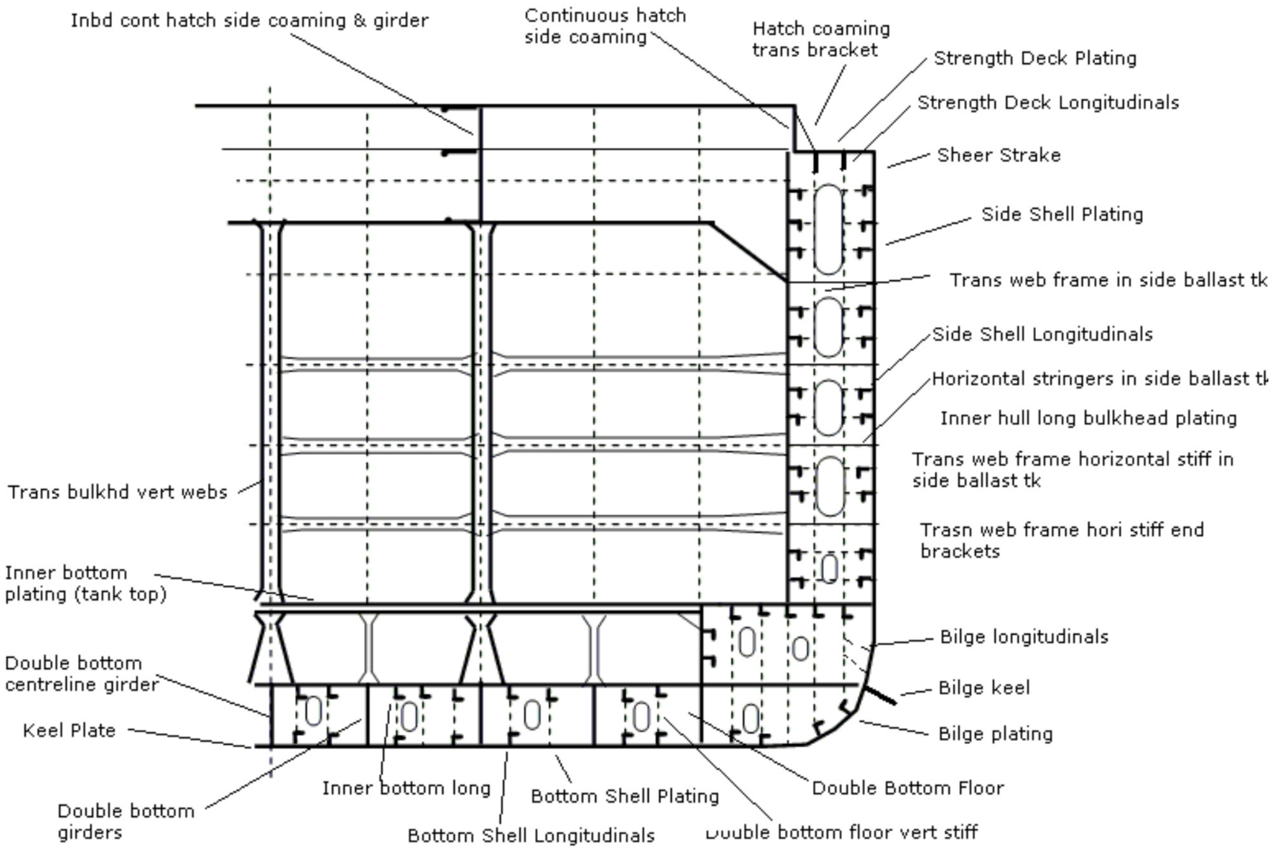
This takes the form of pitch reduction for the thrusters in the event that the reserve power on the main switchboard falls below a set value.

Container carriers

Hatchless carrier

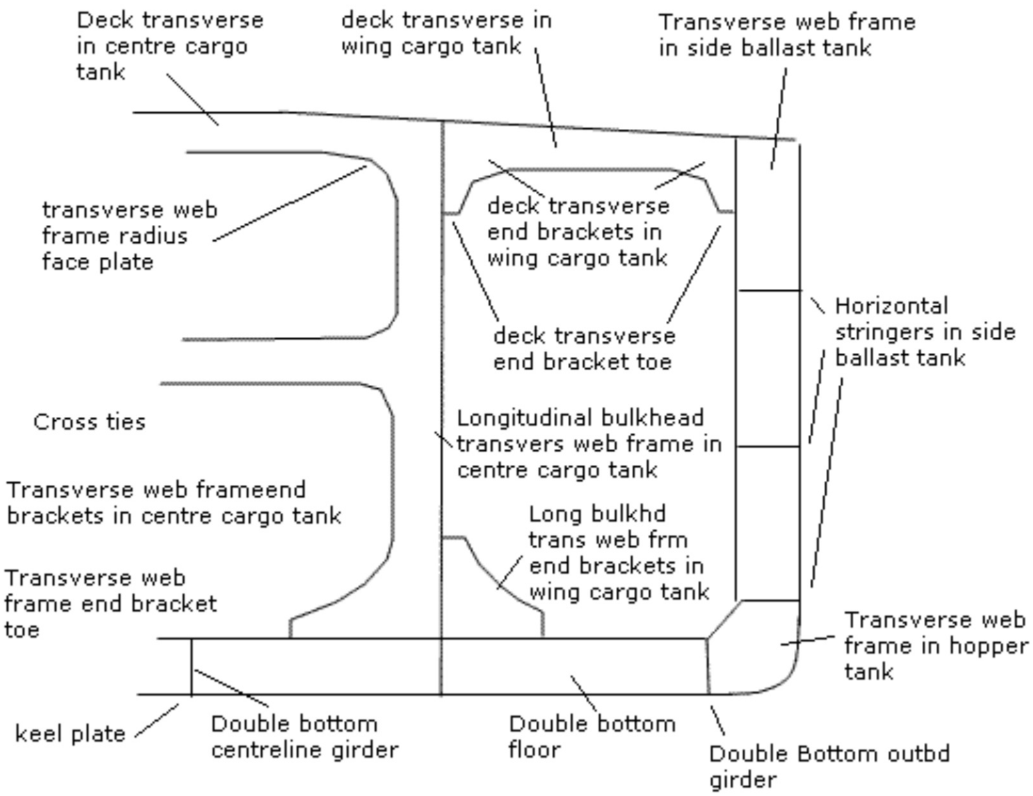


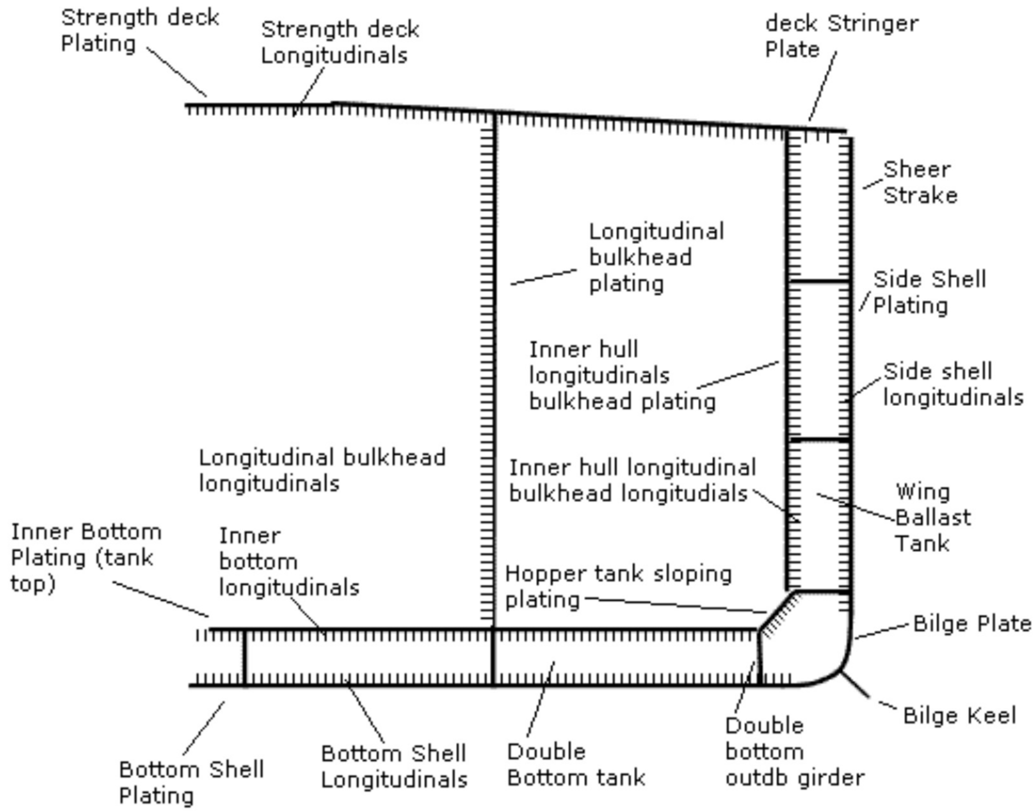
Box type girders are used extensively. These provide considerable strength and rigidity and they allow for a large central opens space.


Inbd cont hatch side coaming & girder
Continuous hatch side coaming
Hatch coaming trans bracket
Strength Deck Plating
Strength Deck Longitudinals
Sheer Strake
Side Shell Plating
Trans web frame in side ballast tk
Side Shell Longitudinals
Horizontal stringers in side ballast tk
Inner hull long bulkhead plating
Trans web frame horizontal stiff in side ballast tk
Trasn web frame hori stiff end brackets
Trans bulkhd vert webs
Inner bottom plating (tank top)
Bilge longitudinals
Double bottom centreline girder
Bilge keel
Keel Plate
Bilge plating
Double bottom girders
Inner bottom long
Bottom Shell Plating
Double Bottom Floor
Bottom Shell Longitudinals
Double bottom floor vert stiff

Tankers

Double Hull- typical mid ships section




Strength deck
Plating
Strength deck
Longitudinals
deck Stringer
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Sheer
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bulkhead
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Side Shell
Plating
Inner hull
longitudinals
bulkhead plating
Side shell
longitudinals
Longitudinal bulkhead
longitudinals
Inner hull longitudinal
bulkhead longitudials
Wing
Ballast
Tank
Inner Bottom
Plating (tank
top)
Inner
bottom
longitudinals
Hopper tank sloping
plating
Bilge Plate
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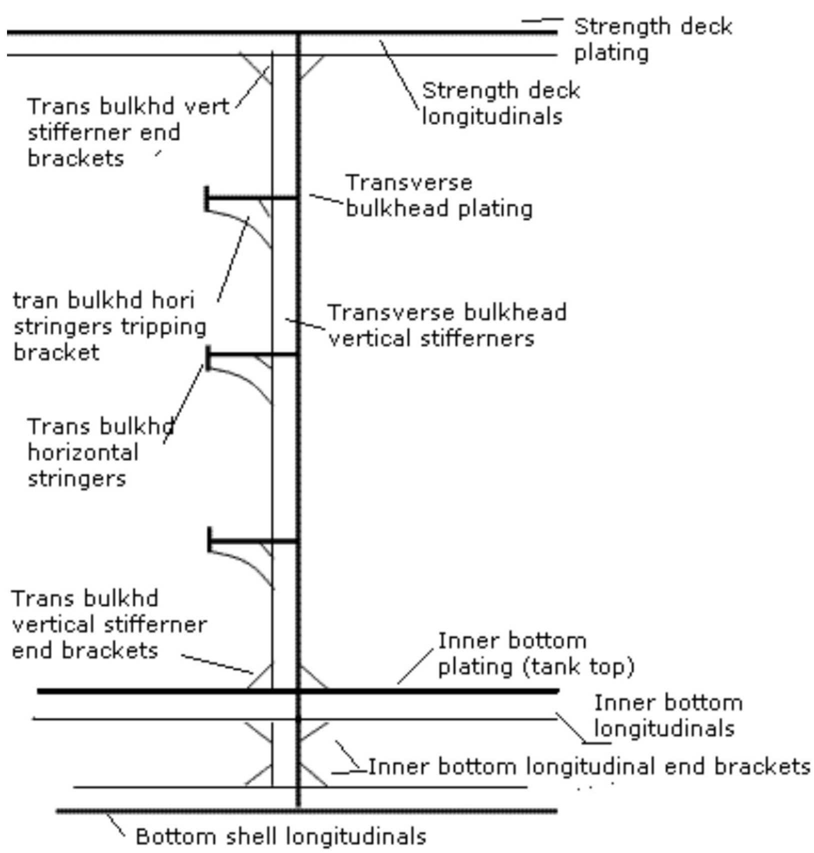
Bottom tank
Double
bottom
outdb girder


Strength deck
plating
Strength deck
longitudinals
Trans bulkhd vert
stifferner end
brackets
Transverse
bulkhead plating
tran bulkhd hori
stringers tripping
bracket
Transverse bulkhead
vertical stifferners
Trans bulkhd
horizontal
stringers
Trans bulkhd
vertical stifferner
end brackets
Inner bottom
plating (tank top)
Inner bottom
longitudinals
Inner bottom longitudinal end brackets
Bottom shell longitudinals

Metallurgical Testing

Non-Destructive Testing

This is carried out on components rather than on test pieces, they are designed to indicate flaws occurring due or after manufacture. They give no indication of the mechanical properties of the material.

Surface flaws may be detected by visual means aided by dye penetrant or magnetic crack detection. Internal flaws may be detected by X-ray or ultrasonic testing.

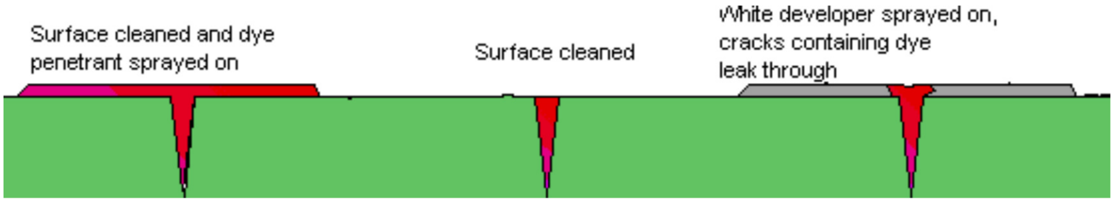
In addition to this there are special equipment able to exam machine finish.

Liquid Penetrant Methods

The surface is first cleaned using an volatile cleaner and degreaser. A fluorescent dye is then applied and a certain time allowed for it to enter any flaws under capillary action. Using the cleaning spray, the surface is then wiped clean. An ultra violet light is shone on the surface, any flaws showing up as the dye fluoresce.

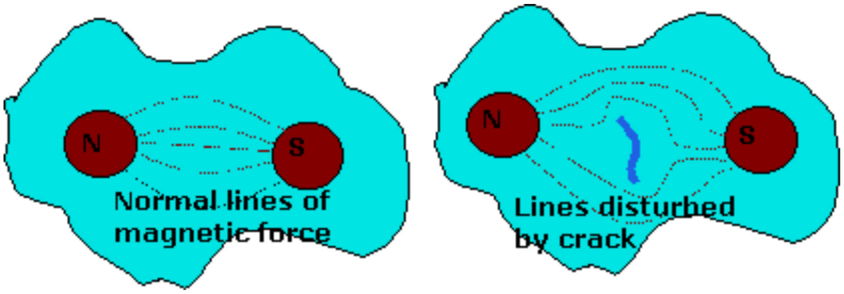
The more commonly used Dye penetrant method is similar in application. The surface is cleaned an d the low viscosity penetrant sprayed on. After a set time the surface is again cleaned. A developer is then used which coats the surface in a fine white chalky dust he dye seeps out and stains the developer typically a red colour.

Both these methods are based loosely on the old paraffin and chalk method.



Magnetic crack detection

A component is place between two poles of a magnet The lines of magnetism concentrate around flaws. Magnetic particles are then applied, in a light oil or dry sprayed, onto the surface where they indicate the lines of magnetism and any anomalies. This method of testing a has a few limitations. Firstly it cannot be used on materials which cannot be magnetised such as austenitic steel and non-ferrous metals. Secondly it would not detect a crack which ran parallel to the lines of magnetism.

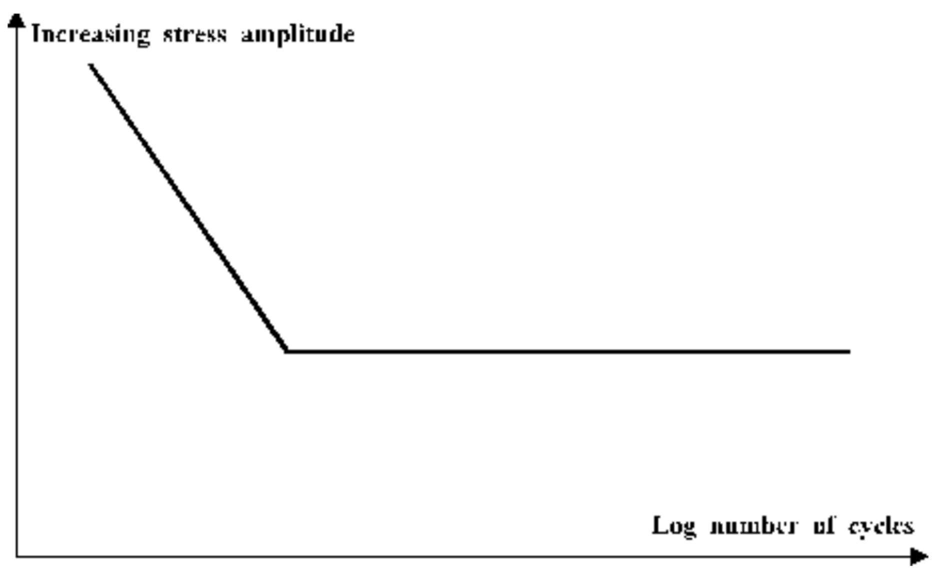


Fatigue

Most engineering component failure is due to fatigue. Fatigue may be defined as the formation and gradual propagation of a crack through a material under conditions of varying tensile stress. The stress must be tensile, cracks will not open up during compressive stress, and it must vary with time, fatigue cracks do not propagate under static tensile stress. A fatigue failed component exhibits two distinct types of surface on its fractured faces. There is the shell line marks of the fatigue crack growth, this may actually be polished due to the rubbing of the crack faces together, and the very rough section of final failure where the remaining material was unable to withstand the applied load causing final failure in a brittle manner.

The relative areas of fatigue crack growth and final failure indicate the type of loading and stress application involved. A large fatigue crack indicates low stress application involved. A large fatigue crack indicates low stress high cycles type of fatigue because the crack has taken a long time to propagate through the material, the relatively small final fracture surface indicates that low stress has been applied. (an example of this is a slightly misaligned motor coupling.) A small fatigue crack surface area but large final brittle failed area indicates low cycle high stress fatigue such as may be found in a pressure vessel like a starting air reservoir.

There is a very close connection between fatigue stress and the number of cycles to failure and this may be seen on the graph for steel.



There is a very close connection between fatigue stress and the number of cycles to failure and this may be seen on the graph for steel.

From this graph it can be seen that on the sloping section there is a set number of cycles to failure for any given stress. This means that the designer must make the dimensions of his component such that the stress induced will not exceed the value for that number of cycles. Alternately he may already have a set working stress and may then determine a safe working life for his component.

Operating speed of the engine must be taken into account when determining the expected lifetime in hours, the faster the machine operates the fewer the number of hours will be needed to reach the number of cycles. This is why bottom end bolts for medium speed engines require changing after a set number of hours whilst those for slow speed engines last much longer. The idea is to replace the bolts before there is any risk of fatigue failure.

There is a value of stress, known as the fatigue limit, where the graph is horizontal. If the stress is kept below this value fatigue failure should, theoretically, never occur. In practice problems can result due to stress raisers as these act to increase the stress locally to much higher values and so cause fatigue failure to take place before it was expected or when when it was not expected at all. These stress raisers include internal material defects such as slag, gas porosity, and existing cracks, but they may also be due to sharp changes in section caused by poor design or surface damage. Fillet radii should be used to avoid such stress raisers at changes in section and often these fillets are rolled because that avoids cutting the material grains and at the same time induces a compressive stress locally which reduces the total tensile stress in the material when working stress is applied. Undercutting the bolt diameter below the root of screw threads avoids the stress raiser effect of these threads and means that the nominal bolt diameter should not be subject to stress raiser effects.

Surface damage during overhaul causes stress raiser effects whilst overtightening of bolts induces a higher static stress so that when working stress is applied very high tensile stresses are obtained causing increased risk of fatigue.

The fact that a crack is not very large on the surface of a component does not mean that serious cracking does not exist. Only by seeing the full extent of a crack internally can the situation be fully assessed, this requires the use of ultrasonic methods. Even then some idea as to the type of loading must be obtained so that the real situation may be known. A small crack may not be near to causing failure with low stress fatigue but a crack of the same dimension may be very close to causing failure with high stress fatigue. In some situations such as piston crown it may be very difficult to detect cracks due to scale and other deposits.

Welds are particularly susceptible to fatigue cracking not because they are highly loaded but because slag and other defects they contain act as stress raisers. The presence of residual tensile stress in a weld also increases the total value of tensile stress when load is applied. Vibration imparts a varying load and many fatigue failures in welds are caused by vibration. Stress due to vibration may be very low but when stress raiser effects and residual stresses are added then the effect is appreciable. Any additional loading on a weld is liable to cause problems. This was the case with the Sulzer engine when jacking screws where first employed for holding the bearing caps as these jacking screws acted upwards on the cross section of the A-frames inducing a stress which was not there previously. Fatigue cracks developed in the weld of the A-frame but this was overcome by extending the cross plates and weld. Then machining a final radius.

Lower sections of bedplate transverse girders are highly stressed in a tensile manner and so are likely to have fatigue cracks especially if

Corrosion in metals

Galvanic Action

Corrosion within cooling systems can occur if the coolant, i.e. water, has not been properly treated. The corrosion can take the form of acid attack with resultant loss of metal from a large area of the exposed surface, or by Oxygen attack characterised by pitting. A primary motive force for this corrosion is Galvanic action

The Galvanic Series.

Or Electromotive series for metals

Cathode

Gold and Platinum

Titanium

Silver

Silver solder

Chromium-Nickel-Iron (Passive)

Chromium-Iron (Passive)

Stainless Steel (Passive)

Copper

Monel

70/30 Cupro-Nickel

67-33 Nickel-Copper

Hydrogen

lead

Tin

2-1 Tin lead Solder

Bronzes

Brasses

Nickel

Stainless-Steel 18-8 (Active)

Stainless Steel 18-8-3 (Active)

Chromium Iron (Active)

Chromium-Nickel-Iron (Active)

Cadmium

Iron

Steel

Cast Iron

Chromium

Zinc

Aluminium

Aluminium Alloys

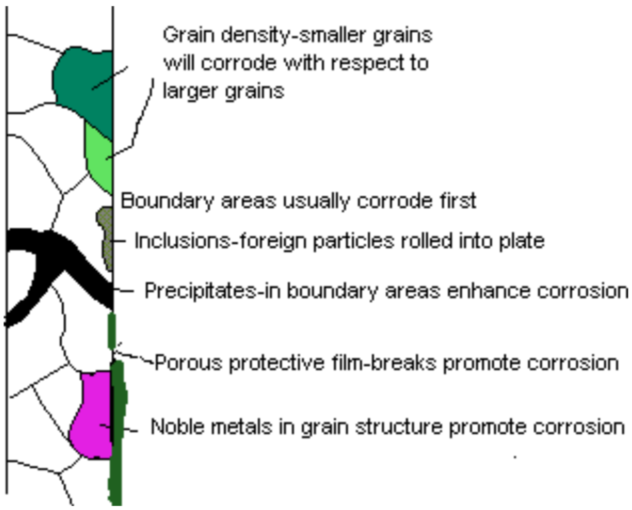
Magnesium

Anode

The metals closer to the anodic end of the list corrode with preference to the metals towards the cathode end.

A galvanic cell can occur within an apparently Homogeneous material due to several processes on of which is differential aeration where one area is exposed to more oxygen than another. The area with less oxygen becomes anodic and will corrode.

Galvanic action within metal



Galvanic action due to temperature gradient

This situation can exist in cooling water systems with complex layout of heat exchangers and passage ways within the diesel engine. Systems containing readily corrodible metals such as zinc, tin and lead alloys can complicate and intensify problems by causing deposit formations.

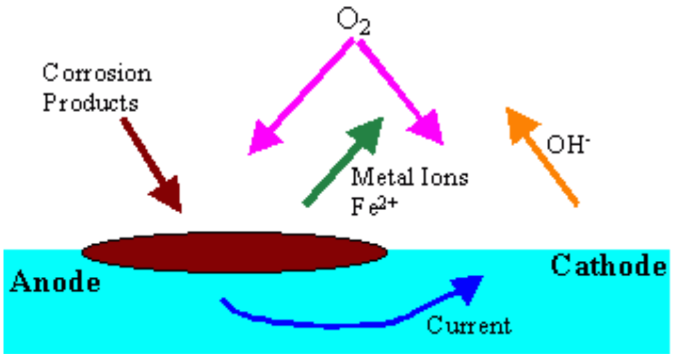
Differential Aeration

-Where only a single metal exists within a system corrosion can still take place if the oxygen content of the electrolyte is not homogenous. Such a situation can occur readily in a jacket water system as regions of stagnant flow soon have the oxygen level reduced by the oxidation of local metal. The metal adjacent to water with reduced levels of oxygen become anodic to metals with higher oxygen content electrolyte in contact with it. Generally, the anodic metal is small in comparison the cathode i.e. the area of stagnant flow is small compared to the area of normal flow of electrolyte, and high rates of corrosion can exist. One clear case of this is the generation of deep pits below rust scabs.

Corrosion of Metals

Steel (Fe)

Will readily corrode by the reaction with oxygen in the water primarily by galvanic action.



The Iron reduces to Iron ions at anode, the oxygen is reduced by combining with water and electrons passed from the anode (by iron changing to ions) to hydroxyl ions. Temperature, pH and the concentration of oxygen all affect the rate of corrosion.

The oxygen reacts with the Fe^{2+} to form Hematite (Fe_2O_3) . This is a reddish brown loose deposit. With reduced oxygen content the formation of Magnetite (Fe_3O_4) will occur. This is a more tenacious layer and forms a protective boundary on the metal preventing further corrosion. This layer may be removed in low pH or high pH conditions.

Scabs and tubercles of Ferric oxides and Ferric hydroxides form over an active pit.

Stainless Steels

These are alloys of steel with high chromium content (around 11%). The alloying process results in a material with excellent corrosion resistance. Oxygen combines with the chromium and iron to form a tenacious self healing oxide layer.

The disadvantage of stainless steel is that in low oxygen environments, such as boil feed, the corrosion resistance is actually reduced. In addition stress corrosion cracking and pitting can occur when in the presence of chlorine ions. In this way stainless steel is not recommended in situations were stagnant sea water might exists at it could perforate quicker than mild steel. The chlorine ions are the correct right size to enter the atomic matrix of the metal and their concentration accelerates corrosion by the propogation of cracks. Catastrophic failure can occur.

Copper(Cu) and Copper alloys

Used in heat exchangers due to there high heat conductivity. Copper corrosion in oxygenated water is slow due to the time taken for oxygen to diffuse throught the oxide layer.

As copper is a relatively soft metal water velocities must be kept low. Its presence can lead to heavy pitting if deposited in steel systems. Ammonia in the water can remove the oxide layer and promote rapid corrosion

Aluminium (Al)

Is essentially inert in neutral water up to about 180'C. It is ampoteric meaning it will corrode rapidly in high and low pH conditions. In the presence of Sodium Carbonate or sodium hydroxide at pH above 9 this corrosion is particularly severe. These conditions may exist were boiling occurs concentrating hydroxyl ions.

Zinc (Zn)

Is anodic to steel and is often used as a protective coating on steel in a process called galvanising. It is ampoteric, corrosion increases in high and low pH conditions.

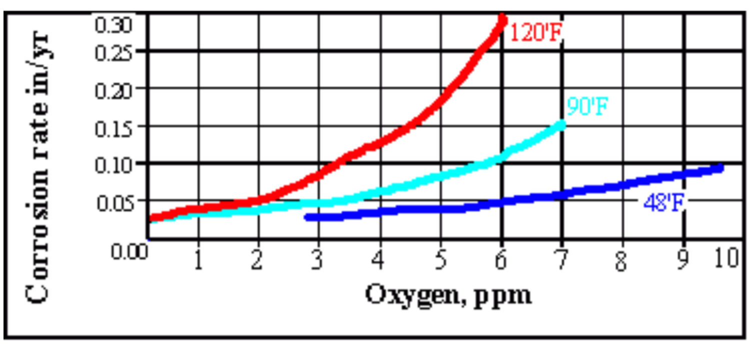
Note! At temperatures above 60'C the anodic/cathodic relationship with steel is reversed. This is of particular importance in engine cooling systems. The author has joined a vessel were the third engineer was merrily fitting anodes to the cylinder heads of a daihatsu generator engine. The fact that the engine was fresh water cooled with inhibitor treatment also was ignored

If galvanised pipes are to be fitted in a cooling circuit the coating must first be removed by controlled acid washing.

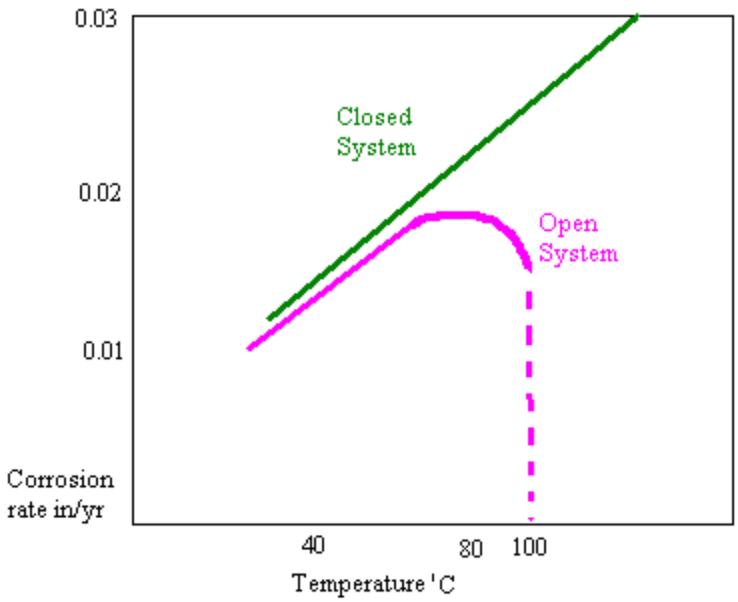
Factors affecting corrosion rates

Temperature

As a rule of thumb for each 10'C rise in temperature doubles the rate of corrosion.

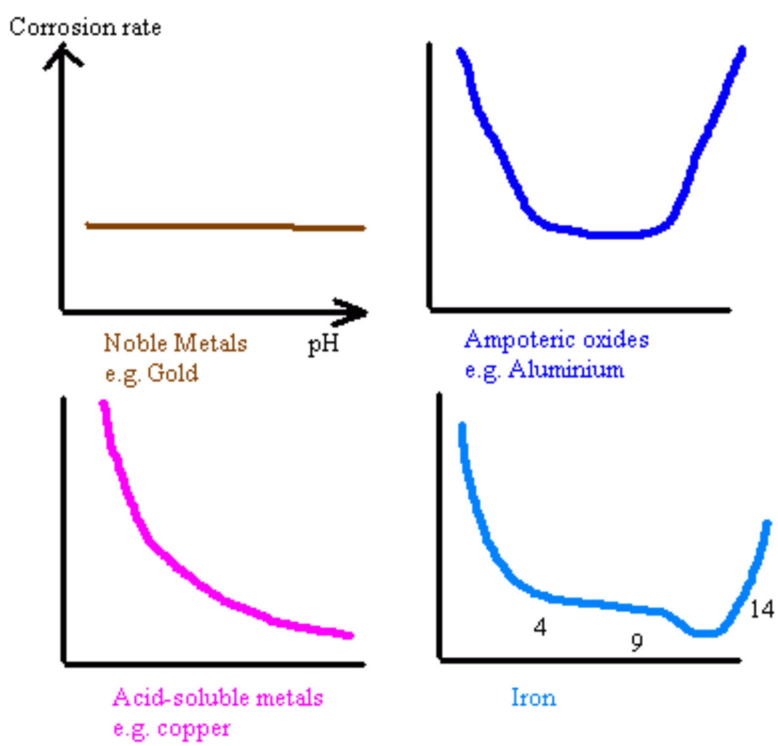


The rate of oxygen diffusion increases in an open system with temperature up to around 80'C. A rapid tailing off then occurs due to the solubility of oxygen. For this reason open system feed tanks seen on many vessels have heating coils which maintain the temepruature at 85'C or higher.. In a closed system there is no such tail off as the oxygen cannot escape



pH/Alkalinity

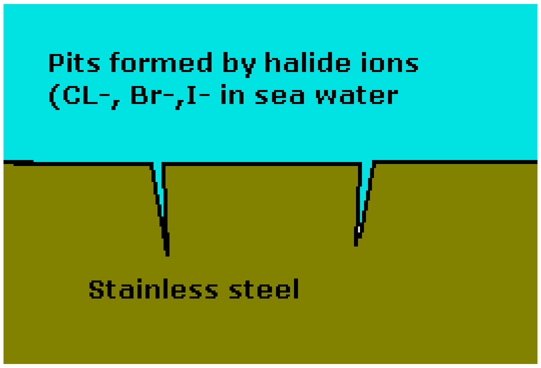
The electrochemical nature of the metal will determine its corrosion rate with respect to pH. The corrosion rate of iron reduces as the pH increases to about 13 due to the reduced solubility of the Fe ions. Aluminium and zinc, being ampoteric, have rates of corrosion that increases with pH higher or lower than neutral



Materials used in ships sea water systems

90/10 Cupro-nickel

1. *Resistant to high sea water velocities allowing reduced tube diameters*
2. *Resistant to corrosion under stagnant flow conditions and pitting*
3. *Resistant to clogging from marine growth*
4. *Ease of manufacture and welding*
5. *Reasonable cost*



Stainless steel

1. *Suffers from deep pitting in stagnant waters-if cleaned regularly this pitting can be reduced*

Expected life spans of some materials

Galvanised steel- 6 to 9 years
Copper-Maximum vel 4ft/sec
90/10 Cupro-Nickel- 10yrs+
70/30 Cupro-Nickel- 22 yrs+

Welding

Electric Arc

Coating

- It creates a gas shield to prevent oxidation of the weld material
- It helps the weld formation by shaping the metal transfer
- It provides an electrical insulation for the user

Coated electrodes are normally supplied in a water proof container. Once opened effort should be made to prevent as far as possible moisture ingress. Some coatings have a high affinity to moisture and must be kept in a heated cupboard. It is a good idea to keep all electrodes in this cupboard as moisture in the coating can severely effect the quality of the weld

Some hints and tips

Take a welding course

Rule of thumb when starting with an unknown set is 40amps per mm of rod e.g 2.5mm=100amps.

