FUNCTION 1: MARINE ENGINEERING AT THE MANAGEMENT LEVEL

Knowledge, understanding and proficiency	Total Hours for each topic	Total hours for each subject area of Required performance
Competence:		
1.1 MANAGE THE OPERATION OF PROPULSION PLANT MACHINERY		
1.1.1 DESIGN FEATURES AND OPERATIVE MECHANISM OF MARINE DIESEL ENGINE AND ASSOCIATED AUXILIARIES	15	
1.1.2 DESIGN FEATURES AND OPERATIVE MECHANISM OF MARINE STEAM TURBINE AND ASSOCIATED AUXILIARIES	5	
1.1.3 DESIGN FEATURES AND OPERATIVE MECHANISM OF MARINE GAS TURBINE AND ASSOCIATED AUXILIARIES	5	
1.1.4 DESIGN FEATURES AND OPERATIVE MECHANISM OF MARINE STEAM BOILER AND ASSOCIATED AUXILIARIES	10	
1.1.5 DESIGN FEATURES AND OPERATIVE MECHANISM OF PROPELLER SHAFT AND ASSOCIATED ANCILLARIES	15	50
1.2 PLAN AND SCHEDULE OPERATIONS Theoretical knowledge		
1.2.1 THERMODYNAMICS AND HEAT TRANSMISSION		
.1 Gas cycles/engine analysis	12	
.2 Properties of vapours	6	
.3 Steam cycles	9	
.4 Refrigeration	6	
.5 Combustion	6	
.6 Heat transfer	12	
.7 Air conditioning	3	54
1.2.2 MECHANICS AND HYDROMECHANICS		
.1 Balancing	4	
.2 Simple harmonic motion	6	
.3 Stress & strain	10	
.4 Torsion	8	
.5 Combined stress	4	
.6 Fluid mechanics	12	44
1.2.3 PROPULSIVE CHARACTERISTICS OF DIESEL ENGINES, STEAM AND GAS TURBINES, INCLUDING SPEED, OUTPUT AND FUEL CONSUMPTION		

.1 Propeller and load diagrams .2 Propulsion characteristics diésel .3 Propulsion characteristics steam plant .4 Propulsion characteristics gas turbines		20
1.2.4 HEAT CYCLE, THERMAL EFICIENCY AND HEAT BALANCE OF THE FOLLOWING Marine diesel engine Marine steam boiler and steam turbine Marine gas turbine	5 10 5	20
1.2.5 REFRIGERATORS AND REFRIGERATION CYCLE Refrigeration and air conditioning system design, operation and maintenance	10	10
PHYSICAL AND CHEMICAL PROPERTIES OF FUELS AND LUBRICANTS Shore side and shipboard sampling and testing Interpretation of test results Contaminants including microbiological infection Treatments of fuels and lubricants including storage, centrifuging, blending, pretreatment and handling	1 1 2 4	8
TECHNOLOGY OF MATERIAL Destructive and non-destructive testing of material Engineering processes used in construction and repair	3 4	7
1.3 OPERATION, SURVEILLANCE, PERFORMANCE ASSESSMENT AND MAINTAINING SAFETY OF PROPULSION PLANT AND AUXILIARY MACHINERY Practical knowledge **1.3.1** START UP AND SHUT DOWN MAIN AND AUXILIARY MACHINERY, INCLUDING ASSOCIATED SYSTEMS Main machinery and associated systems Steam boilers and associated systems Auxiliary prime mover and associated systems Other auxiliary machinery	7 6 4 3	20
1.3.2 OPERATING LIMITS OF PROPULSION PLANTS	-	8

1.3.3 EFFICIENT OPERATION, SURVEILLANCE, PERFORMANCE ASSESSMENT AND MAINTAINING SAFETY OF PROPULSION PLANT AND AUXILIARY MACHINERY		
Diesel engines	10	
Engine components	18	
Engine lubrication	8	
Fuel injection	12	
Scavenging and supercharging	10	
Starting and reversing	8	
Cooling systems	4	
Diesel engine control and safety	4	
Diesel engine emergency operation	2	
Multi-engine propulsion arrangement	2	
Air compressors and compressed air systems	3	
Hydraulic power system	6	
Types of auxiliary boilers	9	
Auxiliary steam system	2	
Safety valves	4	
Boiler water level indicators	6	
Use of sea water in boilers	0.5	
Use of fresh water in boilers	0.5	
Boiler water testing	3	
Boiler water treatment	9	
Auxiliary steam turbines	9	
Boiler defects	3	
Boiler and steam turbine survey and repairs	6	
Evaporators	6	
Thermal fluid heating system	3	148
1.3.4 FUNCTIONS AND MECHANISM OF AUTOMATIC CONTROL	-	
FOR MAIN ENGINE	4	
Diesel engines	3	
Steam turbines	3	10
Gas turbines		
1.3.5 FUNCTIONS AND MECHANISM OF AUTOMATIC CONTROL FOR AUXILIARY MACHINERY		
Generator and distribution system	4	
Steam boiler	5	
Oil purifier	3	
Refrigeration system	3	
Pumping and piping system	1	
Steering gear system	2	
Cargo handling equipment and deck machinery	1	19
1.4 MANAGE FUEL, LUBRICATION AND BALLAST OPERATION		
1.4.1 OPERATION AND MAINTENANCE OF MACHINERY, INCLUDING PUMPS AND PUMPING SYSTEM		
Bilge and ballast.	2	
	4	

Prevention of pollution of the sea by oil Sewage and sludge	4	10
Total for Function 1: Marine Engineering at the Management Level		**428 hours**

1.1. MANAGE THE OPERATION OF PROPULSION PLANT MACHINERY

1.1.1. DESIGN FEATURES AND OPERATIVE MECHANISM OF MARINE DIESEL ENGINE AND ASSOCIATED AUXILIARIES

DIESEL ENGINE THEORY AND STRUCTURE

Engine Types

The choice of a main propulsion engine for a motorship is by no means an easy one. A few years ago a shipowner had the straight choice of a direct coupled slow-speed engine driving a fixed pitch propeller or a geared four-stroke medium-speed engine driving either a fixed or controllable pitch propeller. Today, vessels are entering service with geared and direct coupled two-stroke engines driving either fixed or controllable pitch propellers and geared four-strokes; while for certain ships, particularly those involved with offshore oil exploration and production, diesel-electric power plants are becoming increasingly popular. The choice of either direct or indirect drive of a ship is governed more by the operating profile of the ship and economic factors concerning the power plant as a whole, rather than the characteristics of a particular make or type of diesel main propulsion engine.
Marine engines are required to operate continuously, reliably and safety in unmanned engine rooms and with extended periods between planned overhauls. They may be expected to operate for considerable periods at low power without ill effects, and to be tolerant of low quality fuels while maintaining very high thermal efficiency.
Continuing development and improvement in design are necessary to meet these demands and new generations of engine models are produced to take advantage of advances in research and experience. Considerable improvements in design and performance of turbo-chargers and charge air systems in recent years have contributed substantially to increases in engine power and economy. The supply of charge air at reduced power is sufficient to maintain efficient combustion, and at full power surplus exhaust gas energy can be diverted to operate ‘power take off’ systems which will supplement the main electrical power output.

Changes in world trade may lead to the emergence of different ship types with special demands upon their power systems. Manufacturers produce a range of cylinder sizes and numbers in each model so that a wide selection of power or other parameters is available.

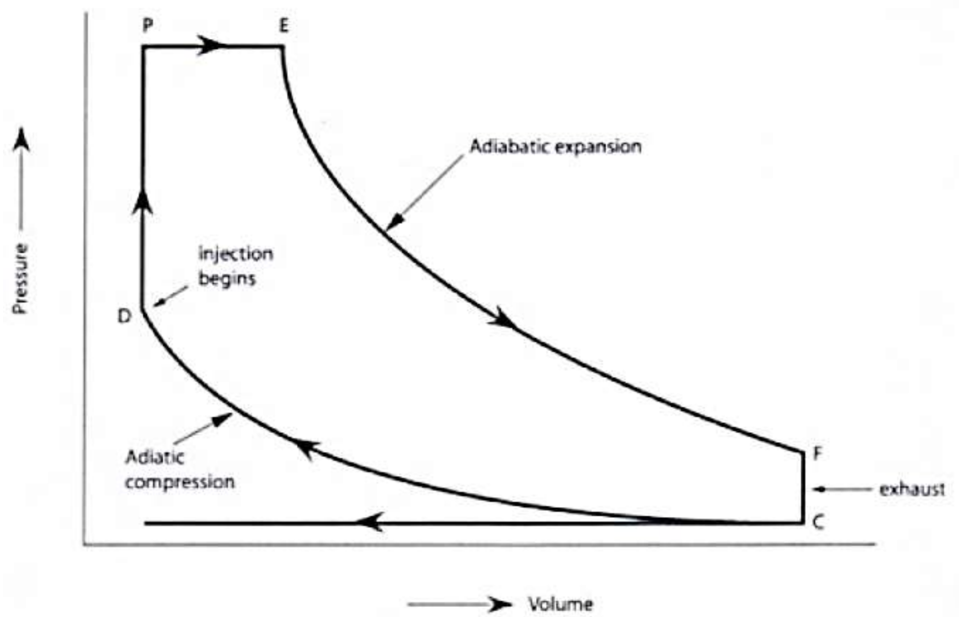
Further sizes are developed when a particular demand becomes evident.
Practically all new merchant ships are powered by diesel engines, and some existing large steamships have been re-engined with diesel power to improve their economy and extend their useful life.

Basically, marine diesel engines can be divided into two main types: large, slowrunning direct drive engines with limited numbers of cylinders, or medium to high speed engines driving through reduction gears. Cylinder sizes do not necessarily distinguish between; slow-speed engines are available with cylinder bores down to 260 mm, while medium speed engines are produced with bores up to 620 mm.

Although there are distinct differences between both types, much of the subject matter in this unit is relevant to all engines. Where necessary their characteristics are dealt with separately.

The Work Done Diagram

In the original patent by Rodulf Diesel, the diesel engine operated on the diesel cycle in which the heat was added at constant pressure. This was achieved by the blast injection principle. Nowadays the term is universally used to describe any reciprocating engine in which the heat induced by compressing air in the cylinders ignites a finely atomised spray of fuel.
This means that the theoretical cycle on which the modern diesel engine works is better represented by the dual or mixed cycle, diagrammatically illustrated below. The area of the diagram, to a suitable scale, represents the work done on the piston during one cycle.



Starting from point C, the air is compressed adiabatically to a point D. Fuel injection begins at D, and heat is added to the cycle partly at constant volume as shown by vertical line DP, and partly at constant pressure, as shown by horizontal line PE. At the point E expansion begins. This proceeds adiabatically to point F when the heat is rejected to exhaust at constant volume as shown by vertical line FC.
The ideal efficiency of this cycle, (i.e. of the hypothetical indicator diagram) is about 55-60%: that is to say, about 40-45% of the heat supplied is lost to the exhaust. Since the

compression and expansion strokes are assumed to be adiabatic, and friction is disregarded, there is no loss to coolant or surroundings.