Increase the current slightly when using long extension cables. Try not to have these cables in a coil when welding

The quality of the weld is directly related to the surface preparation. Take a little extra time to prepare and shape the area to weld

Ensure all slag is removed , if necessary by using an angle grinder to gouge out any pin holes, before welding over a run

If your welding rod sticks then clean with an angle grinder the mark especially on critical welds such as pressure vessels. Check the condition of the coating on the rod. If the coating is damaged say with one side of the wire exposed discard the rod or burn it back to good on a non-essential piece

After finishing a run the end of the rod invariably gets a slag coating. When you come to strike again it is difficult so the tendency is to strike harder and harder. The consequence of this is that not only does the slag come off but a good piece of the coating leading to an erratic arc. Penetrate the slag cap by gently rubbing it on a rough surface, or use your fingers to snap it off (as I do)

Keep you glass clean- the fumes tend to coat the glass with a layer of dust. Keep wiping this off. If you cannot see the weld arc properly you have too dark a tint grade of glass. These tend to be supplied suitable for welding maximum amps (say 300 Amps)

Where the shape of the weld is critical then use two hands. One to hold the holder the other grip the rod a couple of inches back from where the arc is. (I used to do all boiler tube welding in this way and as I get older most of the vertical welding as well)

Position the piece to avoid as much as possible any other type of weld except horizontal- this is not a cheat but is common sense. Watch a coded welded how he works

Brace yourself against something before starting if possible. Loop the cable over your body so that the weight of the cable does not fall onto you hands

When doing a multi run weld into a narrow groove or right angle join use a small diameter gp rod for the root weld as this is critical and any slag inclusion will cause porosity in the rest of the weld runs

If you get porosity dont mess about putting a thousand runs over the top of it, grind the bugger out and start again

Don't be afraid to use rods. For awkward jobs bend the rod half way down if it helps. I welded an economiser using only the final inch of each rod which was bent to suit due to the position of the hole (I also had to use a small inspection mirror to see it). Don't be tempted to use old part used rods for critical jobs as they inevitably have a high moisture content in the coating and make for a very porous and/or brittle weld.

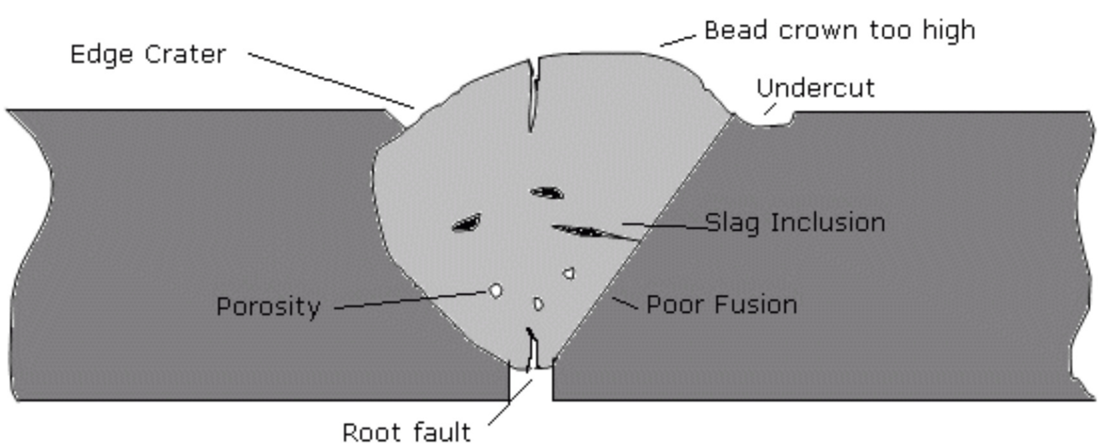
When lighting an oxy-acet flame light the acetylene and increase slowly until you see the carbon smoke just disapear. The put on you oxygen.

When using oxy-acet gas cutters make sure you always have a bucket of water nearby incase of blow back.

If you are going to gas weld aluminium - don't. Reach for the TIG welder or if you must MIG. Or if you really, really must, stick weld. If you do not have these and have to gas weld make sure you well remove the oxide layer (using a non-ferrous wire brush) and weld as soon as possible. Try to make up only the flux you need for the job that day. Get loads of practice.

PRACTICE-that is the main difference between a good and bad welder

Welding faults



Root Faults For deep vee multi run welds the first run or root weld is critical to the quality of the welds laying on top. Typical faults may be caused by too high or low a current of too large a rod .
Fusions Faults The three main causes of this is too low current for rod, too high a travel rate or when too small a rod is used on a cold surface
Bead Edge Defects normally in the form of under cutting or edge craters. The main cause for this is incorrect current setting. Too high will lead to undercutting, too low to edge craters. Similar efects may occur at the correct current due to incorrect arc length. Edge faults are particularly common in vertical welding or 'weave' welding. The general cause for the latter being a failure to pause at the extremes of the weave. Edge defects are stress raisers and lead to premature weld failure.
Porosity May have many causes the most common being moisture in the rod coating or in the weld joint. Poor rod material selection is also a factor
Heat Cracks this is a destuctive fault casued generally due to incompatiblity of the Weld material and weld Rod. Indeed in some cases the material may be deemed unweldable. Heat cracks occur during or just after the cooling off period and are caused byimpurites in the base metal segrateing to form layers in the middle of the weld. The layers prevent fusion of the crystals. The two main substances causing this are Carbon and Sulphur. A switch to 'basic' electrodes may help.
Anouther cause is temsion acroos the weld which , even without segregation in the weld, cause a

crack. This occurs during a narrow critical temerpature range as the bead coagulates. During this period the deformation property is small, if the shrinkage of the base material is greater than the allowed stretch of the weld then a crack will result. One method of preventing this is to clamp the piece inducing a compressive force on the weld during the cooling period
Shrinkage Cracks Thes form due to similar effect of allowed weld deformation being less than base metal shrnkage although it is not associated with the critical temerpature rang above and therefore cannot be elleviated by compression. The use of 'basic' electrodes can help
Hydrogen cracks This is generally associated wht either hardened material or material hardened during the welding process. The hydrogen source can be moisture, oil, grease etc. Ensuring that the rod is dry is essential and preheating the weld joint to 50'C will help. The cracking occurs adjacent to the weld pool and allied to the tension created during the welding porcess will generate a through weld crack.
Slag Inclusion This common fault is caused by insufficient cleaning of the weld between runs. If necessary as well as using a chipping hammer and brush grind back each weld run with an angle grinder. Once the slag is in the weld it is near impossible to removed it by welding only

Welding Fumes

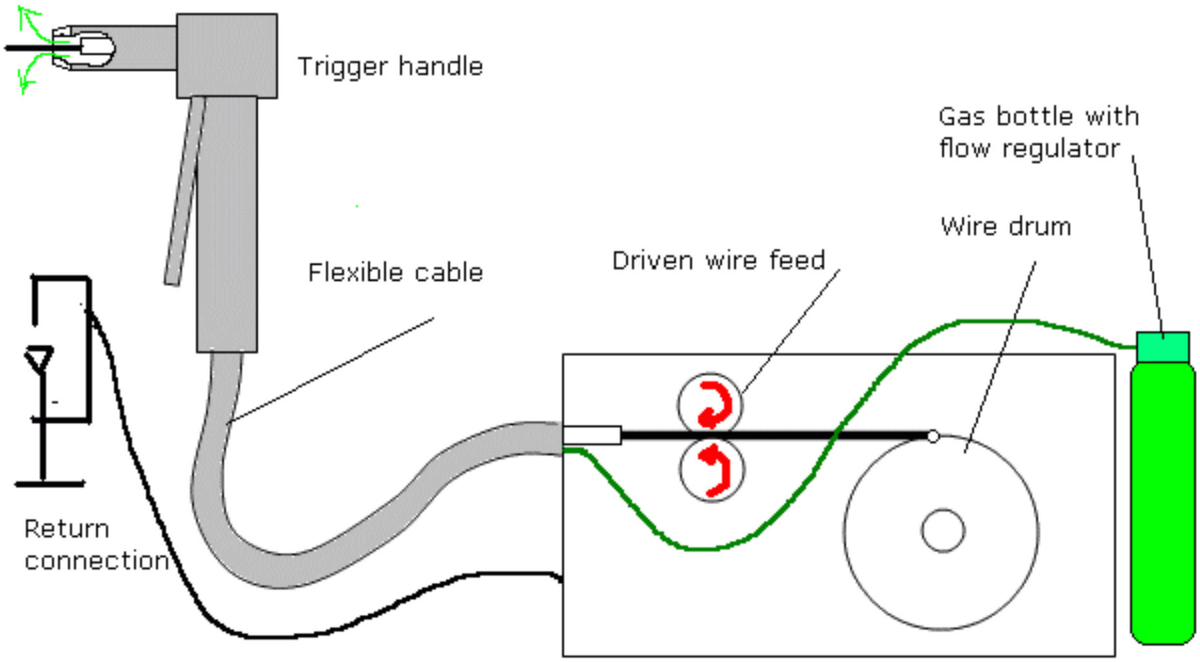
Welding fumes are generated during the welding operation and consist of a mixture of the filler material and the base material gasses and dust.
The best method of preventing inhalation of these fumes is by forced air extraction. Where this is not possible then the personnel in the area should place themselves away from the general air flow.

The following lists the types of fumes and there potential risk	
Fumes from low alloyed or unalloyed steels- no heat treatment	Generally considered a low health risk
Fumes from low alloyed or unalloyed steels- no heat treatment	The surface treatment may cause harmful substances to be present and released during the welding process.
Galvanised or surface trated with zinc	The fumes given off may contain zinc oxide inhalation of which can lead to zinc fume poisoning. This is an unpleasant effect lasting for a couple of hours but it is not believed permenant. I have had this and it takes the form of shortness of breath and can be very frightening at its worst
Cadmium treated surfaces	creates cadmium oxide inhalation of which causes very harmful lung damage a
Lead or mercury coating	Found only as a surface treatment on very old plate
Stainless steels	Fumes contain Nickel and Chrome gasses inhalation of which causes severe respiratory damage
Gas Welding or burning	Nitrous oxides can rapidly build up in enclosed areas when using larger nozzles. This becomes apparent by irritiation to the eyes and throat. where the torch has been incorrectly adjusted there is the risk ofcarbon monoxide being formed which is very dangerous and will lead to suffocation

Note: When welding metals containing or having as a surface treatment Cadmium, Chrome, Lead, Mercury or Nickel then either adequate forced air extraction should be used or the welder should be supplied with an air fed mask- if this is you make sure you do it as the damage will only come apparent later on

Metal Inert Gas (MIG)

Also called Gas Metal Arc Welding (GMAW). Where CO2 is used as the shielding gas the system may also be known as Metal Active Gas (MAG). Generaically the term MIG is applied to the welding sets.

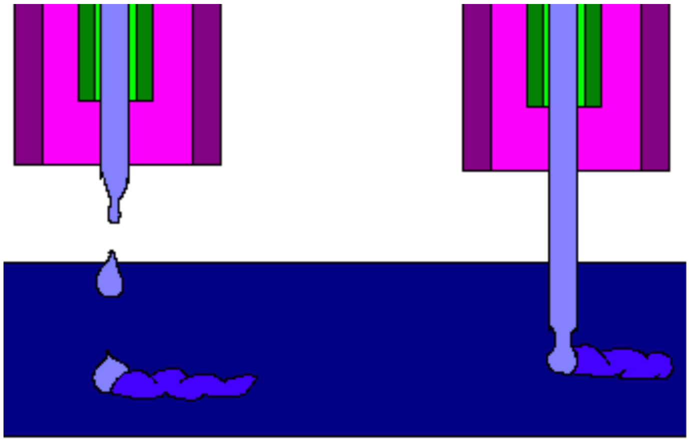


The shield for the arc is formed from a supply of inert gas. Gas stored in a bottle is led via a flow regulator through a tube to the welding torch. When the trigger on th torch is depressed firstly the gas valve is opened and the shield gas emiited from the nozzle. Further depressing the trigger makes an electrical switch and the wire feed is activated and the metal wire electrified.
To start the welding operation the torch is held a set distance-sat 10-15mm, from the work piece, the trigger is pressed and the arc established. Note that the arc is not 'struck' in the same way as stick welding. To improve the arc creation is it advisable to sharpen the wire to a point before starting
Wire Stickout - The amount of wire sticking out of the holder at startup should be controlled. Too long and the weld arc is cool and may not be properly shielded by the gas. Too short and the holder tip can be overheated and weld spatter may enter the nozzle and cause turbulence in the gas flow.

Increaseing stickout

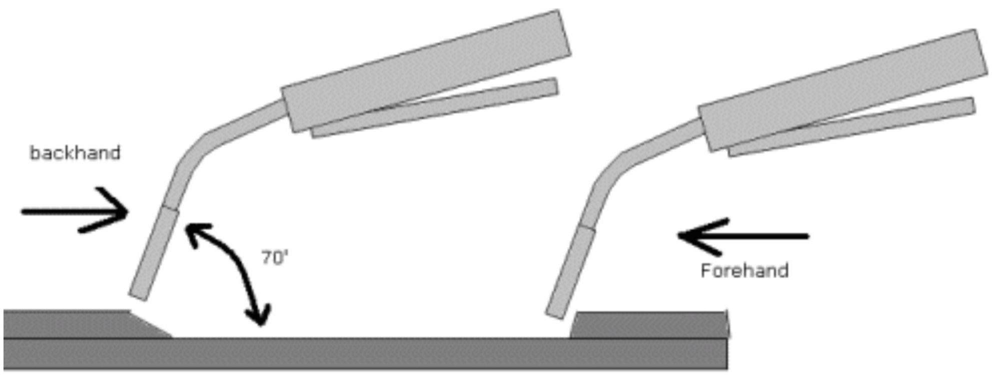
- Decreases penetration
- Increases deposition rate
- Increase weld bead height and bulk
- Decreases bead width

There are then two basic techniques.



Spray Arc Short-Arc

With the current set above a thershold (about 150amps for 0.8mm wire) the metal transfer is in the form of a continuous spray of molten metal. This gives good penetration and is suitable for thicker material (greater than 3mm). With the current reduced the drop size increases until the arc cannot be maintained and the wire torches the material (thus the technique is also known as 'Short Circuit transfer' but more generally as 'Short Arc'. The metal in contact melts and is replaced by the wire as it feeds through the tip. This is particularly suitable for positional welding and thinner material.
Two adjustements are available for control of the arc. One is for current, the other is for wire feed rate. The flow of gas can be adjusted to allow for such as environmental conditions e.g wind blowing.



Backhand

- More stable arc
- Less Spatter
- Deeper penetration
- See weld deposit better

Forehand

- More Spatter
- Less penertration
- See weld/Joint lay better
- Gives better cleaning action when welding aluminium alloys

The angle of the torch will affect the degree of penetration. Too small an angle will also reduce the effectiveness of the shield gas. Weaving the torch may be used for increasing the size of the weld lay. It is important if doing this to pause at the extremes of each weave. Failure to do this leads to undercut and weaknes of the weld. When startin on a cold workpiece penetration is reduced. To improve this the arc should be made on a seperate piece attached to the work piece. Anouther technique is to add heat to the start area by starting the arc at an increased distance (say 2 to 3 cm), the torch is then brough quickly back to the more normal 1-2cm. When finishing the weld the torch should be quickly brough out and the travel rate increase to reduce the heat in the weld pool before the trigger is released

Argon
- Aluminium
- Stainless Steel
- Copper and copper alloys

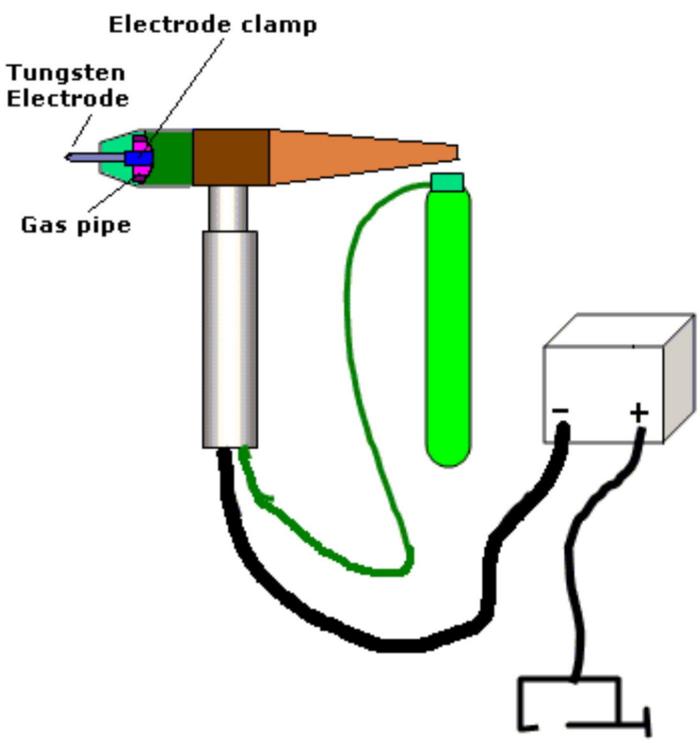
Carbon Dioxide
- Ferrous metals

Argon/CO_2 mix
- Ferrous Metals
- Stainles steels

Other gasses and gas mixes are in use but the above are the most common. For smaller sets flux cored wire is used thereby negating the need for a seperate gas supply

Tungsten Inert Gas (TIG)

Also known as Gas Tungsten Arc Welding

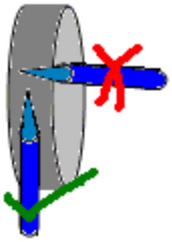


Frequently used in the welding of Aluminium brasses, Cunifer, and stainless steels. This is a particularly effective weld process particularly for the aluminium brasses such as yorcalbro often found in sea water systesm. The small heat effected zone is particularly important as super granulation causes a softening of yorcalbro leading to bulging and failure under pressure

The main advantages are
- Easy to use in all positions
- Stable welld directed heat with small heat effected zone and deep penetration
- Clean smooth welds of high quality

Technique-The basic technique is a cross between Stick welding and gas welding. The arc is struck against the surface, the shield gas is ionised and a stable arc is formed. The elctrode must be quickly brought up to the weld height to prevent contaminationof the weld pool. The tungsten electrode does not melt. A filler rod of correct material is introduced in a similar fashion to gas welding. The electrode holder is held at a 75' angle and thefiller rod held at 30' in the direction of the forehand travel.For TIG the shield gas has the added requirement of preventing oxidation and cooling the tungsten electrode.

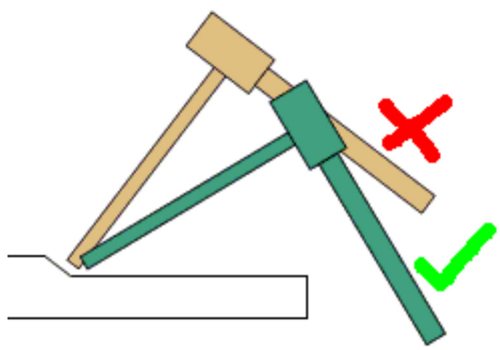
Electrode



The electrode is tungsten or tungsten alloy (with thorium or zirconium) which has a higher melting point. The electrode is grind, using the technique shown above to a point. Too fine a point and the tip can melt and contaminate the weld. Too steep and the arc is unstable and penetration poor. About 3 - 6 mm extends from the nozzle whose throat size is governed by the welding current.

Gouging

This refers to the technique of shaping or cutting metal using specialised electric arc rods. The arc is struck with the rod in the perpendicular position. Oncew the arc is struck the angle is reduced to about 20' (do not point the rod into the weld. This allows for clean displacement of material. For



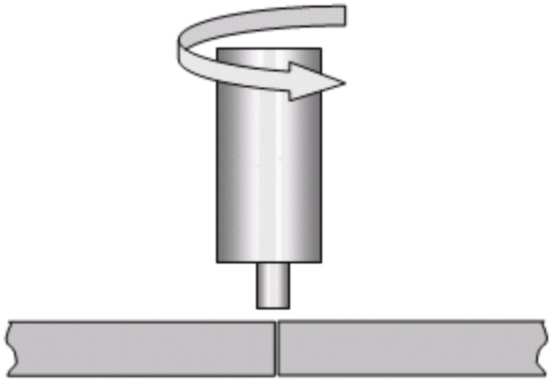
vertical pieces the rod travel is down.

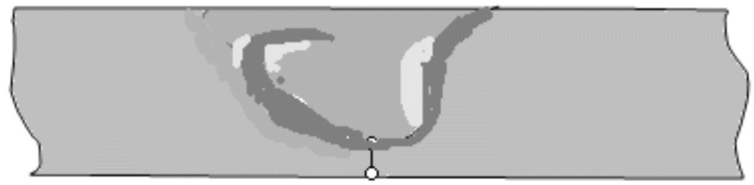
Air Arc Gouging

This is a system similar in manner to standard gouging but using copper coated graphite rods through which compressed air is pumped. The rod melts the metal and the compressed air displaces it. This system is seen in commmon use for underwater repairs.

Friction Stir Welding

This very modern practice is now becoming increasingly used in shipbuilding particularly for joining aluminium.





Two pieces of material are butted to gether. The FSW head, consisting of a profiled probe rotating at high speed is brought into contact with the join. Heat is generated and the metal softened and forced around the the probe to the rear. In this way material from both pieces are merged and thus the join is main. The weld is made in the semi solid state. There is no sparking, fumes and a reducion in noise. Weld speeds are increase by about 10% over conventional means.

Structural Repairs - minimising distortion

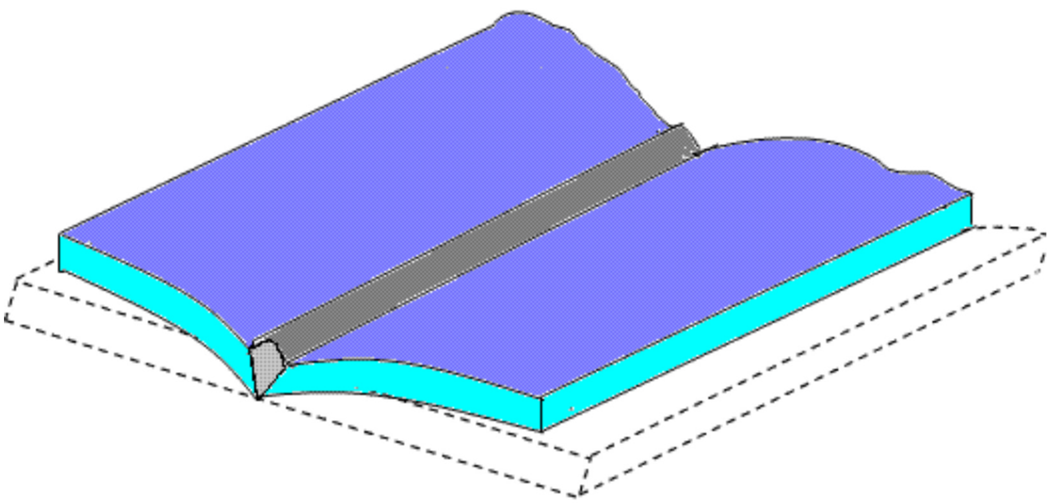
Distortion

Distortion occurs during electric arc welding process due to localised heating of the material and by the hot infill material cooling and shrinking.

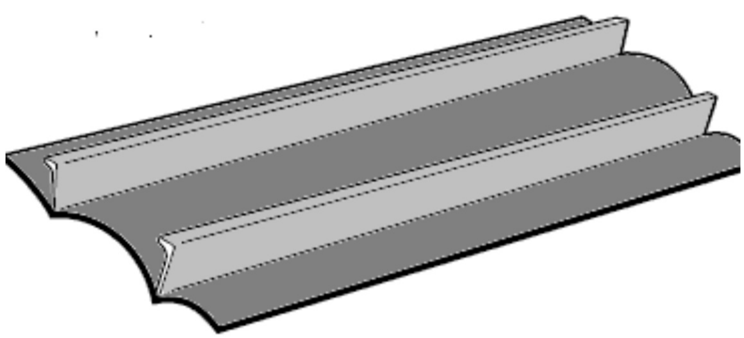
These processes are well knwn and proper selection of preparation and weld technique have largely eliminated this as an area of concern. However faults can still occur and this is due mainly to poor workmnship.

Typical causes of defects are;

- Welders deviating from proceedures
- Poor edge prepation
- Excessive, insufficient uneven gap
- Environmental conditions- high wind, wet surfaces, low steel temperature.



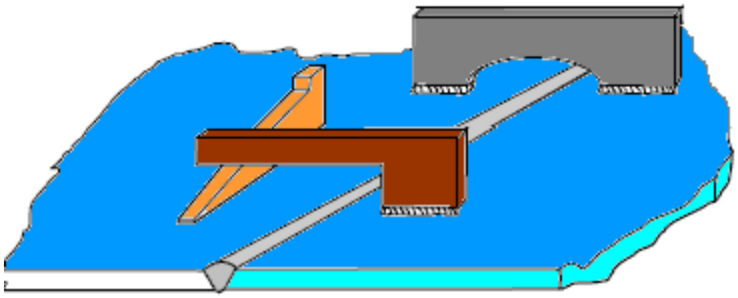
This shows typical angular distortion of a plate. Distortion may be transverse or longitudinal and may also cause bowing or dishing or some bomination of all three



The amount of shrinkage is dependent on the following factors;

- **Plate thickness** Shrinkage will reduce with larger plate thickness
- **Gap** Shrinkage will increase with increased gap due to the increased amount of hot filler material

required
- **Joint Fit** Tack welding should be used to both set and maintain the gap of butt joins. There is a tendency for gaps to close as the weld progresses
- **Parent Metal Properties** The higher the thermal coefficient of expansion the more the metal will expand during the welding process. This hot meterial cannot expand freely but is constrained by the surrounding cool material. The lower heat conductivity of the material the more localised the heat is and the greater the possibiity of distortion. Both of the above factors are important in the welding of stainless steels
- **Joint restraint** To maintain alignement strongbacks may be used to lock plates. The disadvantage of this is that the plates can no longer stress relieve.



For some materials this may require the use of a heat treatment process.
- **Joint Design** Double sided welding will reduce significantly distortion.

Although there is a risk of cracking due to the locked in stresses the reality is that this is very rare. A greater risk comes from the removal of the strongbacks after completion. These should be ground off and not 'hammered' as this tends to tear the parent material. Should a tear occur this has to be ground out, filled with weld and ground back.

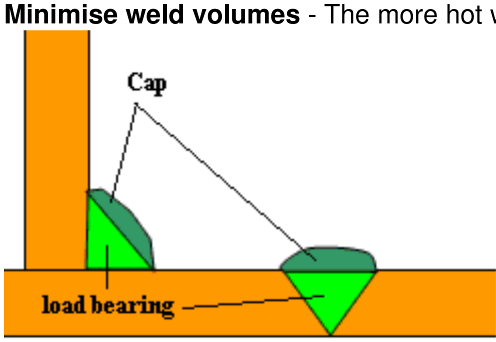
Weld Proceedures

There has to be a balance with the desire for a perfect repair against the practical and commercial viabiity of achieving this.

Distortion can be minimised by the use of double sided welds. However this may prove difficult to achieve in practice. instead single sided welds may be preferred with the use of backing strips.

It should be noted that many yards now prefer MIG welding due to its speed, reduced cleaning requirements and simplicity. The down side of MIG is lack of penetration and great care must be taken to ensure that welds using this techniques have been properly prepared.

To reduce distortion the folowing may be adopted;
- **Reduce the amount of welded joints** - by using extruded and preformed sections such as bulb plate stifferners
- **Minimise weld volumes** - The more hot weld filler material is in the weld the greate will be distortion



The Cap on the weld is weld filler that does not contribute to the load bearing structure of the weld.

The use of double sided welding can reduce the amount of weld used however this is at the cost of time. Proper edge preparation can help to reduce the weld material required especially for single sided welding.

Bevelling one edge of a butt weld can help with compensating for single sided welds

- **limit weld runs** the more weld runs, the more the distortion. Generally a single large run will create less distortion than severl smaller runs.
- **Tack Welds** This should maintain the gap

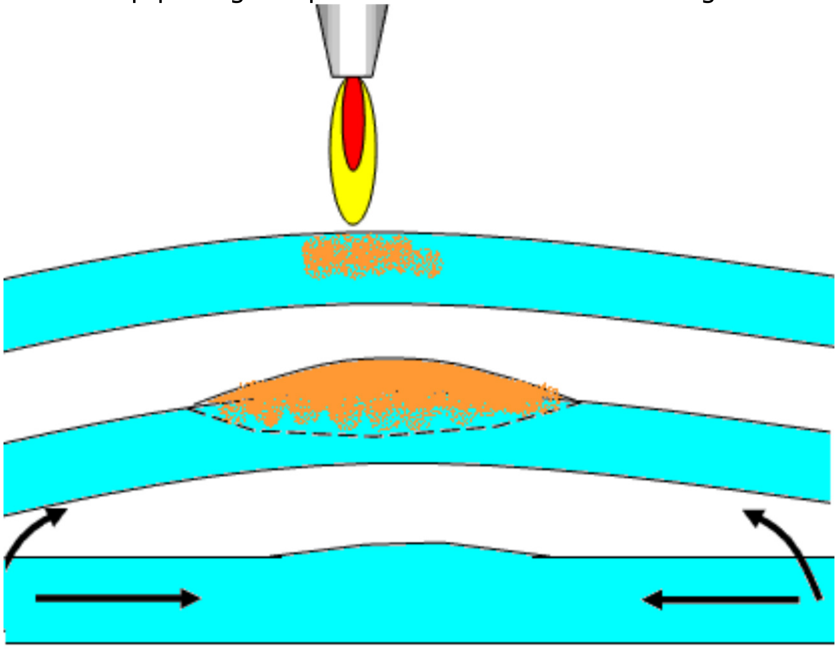
Repair of Distortion

Should distortion occur there are two methods of restoring the shape.

Mechanical - This involves the use of direct force on the material. Typically this will take the form of strong back and jack. As these are considered point loads there is rela risk of further damage and car should be taken.

Thermal - This involves the application f localised heat. The amount of heat is governed by the material but generally the temperature should not exceed 650'C although this may be increased to 1000'C for lw carbon and high tensile steels. Care should be taken with water quenching not to change the structure of the material

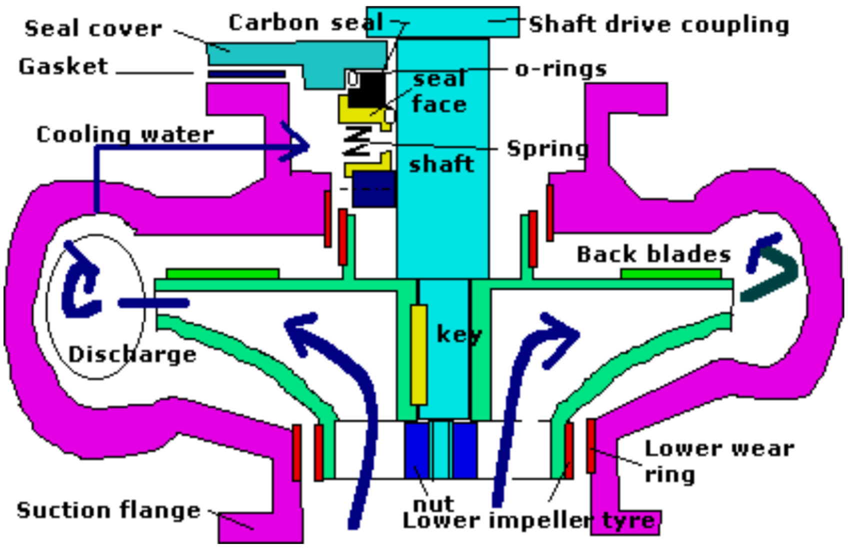
The plate is bent by applying localised heat, this causes a hot spot were the material expands but is constricted by the cold surrounding material. When the heated material cools it tends t bunch up pulling the plate inwards towards the original heat source



Where there is a large area area of distortion suggest as plate dishing, then straightening should be my several point heating rather than a single large one

Types of pumps

Centrifugal

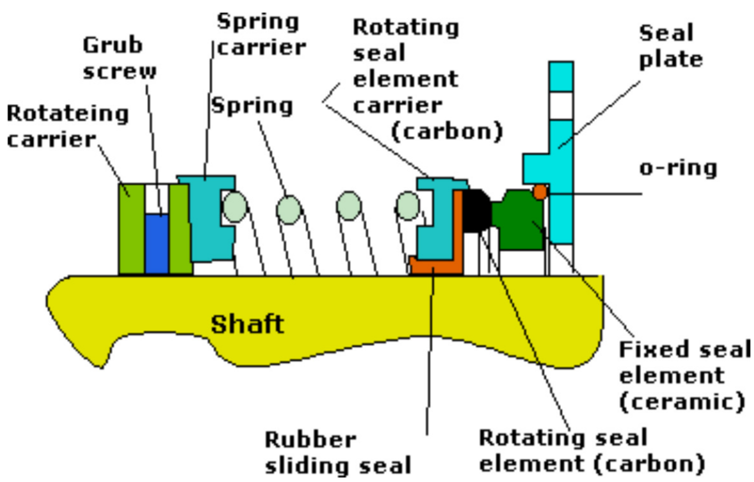


Shown above is a cross section through a vertically mounted centrifugal pump.

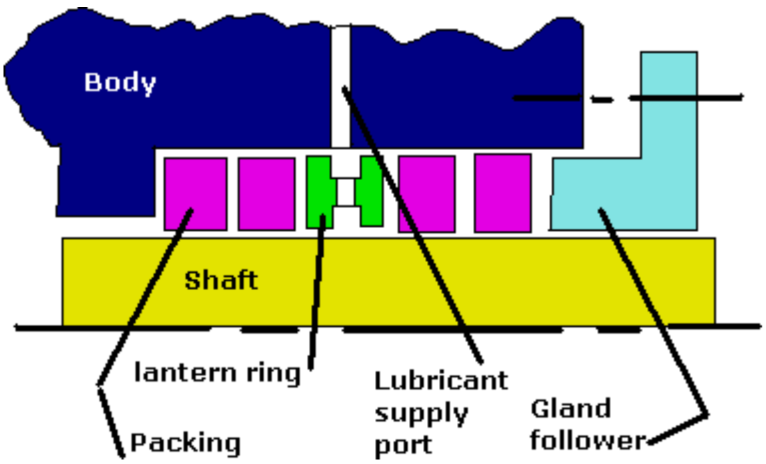
Water is led to the suction eye of the rotating impeller. The water gains energy by the centrifugal action of the pump and is discharged to the volute outlet casing. The volute is created by increasing the area of the outlet port and is greatest at outlet from the pump. By this design the kinetic energy of the water is converted to pressure energy.

Sealing is provided by a mechanical seal (one half of which is shown above and in more detail below) or by packed gland. For the former cooling water is supplied from the discharge side of the pump. For the latter cooling is provided by the allowance of slight leakage, lubrication is by a grease filled manual lubricator.