For a four-stroke engine the exhaust and suction strokes are shown by the horizontal line at C, and this has no effect on the cycle.

Actual Diagrams

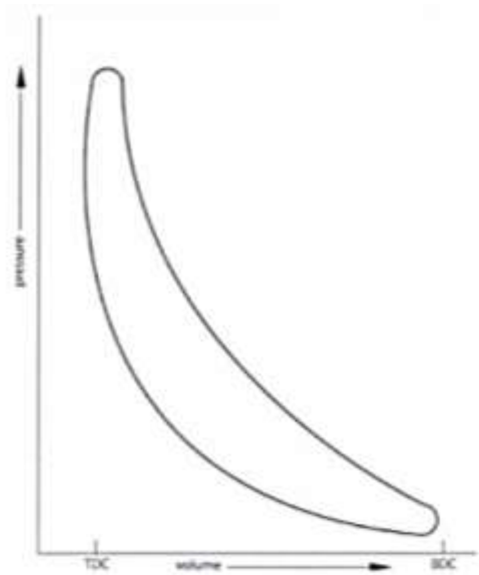
While the theoretical cycle facilitates simple calculations, it does not exactly represent the true state of affairs. This is because:

1. The manner in which, and the rate at which, heat is added to the compressed air (the heat release rate) is a complex function to the hydraulics of the fuel injection equipment and the characteristic of its operating mechanism; of the way the spray is atomised and distributed in the combustion space; of the air movement at and after top dead centre (TDS), and to a degree also of the qualities of the fuel.
2. The compression and expansion strokes are note truly adiabatic. Heat is lost to the cylinder walls to an extent which is influenced by the coolant temperature and by the design of the heat paths to the coolant.
3. The exhaust and suction strokes on a four-stroke engine (and the appropriate phases of a two-stroke cycle) do create pressure differences which the crank shaft feels as 'pumping work'.

It is the designer's objective to minimise all these losses without prejudicing first cost or reliability, and also to minimise the cycle loss, that is, the heat rejected to exhaust.

In practice designers have at their disposal sophisticated computer techniques which are capable of representing the actual events in the cylinder with a high degree of accuracy. But broadly speaking, the cycle efficiency is a function of the compression ratio (or more correctly the effective expansion ratio of the gas/air mixture after combustion).

The theoretical cycle may be compared with a typical actual diesel indicator diagram such as that shown below.

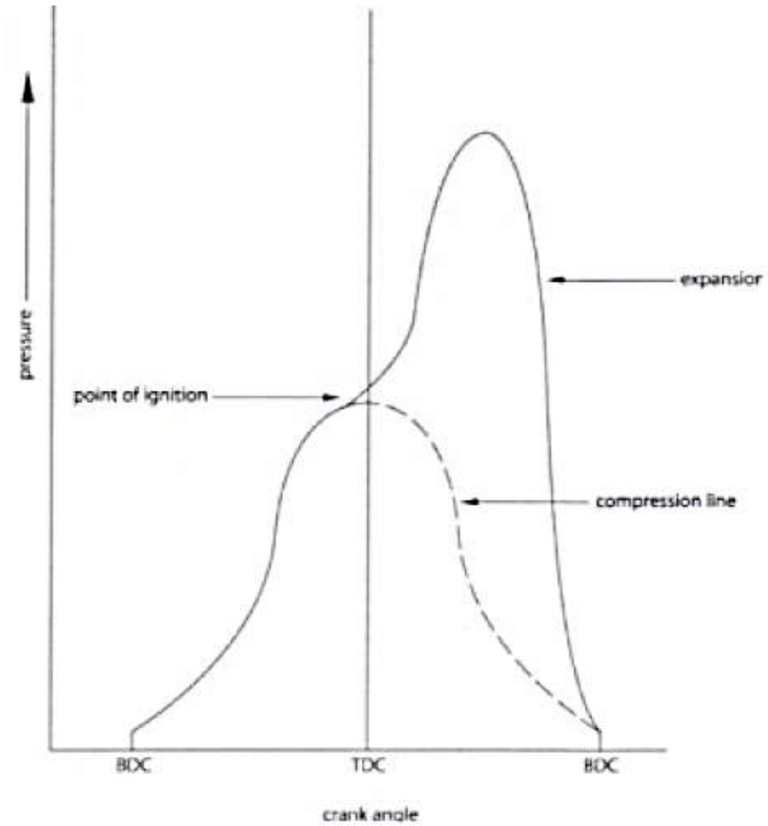


Note that in higher speed engines combustion events are often represented on a crank angel, rather than a stroke basis, in order to achieve better accuracy in portraying events at the top dead centre, as shown below. The actual indicator diagram is derived from it by transposition. This form of diagram is useful too when setting injection timing. If electronic indicators are used it is possible to choose either form of diagram.

An approximation to a crank angle based diagram can be made with mechanical indicators by disconnecting the phasing and taking a card quickly, pulling it by hand: this is termed a 'draw card'. Faults on the engine will be indicated on the draw card,

e.g., Low compression pressure: Blow past and defective piston rings. Late ignition:

Fuel pump timing.



Engine Cycles

The term 'cycle' refers to one complete sequence of operators required to produce power in an engine. This cycle of operations is continuously repeated while the engine is running. For a diesel engine it consists of four operations within the cylinder:

1. Compression of a charge of air.
2. Injection of fuel which then ignites.
3. Expansion of the hot gases formed during combustion.
4. Expulsion of the used gas to exhaust.

The cylinder is then recharged with air and the cycle is repeated. Diesel engines can be designed to complete this cycle once during each revolution and this is termed the two-stroke cycle, or alternatively to take two engine revolutions to complete – the four-stroke cycle. An engine can only operate on the cycle for which it was designed.

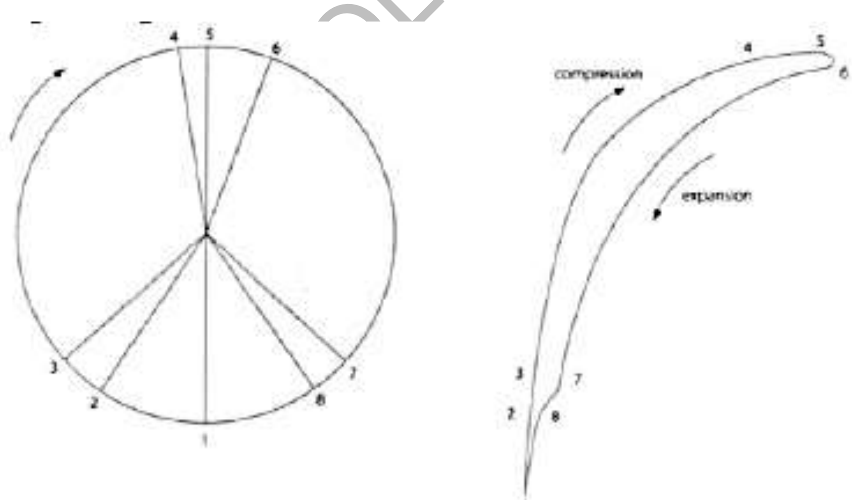
Engine stroke is measured as the full distance through which the piston moves between each end of its travel. It can be seen that it must move through two complete strokes (one up and one down) during each revolution of the engine.

Engine timing refers to the relative time or position of the crank, at which each operation during the cycle is commenced and is completed. It is measured as the angle through which the crank has been rotated from a datum position such as top or bottom centre.

Two-stroke cycle

Practically all large, slow-speed, direct drive marine diesel engines operate on the twostroke cycle. As its name implies a two-stroke cycle takes place in two consecutive strokes of the engine piston, or one revolution of the crankshaft. Thus each operation in the cycle is repeated during every revolution of the engine. The two strokes of the cycle may be termed: Compression stroke and Power or Expansion Stroke. Operations take place in a fixed order and must occur when the piston reaches a corresponding position in its stroke. These positions are show as volumes on an indicator diagram which relates them with pressure within the cylinder. It is convenient to express them in terms of angles of crank position measured from top dead centre (TDS) or bottom dead centre (BDC) and they may be shown as a circle on a timing diagram. (Numbers have been added for reference).

Actual timing may differ between engines due to construction and design differences such as: ratio of connecting rod length/crank length, stroke/bore ratio, engine speed, engine rating etc.



Position 1 represents bottom of stroke (BDC). Position 5 represents top of stroke

(TDC).

1-2 Completion of scavenge. Air is entering the cylinder, expelling exhaust gas and recharging it for the next combustion. Scavenge and exhaust are open.

2-3 Post-scavenge. Scavenge ports have closed and some air within the cylinder may lead to exhaust. In some engines 2 and 3 are made to coincide to eliminate leakage of air.

3-4 Compression. Exhaust has now closed and the air trapped within the cylinder is compressed by the upstroke of the piston to raise its temperature sufficiently to ignite the fuel.

4-5-6 Fuel injection takes place and combustion occurs causing a rapid rise in pressure.

The period for which this continues depends upon the fuel pump setting and power to be produced.

6-7 Expansion. Combustion completed, the hot gases expand forcing the piston downwards and converting the heat energy from combustion into work on the piston.

7-8 Exhaust blowdown. Exhaust has opened allowing gas to pass to exhaust manifold, and pressure drops rapidly in the cylinder.

8-1 Scavenge. Scavenge ports have opened and air enters to expel the remaining exhaust gas.

1-etc Scavenging then continues for the next cycle.

<u>Four-stroke cycle</u>

The majority of medium and high speed diesel engines for main or auxiliary drive operate on the four-stroke cycle, which takes place during four consecutive strokes, or two complete revolutions, of the engine. Exhaust Stroke, and Aspirating or Air

Induction stroke. Numbering the operations in sequence on the timing diagram:

4 and 9 are TDC positions. 1 and 7 are BDC positions.

1-2 Completion of aspiration.

2-3 Compression. Air inlet valve has closed, air in cylinder is now compressed to raise its temperature for combustion of fuel.

3-4-5 Fuel injection. Combustion takes place with corresponding rise in pressure.

Period controlled by fuel pump setting.

5-6 Expansion. Combustion completed, gas pressure does work on piston during downward stroke.

6-7-8 Exhaust. Exhaust valve opened, piston expels exhaust gas on upward stroke.