Mechanical seal

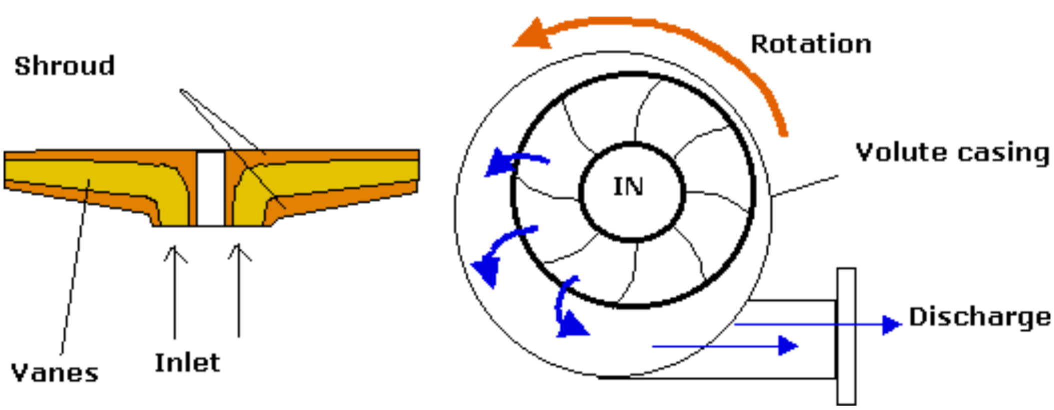


Packed gland seal



The pump unit shown above relies on the driving motor bearings for alignement. For larger pumps a leaded bronze or brass bush may be fitted positioned just below the seal.For the largest pumps, especially those fitted with an inducer the shaft may be extended below the impeller fixing and a second bearing fitted

Impellers



The kinetic energy of the fluid flowing through the impeller is converted to pressure energy by the shape of the volute casing. For high pressure pumps such as boiler feed pumps a diffuser ring is fitted in the casing which converts a greater portion of the pressure energy allowing greater pressures to be generated.

A scroll type inducer may be fitted to the inlet which improves the efficiency of unit and allows the pump to operate with low suction pressures.

Wear rings

For efficient operation it is important to ensure that leakage from the high to low pressure side is kept to a minimum. This is achieved by the use of wearing rings. Traditionally these are fitted to the casing,to increase the longevity of the impeller wear ring tyres may be fitted.

The clearance given for wear rings is often a source of contention especially when dealing with on-ship made rings. A clearance of 1/1000 of the diameter of the bore is often quoted although this may be very difficult to achieve in practice.

Axial force

Without careful design an axial force is created by the action of the impeller. This is due to the low pressure acting on the suction eye whilst the rest of the impeller is subjected to discharge pressure.

One solution is shown above where radial blades are cast into the back (stuffing box side) of the impeller. These blades are commonly called pump-out vanes, and are meant to increase the centrifugal force of the fluid trapped behind the impeller. This causes the fluid to be "thrown" outwards, reducing the pressure behind the impeller for the same reason that the impeller causes a reduction of pressure at the suction eye.

Another method which may be found in conjunction with the pump-out vanes are the balancing holes. These are holes drilled near the center of the impeller, connecting the space in the back of the impeller with the suction eye. This reliefs the pressure behind the impeller by allowing the high pressure fluid trapped there to flow to the low pressure region at the suction eye. In order for this to be effective, there must be a tight clearance between the impeller and the casing to reduce the flow of fluid into the back of the impeller.

Alternately dual back to back impellers may be fitted in common with a double casing

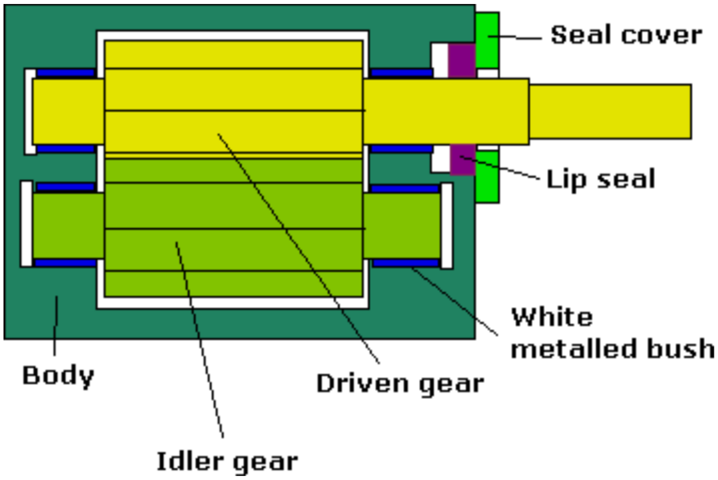
Materials suitable for general service	
Shaft	Stainless steel
Impeller	Aluminium bronze
Casing	Bronze or cast iron
Wear ring	Aluminium bronze or brass

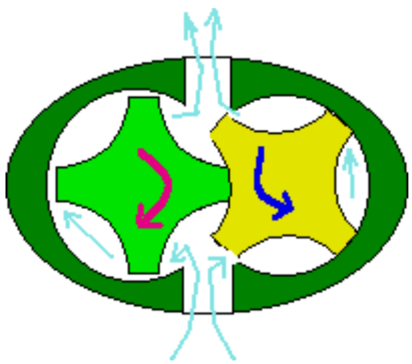
Positive Displacement

This class of pump differs from the centrifugal class by several important factors

- Generally self priming whereas centrifugal generally require a priming means such as a belt driven priming pump
- Require the fitting of a **safety valve** to limit maximum pressure- this pump cannot be started against a shut discharge valve.
  Centrifugal pumps may be started against a shut or partially shut discharge valve. This is especially true for larger pumps where the shutting of the discharge reduces starting and running load.
  It should be noted that the partially shutting of the suction valve on both types of pumps leads to damaging cavitation.
- Positive displacement pumps can handle high differential pressures
- More suited to low to medium flow rates
- May operate with higher viscosity fluids then centrifugal types

Gear

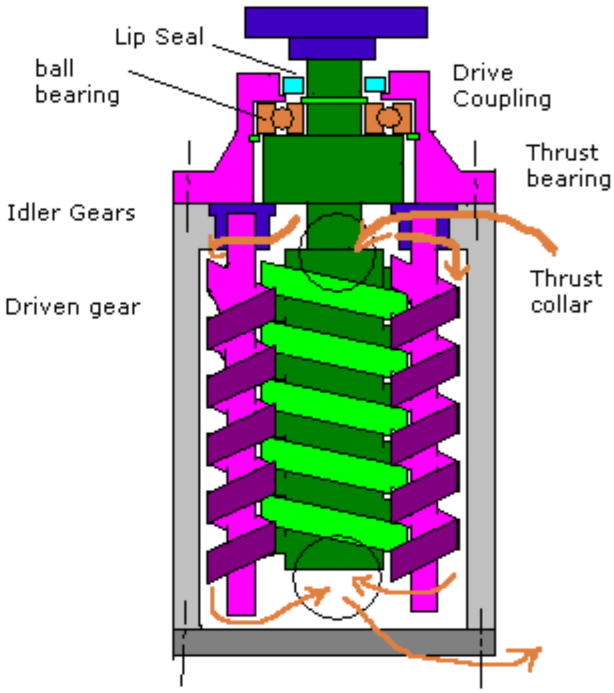


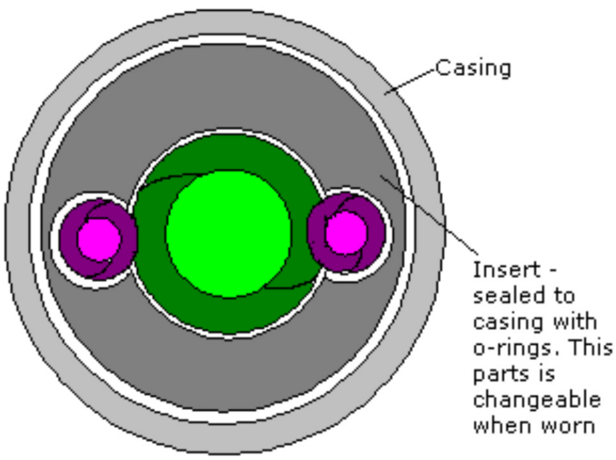


The pump shown above is of very common design. It is used for pumping many types of liquid and gas and is capable of delivering at very high pressures. This makes it suitable for hydraulic supply.

The tooth profile is similar involute gear teeth for liquid pumps. For gas pumps special profiling with very fine tolerances is employed.

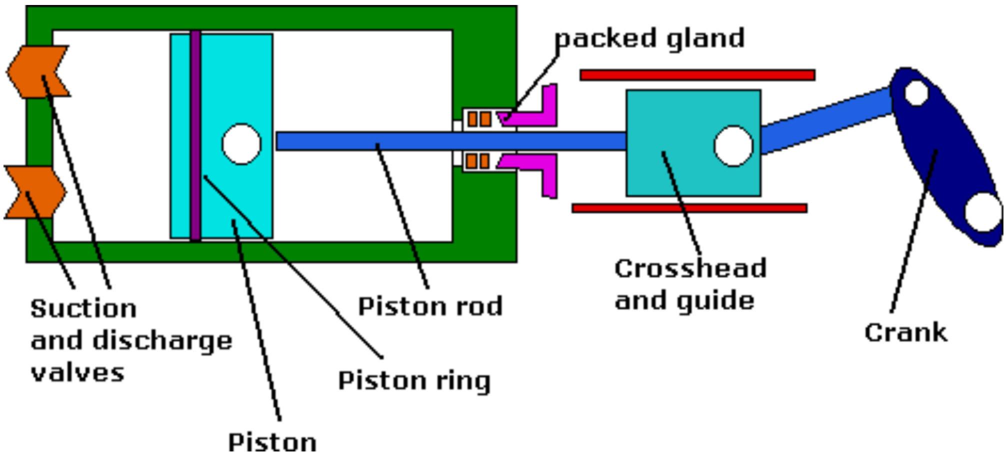
Scroll





These pumps are seen in many applications and have a higher capacity then double row type. Fluid enters the pump and is screwed by the idler shafts along the outer edge to the discharge port. Axial thrust of the idlers is absorbed by the integral thrust collar of the driven shaft. The axial thrust of the driven shaft is absorbed by the thrust bearing.
The scroll sit in a replaceable insert which is sealed to the outer casing by o-rings.

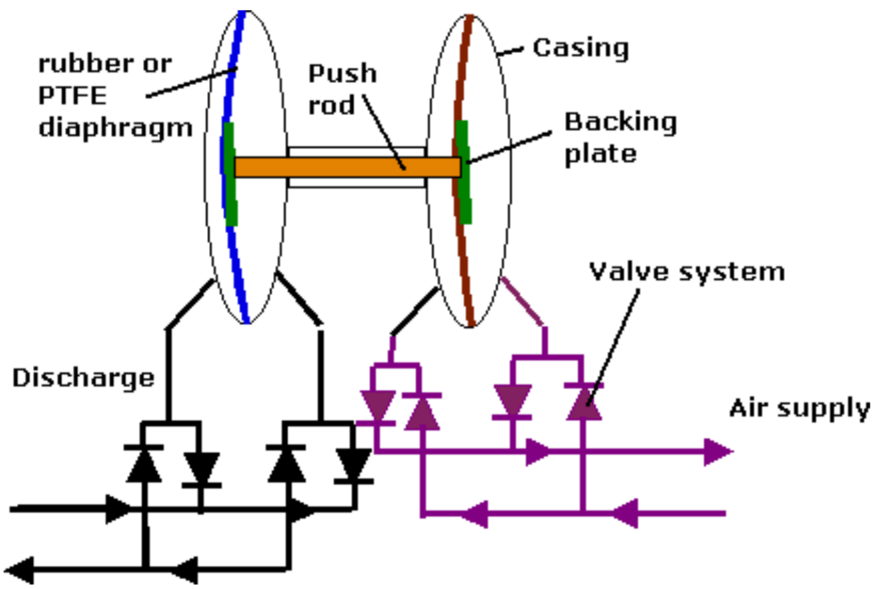
Piston



This type of pump is in common use as a bilge pump or tank stripping pump. For older vessels steam driven varieties served in almost all systems.

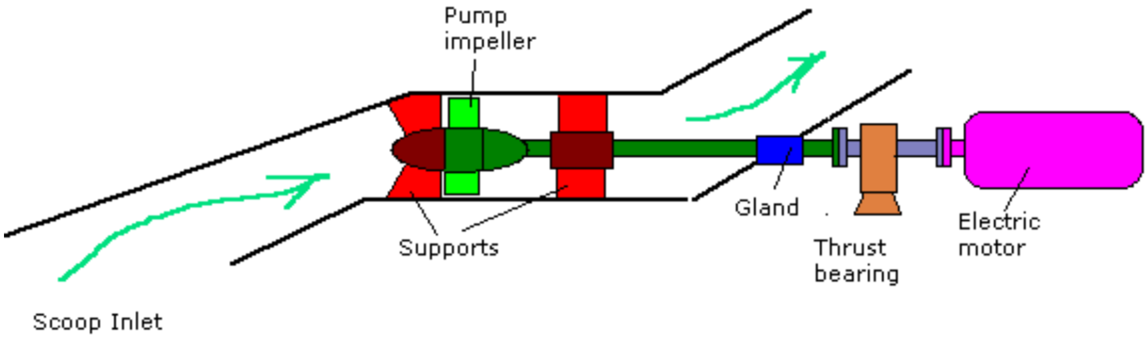
The design is simple, robust and reliable. Materials are very much dependent on the usage but bronze is common for larger parts and stainless steel for piston rods

There are many other forms of positive displacement pump such as rotary vane (often found in use as cooling water pumps, Scroll or Screw pumps were the fluid passes axially along the shaft and Diaphragm Pumps (commonly used as portable salvage pumps)



This air supply valve assembly normally takes the form of a shuttle valve.

Axial Flow



These tend to fit somewhere between postive displacement and centrifugal. They tend to be of the very large capacity type and are oftern seen in use for supply of cooling water for steam ship condensers. This is particularly true where 'scoops' are employed as the axial flow pump offers very little resistance to flow when idling.

During operation cosiderable end trust occurs and a tilting pad thrust bearing is employed. Guide vanes smooth flow into and out of the impeller.

Inducers

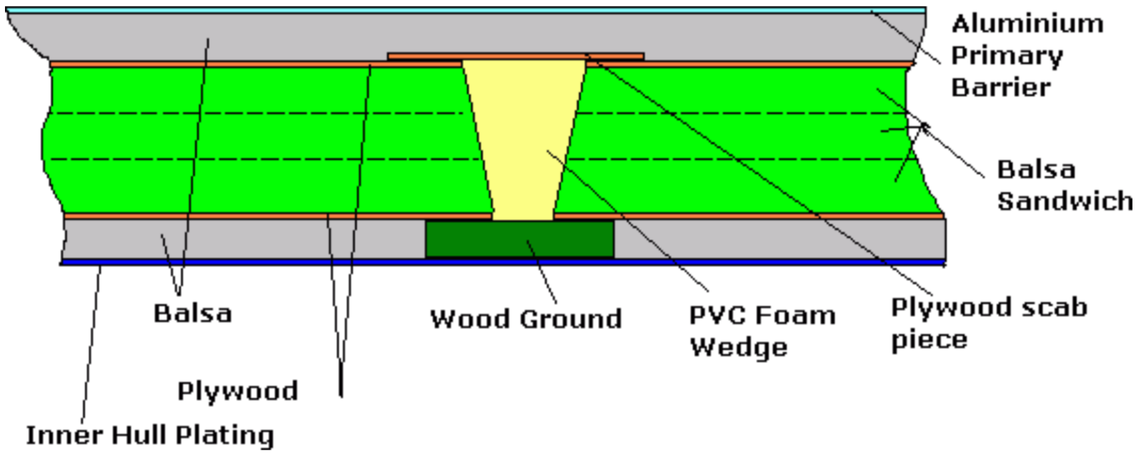
A type of axial flow pump is sometimes attached to the suction side of a centrifugal pump. This is called and inducer and is used where the suction heads are very low or where suction occurs close to the vaporiation pressure of the fluid being pump. Typical examples are the main condenser extraction pumps on steam ships and cargo pumps on LNG and LPG carriers

Cavitation

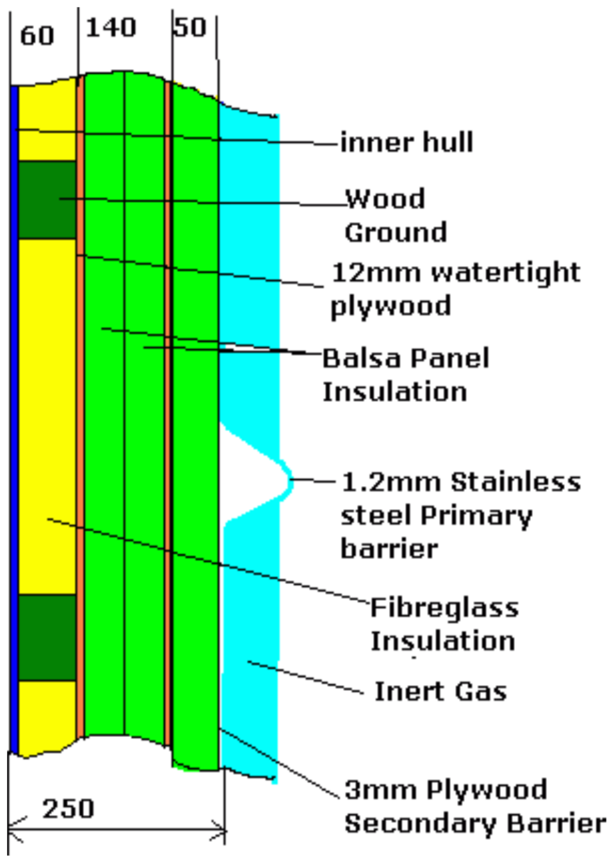
Disturbances in the water flow causes rapid localised pressure variations. This can lead to instantaneous vaporisation and bubble formation. When these bubbles collapse there is a rapid in rush of water. When this occurs near to a surface this slug of water can strike at speeds of up to 500m/s and lead to destructive erosion and removal of protective oixides thereby increaseing rates of corrosion

LNG Containment Designs

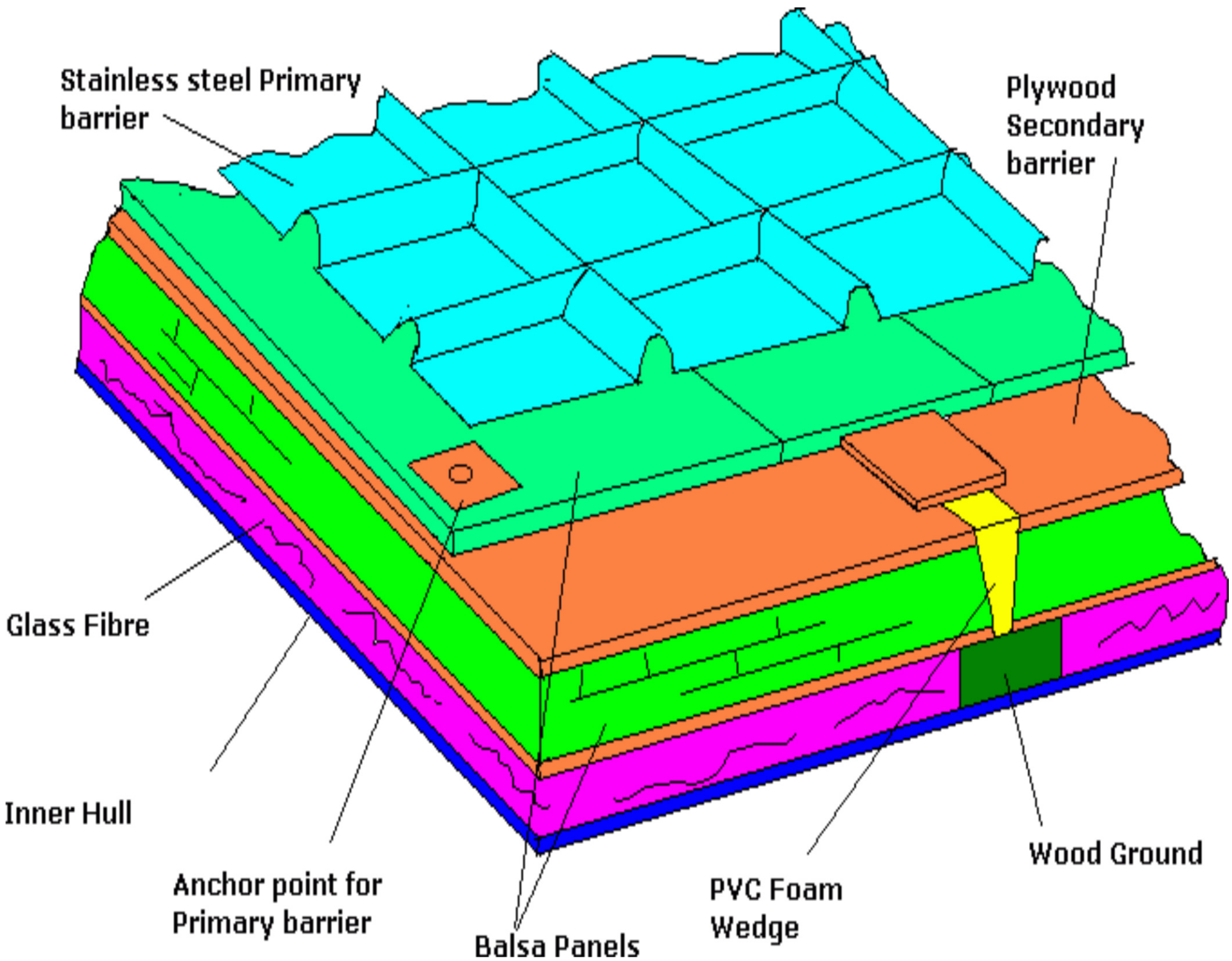
CONCH1



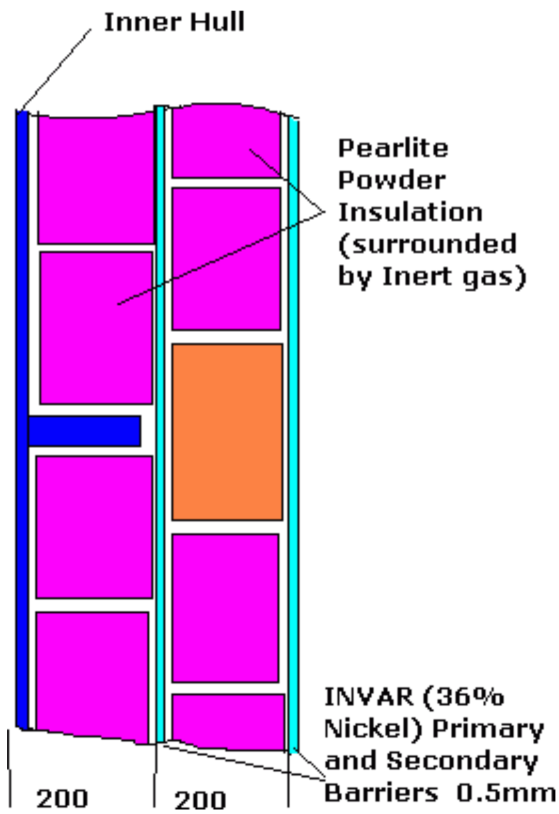
Technigaz 1



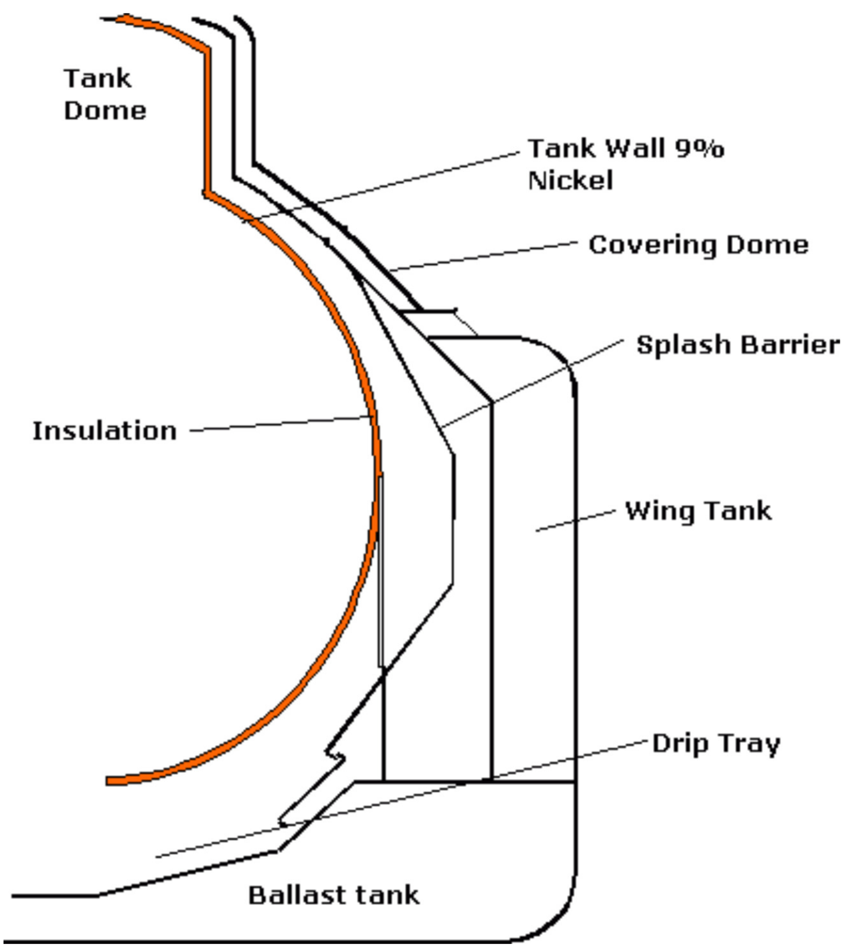
Technigaz II



Gaz Transport II



Moss Rosenberg I



Carriage of LNG Cargos

This deals mainly with the carriage of LNG cargoes although some reference is given to other types,

Cycle of Operations

Typically, the sequence starting from drydock and containing one loaded voyage and then returning to drydock would be;

- Inerting
- Drying
- Cooldown
- Loading
- Loaded passage
- Discharge
- Warm up
- Inerting
- Gas freeing

This pattern differs from normal trading in that once cooldown has been achieved it is normal to maintain tank temperatures as low as practical by keeping a 'heel' or small quantity of liquid in the tank. This quantity is normally initially purchased by the ship owner or charterer.

Inerting

This involves the reduction of oxygen in the atmosphere within the tank sufficiently to prevent combustion.

There are two main methods of inerting;

- Displacement of atmosphere with nitrogen
- Displacement of atmosphere with inert gas supled from inert gas generator

Nitrogen
Requires supply from a shore facility of tender vessel. Liquid nitrogen is passed first through a vaporizer then through a heater.
The gas is passed through the liquid header to the bottom of the tanks. The upward flow exits through the vapour line to atmosphere.

The vaporizer takes the form of a steam heated matrix heater. a gas detector may be fitted to the condensate drains from this heater to check for leaks. Alternately manual measurements may be taken on a routine basis.

The nitrogen is maintained at a temperature 10 to 15'C below the temperature of the atmosphere in the tank. This gives good stratification and reduces mixing allowing for a much more efficient inerting process

The tank pressure is adjusted by control of the liquid header isolating valves to the tank.

Inert gas
May be from boiler uptake, from onboard IG generator or from tender vessel. The former is the least favorable due to the poor quality of the gas.

Drying

The gas used for inerting contains moisture. Large drying plants may be used to dry this gas, alternately, warmed methane may be used.

The methane is pumped from shore facility to the vessels liquid header then via the bypass line to the spray line and on to the vaporizer.
The gas is heated and sent to the tanks via the vapour header.

The gas in the tanks is drawn out via the liquid loading lie by the compressors and return to shore via the vapour return or to the for'd mast riser. The latter is frowned upon due to atmospheric and safety concerns.

The limit for the temperature of the gas is governed by the tank insulation.

The dew point of the exit gas is checked and drying stopped when desired dew point and 100% CH_4 is achieved.

Cooldown

The cooldown process is required to ensure that excessive boil off, thus over pressurisation, is prevented during cargo loading. This procedure is performed before each loading operation.

Cooldown is achieved by supplying liquid CH_4 to the spray headers. The spray enters the tank via distribution grids and may be directed to various levels as required. Boil off vapour is passes to the high duty compressors back to shore via the vapour line.

Boil off occurs during loading of LPG cargos, whether this is passed to shore via the vapour line or must be liquified on board is very much dependent on the shore facility. Generally shore facilities much prefer it to be done on board ship therefore the liquifaction plant must be maintained in top condition.

Heat must be extracted from both the primary barrier and the insulation. Cooldown rates of 30 - 40'c per hour correspond to an overall rate of 8-10'C including the insulation and secondary barrier.

When a liquid level is detected in the bottom of the tank then the cooldown process is considered to be complete. Primary insulation and secondary barrier temperatures should be measured at -80 to -100'C

Tank pressure is maintained by use of the compressors and by varying the flow of liquid to the spray headers.

Cooling the tanks will lead to a drop in pressure in the inter barrier space. Nitrogen should be introduced as required. Test for methane in the barrier gas should be carried out during this procedure to ensure no leakage.

Loading

Before commencing loading the flow from shore used for cooldown is initially reduced.

The liquid loading line to each tank is opened, the spray shut down. As the liquid vaporisers in the header it is drawn out via the vapor line and return to shore.

Depending of the lie of the liquid in the header the tanks are isolated in sequence to ensure each loading line is cooled.

Loading takes place using normal safe working practices. That is,slow start building up gradually to full rate. Tank pressures are monitored, the capacity of the compressors to return vapour to shore governs the maximum load rate.

Ballasting takes place with loading. Great care must be taken with some designs of LNG carriers due to the 'L' shape of the ballast tank.The vertical section (sometime called the 'pipe') empties vary rapidly and has a large effect on the metacentric height.

Emergency Shut Down Systems-A formal of shut down is agreed with shore side facility sometimes taking the form of a remote stop placed on the vessel. Due to the potential damage caused by shutting a valve against a flow of liquid the shut down this takes the form of programmed sequence of events with timed parameters.

On completion of loading, the high duty compressors are stopped and the vapour line is disconnected. Once the tank pressure starts to rise it will be necessary to commence gas burning in the boilers, starting the low duty compressor and bringing into the use the steam dump system as required until the vessel sails.

Loaded passage

During the loaded passage a quantity of the Cargo will boil off removing heat that has leached past the insulation. This gas is used in the propulsion plant as fuel. Although progress has been made with fitting gas burning gear to large diesel plants , the vast majority of LNG tankers are steam powered.

The boil off gas is fed to the propulsion plant by a low duty compressor via a heater. The gas pipe entering the engineroom is surrounded by a gas tight enclosure whose atmosphere is monitored for hydrocarbons. The spaces around the burner platform are positively ventilated and again monitored for hydrocarbons.

The gas flame in the boiler is extremely clean reducing sootblowing from a daily to a fortnightly requirement. However, the flame is clear blue requiring either a special type of flame detector or for a small quantity of fuel to be burnt which can be seen by normal flame detectors.

The gas burner normally takes the form of a simple open ended pipe.

Cold spot inspection It is possible to check the integrity of the insulation during the loaded passage by entering the cargo and cofferdam spaces and look for cold spots were ice has formed. The ice is a very good thermal insulator and this causes the metal underneath to cool to levels which may allow damage to occur.
For severe cold spots then warming of the metal is required. This can take the form of wetting the surface or steam heating of the ballast.

Interbarrier spaces The inert gas in the interbarrier space is tested for hydrocarbons and moisture. The pressure in the space is slightly below the head pressure in the tank in membrane systems.

A test for membrane tanks during drydocking is to apply a small vacuum to the interbarrier space and then monitoring it over a period thereby checking for leaks.

On completion nitrogen is reintroduced slowly. I know one case were this gas was allowed to build up to an extent that the membrane 'blew' off *the wall at huge cost. The C/E, a recipient of an MBE became known as the* **M***embrane* **B***usting* **E***ngineer*

Inducing Boil off -When the LNG cargo is first loaded generally it is supercooled. On sailing very little boil off is experienced for a period which may extend to a few days. It is in the operators, though obviously not the charters, interest to bring on the amount of boil off as this will drastically reduce fuel oil consumption. The author has sailed on liner trade vessels which are capable of operating from discharge to next discharge only burning fuel oil when gas burning is ceased during cargo operations.

There are practices, although not good ones, available to the Marine Engineer to induce the boil off of the gasses. Two of which are;
On first sailing the ships is run at flat out creating hull vibrations. This shakes the cargo and frees gas bubbles trapped within.
Reducing the LP compressor suction pressure below the minimum set by the charterer. This can have the effect of creating a stable supercooled layer on the cargo. Therefore it may be necessary to give the cargo a little 'shake'.

There are other methods but these two are the most common and simplest to carry out, the author can vouch for there efficacy having seen them in action many times. It should be noted that inducing boil off is severely frowned upon by charter parties.

Entering Port

Before entering ports it will be necessary to resume fuel oil burning. In addition the propulsive load will be reduced. This may cause tank pressures to begin to rise due to insufficient boil off gas being burnt. Steam vessels are fitted with large steam dump facilities which allow steam to be dumped to a condenser increasing boiler load.

It should be noted that the majority of countries and/or port authorities will not allow venting with port limits for obvious reasons.

Discharge

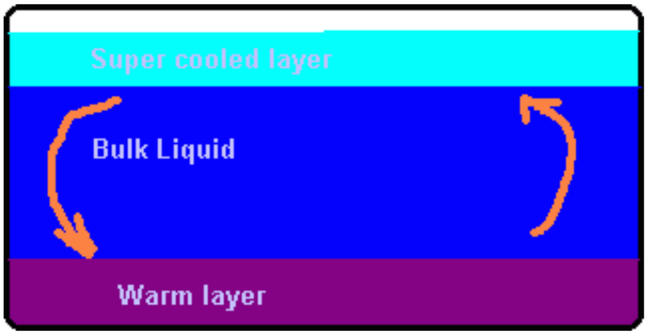
The Liquid header is cooled down before arrival whilst still gas burning. To do this a spray pump is started filling the spray line then the liquid header via the cross-over. Boil off and excess liquid flow back to the tank via the branch pipe.

Cargo Pumps-Before starting the cargo pumps and electrical cables are megger tested.

The pumps are started sequentially against shut discharge valve. After starting the valves are slowly opened to prevent surging.

Rollover

Rollover is a major concern for shore based installations. The constant motion of a vessel plus the relatively high cargo turnover rate means that this is less of a problem.



The upper layer of the cargo remain cool due to evaporation. The lower layers gradually warm by heat transfer.

Rollover may occur withe lighter more bouyant lower layer rapidly moving to the top replacing the heavier cooler layer whcih falls to the bottom. This warm layer is now exposed to lower pressure and rapid boiling occurs which can lead to over pressurisation and extensive damage. This a very serious occurrence.

When loading mixed LPG cargo the warmer cargo should be loaded first which reduces the amount of evaporation.

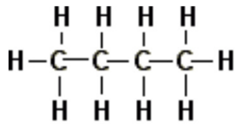
Liquified Gas Cargoes

The following are petroleum and Chemical products which are gases at normal temperatures and pressures but carried as a liquid by means of Refrigeration, pressurisation or a combination of both.