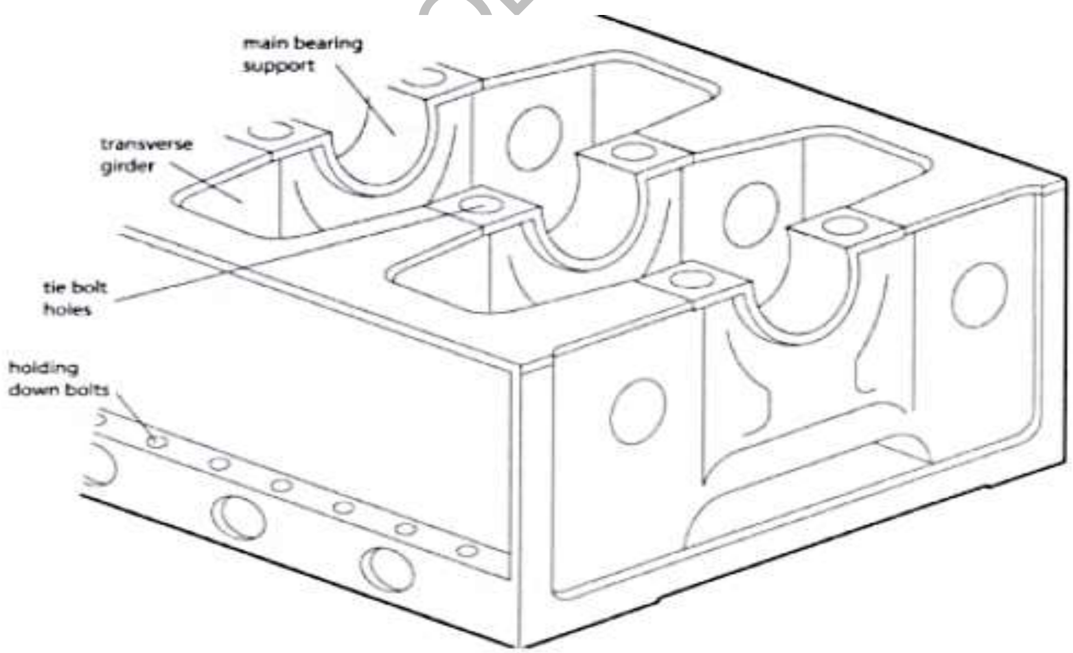
8-9-10Overlap. Air inlet valve opened while exhaust remains open. The length of this is increased in supercharged or high speed engines.

10-1 Aspiration. Exhaust valve closed, piston draws air into cylinder during downward stroke.

1-etc. Aspiration continues for next cycle.

Engine Structure

The bedplate of a large engine acts as the main strength part of its section, providing rigid support for the main bearings and crankshaft. It is also a platform on which other structural components such as frames or columns and guides may be accurately mounted to support the engine cylinders and ensure the alignment of all working parts. In high powered engines the bedplate must withstand heavy, fluctuating stresses from working parts. It must transmit engine loads, including the propellerthrust, to the ship’s structure, distributing these over the necessary area, and may complement the ship’s strength and propeller shaft alignment. The bedplate also collects the lubricating oil from the crankcase, returning it to the drain tank for recycling.



The figure shows part of a bedplate for a large crosshead type of main engine. It is fabricated from steel plates and castings welded together to form a deep longitudinal box structure with stiffening members and webs to give additional rigidity. Lightening and access holes are made with compensating sleeves, to maintain lightness with strength. Transverse members or girders are fitted between each engine unit and at each end of the bedplate. The central section of each is formed by a steel casting shaped to support the main bearing and with holes for a pair of tie bolts. The casting has substantial butt welds securing it to the main box structure.

The depth of the bedplate raises its top flange clear of the sweep of the bottom end bearing in long-stroke engines, keeping overall width to a minimum. To limit overall height, the centre oil pan or sump is lowered and will require a recess in the ship's structure.

a. Two main bearing caps with associated shell bearings, holding down arrangements and oil supply.

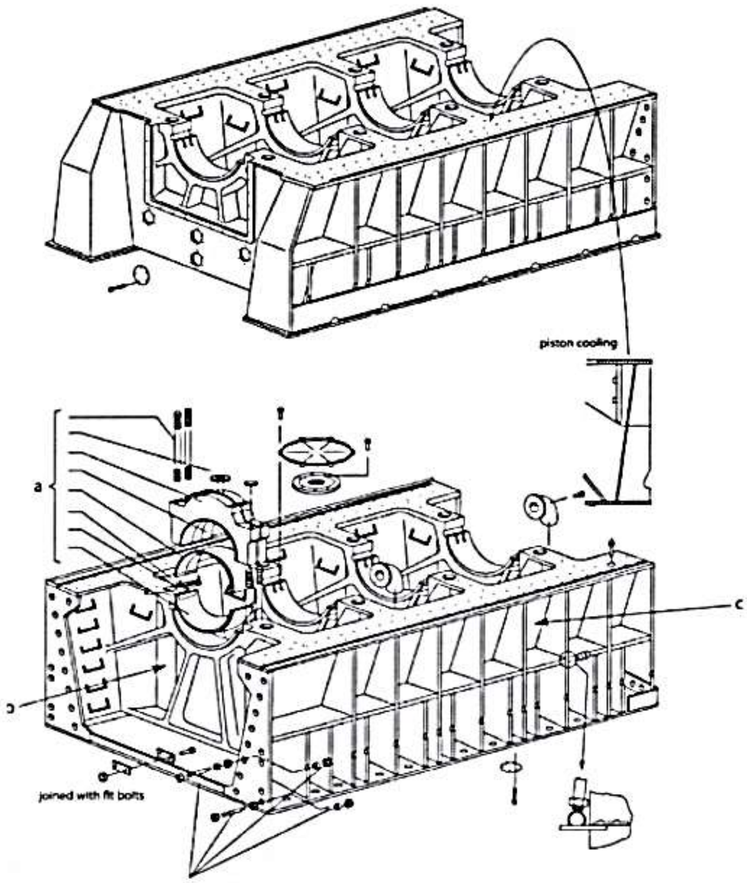
b. Cast transverse girder (with radial webs).

c. Single piece longitudinal girder with substantial ribs.