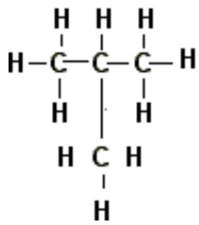
Saturated Hydrocarbons(Alkanes)- stable and unreactive, tend to come in unpure state with some degree of contamination			
Methane	CH_4	-161.6'C	LNG
Ethane	C_2H_6	-88.6'C	
Propane	C_3H_8	-42'C	LPG
Butane	C_4H_{10}	-0.5'C	
Unsaturated Hydrocarbons-reactive and unstable. Polymerise (solidify) when come into contact with air			
Ethylene	C_2H_2	-103.7'C	
Propylene	C_3H_6	-47.7'C	
Butylene	C_4H_8	-6.9'C	
Butadiene	C_4H_6	-4.5'C	Highly reactive, a chemical inhibitor must be added to allow it to be transferred
Chemical Cargoes- very reactive,made very pure			
Ammonia	NH_3	-33.4'C	COnsidered to be inflammable although it will burn
VInyl Chloride Monomer VCM)	C_2H_3Cl	-13.8'C	This is the basis of PVC
Ethylene Oxide	C_2H_4O	+10.7'C	Extremely Flammable

Alkanes

These are saturated hydrocarbons with the formula C_nH_{2n+2}. All above are gasses at normal temperatures and pressures, Pentane, Hexane etc are liquid under normal conditions. Butane and above may occur as isomers



Butane



Is Butane but by convention is now called 2-Methyl-Propane or iso-butane

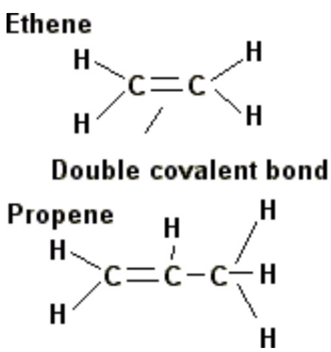
(look for the longest chain then count the number of Methane [methyl] like pairs

Odorisers

Ethyl-Mercapton C_2H_5SH is one of the additives added to normally odourless methane and others before it is distributed to make detection easier

Alkenes

These are unsaturated hydrocarbons with the formula C_nH_{2n}. There is no equivalvent to methane.

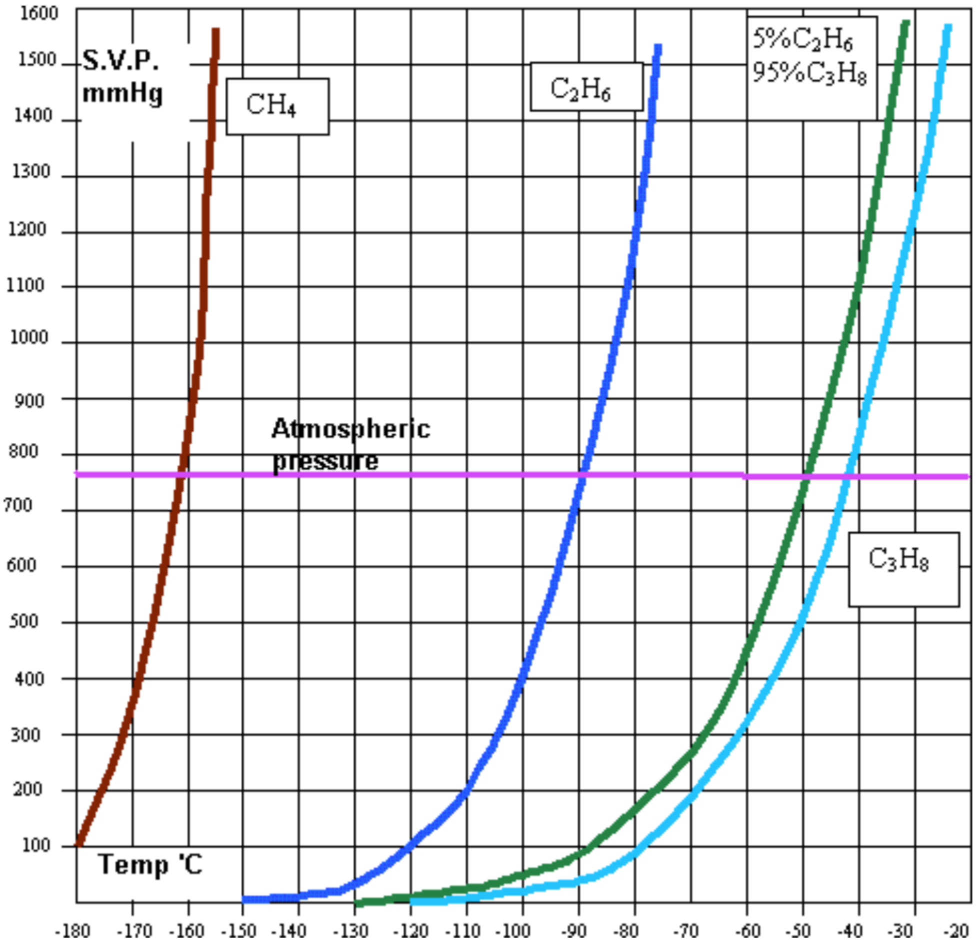


These are joined by the double covalent bond to form Polyethylene or Polythene. They are man made

Inhibitors

alkenes can react when you don't want them to . They polymerise to form one single long molecule. Inhibitors are put in to prevent the double bond acting

Gas Vapours



If a liquid is placed in a vacuated container,then high energy molecules will leave the liquid. These molecules, traveling at high speed (600- 700 km/h) will strike the surfaces of the container and exert a measurable pressure.

At some point the amount of molecules leaving the liquid should exactly equal the number returning. This is called the vapour pressure. If the liquid is heated the number of molecules with sufficient energy to break free is increased and hence a greater presure is exerted.

it can be seen that very little temperature rise is required to increase the pressure. As vapour and liquid are carried, the cargo must be carried on the vapour pressure line

LNG reliquifaction

Traditionally, LNG carriers have used the boil off from cargo as fuel for the propulsion. This led to the use of steam plant as the preferred method as the combustion of this gas is simpler. In addition the steam plant gives the option to safely deal wih excess boil off of gas during pasage or arrival in port without the need to resort to venting.

The use of duel fuel burning diesel engines is becoming more in favour thus requiring alternative methods to deal with the excess boil off.

One method is reliquifaction commonlu seen in LPG shps but previously not sen in LNG due to the very low saturation temperatures of LNG

Reliquifaction process

This generally takes the form of seperate reliquifaction and refrigeration units. The system uses Nitrogen as the refrigerant in the reverse Brayton cycle; a version of the cascae system in which several stages (normally 4) operate in series with the LNG. The final stage is a turbo expander in which the energy of the Nitrogen is used to power the expander stage. Thus with the removal of energy from the nitrogen in the form of work the temperature is low enough to liquify the LNG.

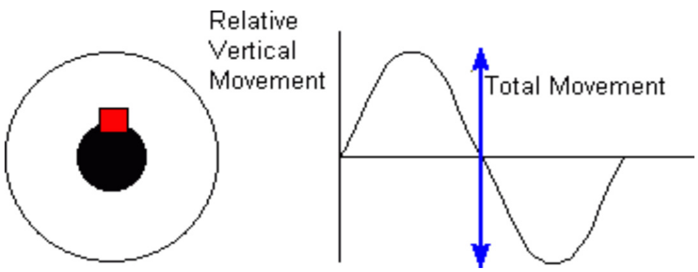
The entire asembly my be either totally enclosed in insulation with repairs only to be carried out at predetermined times. Or it may be enclosed in an insulated work house

It should be noted that hgh levels of nitrogen in the cargo can have a serious effect on the viability of reliquifaction

The power absorbed by this unit is high thus ony recent increases in cargo prices has made it economically viable. A high voltage distribution system is required

Vibration Analysis

Description of vibration



Shown in the diagram is the representation of a shaft with an out of balance in the form of a key. The graph plots the relative vertical displacement of a point on the disc.

The total vertical movement is called the **Peak to Peak Displacement** of the vibration. This is an indication of the amount of lateral movement of the machine and is a good indication of the amount of out of balance in a machine when the value is compared to a standard for that machine. This parameter is often used when balancing.

The **Vibration Velocity** is the speed of movement of this point, being highest as the point passes through its at rest position. It gives a good guide to the amount of energy being generated by the vibrating object. This energy usually results in wear and eventual failure. The amount of energy is proportional to the square of the velocity of vibration. Velocity, being a good indication of the amount of wear taking place in a machine is a used exclusively in monitoring systems.

For analysis purposes the r.m.s value is used.

For very low speed machines where the velocity is low the displacement may be used instead.

The **Vibration Frequency** is the time taken to complete one cycle. The shaft above is said to have a **fundamental** frequency equal to the shaft rotational velocity i.e.

R.P.M / 60 = Fundamental frequency = 1 / Periodic time

There is a formula for working out the frequency that a particular vibration is occurring from knowing only the displacement and the velocity.

Frequency = 0.45 x Vibration Velocity (mils/sec r.m.s)/ Vibration Displacement (mils peak to peak)

The equation is true only when the majority of the vibration occurs at one frequency. In reality machines vibrate in a much more complex way with vibration occurring at several frequencies. By analysis of the frequency at which each of the vibrations are occurring it is possible to ascertain whether they are being generated from with the or externally. By further analysis it is possible to locate the source of vibration within complex machinery.

Vibration phase can be defined as the angular relationship between the positions of maximum vibration and some fixed point on a rotating shaft at any instant.

It is useful during balancing.

Vibration measurement units

There are three different ways of expressing vibration measurements

1. *Peak to Peak*
2. *Half Peak (or Peak)*
3. *Root Mean Square*

they are related as follows

R.M.S. =Peak to Peak/2.83

Half Peak Values = Peak to Peak/2

Units may be in mils (1x 10^{-3} inches) or microns (1x 10^{-3} millimetres) and they may be converted as follows 1 mil =25.4 microns

Causes of vibration

Typical causes could be

- Out of balance
- Misalignment
- Damaged or worn bearings
- Damaged or worn teeth
- Resonance, loose components
- Bending or eccentricity
- Electromagnetic effects
- Unequal thermal effects
- Aerodynamic forces
- Hydraulic forces
- Bad belt drives
- Oil whirl
- Reciprocating forces

The great majority of the above create a vibration at a multiple of the fundamental. The Vibrations source identification table allows identification of the cause.

Sequence of analysis

1. *Assemble equipment*
2. *record operational parameters of machine- lubricating oil temperature, load, history of mal operation, work done*
3. *Run machine until it reaches normal operating temperature*
4. *Take readings at designated points. Analyse frequency of any high readings*
5. *If possible measure vibration at different speeds*
6. *Note changes in temperature, load etc. during measurement period*
7. *If possible double check readings*
8. *Determine source of vibration using identification table*
9. *Remedy fault*

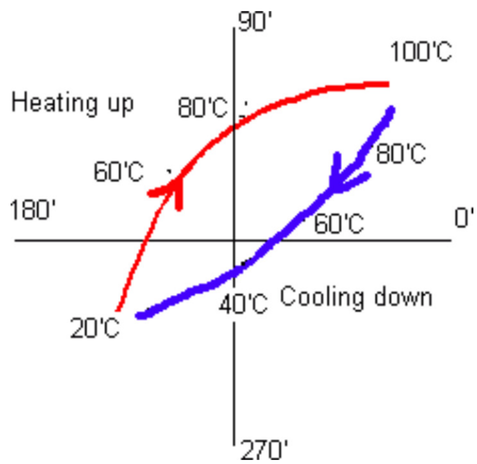
Additional information can be gained by measuring vibration of the shaft itself. This may be done using a Teflon tipped pick up or a piece of hardwood.

Causes of vibration other than initial out of balance

- Non-periodic erratic vibrations can often be sourced to damaged or worn **anti friction bearings**. Where displacement of inner and outer race occurs then axial vibration at fundamental can occur. If the bearing is not concentric to the shaft then a vibration occurs as an out of balance
- Where a **moving component on a rotating** member occurs an erratic fundamental frequency occurs. Balancing will only give temporary relief and indeed may lead to a worsening of the situation
- **Synchronous oil whirl** occurs when the oil whirl in a bearing is at the same frequency as the fundamental. Analysis over a period will find a steadily worsening vibration which will begin to reduce

if the speed of the machine is dropped, and then increase again when brought back to original speed. In this case the bearing clearance may be too large

- **Half speed oil whirl** is indicated by a superimposed wave form at half fundamental on the total wave form. Varying oil temperature and pressures normally rectify but it may be necessary to increase bearing load by reducing bearing surface
- Shafts may sometimes bend due to **thermal asymmetry**. Vibration will vary with temperature. If unequal thermal effects are present then they may be determined by taking displacement and phase measurements during a set of controlled 'heating up' and 'cooling down' periods. If they are plotted on an Argand diagram they will appear as so.

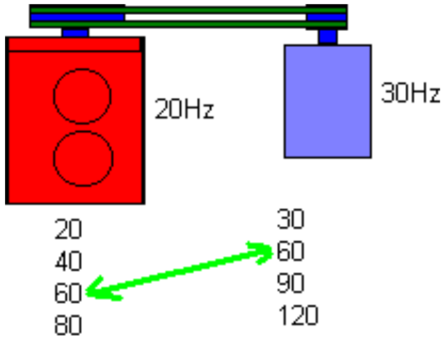


Thermal effects may occur due to the following reasons.

1. *Non-homogenous forging of the rotor causing uneven bi-metallic expansion*
2. *Uneven machining of the rotor forging*
3. *Parts of the rotating element is restrained from expansion*
4. *Friction effects due to parts rubbing*
5. *Uneven ventilation*

Compromise or thermal balancing may be used to help alleviate the problem but these should only be carried out by specialised personnel

- **Double frequency vibration** can have many different sources such as
  a. **Non-isotropic characteristics** of a rotor or shaft e.g. grooves, key ways, slots etc. causing the shaft to have two perpendicular stiffness' resulting in two cyclic deflections for one complete revolution. This can only be remedied by cutting two slots to even the stiffness.
  b. **Electromagnetic** effects most significant in the laminations. Only present when energised, increasing pressure on laminations can cure
  c. Machines with **separate bearing housings which are not aligned** can have vibration at 1,2 or 3 times fundamental. Indicated by large axial vibration component at pedestal.
  d. **Bad belt drives** give 1,2,3,4 harmonics which may not remain constant. Where the belt drive gives a speed change between driver and driven machines vibration can occur at a frequency corresponding to some multiple of both fundamental frequencies.



Fundamentals

   e. Reciprocating parts can give multiple fundamental vibrations, only by redesign can this be cured, Diesel engine can vibrate at 2 x fundamental known as the forcing frequency caused y the action of the crank moving the piston rod. The travel of the piston is not entirely smooth and a slowing and speeding up occurs about the middle of the stroke and is governed by the ratio of crank throw to piston rod length. It may be counteracted by the use of balancers.
   f. **Looseness**
- Three per revolution vibrations
   a. Sleeve bearing worn in a triangular fashion-unusual
   b. Poor belt drives
   c. Higher frequency vibrations can be caused by
      a. Badly mating or worn gears giving very high frequencies
      b. Aerodynamic and hydraulic forces will produce high frequency vibrations. If a fan is the source then the frequency will be at blade number x fundamental and may be caused by
         i. *Unequal pitch of blades giving unequal axial vibration*
         ii. *Blade vibrations as the blades operate at a resonant frequency*
         iii. *Pipework and ducting can cause gas or liquid flows to produce a vibration at resonance*
         iv. *Cavitation or oil pockets may produce high frequency resonant vibrations*
         v. *Wheels on turbine spindles can cause vibration*
   d. Odd harmonics can sometimes be caused by **worn components**. Usually at fundamental the waveform may be erratic and irregular i.e. non- sinusoidal

Determination of rolling element bearing wear using vibration acceleration as the parameter

The condition of rolling element bearings can be accurately determined by taking measurements of acceleration in terms of 'g' peak.

Irregularities in newly fitted bearings lead to dynamic load and vibration detectable as accelerations in a vibration monitor. It is the magnitude and frequency span that determines the condition of the bearing. Accelerations due to a failing bearing will fall between 1 - 5kHz.

When judging the condition of a bearing it is important to take into account the speed at which it is running. Acceleration is proportional to the square of the rotational frequency. Therefore a slow running machine would give accelerations lower then a higher speed running machine for the same bearing condition.

The following table can be used as a rough guide.

State of rolling element bearing	Level of acceleration 'g' peak (in range 1 - 5 kHz)
Satisfactory	1

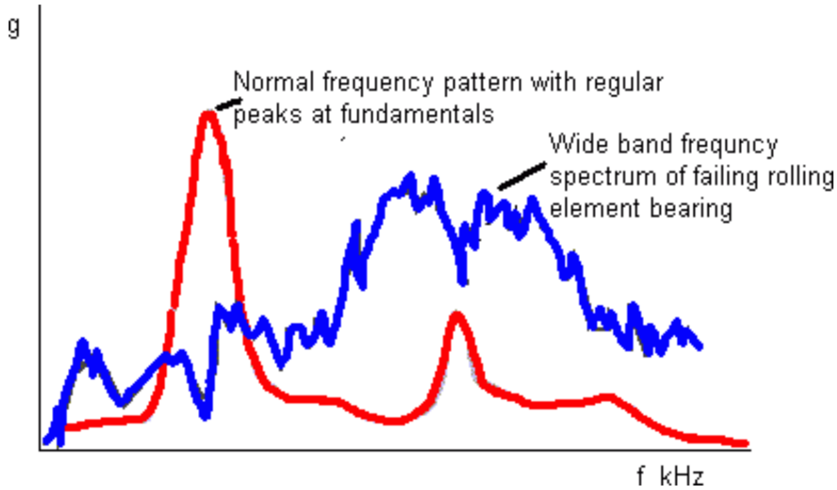
Bearing failing	2 -5
Renew bearing urgently	5+

This does not apply to journal, plain or sleeve bearings

Care must be taken with some the following machinery as they can naturally generate vibration in the 1 - 5 kHz range

- Gearboxes (i.e. gear teeth frequencies)
- High speed screw compressors - lobe passing frequency
- High speed turbines - blade passing frequency.
- Cavitation in pumps
- etc

Pattern of frequency of failing rolling element bearing.



If the peak appears to be isolated then other possible sources such as gear teeth should be investigated.
If the vibration occurs over a broad band then it is probably due to bearing failure. Cavitation can be determined as the source by checking the locality of the source. Whether bearing housing or pump casing. Also the discharge valve may be partially closed which should reduce the cavitation and the vibration.

Method for assessing condition of rolling element bearing.

1. *Measure radial acceleration at each bearing in vertical and horizontal directions and record the lowest value*
2. *evaluate condition of bearing against set levels*
3. *If over 1 (minimum that can be reliably analysed) then use harmonic analyser to check frequency range*
4. *put harmonic analyser in 'fine' mode and check spread of vibration, if over 500 Hz the probably bearing failure*
5. *Repeat as check '4' on velocity mode*

The effect of main engine revolutions on vibration readings
Generally the increase in vibration will be small, their are some cases however were a noticeable rise occurs. This may be due to a flexible bed plate or harmonics.

Effect of flexible and semi flexible bedplates on vibration

Prop revs/min	**Vibration in mils/s r.m.s**

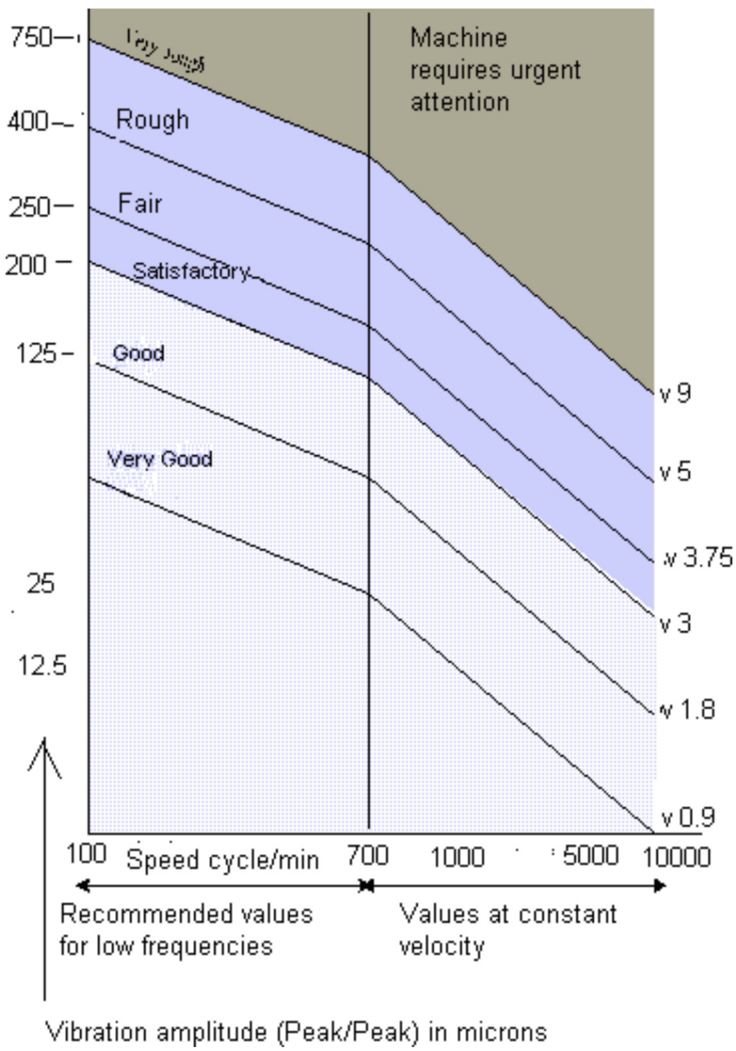
	Machine on semi-flexible bed plate	Machine on very flexible bed plate
60	10	20
70	20	40
80	30	60
90	42	46
100	55	112
110	70	143
120	90	180

If the vibration from a machine only is required then readings should be take below 50 r.p.m or better at anchor. Readings may be taken under full sea going conditions as long as they are continues to do so. In many circumstances it is the trend over a period of time that is the important factor rather than a set of readings at any one instant. In this way the warning levels set for a machine may be safely increased.

Vel [mils/s R.M.S]			
720			
440		Unacceptable	
280			
180		Acceptable	
112		Satisfactory	
72			
50		Good	
28			

All mineral oil separators must be within the good limit

Chart of vibration displacement against frequency for normal machines


750
400
250
200
125
25
12.5
Very rough
Rough
Fair
Satisfactory
Good
Very Good
Machine
requires urgent
attention
v 9
v 5
v 3.75
v 3
v 1.8
v 0.9
100
Speed cycle/min
700
1000
5000
10000
Recommended values
for low frequencies
Values at constant
velocity
Vibration amplitude (Peak/Peak) in microns

Balancing using a vibration analyser

The three point method of balancing.

1. *Measure vibration and record (use analyser to ensure only fundamental frequency is used*
2. *Drill three holes in a suitable place, say in the motor fan. These should be as close to 120o as possible. Each hole should be labelled 1,2 or 3 corresponding to three angles of the polar diagram. Place the calibration weight, which should be small especially for high speed motors, in the three positions and take vibration readings from the same point*
3. *Plot the points on the polar diagram. Looking at the highest reading the scale of the polar diagram can then be determined.*
4. *Join the first point to the second point and bisect this line. Join the second point to the third point and bisect the line, etc.*
5. *From the points of bisection of the lines, draw perpendiculars so that they intersect.*
6. *Using the point of intersection as the centre, draw a circle to cut each of the plotted measured points. This circle indicates the level of vibration that can be made by moving the weight around the circle*
7. *The point at which the circumference of the circle is nearest to the centre of the polar diagram is the point at which the balance weight needs to be fixed*
8. *The amount of weight (ASSUMING THAT THE TRIAL WEIGHT WAS TOO SMALL) is given by;*

   Trial Weight x Initial Vibration Level / (Initial Vibration Level -Vibration Level At Best Position On Circle)

9. *Repeat process if required.*

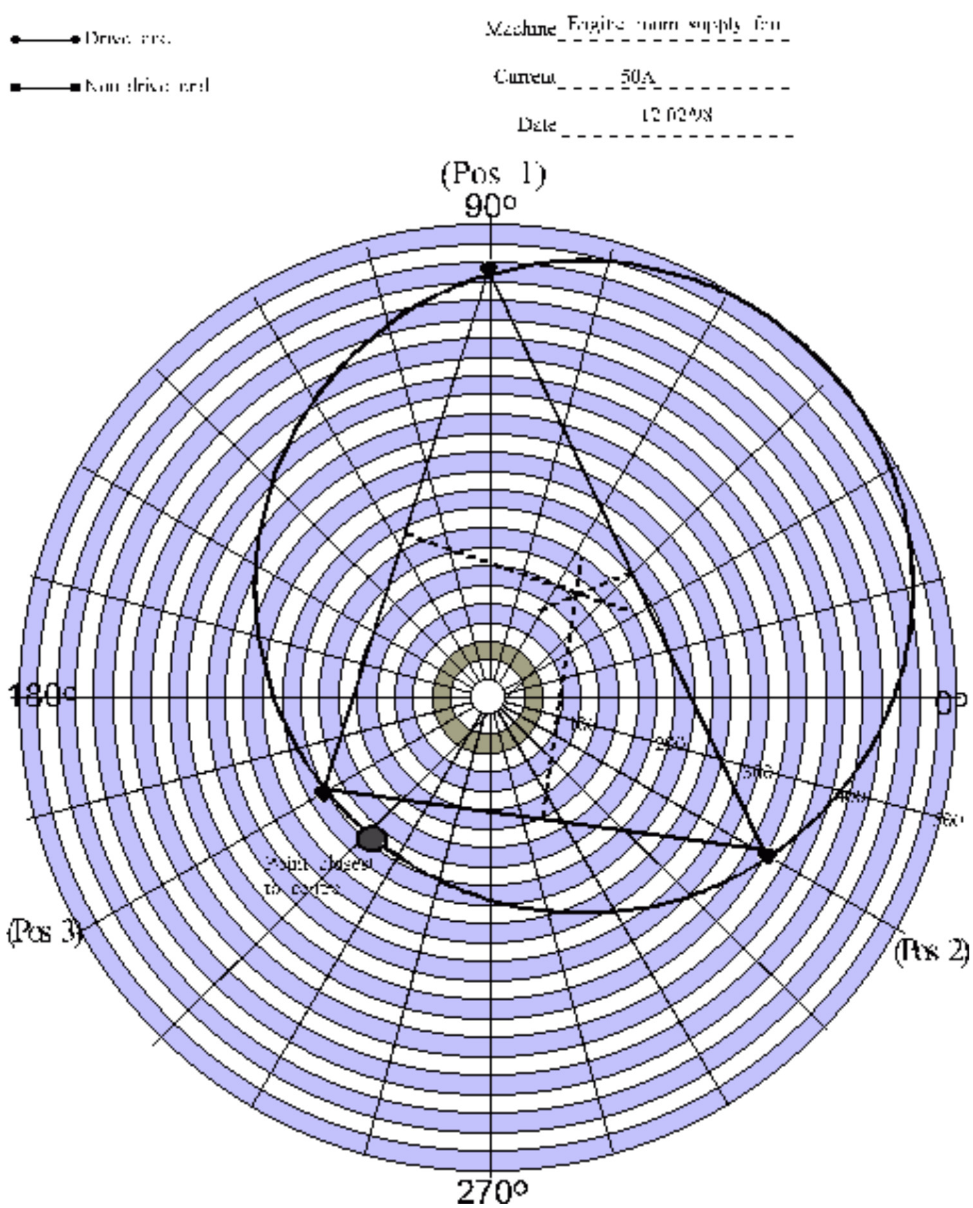
Example-Engine room supply fan	
Vibration velocity (mils)	Comment
300	Initial vibration
450	Trial weight in position 1
340	Trial weight in position 2
200	Trial weight in position 3

Final weight position : 15^{o} from position 3 (Towards position 2)

Final weight = Trial weight x 300 / (300-190)
=**2.7 x Trail weight**

Note: It is possible to divide the balancing weight if it is not practical to fit one large piece. In the example above we could fit 7/8 at position 3 and 1/8 at position 2

Vibration Balancing Polar Diagram



Vibration source identification

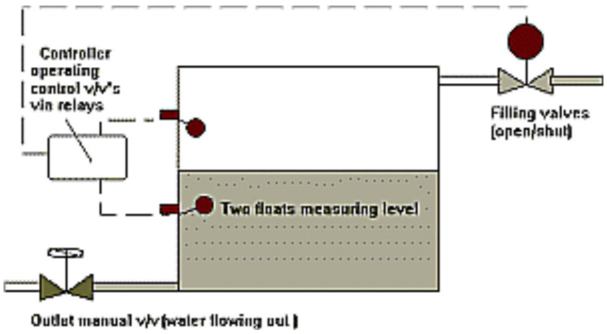
table

Source	Frequency	Magnitude	Remarks
Unbalanced rotating components	1xF	Velocity and displacement highest in radial direction. Proportional to size of out of balance	Common cause of vibration often caused by dirt build up on rotating element or wear. In-situ balancing best solution.
Misalignment of coupling and bearing	2xF usual also 1,3xF	Velocity and displacement large in axial direction	Common cause of vibration. Flex couplings should not be relied upon to take up misalignment
Damaged ball / roller bearing	High 1-5kHz	Acceleration levels high in rolling element bearings. Distinguished by wide history.	Often first component to show vibration though cause may be elsewhere
Worn, damaged or poor gears	Very high, gear teeth x F	Use velocity measurement. Acceleration may be too high	Often vibration accompanied by noise
Resonance, loose components	1,2 and higher x F	Velocity and displacement can be very high. Big variations at joints between components	A common cause of vibration. Resonant readings may be reduced by strenghtening foundations/bearing support.
Bending	1,2 x F	Velocity and Displacement can be high. Often large in axial direction	check shaft bend by clock guages. Check shaft materials correct for operating temperatures, no rubbing at seals
Electo-magnetic effects in stator	pole x F	Vibration disapears when power switched off	Switching power off provides a simple test
Unequal thermal effects	1 x F	Varies with load	Fundamental problem no met often. Compromise balance can sometimes help
Aerodynamic force	Fan blades x F	Velocity high if support structure resonant	Not common
Hydraulic forces	Impellor blades x F	Velocity can be high in associated pipework if resonant	Not common. Cure by stiffening pipework. Cavitation can also cause very high frequency vibration
Bad belt drives	Varying 1,2,3 or 4 x F	Velocity erratic	Can be checked by using stroboscope. Examine belts and pulleys for wear.
Oil Whirl	½, 1 x F	Displacement and velocity unstable and increasing with time. Can be very high	Can create alarming vibrations. Occurs only on high speed plain bearing machines. Check for

CONTROL ACTIONS

Two step control action

This can be defined as 'the action of a controller whose output changes from one state to another due to a variation in its input' One example of this control is that of a float operated filling v/v say for a cistern. In normal condition the output of the float is nil and no water passes through the valve, should the water level drop the float detects this and operates the valve to change to its second state which is open and water flows. When the level re-establishes then the float controls the valve to return to its primary state which is closed. In this way the float is controlling the water level by changing the valve between two different states. A more realistic system is shown below.

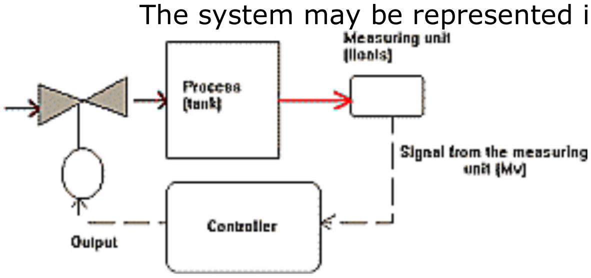


The system works as follows; the level drops until the lower float is uncovered, the controller detects this and opens the filling valve, the filling v/v remains open until the top float is covered and then the controller shuts the valve

The distance between the floats is termed the **'Overlap'** i.e. the distance between the high and low controlling values (on some systems this can be altered by altering the high or low set point of the controller, in the above system this would mean altering the position of the floats)

If there where any delays or lags in the sensing side, say the float switch was a little sticky or the filling v/v was slow to fully open then the level would fall below rise above the low and high set points respectively. This is termed **'Overshoot'**, it can be seen if the controller 'response to change' time was speeded up so the overshoot could be reduced.

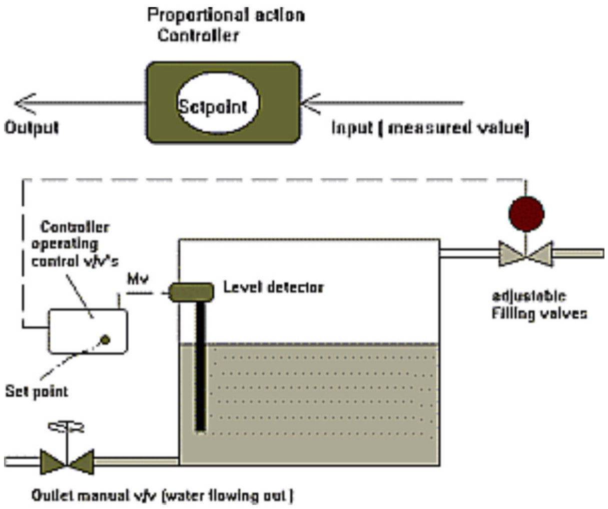
The system may be represented in block form as follows;



The measuring unit signal (in this case an electrical on/off) is the **Measured value** on which the controller operates. The signal is being 'fed back' to the controller hence to measured value is **Feed back** for the controller; i.e. the controller can see the direct results of its action.

Feed forward signals are sometimes used on systems which have an inherently high Process Lag; an example of this may be on a Marine Diesel engine jacket fresh water cooling system where part of the control is that the inlet temperature to the engine is monitored and fed forward to the controllers, should the temperature at inlet rise then consequently the outlet temperature must also rise. As the rise has already been detected then the controller can start increasing the sea water cooling to the jacket water coolers even though no temperature rise on the outlet from the engine may have been detected. This type of control, as it takes no account of what is happening to the process (is the engine running and hence requires the extra cooling or is it stopped) is not very accurate and normally (and as in this case) required Feedback to improve it.

The actions of controllers having variable output



Proportional control action

This where the change in output signal from a controller is proportional to the change in input signal

The control can be summed up in the following;

Output = Constant x Deviation

Output - this is the output from the controller and goes to the control element (say the filling v/v on the previous example i.e. the piece of equipment that actually alters the process.
Constant- This is the 'Gain' of the controller, as the output varies with the deviation, the amount it varies can be altered.

Say if the deviation changes by one unit the output changes by one unit, hence the gain is one. If the output varied by two for the same one change in deviation then the gain would be two. Similarly if the change in output was one half a unit for a one unit change in input then the gain would be half. Another way used to describe Gain is 'Proportional band', here a gain of one is described as a proportional band (Pb)of 100%. For a gain of two the Pb is 50%, and for a gain of a half the Pb is 200%, hence it can be seen that the magnitude of the Pb is opposite to the gain.
Deviation- This is the difference between the set point of the controller and the measured value. If the set point was one unit and the measured value was two units the deviation would be one unit.