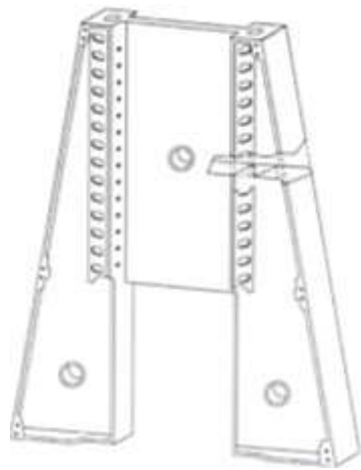
All welding in the bedplate must be to a very high standard, carefully controlled and inspected. It must be stress-relieved, shot blasted and tested for flaws. All plate edges must be correctly prepared, with double butt welds and complete penetration where possible. Plates of different thickness should not be butt welded together. Bedplate flanges are finally machined for landing on support chocks or for assembly of other members.

Fatigue cracks may commence at points of high stress or sudden change in section and regular internal inspection must be carried out, particularly after heavy weather or damage has occurred. All nuts, including holding down and tie bolts, must be checked for tightness on a running hours planned maintenance basis and to ensure fretting has not occurred between mating surfaces.

Earlier engines with lower stroke/bore ratio had bedplates formed by a longitudinal box shaped girder at each side joined by transverse girders supporting main bearings and tie bolts in steel castings.

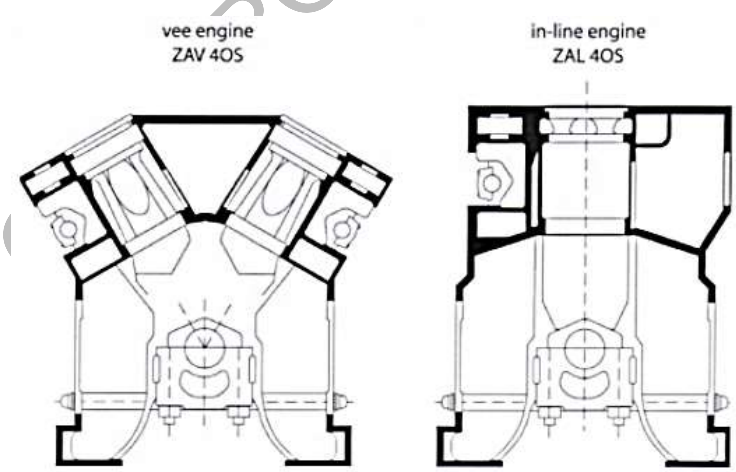


In crosshead type engines frames or columns are used to support the cylinder block from the bedplate. These are terms 'A' frames because of their shape; they are fitted at each transverse girder and at both ends of the engine. 'A' frames are fabricated from steel plates welded to form a hollow structure on each side. There is clearance to allow access to main bearings. Transverse stiffening webs are fitted and flanges added for necessary connections. Brackets secure the crosshead guides and other internal fittings. Bottom flanges allow the frame to be accurately aligned and secured by fitted bolts and studs to the bedplate and transverse girder. The top flange is fitted to the cylinder block, scavenge trunk etc. Longitudinal bars and crankcase casing plates are attached to the outer edges. Tie bolts pass vertically within the frame; the prestressing of these maintains the frame in compression at all times.



In some designs, a number of frames with the crankcase casing are fabricated together to form a box before attachment to the engine.

In medium speed trunk piston engines the main strength member may consist of a single frame or block which incorporates the crankcase, bedplate, frames and even the cylinder block. These may be formed as a single casting of either grey or nodular cast iron machined on all necessary faces. Alternatively they may be fabricated from steel plates and castings. Main bearings are under-slung from the frames and horizontal tie bolts may add to the rigidity at this position. Typical frames for in-line and Vee engines are shown in the figure.



In most single-acting engines, except opposed piston engines, the main gas loads from the cylinder covers are transmitted by long tie bolts. Two bolts are fitted to each transverse girder and they pass up through the casting, through tubes constructed in the engine frames and entablature to the top of the cylinder block where locking nuts are hydraulically tightened to pre-stress the structure, maintaining the cylinder block and frames in compression. Transverse locating bolts prevent vibration in the tie bolts, which may be assembled in screwed sectional lengths to limit the access and removal Height. Tie bolt centres should be as close to the crankshaft axis as possible to reduce bending stress on the girders and to prevent unbalanced loads being transmitted to the welds.

1.1.2. DESIGN FEATURES AND OPERATIVE MECHANISM OF MARINE STEAM TURBINE AND ASSOCIATED AUXILIARIES

A steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Its modern manifestation was invented by Sir Charles Parsons in 1884.

Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator – about 90% of all electricity generation in the United States (1996) is by use of steam turbines. The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency from the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible expansion process.

Principle of operation and design

An ideal steam turbine is considered to be an isentropic process, or constant entropy process, in which the entropy of the steam entering the turbine is equal to the entropy of the steam leaving the turbine. No steam turbine is truly isentropic, however, with typical isentropic efficiencies ranging from 20–90% based on the application of the turbine. The interior of a turbine comprises several sets of blades, or buckets as they are more commonly referred to. One set of stationary blades is connected to the casing and one set of rotating blades is connected to the shaft. The sets intermesh with certain minimum clearances, with the size and configuration of sets varying to efficiently exploit the expansion of steam at each stage.

Turbine efficiency

To maximize turbine efficiency the steam is expanded, doing work, in a number of stages. These stages are characterized by how the energy is extracted from them and are known as either impulse or reaction turbines. Most steam turbines use a mixture of the reaction and impulse designs: each stage behaves as either one or the other, but the overall turbine uses both. Typically, higher pressure sections are reaction type and lower pressure stages are impulse type.