Deviation = Set point - Measured value

The important think to remember is that the narrower the Proportional band the higher the gain and hence the higher the output varies for a change in deviation, this has the effect of making the controller control the process quicker by operating the controlling element more for smaller variations measured value. This has the negative effect as will be seen of making the system unstable

OFFSET

For a proportional controller to work there must be an deviation, if the deviation is zero then the controller output to the controlling element is zero. For the example of the tank and filling v/v obviously this is not possible, with the water constantly flowing out of the manual outlet v/v then the filling valve (or controlling element) must always be some degree open. If the level is at the level of the set point then the output is nil, the filling v/v is shut and the level drops, deviation occurs and the filling v/v opens. with this it can be seen that the system is not stable; what would happen in reality is the level would change (say the level was low and was now rising) until it reached a point close to the set point where the deviation multiplied by the gain would give an output signal to the filling v/v such that the flow of water in to the tank equalled the flow of water out of the tank.

This deviation is called 'offset'

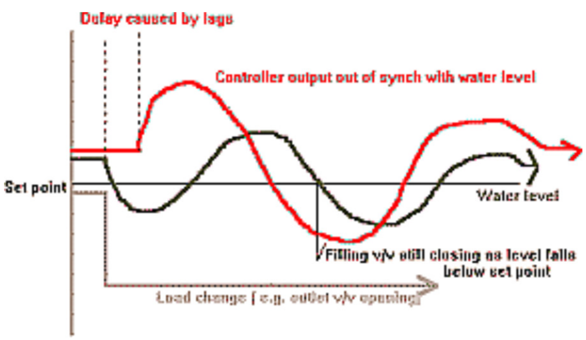
Therefore a proportional only controller when in equilibrium must have offset
The amount of offset will be determined by the Gain, for the tank system if the gain is high the deviation can be small for a larger output

The offset will increase for increased loads on the system i.e. if the outlet v/v on the example where to be opened further obviously the filling v/v would have to be opened further, and hence the deviation (offset) to give the required output would have to be greater.

For the system above all the control would be positive as the filling v/v would only be open if the level was low and hence the offset would always be positive, when the level rose above the set point, say caused by Lags leading to Overshoots or the filling v/v leaking slightly the deviation would be negative and the output zero.

Proportional action and instability (Hunting)

As the gain increases so the output increases for smaller and smaller changes in deviation, eventually the response starts to look similar to that of a two step controller with the control valve flying from full open to full shut with the slightest deviation from the set point. This would be o.k. if the system was devoid of all Lags, with lags however, particularly between the controller and controlling element, there is a tendency for 'over shoot'.



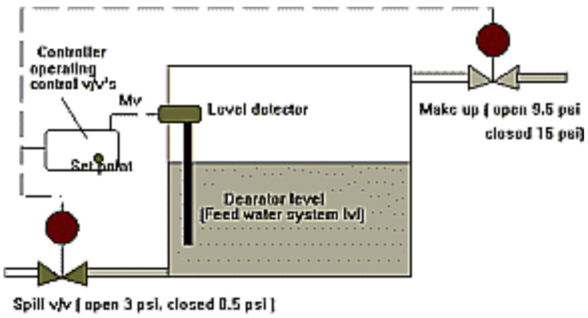
This can occur with reduced gain when the process lags are increased, for systems with a very large lags even small changes in gain can seriously effect the stability of a system and especially its ability to resist step (or rapid) load changes.

For smaller values of gain the system can be set up to have minimum of hunt and be self stabilizing .

Split range control(negative and positive offset)

A system could be designed to control both the outlet valves and inlet valves (this is what is seen on the feed water system level control with the spill and filling being controlled from the one controller) ; here the controller would be set up so that when the level is at the set point its output is mid range (say for a controller operating in the 3 to 15 psi range this would be 9 psi)

The control valves would be set up so that one, say the filling v/v would go from close at 9.5 psi to open at 15 psi, and the spill v/v would go from close at 8.5 psi to open at 3 psi. The 1 psi in the middle is called the **'Deadband'** and is there to ensure both v/vs are not open at the same time.(The v/v acting to open with increasing input signal is called '**Direct Acting**' and the v/v closing with increasing pressure is called '**Reverse Acting**')



It can be seen that there can now be an offset in the positive i.e. water being used and hence the make up v/v has to be open and in the negative i.e. there is too much water entering the system and the spill v/v's have to be opened.

Offset is not a desired result of the control of a system, however for proportional only controllers this is a direct consequence. That is why for all controllers performing important functions; including the make up/spill system controller above other types of controlling action are added to remove the offset

Other types of controlling action

Integral action (and the removal of offset)

Integral action is defined as the action of a controller whose output signal changes at a rate proportional to the input(deviation from the set point) signal.

What this means is that if a controller has a constant deviation then the integral action controller will increase its output continuously until it reaches maximum (often referred to as **'Saturation'**)
If the deviation is zero the integral action controller is zero
If the deviation is small the rate the controller output increases by is small
If the deviation is great then the integral action controller will rapidly increase its output.

Integral action is included in proportional controllers to remove the inherent offset of the proportional action, the offset is the deviation the integral action requires to alter the output

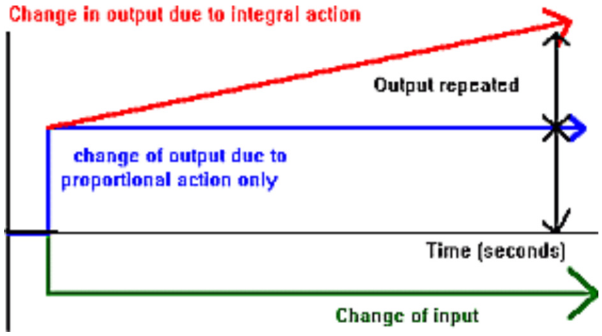
Integral action time
The amount of integral action, or how fast the integral action increases or decreases the output for one unit of deviation is expressed as the time taken to repeat the proportional action after a stepped change in input.

Rate of increase of output = Deviation x Integral action time

What this means is say the load changes in the simple filling system example by the manual v/v being opened and the level suddenly dropping by a foot, the proportional action will see this load change and give a stepped change in output i.e. if the foot drop in water level equals a change in input signal to the controller of one unit away from the set point, the controller will give a stepped change in output equating to the gain (which is say two) times the deviation (one unit) which equals a change in output of two units.

Whilst all this has been going on the integral part of the controller has seen the deviation and has decided to increase the rate of output by an amount equal to the deviation multiplied by the integral action time. The time taken for the output to increase by a further two units (remembering that this was how much the proportional action changed the output) is the integral action time and is measured in seconds.

The shorter the integral action time (less seconds) the more rapidly the integral part of the controller will increase the output; The longer the integral action time the slower the integral action will increase the output.



A common way of expressing integral action is in 'Repeats per minute', integral action time is seconds per repeat, hence if the IAT is 10 (seconds per repeat), this would equate to 10/60 minutes per repeat, or more simply 1/6 mins. The repeats per minute is therefore 6.

Integral action and stability

The introduction of integral action into a controller introduces an extra time lag, remembering the diagram showing that the integral action will take time to increase the output to a stepped load change, whereas the proportional action will give a stepped change. Lags introduce instability, hence it would more difficult to find settings which give a stable output.

Integral action is always used with proportional action

Derivative action

The definition of this is the action of a controller whose output is proportional to the rate of change of input.

That is to say for the filling system if the level was falling slowly the output of the controller would be small. If the level was flying down at a great rate of knots then the derivative controller would give a high output. It is quite obvious that the derivative action takes no account of the deviation from the set point but is only interested in the rate of change of deviation and hence;

Derivative action by itself cannot be used for control.

The purpose of adding derivative action to a controller is to increase the responses that deviation is removes as quickly as possible. That is to say if the level in our filling system is falling the proportional action will increase the filling at a the same rate, however as with seen, if there is a lag in the system particularly between the controller and controlling element; then there is a possibility of instability and a hunt.

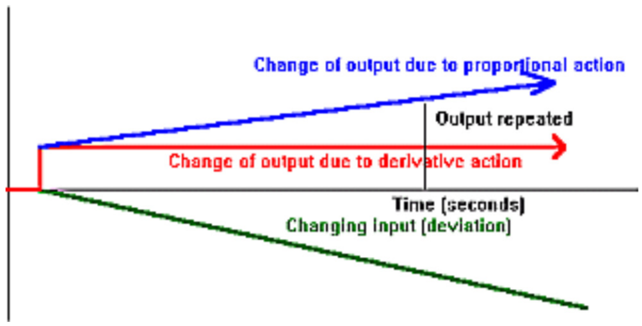
If we where at the point where the water level was just starting to fall less rapidly but not at the point where it was actually starting to rise, all the proportional and integral action see is a large deviation and so keep the water v/v wide open, the derivative action, however, sees this slowing down of the drop in water level, its output is dependent on the rate of change and hence reduces, and so the output from the controller reduces.

The introduction of derivative action introduces a stabilizing effect into a control system

Derivative action time

Output = Derivative action x rate of change of input

Derivative action [coefficient]- This is described as the time the proportional action takes to repeat the derivative action after a ramped (or constant rate of change) input. The units are seconds.

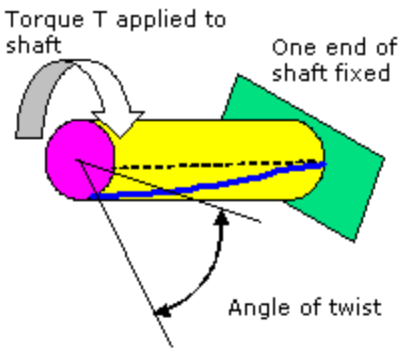


Torsionmeters

Angular Displacement

Torsion meters are used for the measurement of power transferred through a propulsion shaft.

Principle

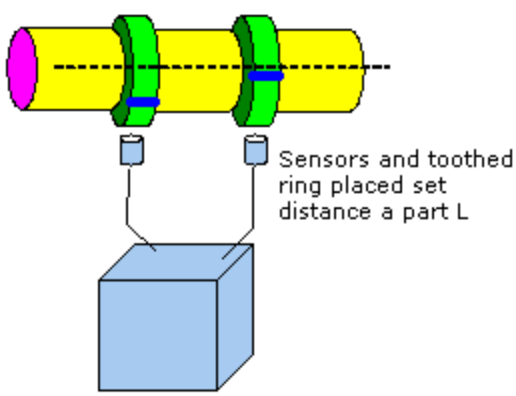


A torque of value T is applied to a shaft of fixed length L and radius r. An angle of twist θ is generated and is dependent of the modulus of torsional rigidity G and given by

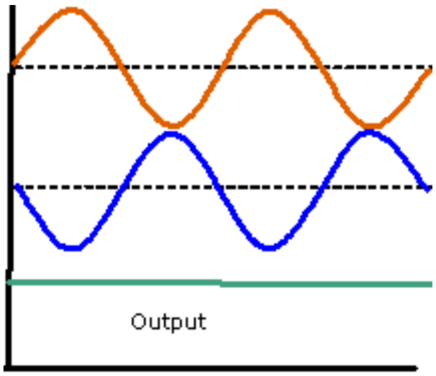
$T/r = G\theta/L$

The modulus of rigidity, the raidus and the length of the shaft are all fixed thus the torque on the shaft is proportional to the angle of twist

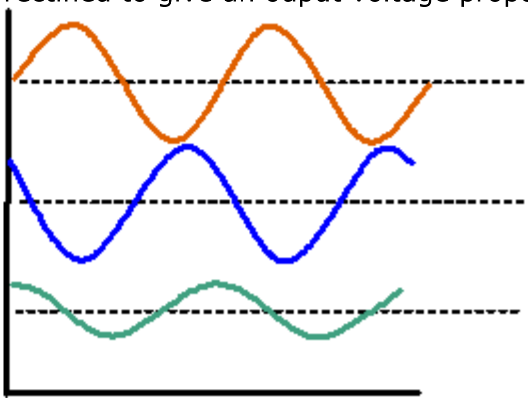
Typical system



Two AC generators are mounted so that they are driven by the main shaft and area at set distance apart L. A sinusoidal waveform is produced. One of the generators is adjusted so that at minimum torque the generated waveforms are 180' out of phase. The outputs from the two generators are then added and the resultant voltage is used as the measurement of torque



As the torque is applied to the shaft so the twist causes the waveforms to shift in phase. When the two waveforms are now added an output ac current is produced which may be amplified and rectified to give an ouput voltage proportional to the torque appled to the shaft.



Another method of achieving this is to replace the generators wit sensors and toothed ring.

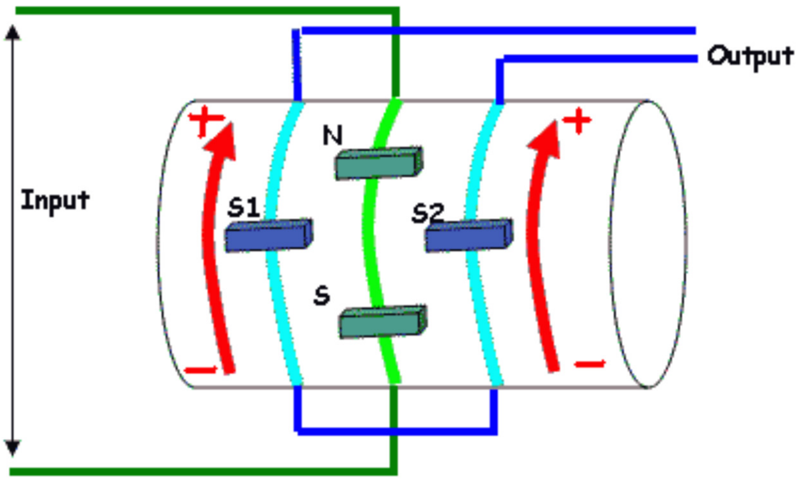
Power Calculation

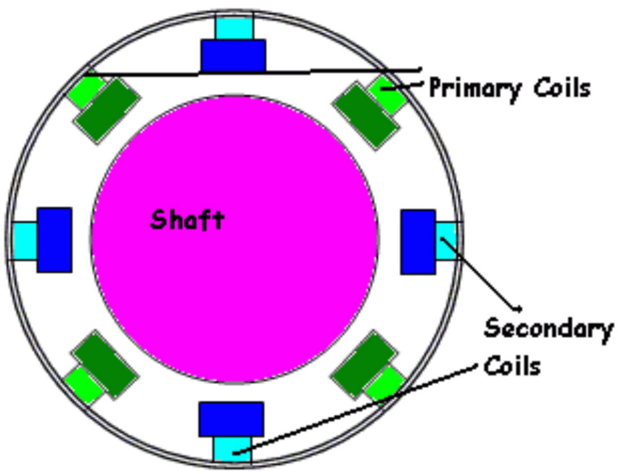
Power is a product of the Torque and revs of the shaft, one of the generator outputs is used to measure the shaft rev/s and a calculation performed

Magnetic Stress Sensitivity

This type measures magnetic fields in the shaft surface, the distortion of these fields gives and indication of the torque. The principle behind this is that in some ferromagnetic materials reluctance (magnetic resistance) is less along the plane of stress than across it.

In the torductor three rings are fitted around the shaft each ring having four electromagnetic poles. The centre ring acts as a transformer primary with the two outer secondary rings having their poles arranged 45' apart to the primary poles but in line with each other. The poles are held in a frame so that there is no contact between the poles and the shaft which have a gap of about 3 mm between them.





An alternating current is fed to the centre ring thus generating a magnetic field. This educes an emf in the outer two rings. The outer two ring coils are connected in series in such away that at zero stress the emf generated in each ring is opposite and equal in value giving an output of zero volts.

When torque is applied to the shaft the sress lines are distorted to to the axial. The distorion of this field affects the emf induced in the coils increasing on one side and reducing on the other. Thus a resultant emf of a few milivolts is available at the output. The size of the output is proportional to the stress applied.

PID tuning

The setting up of PID controllers is complex and contains many varaibles. Following are two examples of methods that may be adopted

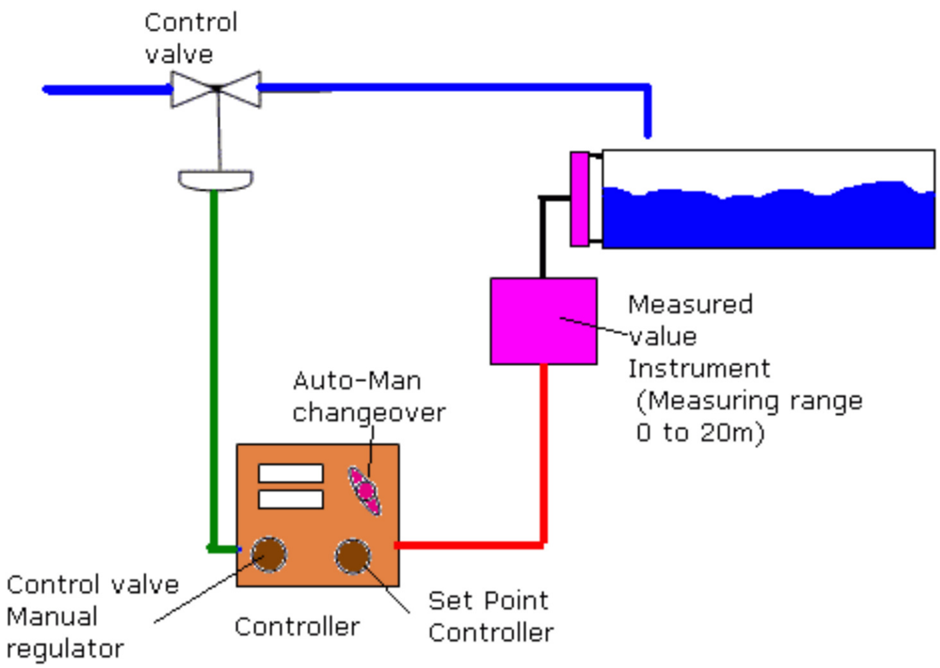
Ziegler-Nichols Closed Loop (Hunt) Method

i. *Set up the system in closed loop i.e. with the controller in auto mode*
ii. *Remove integral and derivative action*
iii. *Increase the gain (reduce proportional band) untill the controller just begins a steady hunt*
iv. *record the Proportional Band setting as value P*
v. *Record the periodic time of the sinusoidal hunt as value T*

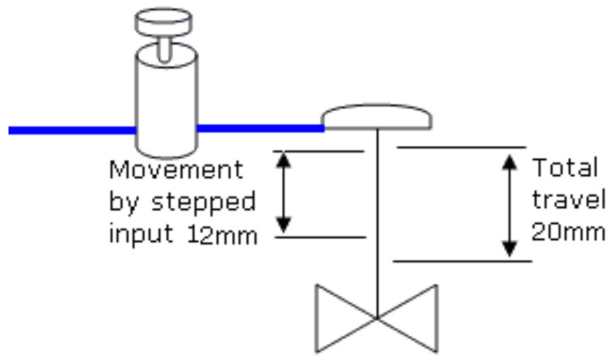
- **For Proportional only**- Proportional Band = 2 x P
- **For Proportional + integral**- Proportional band = 2.2 x P, Integral Action Time = T/2
- **For Proportional + Integral + Derivative**- Proportional band = 1.67 x P, Integral Action Time = T/2, Derivative action time = T/8

Ziegler-Nichols Open Loop Method

i. *Switch controller to manual ensuring that the system is open loop. i.e. that the controller is disconnected from the controlling unit which can be manually adjusted*

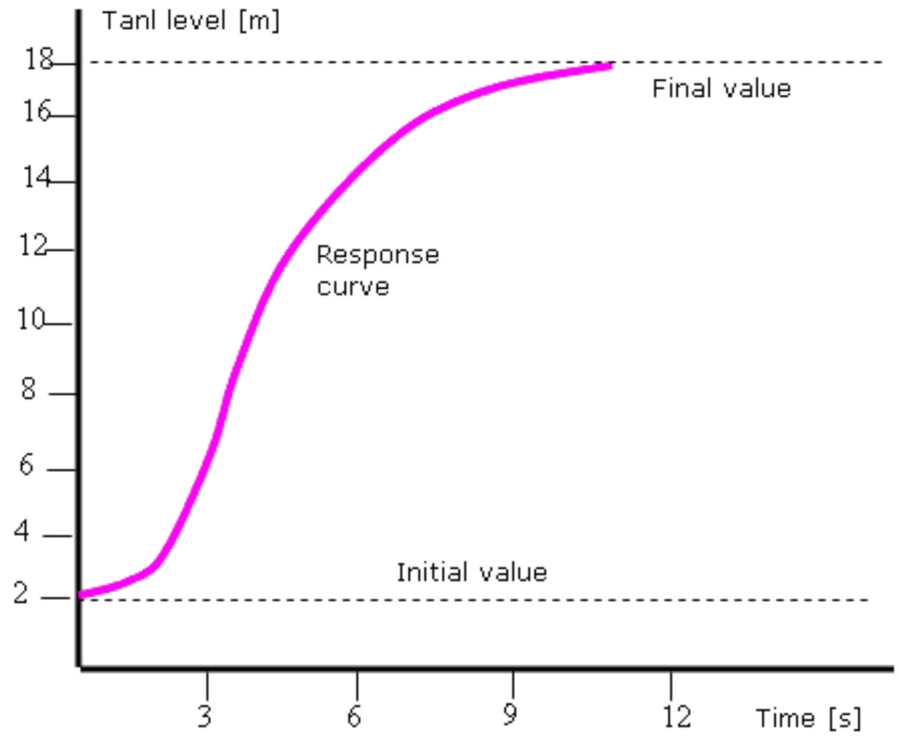


ii. *Rapidly alter manual regulator to cause a stepped change in the control valve by a set amount. Record the movement of the control valve as a percentage of total travel. Record this as δR*

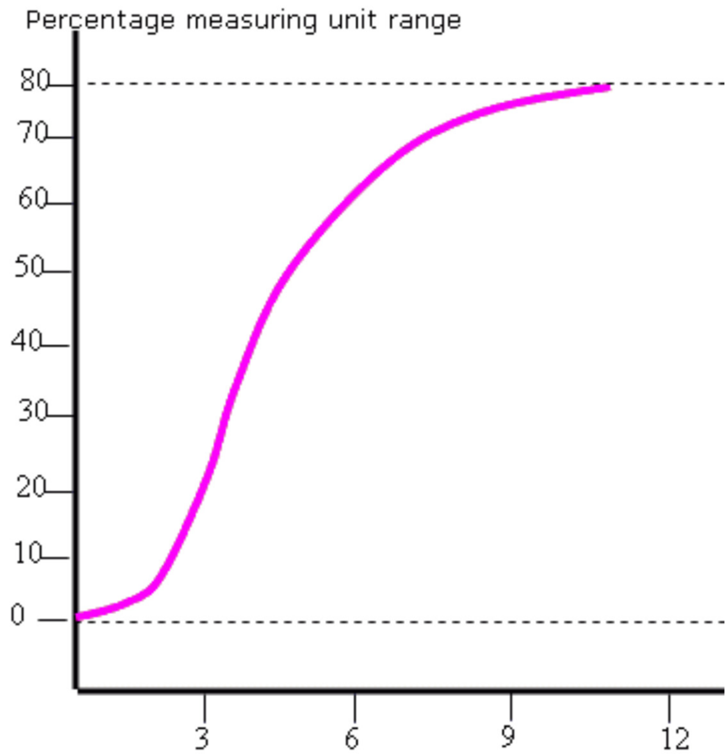


In the above example the valve has moved by 12 out of a total 20mm therefore is has move 60% of its total travel.δR = 60

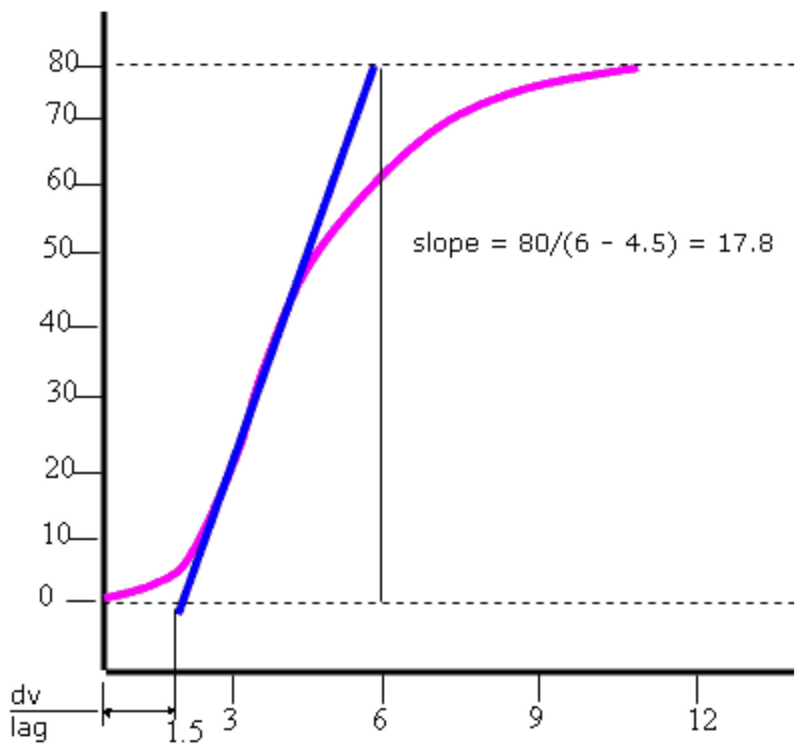
iii. *Record the system open loop resonse. That is record the intial valve from the measured valve transmitter, initiate the stepped input then record how the measure valve responds in relation to this*



iv. *Change the vertical axis of the response graph so that it is scaled as a percentage of the measure value range (which from above we see is 20m).*



v. *From the grap dtermine values as best as possible for dv (distance-velocity- time between controller output signal being generated and contolled element receiving it) lag T[s]and the maximum slope N[%/s]*



- **For Proportional only**- Proportional Band = N xT/δR x 100%
- **For Proportional + integral**- Proportional band = N x T/δR x 110%, Integral Action Time = 3.33 x T
- **For Proportional + Integral + Derivative**- Proportional band = N x T/δR x 83%, Integral Action Time = 2 x T, Derivative action time = 0.5 x T

For the above worked example this would give the following results

Proportional only

PB = N x T/δR * 100 = 17.8 x 1.5 / 60 * 100 = 44.5%

Proportional + Integral Action

PB = N x T/δR * 110 = 17.8 x 1.5 / 60 * 110 = 49%

IAT = 3.33 x T = 3.33 x 1.5 = 5 [s]

Proportional + Integral Action + Derivative Action

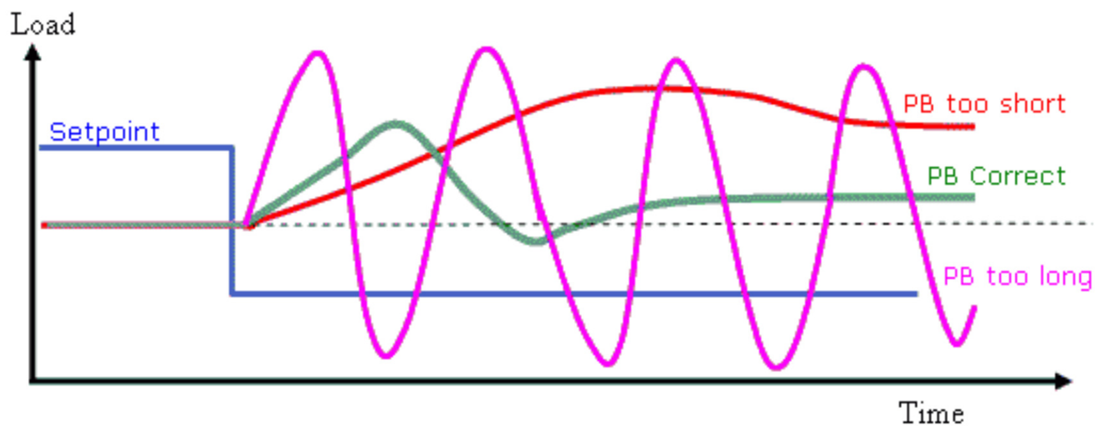
PB = N x T/δR * 83 = 17.8 x 1.5 / 60 * 83 = 37%

IAT = 2 x T = 2 x 1.5 = 3 [s]

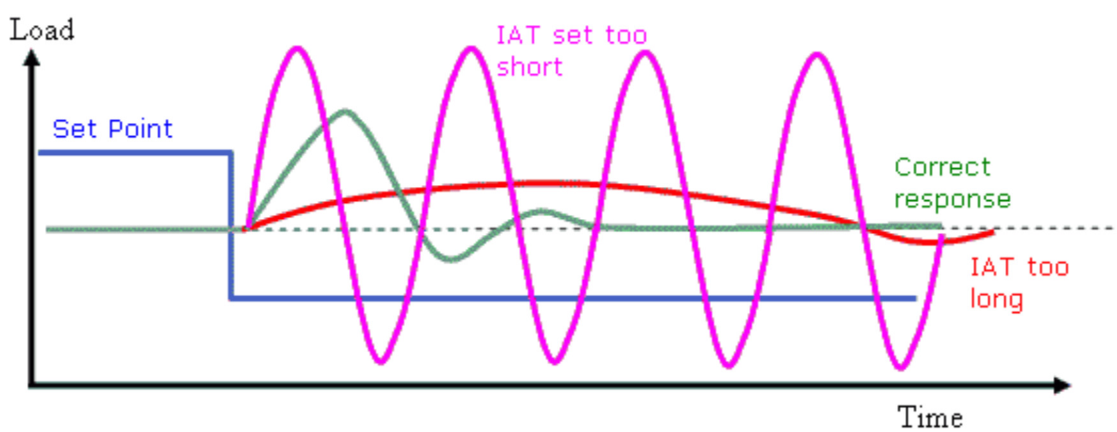
DAT = 0.5 x T = o.5 * 1.5 = 0.75 [s]

System responses

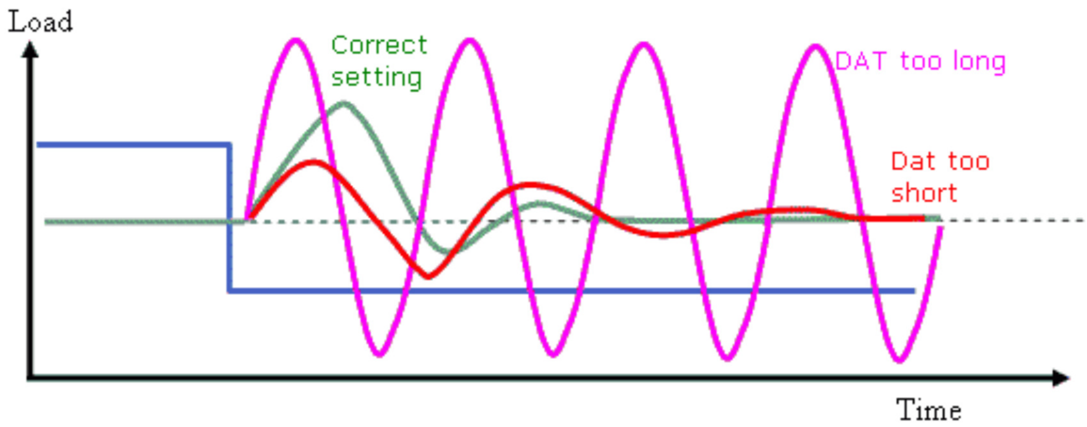
Effects of changing Proportinal Band on P controller



Effects of changing Integral Action Time on P + I controller

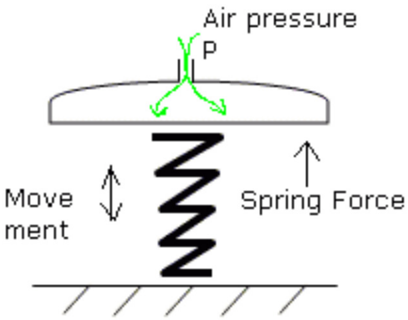


Effects of changing Derivative Action Time on P + I + D controller


Load
Correct
setting
DAT too long
Dat too
short
Time

Valve Characteristics

Pneumatic Valve Characteristic



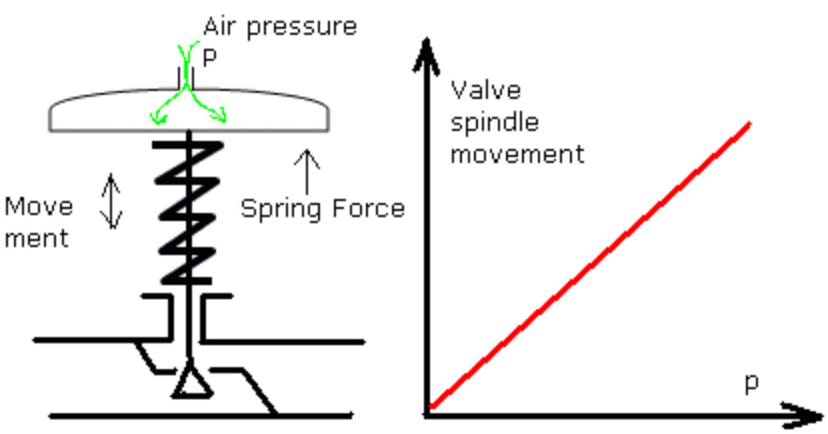
The force acting to compress the spring is given by pressure P x Area A

The force acting against this is given by the spring Constant K x Spring compression distance L

PA = KL

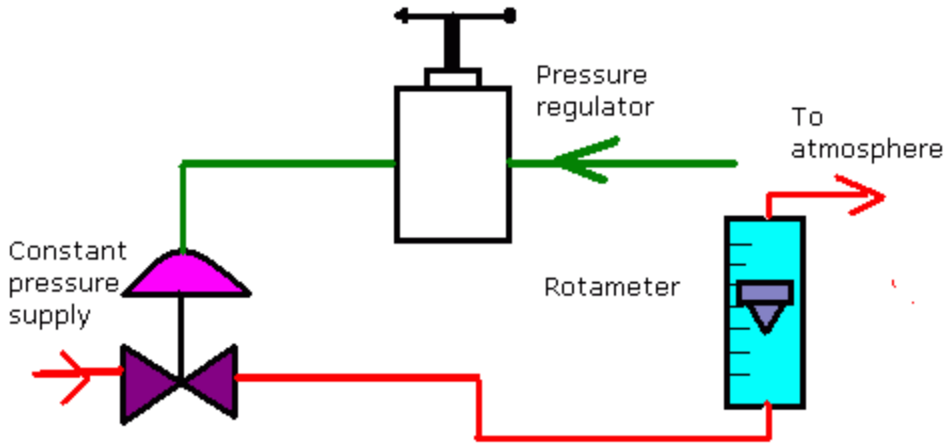
L = P(A/K)

Since the area of the diaphragm and the spring constant are constants for any given set up it can be seen that the spring movement is directly proportional to applied pressure