Impulse turbines

An impulse turbine has fixed nozzles that orient the steam flow into high speed jets. These jets contain significant kinetic energy, which is converted into shaft rotation by the bucket-like shaped rotor blades, as the steam jet changes direction. A pressure drop occurs across only the stationary blades, with a net increase in steam velocity across the stage. As the steam flows through the nozzle its pressure falls from inlet pressure to the exit pressure (atmospheric pressure, or more usually, the condenser vacuum). Due to this high ratio of expansion of steam, the steam leaves the nozzle with a very high velocity. The steam leaving the moving blades has a large portion of the maximum velocity of the steam when leaving the nozzle. The loss of energy due to this higher exit velocity is commonly called the carry over velocity or leaving loss.

The law of moment of momentum states that the sum of the moments of external forces acting on a fluid which is temporarily occupying the control volume is equal to the net time change of angular momentum flux through the control volume.

The swirling fluid enters the control volume at radius r_1 with tangential velocity V_{w1} and leaves at radius r_2 with tangential velocity V_{w2}.

A velocity triangle paves the way for a better understanding of the relationship between the various velocities. In the adjacent figure we have:

- V_1 and V_2 are the absolute velocities at the inlet and outlet respectively.
- V_{f1} and V_{f2} are the flow velocities at the inlet and outlet respectively.
- $V_{w1} + U$ and V_{w2} are the swirl velocities at the inlet and outlet respectively.
- V_{r1} and V_{r2} are the relative velocities at the inlet and outlet respectively.
- U_1 and U_2 are the velocities of the blade at the inlet and outlet respectively.
- α is the guide vane angle and β is the blade angle.

Then by the law of moment of momentum, the torque on the fluid is given by:

$$T = \dot{m}(r_2 V_{w2} - r_1 V_{w1})$$

For an impulse steam turbine: $r_2 = r_1 = r$. Therefore, the tangential force on the blades is $F_u = \dot{m}(V_{w1} - V_{w2})$. The work done per unit time or power developed: $W = T * \omega$.

When ω is the angular velocity of the turbine, then the blade speed is $U = \omega * r$. The power developed is then $W = \dot{m}U(\Delta V_w)$.

Blade efficiency

Blade efficiency (η_b) can be defined as the ratio of the work done on the blades to kinetic energy supplied to the fluid, and is given by

$$\eta_b = \frac{Work\ Done}{Kinetic\ Energy\ Supplied} = \frac{2UV_w}{V_1^2}$$

Stage efficiency

A stage of an impulse turbine consists of a nozzle set and a moving wheel. The stage efficiency defines a relationship between enthalpy drop in the nozzle and work done in the stage.

$$\eta_{stage} = \frac{Work\ done\ on\ blade}{Energy\ supplied\ per\ stage} = \frac{U\Delta V_w}{\Delta h}$$

Where $\Delta h = h_2 - h_1$ is the specific enthalpy drop of steam in the nozzle.

By the first law of thermodynamics: $h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$

Assuming that V_1 is appreciably less than V_2, we get $\Delta h \approx \frac{V_2^2}{2}$ Furthermore, stage efficiency is the product of blade efficiency and nozzle efficiency, or $\eta_{stage} = \eta_b * \eta_N$

Nozzle efficiency is given by $\eta_N = \frac{V_2^2}{2(h_1 - h_2)}$, where the enthalpy (in J/Kg) of steam at the entrance of the nozzle is $h_1$and the enthalpy of steam at the exit of the nozzle is h_2

. $\Delta V_w = V_{w1} - (-V_{w2})$ $\Delta V_w = V_{w1} + V_{w2}$ $\Delta V_w = V_{r1}\cos\beta_1 + V_{r2}\cos\beta_2$

$$\Delta V_w = V_{r1}\cos\beta_1(1 + \frac{V_{r2}\cos\beta_2}{V_{r1}\cos\beta_1})$$

The ratio of the cosines of the blade angles at the outlet and inlet can be taken and denoted $c = \frac{\cos\beta_2}{\cos\beta_1}$. The ratio of steam velocities relative to the rotor speed at the outlet to the inlet of the blade is defined by the friction coefficient $k = \frac{V_{r2}}{V_{r1}}$.

$k < 1$ and depicts the loss in the relative velocity due to friction as the steam flows around the blades ($k = 1$ for smooth blades).

$$\eta_b = \frac{2U\Delta V_w}{V_1^2} = \frac{2U(\cos\alpha_1 - U/V_1)(1 + kc)}{V_1}$$

The ratio of the blade speed to the absolute steam velocity at the inlet is termed the blade speed ratio $\rho = \frac{U}{V_1}$

η_b is maximum when $\frac{d\eta_b}{d\rho} = 0$ or, $\frac{d}{d\rho}(2\cos\alpha_1 - \rho^2(1+kc)) = 0$. That implies $\rho = \frac{\cos\alpha_1}{2}$ and therefore $\frac{U}{V_1} = \frac{\cos\alpha_1}{2}$. Now $\rho_{opt} = \frac{U}{V_1} = \frac{\cos\alpha_1}{2}$ (for a single stage impulse turbine)

Therefore the maximum value of stage efficiency is obtained by putting the value of $\frac{U}{V_1} = \frac{\cos\alpha_1}{2}$ in the expression of η_b/

We get: $(\eta_b)_{max} = 2(\rho\cos\alpha_1 - \rho^2)(1+kc) = \frac{\cos^2\alpha_1(1+kc)}{2}$.

For equiangular blades, $\beta_1 = \beta_2$, therefore $c = 1$, and we get $(\eta_b)_{max} = \frac{cos^2\alpha_1(1+k)}{2}$. If the friction due to the blade surface is neglected then $(\eta_b)_{max} = \cos^2\alpha_1$.

Conclusions on maximum efficiency

$(\eta_b)_{max} = \cos^2\alpha_1$

1. For a given steam velocity work done per kg of steam would be maximum when $\cos^2\alpha_1 = 1$ or $\alpha_1 = 0$.

2. As α_1 increases, the work done on the blades reduces, but at the same time surface area of the blade reduces, therefore there are less frictional losses.