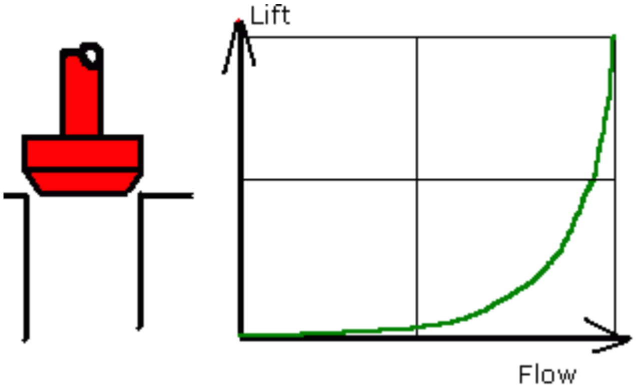


Inherent or designed characteristic

The characteristic of a valve is its relationship between valve lift and flow across it for a constant pressure drop across it. A typical set up for measuring this is shown below

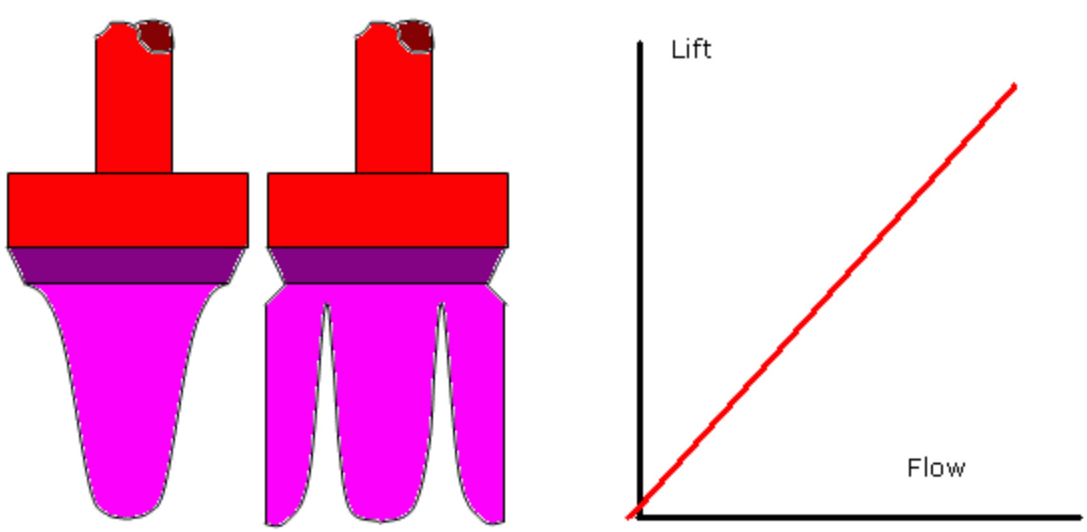


Quick Opening (poppet) Characteristic



These valves re used in control systesm mainly as isolating valves. Their main use is for relief or safety valves. Full bore is achieved at one quarter of the diameter\

Linear Characteristics



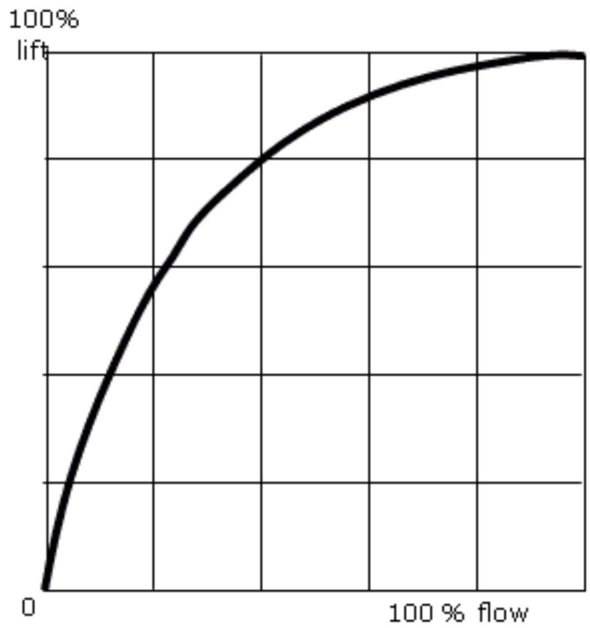
In this design the flow through the valve is proportional to the lift. The normal design is the vee port (or fluted) type although for smaller sizes the plug type is used

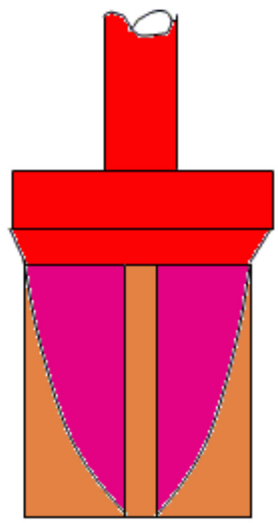
Equal Percentage Characteristics

In this design for equal increments of valve movement the flow increases by and equal percentage.e.g. if the valve is 10mm open and the flow 20, if the valve opens anouther 10mm (100%) the flow increases to 40. If the valve opens a further 10mm (50%) then the flow increase by 50% of 40 which is anouther 20. The action may be expressed as

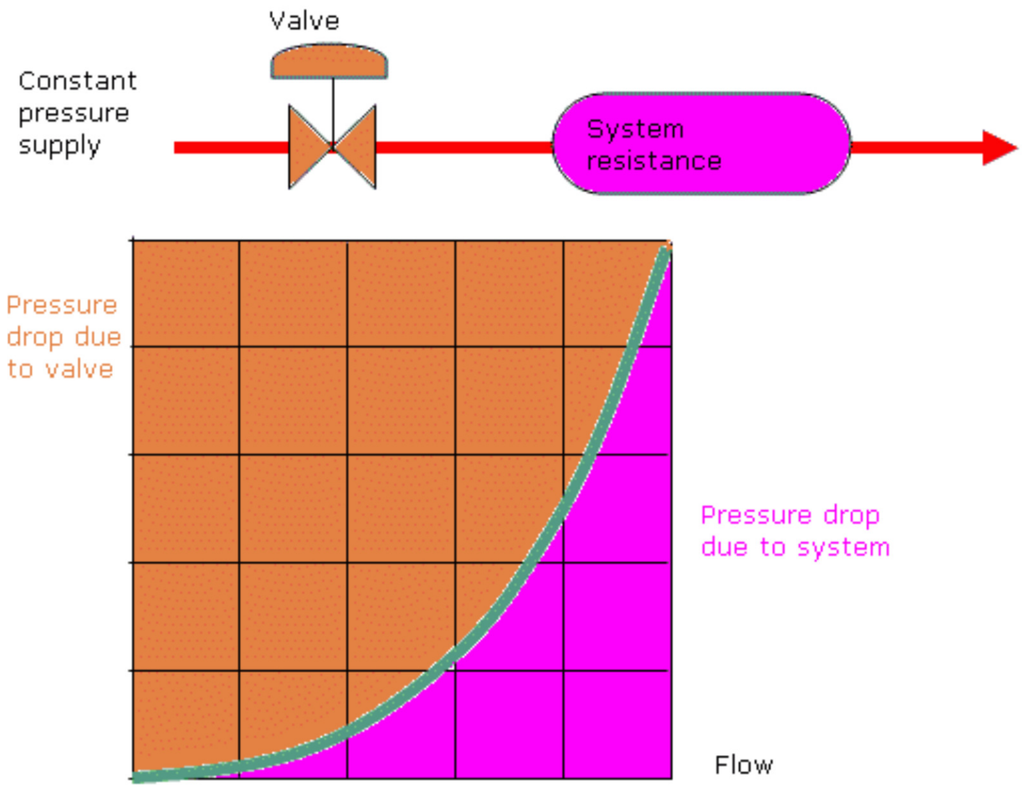
$L = \log_e Q / K$

It should be noted that for true equal percentage the minimum flow is 1%. Therefore if closing is required some adaption is required

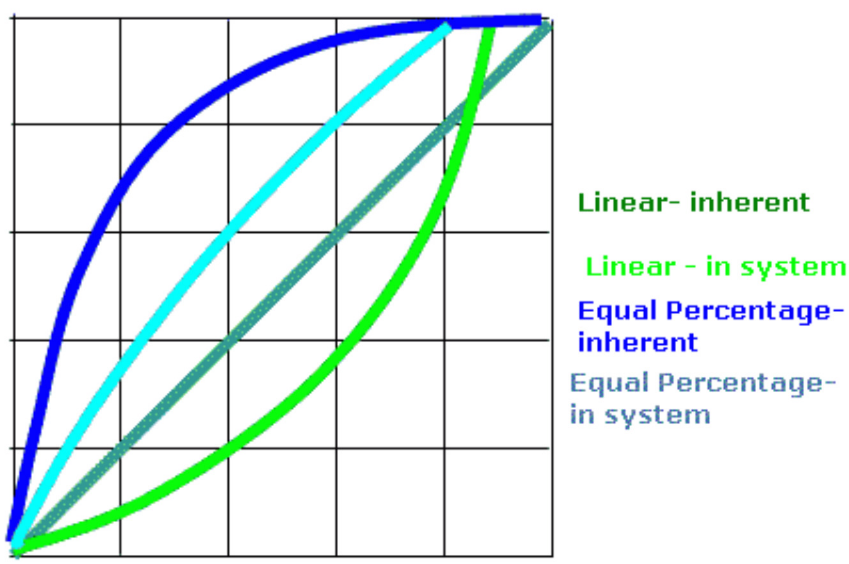




System characteristics



The above graph shows the efects the system has on the flow through the valve. It can be seen that as flow increases the pressure drop across the valve falls thus significantly effecting the characteristic effect of the valve



Fitting a valve with equal percentage trim produces a near linear characteristic. This will be effected by things like varying system pressure drop and maximum flow rates. If the repssure drop across the system is low at the required flow rate then the rpessure drop across the valve will not significantly alter and a linear characteristic shoudl be used.

In practice chracteristics are available which offer a balance between linear and equal percentage (parabolic).

Valve Sizing Coefficients

In order to to make the purchasing of valves simple sets of standard valve sizings are available. Finding the correct size may be achieved by use of valve sizing equations.
Calculation must be at the extremes of low and pressure drop and it is standard practice to oversize to the next size up.Following is a list of the more common coefficients

BS4740 Valve Sizing Coefficient Av

Q= Av. √ (ΔP / P)

Q = Flow (usually max rate through valve (m^3 / s)
ΔP = Corresponding Pressure drop acrtoss valve (N / m^2)
P = Density of liquid (Kg / m^3
Av Valve Sizing Coefficient [m^2

Due to its units the valve sizing coefficient is often called the Area Coefficient

American Valve Sizing Coefficient Cv

Q= Cv. √ (ΔP / SG)

Q = Flow (usually max rate through valve (US Gallons / min)
ΔP = Corresponding Pressure drop acrtoss valve (lbft / in^2)
SG = Specific (realtive) gravity of the liquid relative to water at 20'C

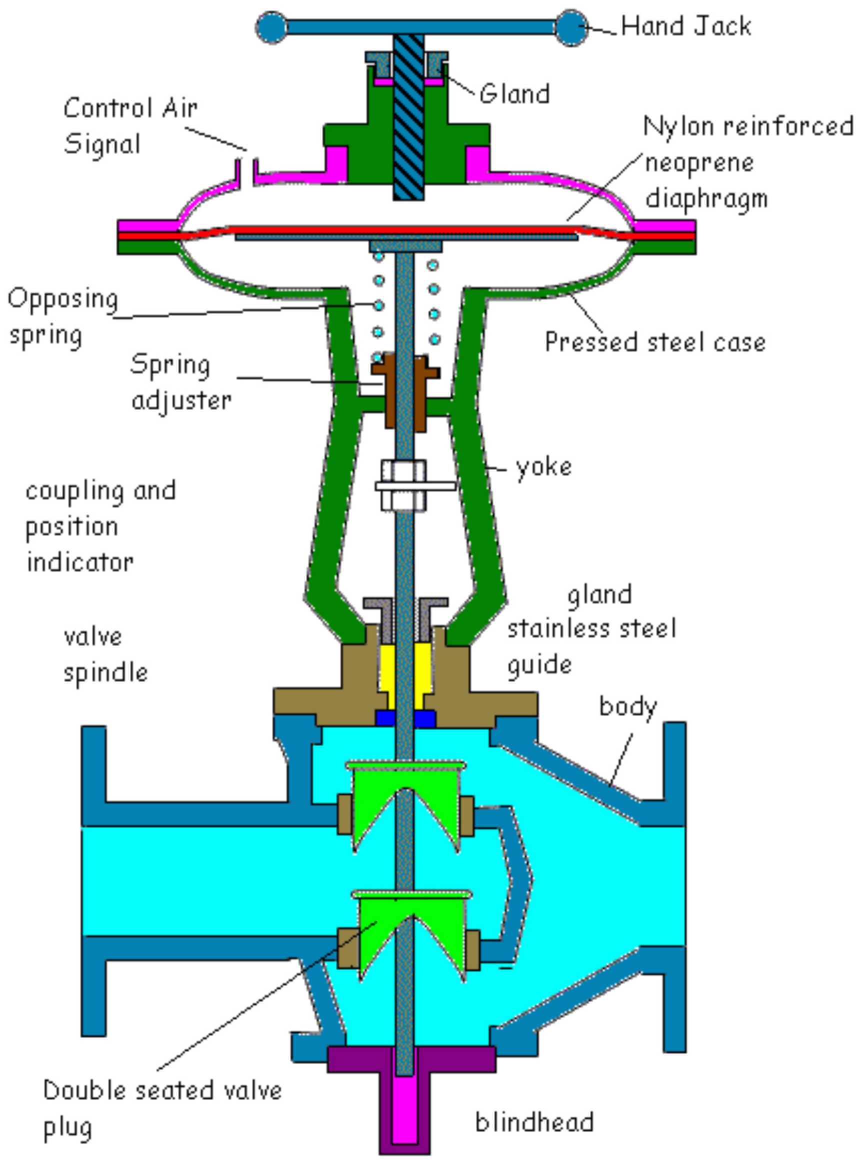
This is the most common coefficient quoted although difficulty in working with the units means it is easier to work in anouther and convert to it

European Valve Sizing Coefficient Kv

Q= Kv. √ (ΔP / P_{rel})

Q = Flow (usually max rate through valve (m^3 / Hr)
ΔP = Corresponding Pressure drop across valve (Kgf / cm^2)
P_{rel} = Relative Density of liquid

Diaphragm operated control valve



Hand jack

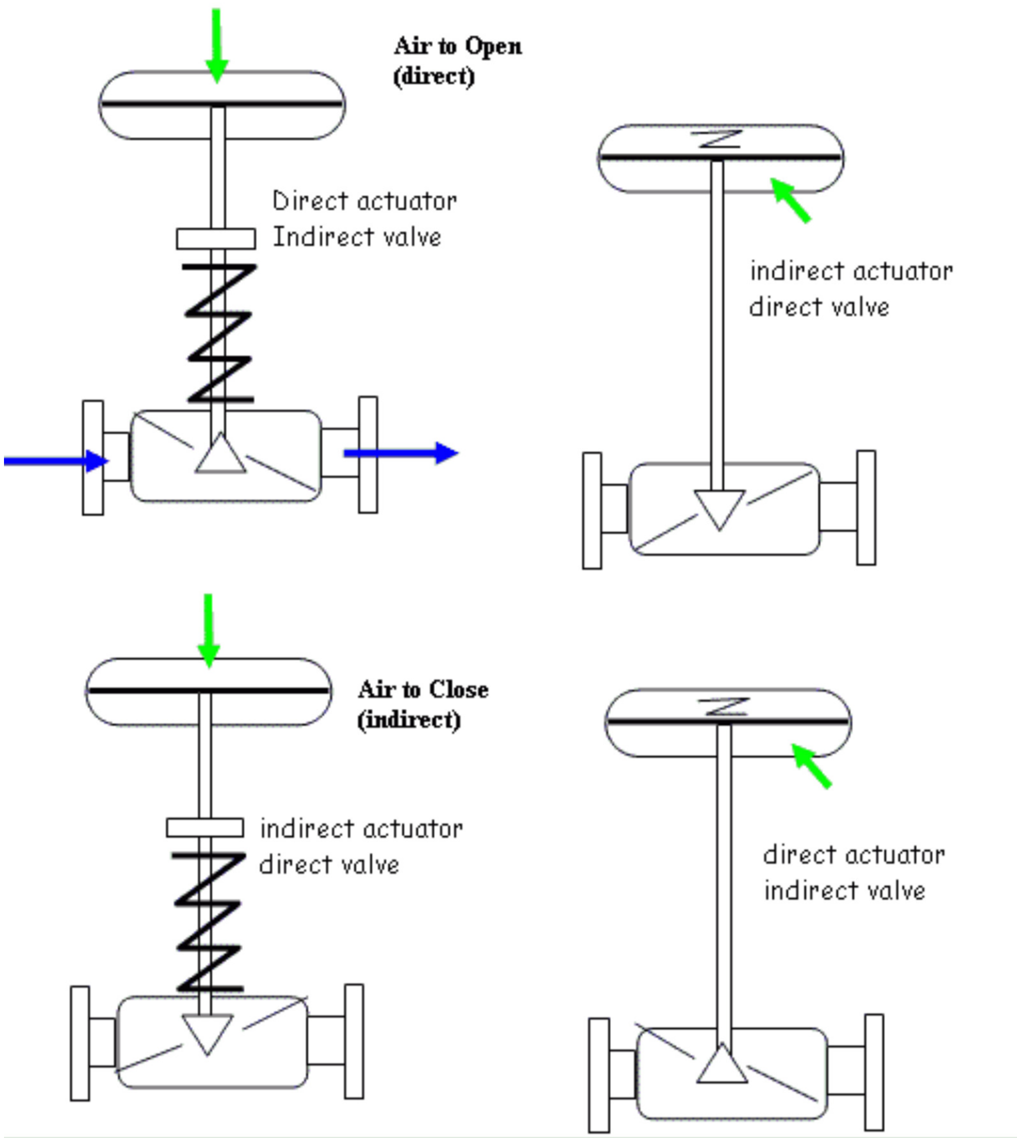
May be used either for local manual control in the event of signal failure. Or it may be used to prevent or limit opening of the valve

Valve glands

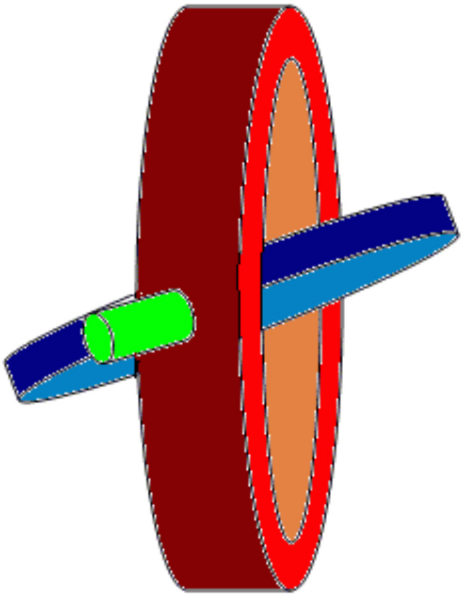
For accurate valve positioning it is important to keep friction to a minium. The largest source of friction is the valve gland. For steam valves using asbestos type packing a suitable lubricant must be applied. A better solution takes to form of a pack of several v seals made from teflon. Fins may be cast or machined into the galnd housing for cooling

Fail safe- air to open/close

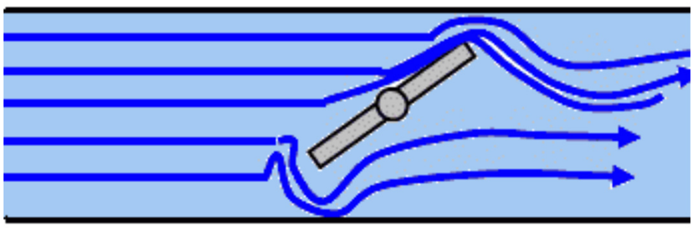
The control valve may be so designed to fail in either a full open or full closed direction. In addition the pneumatic signal may open or close the valve



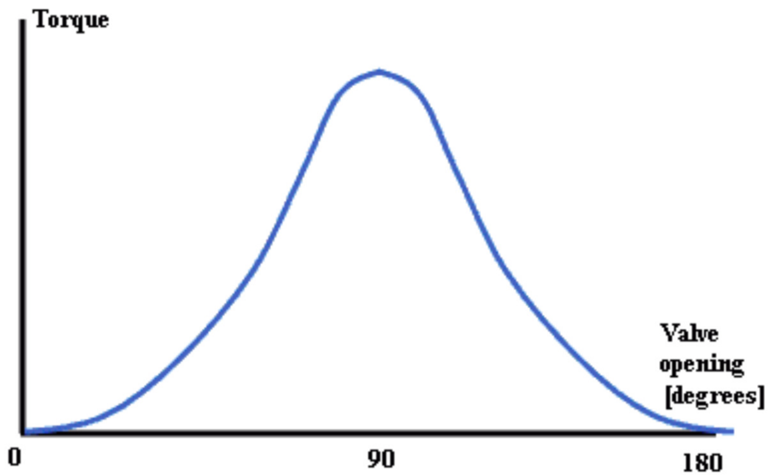
Butterfly valve



Consists of a short cyclinder generally rubber lined both for corrosion protection and to act as a seal for the disc. The disc forms the closing device and is locked to a spindle. The spindle gland generally takes the form of an o-ring or v-seals.



The torque acting on this disc is caused by the dynamics of fluid flow across it. When the valve is partially open the flow across the top half is much smoother than the bottom. This results in a torque acting on the driving spindle

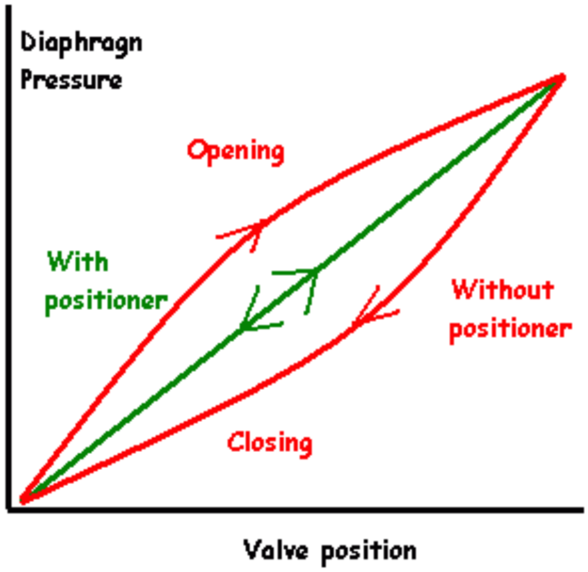


The torque rises from zero to a peak when the valve is in mid position and falls again to zero . This non-linearity makes for difficult accurate positioning. To overcome this it is normal to fit oversized actuators. The flow through the valve is also very non linear rising quickly after intiall openig and near full flow being achieved before the valve is 50% open

Valve Positioners

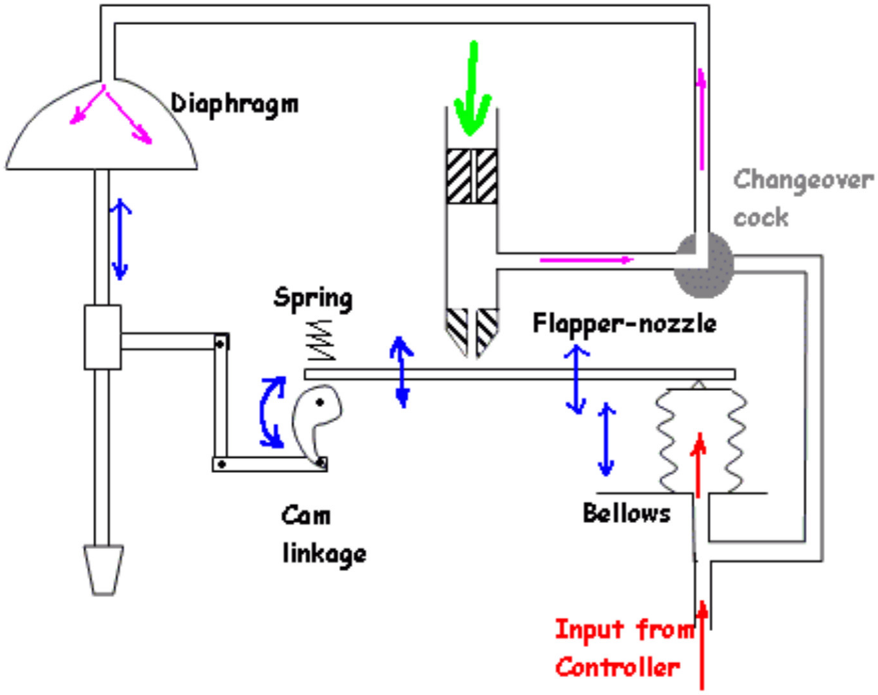
Valve positioners are used on controlling valves where accurate and rapid control is required without error or hysterises.

- Precise postioning
- can cope with large variations in forces acting on plug
- Rapid postioning
- Removes stiction and friction effects of gland
- Removes effects of large distances between vale and postioner
- Elimates hysterises



Assembly

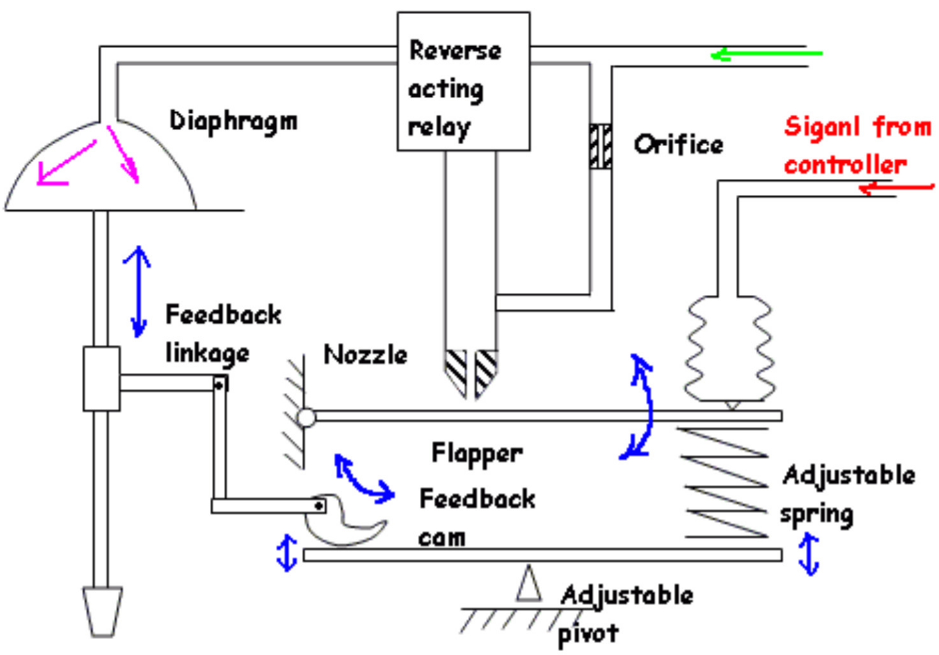
A valve positioner consists of a very high gain amplifier- this may be pneumatic, electricpneumatic etc, and a feed back link which detects the actual position of the valve.



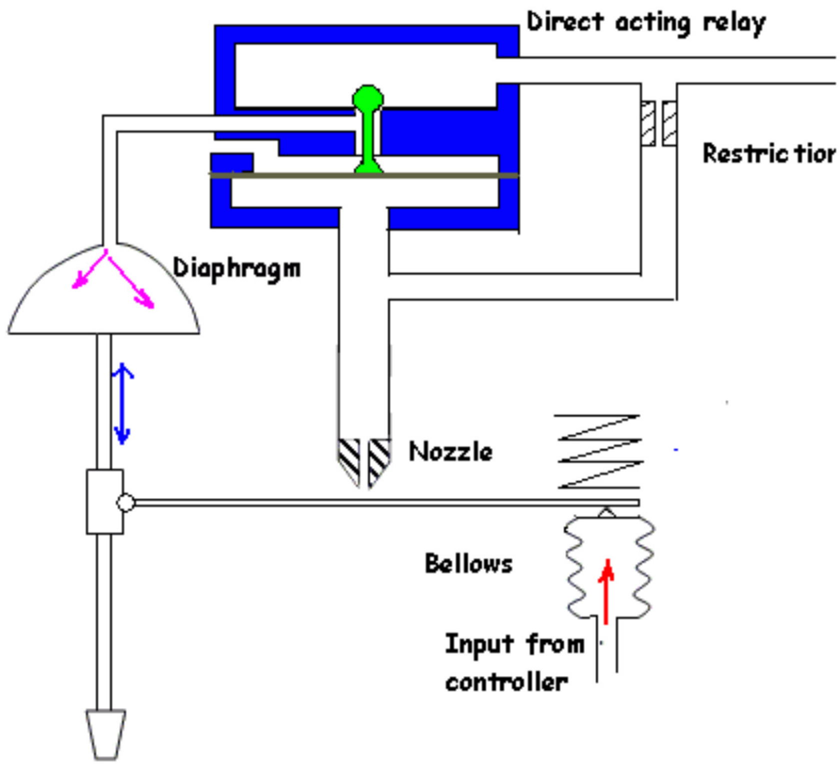
The required movement is for the valve to close. The input pressure from the controller to the bellows falls. The flapper moves away from the nozzle and the presure after the orifice falls. The pressure to the diaphragm falls and the valve begins to close. The feed back arm moves up rotating the cam clockwise. This raises the beam increasing back pressure in the nozzle until equilibrium is again achieved.

The change over cock allows the signal from the controller to be placed directly on the diaphragm

Force balanced Valve Positioner



Motion balanced Valve Positioner



Direct acting relay
Restriction
Diaphragm
Nozzle
Bellows
Input from controller

Overview of Microbiological Attack

Microbial problems were seen at their height in the early eighties. There has been a reduction in the number of incidents although the problem has never fgone away. In addition whereas effects were seen ainly in distillate fuels and lubricants, it is now seen in residual fuels, drinking and ballast water. Failure to eradicate completely a re put down to advserse trading, poor training and housekeeping, environmental restrictions in the use of microbial agents and the restrictions in bilge pumping placed by MARPOL

MICROBES

Microbiological contamination consisting of bacteria, yeasts and moulds, are easily tolerated at low contamination levels. It is only when their numbers are not controlled that rapid infestation occurs

From a marine point of view there are six main areas of concern for microbiological infestation. These are:

1. Distillate fuel;
2. Lubricating oil;
3. Cooling water;
4. Bilge water;
5. Ballast water;
6. Distillate cargoes.

Conditions promoting growth

In each case, it is to be remembered that microbes are living organisms and their growth depends upon the readily availability of water, nutrients, heat, oxygen (or sometimes lack of it) within an otherwise acceptable environment.

Water

The main requirement for microbiol activity is water. This must be available water and not just water content. bA typical minimum value is 1%. This can happern due to insufficient draining. The presence of free water can lead to rapid micorbiol growth after 1 week at 30'C. Where water is dispersed then growth is limited the microbes existing in water droplets or surrounded with a water sheath.
Modern lead-free gasolines contain water soluble oxygenates such as methyl and ethyl alcohol, methyl tertiary butyl ether these along with antifreeze glyciol when migrted to the water phase cause a depression in microbiol activity. The level of glycol must be above a minimum as below this the glycol can actually promote growth

Nutrients
Hydrocarbons and chemical additives in the fuel and lubricant act as their food source. In addition to this are nutritive matter found in contaminated water either fresh or sea water. Sea water in addition promotes the growth of sulphate reducing bacteria. Cargo residues , particularly for ships carrying such thinks like fertilisers are also sources. The presence of rust and other particulates can promote growth.

Note that clean dry fuel kept at reasonable temperature will never permit any significant growth

Temperature
Warm enginerooms (15 - 35'C) provide the ideal breeding ground for microbiol growth. Too hot (70'C) or too cold (5'C) will retard growth

Environment
Most corrosive forms of bacteria prefer astable environment and dislike adgitation. Thus ships in lay up or ships that spend long periods inactive are particularly susceptible. Water leakage or condenstaion will ten provide the living environment. The microbes live in the water phase but feed on nutrients in the oil phase this the boundary area sees agressive growth.

Indications
The unpleasant by-products of their digestion, after hydrocarbons have been oxidised into acids, include toxic and pungent hydrogen sulphide. This is produced from any sulphurous compounds within the fuel, lubricant, seawater or waste product. Microbial growth is seen as a characteristic sludge formed from accumulated cellular material which may restrict fuel and lubricant pipe lines and filters.

Types of Microbes

There are three basic types of micro organsims that cause problems in the marine industry, these are bacteria, yeasts and moulds.

Bacteria

Bacteria can be subdivided into

1. *Aerobic Bacteria Require oxygen to survive.*
2. *Anaerobic Bacteria Live in the absence of oxygen*
3. *Facultative Bacteria Live with or without oxygen*

Bacteria is a highly diverse group of single celled organisms with rigid cell walls. They may be rod like, spherical or spiral and many are actively mobile with a whip like appendage (flagellum). They can reproduce asexually and rapidly using binary fission with a doubling time of as low as 20 minutes. They are design to reproduce rapidly when the time is rigth and some are able to produce extremely resistant spores able to withstand high temperatures and disinfectants.

Although in the main they prefer neutral or slightly alkaline environments some can exist in the extremes of acid. They can excrete partial breakdown products on which other forms of bacteria can feed. In addition they can produce large amounts of extra-cellular slime which coats and stabilises the living environment. This slime can protect against or deactivate biocides. This slime can prevent the diffusion of oxygen to the base of the growth and thereby promote Suulphate Reducing Bacteria which are particularly agressive.

Yeasts

These are unicellular, being ovoid or spherical in shape some may also produce rudimentary filaments. They reproduce by budding and growing off the parent untill large enough to seperate. This process may take several hours.They prefer slightly acidity

Moulds

Multicellular with hard chitinous cell walls.They are ususally found as branched hyphaeforming a thick, tough intertwined mat occurring most commonly at oil/water interfaces. They reproduce by branching and can double there length in a few hours. They can also produce spores.

They prefer slightly acidic conditions, using oxygen in their feeding process they produce by products suitable for other microbes to feed and an atmosphre suitable for Sulphate Reducing bacteria.

They reduce complex hydrocarbons to simpler carbon compounds. Intensive corrosion can occur under the mat. They can be both sea water and temperature tolerant

Sulphate Reducing Bacteria (SRB)

These are a specific group of anaerobic bacteria with special growth requirements. They can only use simple carbon compounds therefore they require the prescence of other microbes. They will produce hydrogen Sulphide in the prescence of sulhure containing compounds such as sulphates found in sea water.

Desulfotomaculum has the added ability to produce extremely hardy spores able to resist exposure to air, heat and most biocide chemicals. Both this and Desulfovibrio are very insiduous and able to rapidly cause corrosion in ships hull and machinery

Sources of contamination

Infestation can come from contaminated sea water or hydrocarbons, from a source already onboard or by poor onboard practices

Sea Waters

The oceans contain a very small density of microbes, htis was also partially true for harbours until such things like contamination by oil spills and fertiliser wash off from arable land as well as chemicals such as corrosion inhibitors changed the constituents of the water. Harbours can thus be rich in microbes includig hydrogen degraders and large numbers of SRB

Refinery Practices

Recent years have seen a dramatic increase in the supply of contaminated fuels to vessels with an underlying cause of bad housekeeping. This has been particularly prevalent in Eastern Europe where protection by detection, heating, filtering and biocides are recommended. On particular cause is the washing of tanks using contaminated river water that not only introduces the microbes but also sources of nutrients particularly Nitrogen and Phosphorus
It should be noted that generally microbes have and sg of about 1.05 so will tend to settle to the bottom of the tank. It is therefore possible to limit the delivery of contamination by settling and floating suctions

Onboard

Typical locations where contamination is found are;

- **Bilges**Polluted water and the presence of hydrocarbons in wells that are not pumped fully dry can lead to infestation with SRB, localised pitting and eventually perforation. It is recommended that were it is not posiible to remove all the contents from a well then the contents should be agitated or freshen by the introduction of water to prevent stagnation.
- **Fuel**It is inevitable that some contamination will always be brought on board with this. It is then essential to ensure that the amount of available water in the fuel be kept to an absolute minimum. In addition warmth promotes the growth and tanks such as service tanks that receive the heated recirculated fuel form the engine are particularly susceptible.
- **Lubricating Oils** It is unusual to find microbiol growth in normal use lube oil systesm due to the operating temperatures. However it can occur after a period of inactivity.

  the worst case I have seen was on a steam turbine vessel after a period in dock. This occurred early on in my career so I cannot remember all the facts but in a similar circumstance I would look at the condition of the dehumdifier for the gearbox to ensure it is working correctly.

  Hydraulic oil s are more susceptible especially were air ingress occurs and the oxygen diffuses into it. Microbes can increase cavitation damage by acting as nucleus for the bubble formations. Thus it is common to have biocides encompassed into the oil

Symptoms

MEDIUM	FUEL	LUBRICANT	BILGE & BALLAST WATER
Visual	Aggregation of microbes into a biomass, observed as discolouration, turbidity and fouling. Biosurfactants produced by bacteria promote stable water hazes and encourage particulate dispersion. Purifiers and coalescers which rely on a clean fuel/water interface, may malfunction. Tank pitting.	Slimy appearance of the oil; the slime tends to cling to the crankcase doors. Rust films. Honey-coloured films on the journals, later associated with corrosion pitting. Black stains on white metal bearings, pins and journals. Brown or grey/black deposits on metallic parts. Corrosion of the purifier bowl and newly machined surface. Sludge accumulation in crankcase and excessive sludge at the purifier discharge. Paint stripping in the crankcase.	The formation of slimes and sludges which are black themselves or are black when scraped. Pitting of steel work, pipes and tank bottoms. Rapid corrosion of plating.
Operational	Bacterial polymers may completely plug filters and orifices within a few hours. Filters, pumps and injectors will foul and fail. Non uniform fuel flow and variations in combustion may accelerate piston rings and cylinder liner wear rates and affect cam-shaft torque.	Additive depletion. Rancid or sulphitic smells. Increase in oil acidity or sudden loss of alkalinity. (BN) Stable water content in the oil which is not resolved by the purifier. Filter plugging in heavy weather. Persistent demulsification problems. Reduction of heat transfer in coolers.	Unusual foul or sulphitic smells. Structural damage. Loss of suction in pipelines.

Fuel

When heavily contaminated fuel is brought onboard some or all of the problems listed above will be encountered within a short period of time. Particularly filter blocking and purifier malfunction. More long term will see injector and pump failures

Quick Appraisal of distilates

It is possible to make a quick judgement on the degree of contamination in distillates

- Sterlise a clear bottle and take a sample
- Any contaminationa will be apparent as a haze causes by the presence of sludge. This sludge shoiuld readily disperse by agitation. It will tend to settle out and stick to the sides. A black coloured sludge indicates the presence of SRB
- Repaeat the process for each fuel location to find the cleanest fuel. If only heavily contaminated is available this should be left to settle as long as possible. Were possible fuel should be drawen only via a filter, coalescer or purifier from the higher levels in the tanks. The use of a biocide at this point is inadvisable as the dislodges biofilms will tend to block all filters.
- Take a sample from the bottom of the tank and send to labratory for 'fingerprinting' against the bunker supplier

Lubricating Oil

When operated normally there are few microbes able to live succesfully in the nutrient and environmentally deficient lubricating oil

Bilge & ballast Water

Problems are normally associated with the presence of SRB pitting corrosion and is indicated by a sulphorus smell. Preventative action should be taken as soon as possible

Systems Affected by Microbiol attack

Fuel

Microbiologicalcontamination of distillates (rather than residual) fuels have been a well known phenomenom for some time. The changing chemistry of the fuels and the increaseing use of fuel additives have exasperated this.

Whilst being rich in carbon sources the fuels are often poor in inorganic nutrients such as Nitrogen, Phosphorous and Potassium and this by themselves do not promote rapid growth. These may be supplied by contaminated water or fuel additives entering the fuel.

Initial infestation will break down such components as n-alkenes to form alcohols and fatty acids. These are in turn used by other microbes and thus a self replensishing system is created in the free water

Evolution has led to new species of bacteria in distillate fuels that produce sticky polysaccharide polymers similar to чling fim'. These clog filters and other apertures by trapping rust. Thus the microbila contamination appears as a grey/brown sludge at the water/oil interface.

Stagnancy can lead to severe microbiol activity in long term fuel sorage tanks. The effect of this is to reduce the chain length of the hydrocarbons reducing the overall calorific value. In addition souring may occur as the microbes metabolises hydrogen sulphide. Altering the fuels chemical structure can have the effect of changing its pour point, cloud point and its thermal stability.

The formation of stable growth at the water interface can lead to maloperation of purifiers and coalescers

Attack by SRB and moulds can infuse hydrogen sulphide and other acidic products into the fuel leading to direct acidic attack. The lower pH particularly effects copper, aluminium and there alloys such as bronze. The depolorisation of steel leads to pitting

The most obvious effect of microbiol attack is filter and component blocking. In addition the fuel can become non-homogenous leading to variations in combustion and cylinder pressures. Increase liner and piston ring wear rates can result

It should be noted that the higher temerpatures of residual fuels dissuade the growth of microbes although not completely

This shows a gas oil service tank opened up for inspection after premature fuel filter blockages. The overall depth of the sludge seen in the bottom is about 5cm. The black growth occurred in several patches to a height of a few centimeters and was foamy in texture. The tank was cleaned and refilled with gas oil. Biocide was dosed to normal preventative levels and instructions given to watchkeepers for better drainage of this tank. No further problems was experienced

Lubricating Oil

Generally associated with egines with water cooled pistons were the chance of water ingress is higher. Infestations, including those found in hydraulic oils are indicated by a slimy deposit and blocked filters

I have seen this in a CPP system which had blade seal leakage. Before the system was overhauled it was necessary to change the pressure filters every two months. After overhaul and the removal of water this dropped to 1 year and event then only on running hours

Black stains may be seen and a rancid odour noticeable. If SRB as present, this is normally only the case in laid up ships, then severe pitting on ferrous and non-ferrous components may result

As the microbes tend to feed on the constituents and additives of the lube oil it effectiveness will be reduced as well as increased acidity and emulsification.

Typical sources of contamination are sea water (from coolers),bilge water, fuel and cooling water. The latter has increased in severity due to the banning of the use of chromates for cooling water treaments which had good biocide properties.

The use of increase alkaline lube oils has seen a reduction of microbiol attacks

Cooling water

The first indication is often destruction of the treatment reserves and the water will gradually become acidic. The coolant may be discoloured and have a strong odour and deposit scums or slimes. Oil emulsion coolants will tend to stratify.

The initial infestation will be by aerobic bacteria which, when they have depleted the dissolved oxygen the can then get the oxygent by reducing chemicals such as Nitrates producing ammonia or nitrogen. Eventually the water becomes so oxygen depleted that anaerobic microbes such as SRB will grow. this progression can occur in a matter of days

Bilge Water

This can contain complex groups of bacteria, yeast of moulds. These groups can contain varieties of species not only at a ships level but even in the same system. Thus it is difficult to identify exactly what individual components are required to lead to corrosion it is more useful to identify what groups will.

Hydrocarbons and other organic matter enter the bilge water and are degraded by specilaised microorganisms call 'hydrocarbonclastic'. This requires the presence of dissolved oxygen. The degraded carbon compounds can then act as food for SRB which extract and use the oxygen in sulphates (but cannot toleretate molecular or dissolved oxygen). Thus there are two distinct environments in the bilge water. The position of the boundary depends upon the level of reoxygenation of the water surface. This in itself is dependent on such things as surface area, agitation etc but is unlikely to be much above the base of the bilge and more likely to be found in any mud there.

The reduction of the sulphates found in sea water produces corrosive sulphides. Sulphur containing hydrocarbons tend to lead to hydrogen sulphide

Any detection of SRB in the bilge water will generally inndicate a severe infestation as the majoritory of the bacteria will be found in a slime at the steel plate surface.

Microorgansim action can have the affect of altering the electro-potential of the water and accelerate the electrochemical corrosion process. The process may be desribed as follows

1. *Aerobic microorganisms aggregating in slimes, muds or crevices use up the available oxygen in their immediate vicinity and create an oxygen deficient area. In electrochemical terms, such an area will be anodic in relation to relatively oxygen rich zones with fewer microbes. This oxygen gradient may be regarded as an electrochemical cell, precipitating the electron flux from the cathode to the anode, allowing deep anodic corrosion pits to develop. In addition, the microbial by-product which is a very corrosive acid, also acts as an electrolyte within the cell.*
2. *The formation of pits is not entirely an electron process based upon aerobic bacteria. These oxygen deficient areas are colonised by the anaerobic SRB, which produces HS and S^{2-} ions and hydrogen sulphide. These ions are highly aggressive towards steel and yellow metals, and form the characteristic craters. In carbon steel, a carbon skeleton remains visible as a graphite black colour and the bottom of each pit is usually black ferrous sulphide.*
3. *Simultaneously, SRB depolarise the surface steel. The steel becomes progressively more porous, susceptible to hydrogen ingress and hydrogen embrittlement. When ferrous sulphide forms, it is itself*

cathodic and thus continues to drive the electron flow and anodic pitting, even after the SRB have died or become less active. Corrosion driven by ferrous sulphide is thought to be most pronounced during intermittent aeration or in the presence of oxygen gradients.

These effects can occur in isolation or together and can have the effect of increasing natural corrosion rates of 0.05mm per year to 10mm per year.

Factors effecting microbiological attack in bilge water include;

- Ingress into bilge of polluted water
- Nutrients contained in water ingress
- Some micribes sucha s SRB are very temperature senisitve, Bilges tend to be at the ideal of 15 to 35'C. A reduction to 5'C will see a significant reduction in microbe growth. Where warm water continuoulsy enters bilge (say condensate drain) then this area may see significantly more activity.
- Regular pumping of bilges not only removes the nutrients fror SRB (remembering that they require other bacteri to break down chydrocarbons to simpler compounds) but will also remove the aerobic bacteria themselves and lowers the oxygen depletion layer to a position it can effect the SRB on the plates.
- Ingress of nutrients through shipboard sources. In addition detergents emulsify the oil and tend to make it more available for the microbes to use.

Ballast Water

Corrosion follows as similar process as seen in bilge water. In addtion it may contain microorganisms that are also harmfull to health such as cholera and botulism.
The ballast water can act as a transport for microbes distributing them into areas where they can act as parasites and pathogens. Recent legislation requiring the freshening of ballast mid ocean has only partly solved this with microbes able to remain in the mud and silt oin the bottom of the tank

Distillate Cargoes

There are many types of microbes taht can use hydrocarbons and these can form the basis of differing symbiotic groups. THese differing froups allow finger printing of the carog and the source of contamination (say from previous loadings) can be tracked.

Prevention and elimation of Microbial Contamination

Prevention

There are three generally accepted and commercially viable methods of prevention. These are good housekeeping, physical cleaning and biocides.

Factors controlling the rate of microbiological problems are;

- Infestation, this is nearly impossible to prvent
- The size of inital infestation

Phsyical prevention

Without water it is not possible to have microbial growth. Thus the first line in prevention is the removal of water, generally the more water the greater will be the problem. It is inevitable that there will always be some water with the oil, whether brought in when loading , through leaks or through condensation. Thus the need to constantly purify a system. This is seen on fuel systems where oil is taken from a settling tank to a service tank where it overflows back to the settling tank.(it should be noted that purifiers can act as a source of cross contamination and sterilisation after use on a system is recomended. Tanks should be fitted with drain cocks at there lowest points and should be drained regularly.

It should be noted that dead legs and other area where flow is minimal will tend to see increased attack therefore these should be designed out of the system. Rust and mud should not be allowed to accumulate as these can lead to growth.

Where possible tanks temperatures should be outside the 15-35'C optimum growth range and preferably be as high as practical which ensures sterilisation. The down side of this is an increase in boil off of lighter fractions in residual fuels which has led to the use of vapour recovery systems

It should be noted that modern microbes are capable of enclosing them selves in protective coatings against water removal. Biofilms on the plate surface are unlikely to be removed by water draining alone. Water draining should be carried out regularly. At each occasion the vale should be operated in small bursts to allow water to move to the cock. The used of surfctants for cleaning can cause increased attack in bilge water as it allows the microbes to move more freely into the oil phase. The commonest source of water contamination in Lube oil is coolers and piston cooling water. Every effort should be made to keep leakage to a minimu and water content should not be allowed to increase to greater than 0.5% per vol. The purifier should be set to a minimum temperature of 70'C and preferably higher and a flow rate ensuring complete charge circulation every 8 to 10 hours.

Cooling Water

It should be recognised that cooling water is not only affected by microbial attack it is also a common cause of infestation in other systems.

The following recomendations are made;

- Ensure correct treatment levels
- monitor alkalinity and ensure pH greater than 8
- Minimise amount of salts in the system that can act as nutrients
- Test for microbial contamination regularly. A polished mild steel bar placed in the bottom of the tank can act as an indicator of the prescence of SRB

Bilge Water

The present restrictions with regard to the pumping of bilges is the main reason for the increase occurence of microbial related failures. It should be noted that once infestation has occurred dosing with biocides will not remove it by itself as it will not penetrate the biofilm at normal, safe dosages. Cleaning is essential not only to remove the microbes but also to remove the mud & slime environments. This can have the added advantage of removing the ferrous sulphide formed by the SRB which acts as a cathoe to the steel of the hull.

The following recomendations are made;

- Pump regularly and prevent stagnation. This will help remove the hydrocarbon food and re-oxygenate the water
- Apply coating. This must be complete or holidays will act as foci for attack
- Use cathodic protection to remove the electro potential that is generated by feeding micorbes

Ballast Water

Problems are usually attributed to SRB

The following recomendations are made;

- inspect tank coatings for failures

- Regularly remove mud and slime
- Where tansk are not in use they should be kept as dry as possible
- Where possible restrict using poor sources of water and test regularly.

Chemical Prevention

Fuel preservatives or biocides are not designed to cope with large infestations. Instead they should be used as a preventative. The biocide may be water soluble or fuel solubel depending on the longevity required of protection. For tanks requiring long term protection water soluble agents are generally used. The agent remaining in the tank during fuel changes.

Typical properties of duel preservatives are;

- Combustible and clean burning without ash
- Not surface active
- compatible with fuel additives and system components
- Not affect flash point
- Not promote corrosion
- safe to use in normal use concentrations
- Destroy a wide range of microbes
- Fast acting
- Able to penetrate and disperce biofilm
- Not effect quality of fuel (or lubricating qualities when added to lubricating oils)
- in the main they should be water soluble
- they should contain dispersants to aid with the removal of debris
- environmentally friendly

Lube oil preservatives or biocides may be useful as a preventative but tend to break down rpaidly under normal operating temperatures

Water preservatives or biocides are watersoluble as in water soluble fuel treatment. They must adhere to requisite safety standards especially with jacket water heated evaporators.

Elimination

Physical Decontamination

Microorganisms do not die naturally they must be killed. Once microbial infection is established onboard it may be combatted by physical treatment methods e.g. heat and/or by the use of biocides. The dead microbes can still block filters.

Physical removal can be one of the following methods

- **Settling** The microbes can settle out to the bottom of a tank because they have an sg of 1.05
- **Centrifuges** . They can be efficiently removed with purifiers.
- **Filtration** Even though the microbes can be much smaller than the filter mesh it is still possible to remove them by proper staged filteration
- **Heat** This is a function of both temperature and time at that temperature. A temperatue of over 70'C for 20 minutes is effective in killing the microbes. However this is difficult to acheive at the plate surfaces and it may be necessary to sterilse the tank first say by the use of steam lances before filling with oil for heat reating.

Chemical Decontamination

Killing microbes using microbes is easy and effective, however the selection of chemicals appropriate for the system application and should be done with care. Such things as compatibility and hazards should be taken into account.

It is arguable that elimination after infestation is cheaper than continuous preventative dosing.Where contamination is heavy it may be necessary to add such high concentrations of biocide to make the fuel unusable. It would then ahave to be discharged and the system mechaincally cleaned.

similarly for lube oils heavy contamination will lead to loss of the lube oil.

For cooling water care hs to be taken when chosing the biocide to ensure it is temperature stable.

Whilst biocide treatment of bilge water is commercially viable (taking into account the cost of steel replacement), it is difficult to select and effective solution. This is particularly the case for SRB which is able to produce extremely resistant spores.

Suggeested course of action for bilges suffering microbial attack;

- Use commercial detergent hypochlorite bleaches to break down bio films
- Use broad spectrum biocide to supress all growth
- Use narrow spectrum biocides to target against SRB
- Pump bilges regualarly and prevent stagnation
- Add alkaline nitrate cooling water treatments to area where known SRB attack is occuring to reduce effects of hydrogen sulphide and other acidic by products.
- It is advantageous to oxygentate the water using chemicals such as hydrogen peroxide

For ballast systems the only effective method of elimination is the removal of sludges, muds and slimes

Alternatives to biocides

These include;

- UV Radiation
- Gamma and x-ray
- Ultrasound
- Microwave
- Continuous pasteuristion and heat control

health considerations

Normal disease producing microbes are not usually found in fuel or lubricating oils. However there are some aerosol born bacteria that can cause flu like symptoms

Of more concern is hydrogen Sulphide produced by **Sulphate Reducing bacteria (SRB)**. This is very toxic in even mild doses. It initally produces a distinctive 'rotting egg' smell. However a small increase in concentratin is enough to allow it to neutralise the sense of smell therefore it is possible to believe the source has disapeared when in fact it is increasing. It will eventually lead to death

- 3-50 ppm Offensive odour.
- 50-300 ppm Injuries to eyes, respiratory tract, dizziness.
- 100 ppm Loss of sense of smell.
- 300 ppm Life threatening.
- 700 ppm Rapidly lethal.

Biocide chemicals are themselves toxic and care should be taken in their handling and dosage.

The traditional method of using chlorine against such bacteri found in air conditioning etc can be limited especially against the biofilm in which the multi-specy microbe colonies are able to exist stably.

*The above is based for the main part by an artical by **R.A. Stuart***

Microbes of Microbiological Attack

Microbial problems were seen at their height in the early eighties. There has been a reduction in the number of incidents although the problem has never fgone away. In addition whereas effects were seen ainly in distillate fuels and lubricants, it is now seen in residual fuels, drinking and ballast water. Failure to eradicate completely a re put down to advserse trading, poor training and housekeeping, environmental restrictions in the use of microbial agents and the restrictions in bilge pumping placed by MARPOL

MICROBES

Microbiological contamination consisting of bacteria, yeasts and moulds, are easily tolerated at low contamination levels. It is only when their numbers are not controlled that rapid infestation occurs

From a marine point of view there are six main areas of concern for microbiological infestation. These are:

1. Distillate fuel;
2. Lubricating oil;
3. Cooling water;
4. Bilge water;
5. Ballast water;
6. Distillate cargoes.

Conditions promoting growth

In each case, it is to be remembered that microbes are living organisms and their growth depends upon the readily availability of water, nutrients, heat, oxygen (or sometimes lack of it) within an otherwise acceptable environment.

Water

The main requirement for microbiol activity is water. This must be available water and not just water content. bA typical minimum value is 1%. This can happern due to insufficient draining. The presence of free water can lead to rapid micorbiol growth after 1 week at 30'C. Where water is dispersed then growth is limited the microbes existing in water droplets or surrounded with a water sheath.

Modern lead-free gasolines contain water soluble oxygenates such as methyl and ethyl alcohol, methyl tertiary butyl ether these along with antifreeze glyciol when migrted to the water phase cause a depression in microbiol activity. The level of glycol must be above a minimum as below this the glycol can actually promote growth

Nutrients

Hydrocarbons and chemical additives in the fuel and lubricant act as their food source. In addition to this are nutritive matter found in contaminated water either fresh or sea water. Sea water in addition promotes the growth of sulphate reducing bacteria. Cargo residues , particularly for ships carrying such thinks like fertilisers are also sources. The presence of rust and other particulates can promote growth.

Note that clean dry fuel kept at reasonable temperature will never permit any significant growth

Temperature

Warm enginerooms (15 - 35'C) provide the ideal breeding ground for microbiol growth. Too hot (70'C) or too cold (5'C) will retard growth

Environment
Most corrosive forms of bacteria prefer astable environment and dislike adgitation. Thus ships in lay up or ships that spend long periods inactive are particularly susceptible. Water leakage or condenstaion will ten provide the living environment. The microbes live in the water phase but feed on nutrients in the oil phase this the boundary area sees agressive growth.

Indications
The unpleasant by-products of their digestion, after hydrocarbons have been oxidised into acids, include toxic and pungent hydrogen sulphide. This is produced from any sulphurous compounds within the fuel, lubricant, seawater or waste product. Microbial growth is seen as a characteristic sludge formed from accumulated cellular material which may restrict fuel and lubricant pipe lines and filters.

Types of Microbes

There are three basic types of micro organsims that cause problems in the marine industry, these are bacteria, yeasts and moulds.

Bacteria

Bacteria can be subdivided into

1. *Aerobic Bacteria Require oxygen to survive.*
2. *Anaerobic Bacteria Live in the absence of oxygen*
3. *Facultative Bacteria Live with or without oxygen*

Bacteria is a highly diverse group of single celled organisms with rigid cell walls. They may be rod like, spherical or spiral and many are actively mobile with a whip like appendage (flagellum). They can reproduce asexually and rapidly using binary fission with a doubling time of as low as 20 minutes. They are design to reproduce rapidly when the time is rigth and some are able to produce extremely resistant spores able to withstand high temperatures and disinfectants.

Although in the main they prefer neutral or slightly alkaline environments some can exist in the extremes of acid. They can excrete partial breakdown products on which other forms of bacteria can feed. In addition they can produce large amounts of extra-cellular slime which coats and stabilises the living environment. This slime can protect against or deactivate biocides. This slime can prevent the diffusion of oxygen to the base of the growth and thereby promote Suulphate Reducing Bacteria which are particularly agressive.

Yeasts

These are unicellular, being ovoid or spherical in shape some may also produce rudimentary filaments. They reproduce by budding and growing off the parent untill large enough to seperate. This process may take several hours.They prefer slightly acidity

Moulds

Multicellular with hard chitinous cell walls.They are ususally found as branched hyphaeforming a thick, tough intertwined mat occurring most commonly at oil/water interfaces. They reproduce by branching and can double there length in a few hours. They can also produce spores.

They prefer slightly acidic conditions, using oxygen in their feeding process they produce by products suitable for other microbes to feed and an atmosphre suitable for Sulphate Reducing bacteria.

They reduce complex hydrocarbons to simpler carbon compounds. Intensive corrosion can occur under the mat. They can be both sea water and temperature tolerant

Sulphate Reducing Bacteria (SRB)

These are a specific group of anaerobic bacteria with special growth requirements. They can only use simple carbon compounds therefore they require the prescence of other microbes. They will produce hydrogen Sulphide in the prescence of sulhure containing compounds such as sulphates found in sea water.

Desulfotomaculum has the added ability to produce extremely hardy spores able to resist exposure to air, heat and most biocide chemicals. Both this and Desulfovibrio are very insiduous and able to rapidly cause corrosion in ships hull and machinery

Symptoms of Microbiological Attack

Symptoms

MEDIUM	FUEL	LUBRICANT	BILGE & BALLAST WATER
Visual	Aggregation of microbes into a biomass, observed as discolouration, turbidity and fouling. Biosurfactants produced by bacteria promote stable water hazes and encourage particulate dispersion. Purifiers and coalescers which rely on a clean fuel/water interface, may malfunction. Tank pitting.	Slimy appearance of the oil; the slime tends to cling to the crankcase doors. Rust films. Honey-coloured films on the journals, later associated with corrosion pitting. Black stains on white metal bearings, pins and journals. Brown or grey/black deposits on metallic parts. Corrosion of the purifier bowl and newly machined surface. Sludge accumulation in crankcase and excessive sludge at the purifier discharge. Paint stripping in the crankcase.	The formation of slimes and sludges which are black themselves or are black when scraped. Pitting of steel work, pipes and tank bottoms. Rapid corrosion of plating.
Operational	Bacterial polymers may completely plug filters and orifices within a few hours. Filters, pumps and injectors will foul and fail. Non uniform fuel flow and variations in combustion may accelerate piston rings and cylinder liner wear rates and affect cam-shaft torque.	Additive depletion. Rancid or sulphitic smells. Increase in oil acidity or sudden loss of alkalinity. (BN) Stable water content in the oil which is not resolved by the purifier. Filter plugging in heavy weather. Persistent demulsification	Unusual foul or sulphitic smells. Structural damage. Loss of suction in pipelines.

		problems. Reduction of heat transfer in coolers.	

Fuel

When heavily contaminated fuel is brought onboard some or all of the problems listed above will be encountered within a short period of time. Particularly filter blocking and purifier malfunction. More long term will see injector and pump failures

Quick Appraisal of distilates

It is possible to make a quick judgement on the degree of contamination in distillates

- Sterlise a clear bottle and take a sample
- Any contaminationa will be apparent as a haze causes by the presence of sludge. This sludge shoiuld readily disperse by agitation. It will tend to settle out and stick to the sides. A black coloured sludge indicates the presence of SRB
- Repaeat the process for each fuel location to find the cleanest fuel. If only heavily contaminated is available this should be left to settle as long as possible. Were possible fuel should be drawen only via a filter, coalescer or purifier from the higher levels in the tanks. The use of a biocide at this point is inadvisable as the dislodges biofilms will tend to block all filters.
- Take a sample from the bottom of the tank and send to labratory for 'fingerprinting' against the bunker supplier

Lubricating OIl

When operated normally there are few microbes able to live succesfully in the nutrient and environmentally deficient lubricating oil

Bilge & ballast Water

Problems are normally associated with the presence of SRB pitting corrosion and is indicated by a sulphorus smell. Preventative action should be taken as soon as possible

Deck Crane Lifting Operations

The following contains subjective comment on lifting operations with the Grove AT1500, telescoping crane with flyboom It does not constitute a set of instructions and does not supersede in any way LOLER of other lifting operation regulations. In addition there are several factors such as outrigger extension, outrigger pad size and ground state which have been specifically excluded as they apply only to a shore based lift. We assume that the counterbalance weight is fixed and that the stability area of the load capability chart does not apply

In addition not considered here is the trim of the vessel although this will have an effect and should be considered

Crane Mounted Load Computer

The Grove Crane has a load computer which measures the load weight, Boom Extension and Boom angle. Form this it can compare computed load against a model stored within its memory. As the load approaches overload alarms are sounded. The computer has an extra mode which takes into account operation with the flyboom. This load computer is there as a safety factor and in no way should be considered to replace proper planning.

Lifting operations.

To carry out a safe lifting operation a set of variables must be known; these consist of the following

The weight of the lift.
- The height of the lift
- The Radius of the lift
- Obstructions within the lift area
- The Sea State

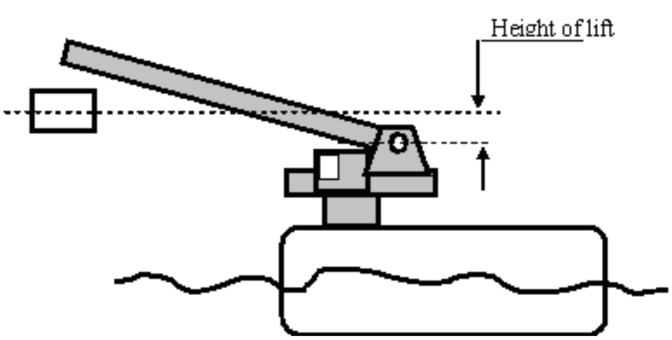
Weight Of lift

This may be either a known weight i.e. a weight which is certified and clearly marked, or an unknown estimated weight- in which case the weight is estimated and a factor of safety applied

To be added to the lift weight is the weight of the hook and lifting accessories before calculations are carried out. For the hook this is given as a test weight of
- **0.20 tonne for 10t hook and headache ball**
- **0.65 tonne for 50t 3 sheave block**

Note that unless the lift weight is certified it is always classed as estimated in all circumstances.

Height of the Lift.

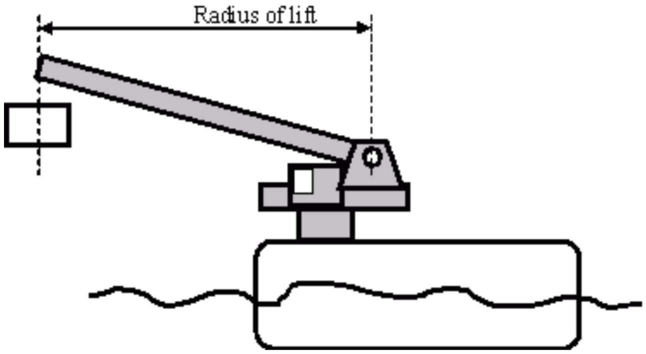


Note this is measured form the boom pivot point and not the deck.

The height of the pivot point above the deck is 4.2m

Radius of Lift

In a similar fashion the radius is measured from the pivot point and not the centreline of the crane. The distance from the pivot to the centreline is 2.1m



Obstructions within lift area

The area not only where the load will be lifted and put down, but also the area covered whilst the crane is slewing. Should this be of particular concern a lifting plan should be created and discussed with the crane driver highlighting areas of concern and how best the Crane drive may avoid them. It should be understood that the crane driver may be unsighted of some of these obstructions therefore where this is considered to be a high risk a lift supervisor should be designated to guide the crane driver at all times.

Special consideration has to be given to lifts of unusual shape or where spreader bars are in use.

The Sea State

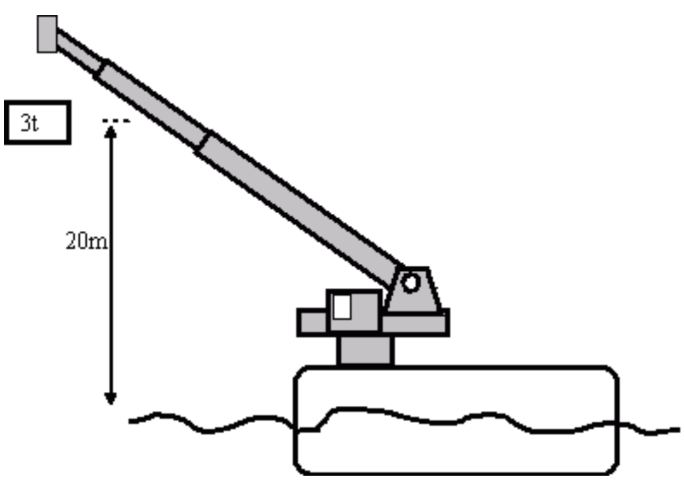
Vessel lift operations differ from shore based operations in that dynamic load forces have to be taken into consideration. The worst sea state condition considered to occur during the whole operation should be used and lift calculations based on that The Dynamic Loading factor stated in QGPS Lifting Equipment Regulations is 2.4 times for routine loading/unloading. A factor of 1.35 may be applied after written consent. maximum wind speed is given as 25knots and maximum wave height of 2m

Lifting tackle Inspections

A lifting tackle inspection by a competent person is required on all lifting accessories every 6 months. However, it is also required that all lifting accessories are examined for defects before use and this includes all crane operations. Appendix C gives a listing of the failure parameters applicable to typical lifting accessories

Worked Example

A load of estimated weight 3 tonne is to be lifted from a platform at a level of 20m above sea level. The vessel can manoeuvre so that the base of the centreline of the crane is within 20m of the lift. The sea state is calm



Lift Weight

The weight is a estimated 3tonne lift with a 100% factor of safety this gives a weight of 6 tonne for calculation. The 10 tonne block is fitted adding 0.2 tonne. The lifting accessories are estimated at 0.1 tonne. This gives a total weight to lift of 6.4 tonne

Lift Height

The height of the lift above sea level is 20m. The freeboard is 1.5m and the crane pivot is 4.1m above the deck This gives a lift height of 14.4m

Lift radius

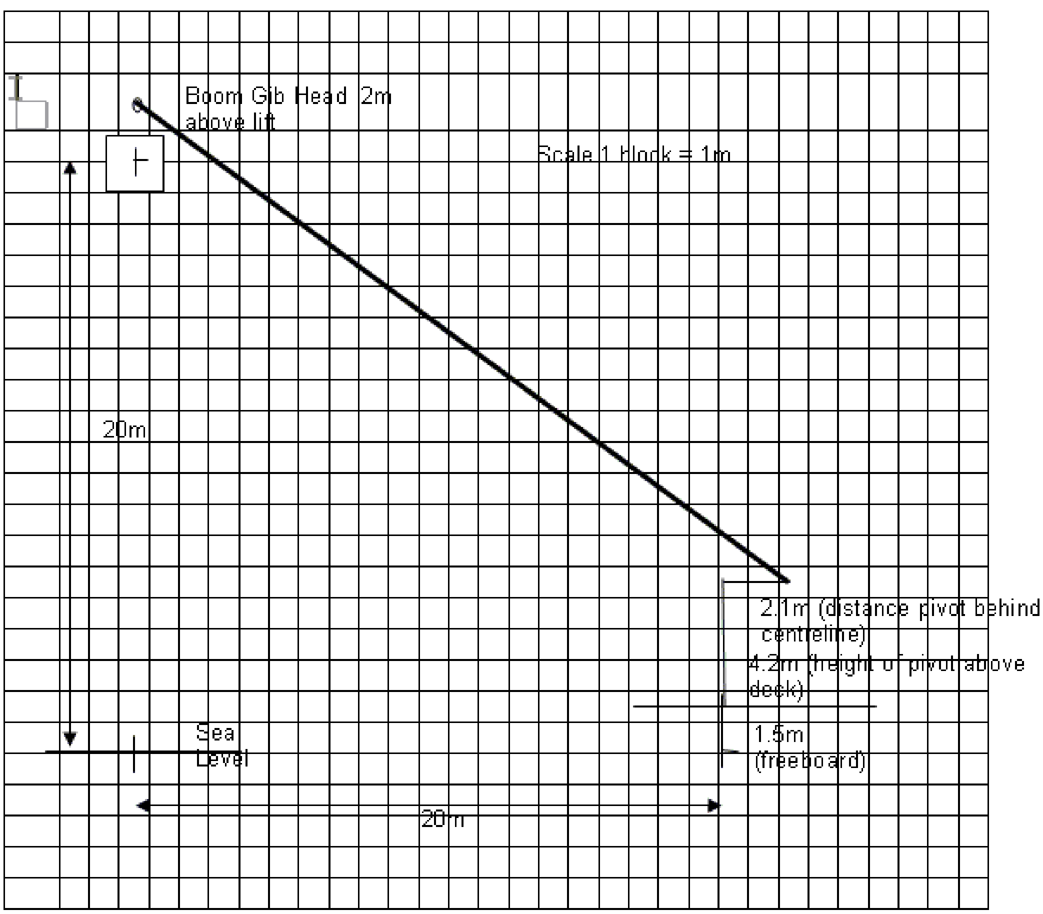
The Lift is 20m from the centre line. The pivot is 2.1m behind the radius therefore the lift radius becomes 22.1m

Obstructions

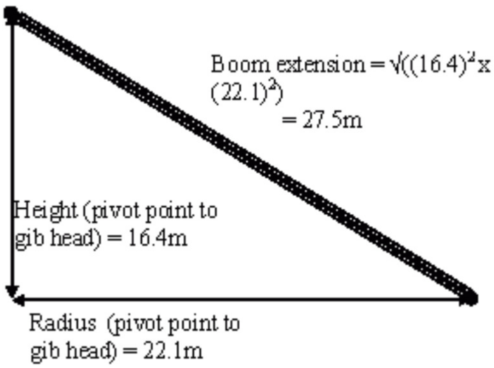
The lift is clear of obstructions. However to clear the lift and ensure that the accessories are properly placed the Gib head has to be 2m above the lift. This changes the height of the boom to 16.4m

Calculation of Boom extension

The easiest way to do the following is with graph paper with suitable scaling



however it is possible to calculate the required boom length.



Checking the Cranes Capability

We now look at the Lifting capacity chart for the crane

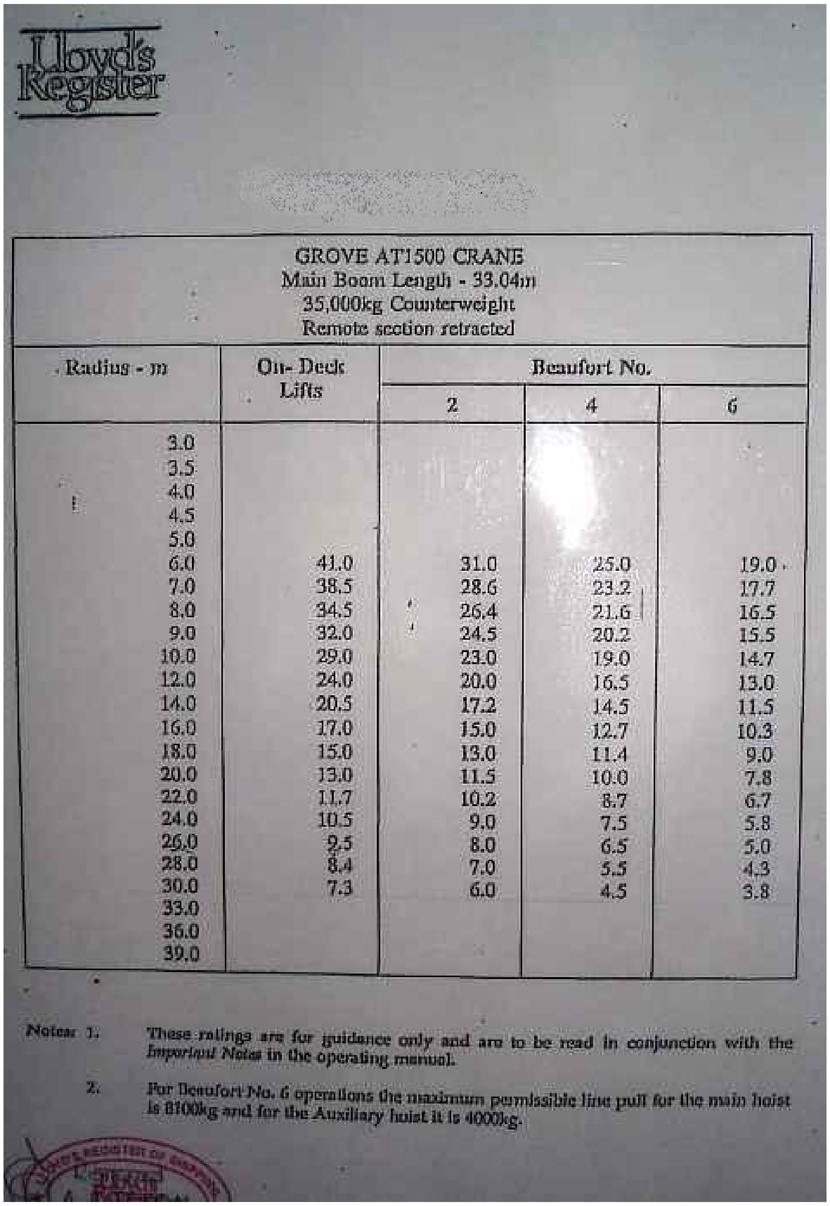
RADIUS IN METRES	MAIN BOOM LENGTH (M) [FLYBOOM RETRACTED]									TELESCOPIC BOOM LOCKED, FLYBOOM EXTENDED	
	13.58	15.85	18.29	20.73	23.16	25.60	28.04	30.48	33.04	42.76	
2.80	136.00									LOAD	ANGLE
3.00	127.00	70.70	69.50								
4.00	107.00	70.70	67.00	60.00	57.00						
5.00	93.00	70.70	63.50	57.00	53.50	48.50					
6.00	85.00	70.70	60.00	53.50	50.00	46.20					
7.00	77.20	70.70	57.50	51.00	47.50	44.10	37.50	35.10			
8.00	66.00	64.50	52.50	46.20	43.00	39.40	36.00	33.60	29.20		
9.00	56.90	56.20	48.50	42.20	39.00	35.75	33.00	30.50	26.80		
10.00	50.50	49.70	43.70	38.00	35.20	32.90	30.00	27.90	24.20	20.40	79.5^{0}
12.00	44.90	44.70	39.00	35.00	32.00	30.10	27.60	25.60	21.80	20.20	78.0^{0}
14.00	39.60	39.60	35.50	32.00	29.00	27.70	25.40	23.60	19.80	19.80	77.0^{0}
16.00		31.60	30.00	27.00	24.85	23.00	21.60	20.30	16.40	17.70	74.0^{0}
18.00			25.70	23.30	21.00	20.15	18.20	17.30	14.00	15.50	71.5^{0}
20.00				20.30	18.00	16.80	16.40	14.80	11.80	13.70	68.0^{0}
22.00				17.50	15.70	14.60	13.85	13.20	10.20	11.90	65.0^{0}
24.00					13.80	12.80	11.90	11.60	8.85	10.45	62.0^{0}
26.00						11.30	10.50	9.90	7.70	9.30	58.5^{0}
28.00							9.20	8.70	6.70	8.30	56.0^{0}
30.00								7.8	5.90	7.40	52.0^{0}
33.00									5.20	6.50	48.0^{0}
36.00									4.70	5.60	43.5^{0}
39.00										4.55	37.5^{0}
										3.80	29.5^{0}
										2.90	20.0^{0}

. Here we can see that at 20m radius/28.04m boom extension the lift capability is 11.9 tonne. For a 22m radius with same boom extension the lift capability is 10.5 tonne. As are lift is 6.4 tonne the crane is suitable.

We therefore instruct the crane driver to Gib Up and Boom out to 27.5 m placing the Gib 2 metres above the lift

These instructions may also be used for shore crane operations. On the capability chart a darkline denotes the limit of stability and refers to lifting weights with the boom at right angles to the bed rather than over the cab. For shore operations the capability chart refers to full outrigger extension only and a separate chart must be in place if half outrigger extension is to be used

Effects of sea state


Lloyd's Register

GROVE AT1500 CRANE
Main Boom Length - 33.04m
35,000kg Counterweight
Remote section retracted

Radius - m	On- Deck Lifts	Beaufort No.		
		2	4	6
3.0				
3.5				
4.0				
4.5				
5.0				
6.0	41.0	31.0	25.0	19.0
7.0	38.5	28.6	23.2	17.7
8.0	34.5	26.4	21.6	16.5
9.0	32.0	24.5	20.2	15.5
10.0	29.0	23.0	19.0	14.7
12.0	24.0	20.0	16.5	13.0
14.0	20.5	17.2	14.5	11.5
16.0	17.0	15.0	12.7	10.3
18.0	15.0	13.0	11.4	9.0
20.0	13.0	11.5	10.0	7.8
22.0	11.7	10.2	8.7	6.7
24.0	10.5	9.0	7.5	5.8
26.0	9.5	8.0	6.5	5.0
28.0	8.4	7.0	5.5	4.3
30.0	7.3	6.0	4.5	3.8
33.0				
36.0				
39.0				

Notes: 1. These ratings are for guidance only and are to be read in conjunction with the *Important Notes* in the operating manual.

2. For Beaufort No. 6 operations the maximum permissible line pull for the main hoist is 8100kg and for the Auxiliary hoist it is 4000kg.

A set of Class approved Guidance charts indicate the effects of seat state on the lifting capabilities of the vessel. These supersede the lifting capability chart although they are for guidance and care must be taken to observe additional factors given by the crane manufacturer.

Fly Boom Extended

Extending the flyboom creates a special case. The flyboom is only used with all the sections at maximum extension. For this crane that is a boom extension of 42.76m. The lifting capacity chart now changes from a radius/boom length relationship to a boom angle/fixed boom length relationship. Again the required angle to check the capability of the crane can be found by either by use of graph paper or by calculation

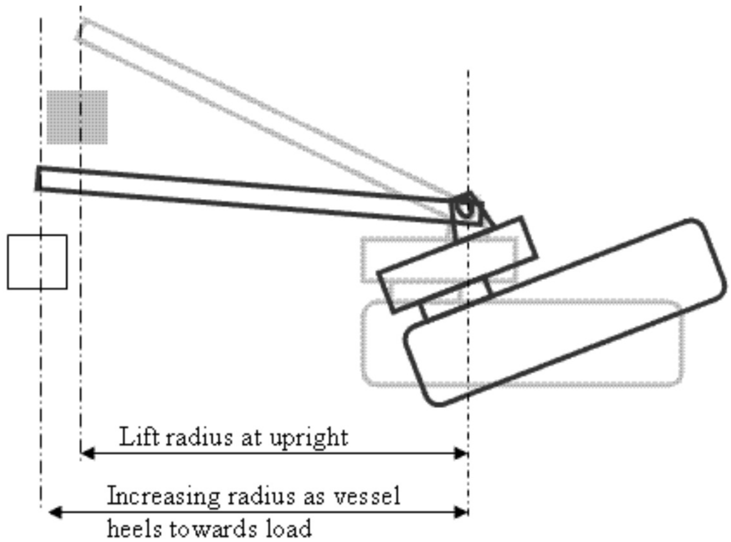
It should be noted that great care when operating with the flyboom extended must be taken to ensure that the crane is not overloaded something which is entirely possible even with no load on the hook when Gibbing down

In addition a **Swing Away** may be used which takes the form of a fixed boom that bolts to the jib head and generally sits at an angle to the boom.

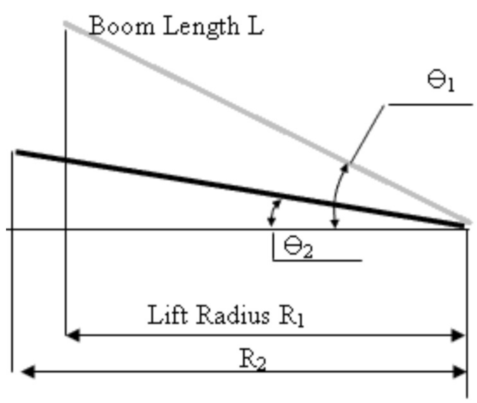
The Effects of Dynamic Loading on the Lifting Capability of a Crane

For this document 'Dynamic loading refers only to the effects of movement of the vessel due to rolling only. The effects of Pitching, lift and lower acceleration and deceleration, relative movement between vessel and platform from which weight is being lifted or lowered to is not considered.

Effects of Heel Angle



As the crane comes under load there is a tendency for the vessel to heel towards the load. The effect of this is to increase the lift radius. This effects increases with increasing boom length.



Increase in Lift Radius = New Lift Radius R2 - Original Lift Radius R1

= $L\cos Ø_2 - L\cos Ø_1$

= $L(\cos Ø_2 - \cos Ø_1)$

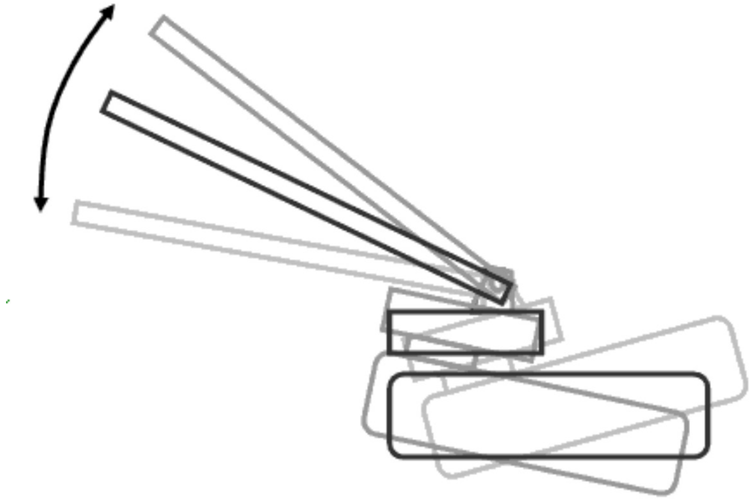
It can be seen that this effect increases with increasing boom angle.
For example with an original boom angle of 20^o a heel of 5^o will increase lift radius by about 3%
At 65^o the same heel will increase lift radius by about 8%

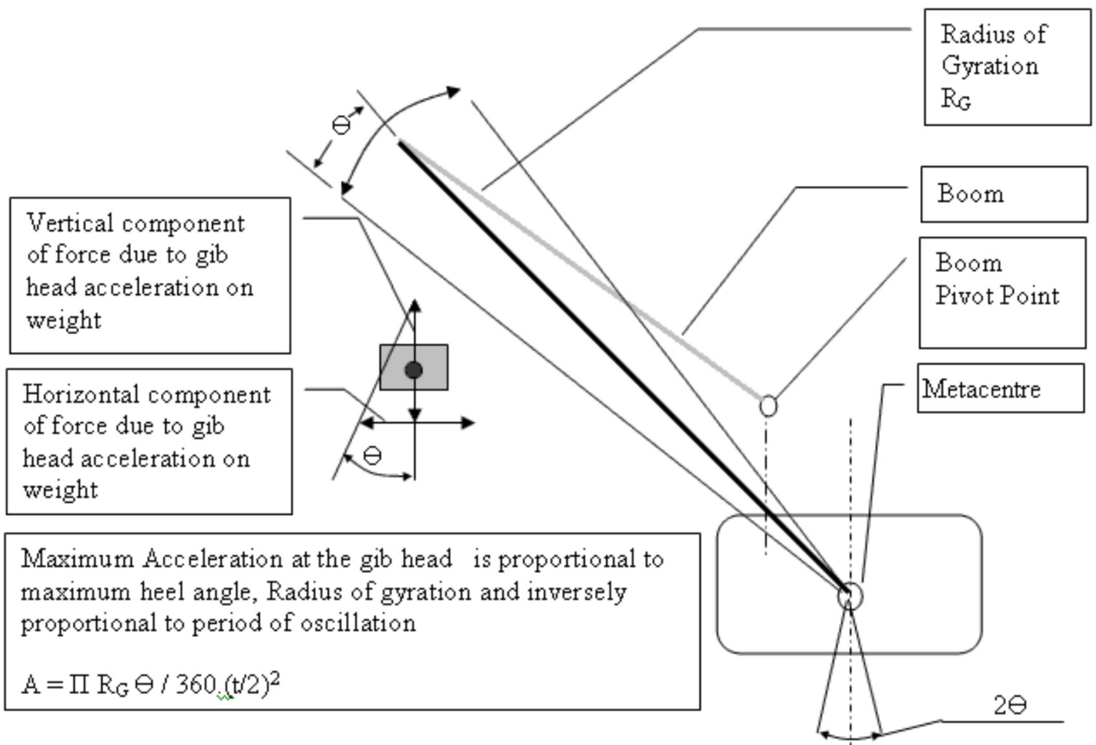
Lift radius is computed as a function of Boom angle and Boom Extension only; no compensation is given for Heel. In such conditions Overload may occur and proper planning including a reduction in the Lift capacity should be made.

Effects of Rolling

The effects of rolling are two part;
Firstly they increase the Lift radius in the same fashion as described under 'Effects of Heel'.
Secondly they accelerate and decelerate the Gib head and thereby the Lift weight, as well as the main structure itself. All of which adds up to increased load on the crane.

Considering the effect of the lift weight only



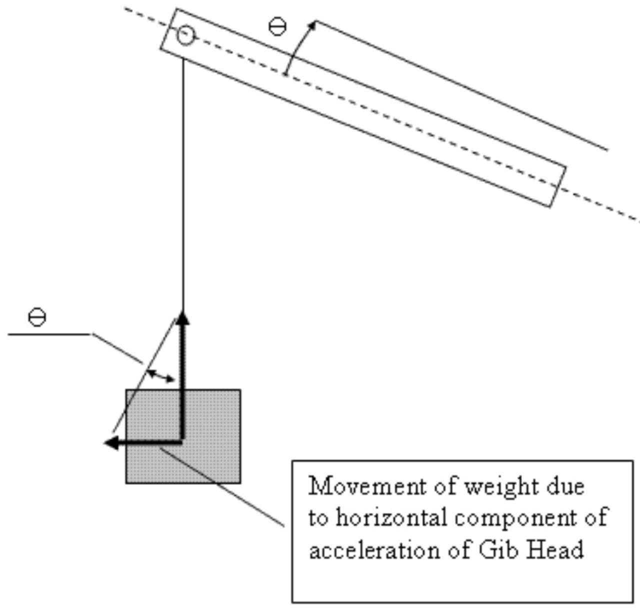


For example a max heel angle of 10o, radius of gyration 40m and a period of oscillation of 6s would cause acceleration of the head of about 0.4g increasing load due to weight by 2.5 to 3.5% dependent on Boom Angle

This effect increases with increase boom length and boom angle and worsening weather condition

The effect of this will be rapid transients in the indicated load on the computer; the effect of increased radius of lift would not be accounted for. In such conditions Overload may occur and proper planning including a reduction in the Lift capacity should be made.

Pendulum Effects on Weight during Rolling



The effects of this is to increase the radius of Lift as the weigh moves away from the Gib Head as well as to impart forces onto the Gib head for which it was not designed.

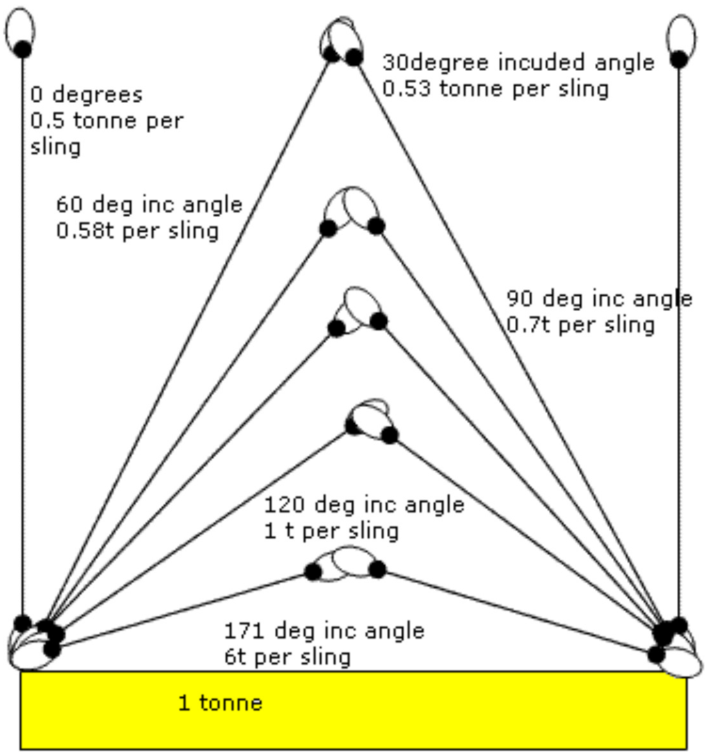
This action tends to increase with increased distance between gib head and load as well as rolling severity.

Please note that the above information is given without guarantee but based on my training as an Appointed Person.

Lifting- slinging

when taking a course as a'designated person for lifting operations I was horrified to reaise just how dngerous some of the operations I had been carrying out. This page demonstrates the lifting factors that you should be applying to lifting accessories

Sling Angles

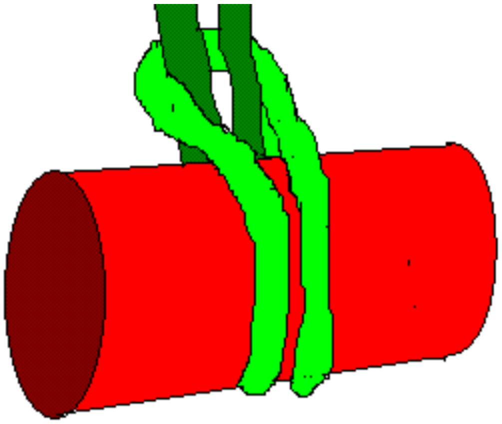


The abve shows the loading in slings depending on the included angle. It can be seen that fitting too short a pair of slings and thereby creating too great an included angle can substantially increase the loading in the sling and cause it to fail

You should not consider any lifting operation with an included angle greater than 90 degrees and then you should give a 1.5 factor for the slings i.e. the slings should be at least 0.75 tonne each to lift the 1 tonne weight

Choking

This effect also occurs when choking a sling



Should the choke be batterned down it is possible to generate very high included angles severely straining the sling in this area and can easily lead to failure. Should it be necessary to put a wrap on a lift for security then you always consider making 2 full turns. If this is not possible then the included angle should never be reduced below 90 degrees and a 1.5 factor should be applied to the sling.

This is a representation of two different KUPLEX chain sling load charts, these charts are for demonstration purposes only you must always check with the manufacturers own load charts. ATSL cannot be held responsible for any inaccuracies.

General Purpose Slings – Uniform Load Method

Size	Single	Endless	Two Leg		Three Leg		Four Leg		Size
			90°		30°		90°		
mm	t	t	0°-90°	90°-120°	0°-45°	45°-60°	0°-90°	90°-120°	mm
7	1.5	2.25	2.1	1.5	3.1	2.2	3.1	2.2	7
10	3.2	4.8	4.4	3.2	6.7	4.8	6.7	4.8	10
13	5.4	8.1	7.5	5.4	11.3	8.1	11.3	8.1	13
16	8.0	12.0	11.2	8.0	16.8	12.0	16.8	12.0	16
19	11.5	17.2	16.1	11.5	24.1	17.2	24.1	17.2	19
23	16.9	25.3	23.6	16.9	35.4	25.3	35.4	25.3	23
26	21.6	32.4	30.2	21.6	45.3	32.4	45.3	32.4	26
32	32.0	48.0	44.8	32.0	67.2	48.0	67.2	48.0	32

Special Purpose Slings – Trignometric Method of Rating

Size	Single	Endless	Two Leg				Three Leg				Four Leg				Size
			90°				30°				90°				
mm	t	t	@33°	@60°	@90°	@120°	@33°	@60°	@90°	@120°	@33°	@60°	@90°	@120°	mm
7	1.5	2.25	2.8	2.5	2.1	1.5	4.3	3.8	3.1	2.2	5.8	5.2	4.2	3.0	7
10	3.2	4.8	6.1	5.5	4.5	3.2	9.2	8.3	6.7	4.8	12.3	11.0	9.0	6.4	10
13	5.4	8.1	10.4	9.3	7.6	5.4	15.6	14.0	11.4	8.1	20.8	18.7	15.2	10.8	13
16	8.0	12.0	15.4	13.8	11.3	8.0	23.1	20.7	16.9	12.0	30.9	27.7	22.6	16.0	16
19	11.5	17.2	22.2	19.9	16.2	11.5	33.3	29.8	24.3	17.2	44.4	39.8	32.5	23.0	19
23	16.9	25.3	32.6	29.2	23.9	16.9	48.9	43.9	35.8	25.3	65.3	58.5	47.8	33.8	23
26	21.6	32.4	41.7	37.4	30.5	21.6	62.5	56.1	45.8	32.4	83.4	74.8	61.0	43.2	26
32	32.0	48.0	61.8	55.4	45.2	32.0	92.7	83.1	67.8	48.0	123.6	110.8	90.5	64.0	32

Inspection Criteria

Eyebolt(Dynamo)

Check Code and SWL legible
Ensure valid test certificate
Check Threads for wear and distortion
Ensure minimum 1.5 threads remaining when pin home
Ensure wear less than 8%
Ensure no nicks, cracks or distortions
Remove corrosion and treat as wear
Ensure no indication of heat damage or weld splatter

Eyebolt(Shoulder)

Check Code and SWL legible
Ensure valid test certificate
Check Threads for wear and distortion
Ensure minimum 1.5 threads remaining when pin home
Ensure wear less than 8%
Ensure no nicks, cracks or distortions
Remove corrosion and treat as wear
Ensure no indication of heat damage or weld splatter

Shackle (Dee)

Check Code and SWL legible
Ensure valid test certificate
Check Threads for wear
Ensure Pin correct for body, of the same material
Ensure pin head shoulder is well seated
Ensure minimum 1.5 threads remaining when pin home
Ensure wear less than 8%
Ensure no nicks, cracks or distortions
Check shackle not opening up
Remove corrosion and treat as wear
Ensure no indication of heat damage or weld splatter

Shackle (Bow)

Check Code and SWL legible
Ensure vald test certificate
Check Threads for wear
Ensure Pin correct for body, of the same material
Ensure pin head shoulder is well seated
Ensure minimum 1.5 threads remaining when pin home
Ensure wear less than 8%
Ensure no nicks, cracks or distortions
Check shackle not opening up
Remove corrosion and treat as wear
Ensure no indication of heat damage or weld splatter

Masterlink

Check Code and SWL legible
Ensure valid test certificate
Ensure wear less than 8%
Ensure no nicks, cracks or distortions
Remove corrosion and treat as wear
Ensure no indication of heat damage or weld splatter

Padeye

Check Code and SWL legible
Ensure valid test certificate
Ensure wear less than 8%
Ensure no nicks, cracks or distortions
Remove corrosion and treat as wear
Remove paint and NDT test weld as required
Ensure no indication of heat damage or weld splatter

Sling(Chain)

Check Code and SWL legible
Ensure valid test certificate
Ensure wear less than 8%
Ensure stretch less than 5%
Ensure Turn or twist a maximum 1/2 turn in 4 metres (hanging)
Ensure no nicks, cracks or distortions
Remove corrosion and treat as wear
Ensure no indication of heat damage or weld splatter
Ensure hooks are of the 'C' design or fitted with safety hook
Ensure hook end is in align with shank
Ensure hook throat opening has not increased by 15%
Ensure hook throat shank wear less than 10%
Ensure Clutch in good condition

Sling(Wire)

Check Code and SWL legible
Ensure valid test certificate
Ensure diameter consistent over length
Ensure no more than 5% randomly broken wires in 10 rope diameters
Ensure no more than 3 wires broken in local group in any one strand or 6 rope diameters
Check external wear less than 10 & of nominal
Remove corrosion and treat as wear
Check for excessive waviness
Check for strand protrusion
Check for core protrusion
Check for localised increase in core diameter due to core deterioration
Check for localised reduction in diameter
Check for memory kinks
Check for flatterned portions
Check integrity of eyes and fittings
Check for heat distortion
Check for pitting and prescence of weld splatter

Sling(Web)

Check Code and SWL legible
Ensure valid certificate of compliance
Check scuffing damage not excessive
Check for chemical/contaminants damage
Check for selvedge damage
Check non load bearing outer sheaf of Round slings not broached
Check for Heat and friction damage
Check integrity of eyes and fittings
Ensure less than 8 lines in 25mm damaged stitching
Check for pitting and prescence of weld splatter

Sling(Multileg)

Check Code and SWL legible
Ensure vald test certificate
Ensure wear less than 8%
Ensure stretch less than 5%
Ensure Turn or twist a maximum 1/2 turn in 4 metres (hanging)
Ensure no nicks, cracks or distortions
Remove corrosion and treat as wear
Ensure no indication of heat damage or weld splatter
Ensure hooks are of the 'C' deisgn or fitted with safety hook
Ensure hook end is in align with shank
Ensure hook throat opening has not increased by 15%
Ensure hook throat shank wear less than 10%
Ensure Legs are of the same length
Ensure Clutch in good condition

Chain Block

Check Code and SWL legible
Ensure valid test certificate
Degrease, disassemble and clean for inspection
Ensure load Chain has wear less than 8%
Ensure load Chain has stretch less than 5%
Ensure load Chain has Turn or twist a maximum 1/2 turn in 4 metres (hanging)
Ensure load Chain has no nicks, cracks or distortions
Remove corrosion and treat as wear
Ensure load Chain has no indication of heat damage or weld splatter
Ensure hooks are of the 'C' design or fitted with safety hook
Ensure hook end is in align with shank
Ensure Gears in good condition
Check chain attachements and Clevis pins
Check bearings, pins rollers for distortion and wear
Check pawl and ratchet for work and operation
Ensure hook throat opening has not increased by 15%
Ensure hook throat shank wear less than 10%

Lever Hoist

Check Code and SWL legible

Ensure valid test certificate
Degrease, disassemble and clean for inspection
Ensure load Chain has wear less than 8%
Ensure load Chain has stretch less than 5%
Ensure load Chain has Turn or twist a maximum 1/2 turn in 4 metres (hanging)
Ensure load Chain has no nicks, cracks or distortions
Remove corrosion and treat as wear
Ensure load Chain has no indication of heat damage or weld splatter
Ensure hooks are of the 'C' design or fitted with safety hook
Ensure hook end is in align with shank
Ensure Gears in good condition
Check chain attachements and Clevis pins
Check bearings, pins rollers for distortion and wear
Check pawl and ratchet for work and operation
Ensure hook throat opening has not increased by 15%
Ensure hook throat shank wear less than 10%

Beam

Check Code and SWL legible
Ensure valid test certificate
Check condition as required

Other

Check Code and SWL legible
Ensure valid test certificate
Check condition as required

Lifting using Accessories

Lifting using Accessories

Calculation of Load

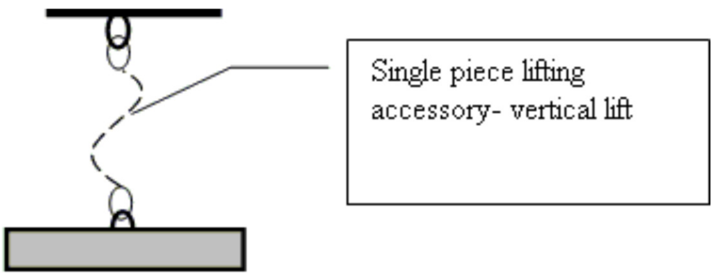
There are only two types of load to be lifted

- **Known-** there must be a Certificate of Weight or a Guaranteed Weight name plate attached.
- **Estimated-** Any other weight. When doing lift calculations 50% must be added to estimated weight

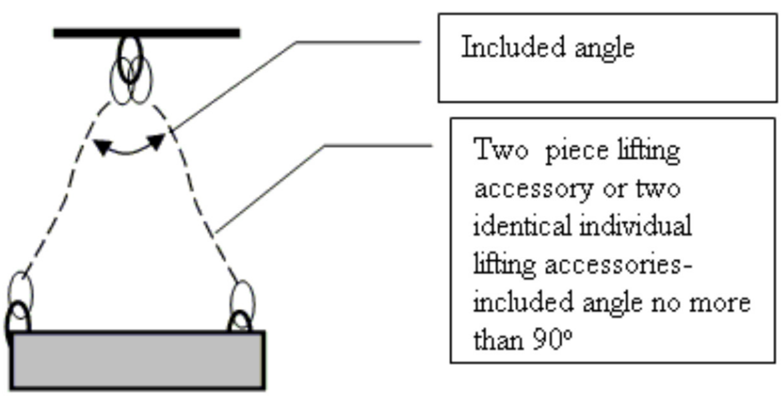
Note that in addition to the load itself additional factors such as ground effect e.g stiction and dynamic loading effects of lifting with relative motion between crane mount and load platform must be taken into account

Safe Working Loads

For a straight vertical lift the maximum lift weight is the Safe Working Load (SWL) of the lifting accessory

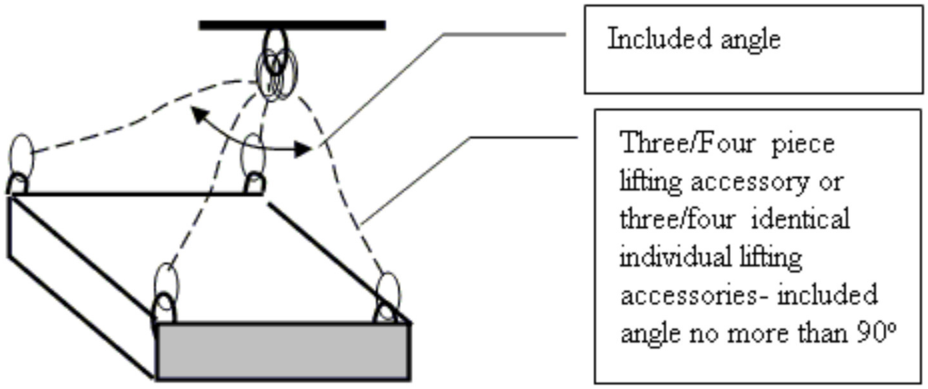


For a lift using an accessory with two legs or two matched pairs used at angles up to 45^{o} from vertical (i.e. non vertical to 90^{o} included) then the maximum SWL is 1.4 (normally rounded up to 1.5) times the SWL in each leg e.g. the maximum lift for two matched 5 tonne strops is 7.4 tonnes



The maximum included angle is 90^{o}, no lift should take place with angles greater than this.

For 3 or more piece lifting accessories of 3 or more identical lifting accessories used at angles up to 45^{o} from vertical then the maximum Lift is 2.1 times the SWL or each leg. e.g the maximum lift weight of four matched 5 tonne strops is 10.5 tonnes



The maximum included angle is 90°

Note

- For lifting accessories such as Multileg chain slings (Brothers), the SWL takes in to account that may be used at angles up to 45° and therefore the maximum lift weight would be the SWL of each leg times the number of legs (or stated Total Lift) although this should be clear stated on Test Certificate.
- The reduction in capability also applies to Shackles used when used in non vertical Lifts (Dee Shackles must only be used in vertical lifts)
- The reduction in capability also applies to Chain blocks, lever hoists which are in use.
- For non uniform shaped loads special consideration has to be given to the Centre of Gravity and possible localised overloading.