Reaction turbines

In the reaction turbine, the rotor blades themselves are arranged to form convergent nozzles. This type of turbine makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor. Steam is directed onto the rotor by the fixed vanes of the stator. It leaves the stator as a jet that fills the entire circumference of the rotor. The steam then changes direction and increases its speed relative to the speed of the blades. A pressure drop occurs across both the stator and the rotor, with steam accelerating through the stator and decelerating through the rotor, with no net change in steam velocity across the stage but with a decrease in both pressure and temperature, reflecting the work performed in the driving of the rotor.

Blade efficiency

Energy input to the blades in a stage:

$E = \Delta h$ is equal to the kinetic energy supplied to the fixed blades (f) + the kinetic energy supplied to the moving blades (m).

Or, E = enthalpy drop over the fixed blades, Δh_f + enthalpy drop over the moving blades, Δh_m.

The effect of expansion of steam over the moving blades is to increase the relative velocity at the exit. Therefore the relative velocity at the exit V_{r2} is always greater than the relative velocity at the inlet V_{r1}.

In terms of velocities, the enthalpy drop over the moving blades is given by:

$$\Delta h_m = \frac{V_{r2}^2 - V_{r1}^2}{2}$$

(it contributes to a change in static pressure)

The enthalpy drop in the fixed blades, with the assumption that the velocity of steam entering the fixed blades is equal to the velocity of steam leaving the previously moving blades is given by:

$\Delta h_f = \dfrac{V_1^2 - V_0^2}{2}$ where V0 is the inlet velocity of steam in the nozzle

V_0 is very small and hence can be neglected

Therefore, $\Delta h_f = \dfrac{V_1^2}{2}$

$$E = \Delta h_f + \Delta h_m$$

$$E = \frac{V_1^2}{2} + \frac{V_{r2}^2 - V_{r1}^2}{2}$$

A very widely used design has half degree of reaction or 50% reaction and this is known as Parson’s turbine. This consists of symmetrical rotor and stator blades. For this turbine the velocity triangle is similar and we have:

$\alpha_1 = \beta_{2,} \beta_1 = \alpha_2$

$V_1 = V_{r2,} V_{r1} = V_2$

Assuming Parson's turbine and obtaining all the expressions we get

$$E = V_1^2 - \frac{V_{r1}^2}{2}$$

From the inlet velocity triangle we have $V_{r1}^2 = V_1^2 - U^2 - 2UV_1 \cos\alpha_1$

$$E = V_1^2 - \frac{V_1^2}{2} - \frac{U^2}{2} + \frac{2UV_1 \cos\alpha_1}{2}$$

$$E = \frac{V_1^2 - U^2 + 2UV_1 \cos\alpha_1}{2}$$

Work done (for unit mass flow per second): $W = U * \Delta V_w = U * (2 * V_1 \cos\alpha_1 - U)$

Therefore the blade efficiency is given by

$$\eta_b = \frac{2U(2V_1 \cos\alpha_1 - U)}{V_1^2 - U^2 + 2V_1 U \cos\alpha_1}$$

Condition of maximum blade efficiency

If $\rho = \frac{U}{V_1}$, then

$$(\eta_b)_{max} = \frac{2\rho(\cos\alpha_1 - \rho)}{V_1^2 - U^2 + 2UV_1 \cos\alpha_1}$$

For maximum efficiency $\frac{d\eta_b}{d\rho} = 0$, we get

$$(1 - \rho^2 + 2\rho\cos\alpha_1)(4\cos\alpha_1 - 4\rho) - 2\rho(2\cos\alpha_1 - \rho)(-2\rho + 2\cos\alpha_1) = 0$$

and this finally gives $\rho_{opt} = \frac{U}{V_1} = \cos\alpha_1$

Therefore $(\eta_b)_{max}$ is found by putting the value of $\rho = \cos\alpha_1$ in the expression of blade efficiency

$$(\eta_b)_{reaction} = \frac{2\cos^2\alpha_1}{1 + \cos^2\alpha_1}$$

$$(\eta_b)_{impulse} = \cos^2 \alpha_1$$

Operation and maintenance

Because of the high pressures used in the steam circuits and the materials used, steam turbines and their casings have highthermal inertia. When warming up a steam turbine for use, the main steam stop valves (after the boiler) have a bypass line to allow superheated steam to slowly bypass the valve and proceed to heat up the lines in the system along with the steam turbine. Also, a turning gear is engaged when there is no steam to slowly rotate the turbine to ensure even heating to preventuneven expansion. After first rotating the turbine by the turning gear, allowing time for the rotor to assume a straight plane (no bowing), then the turning gear is disengaged and steam is admitted to the turbine, first to the astern blades then to the ahead blades slowly rotating the turbine at 10–15 RPM (0.17–0.25 Hz) to slowly warm the turbine. The warm up procedure for large steam turbines may exceed ten hours.

During normal operation, rotor imbalance can lead to vibration, which, because of the high rotation velocities, could lead to a blade breaking away from the rotor and through the casing. To reduce this risk, considerable efforts are spent to balance the turbine. Also, turbines are run with high quality steam: either superheated (dry) steam, or saturated steam with a high dryness fraction. This prevents the rapid impingement and erosion of the blades which occurs when condensed water is blasted onto the blades (moisture carry over). Also, liquid water entering the blades may damage the thrust bearings for the turbine shaft. To prevent this, along with controls and baffles in the boilers to ensure high quality steam, condensate drains are installed in the steam piping leading to the turbine.

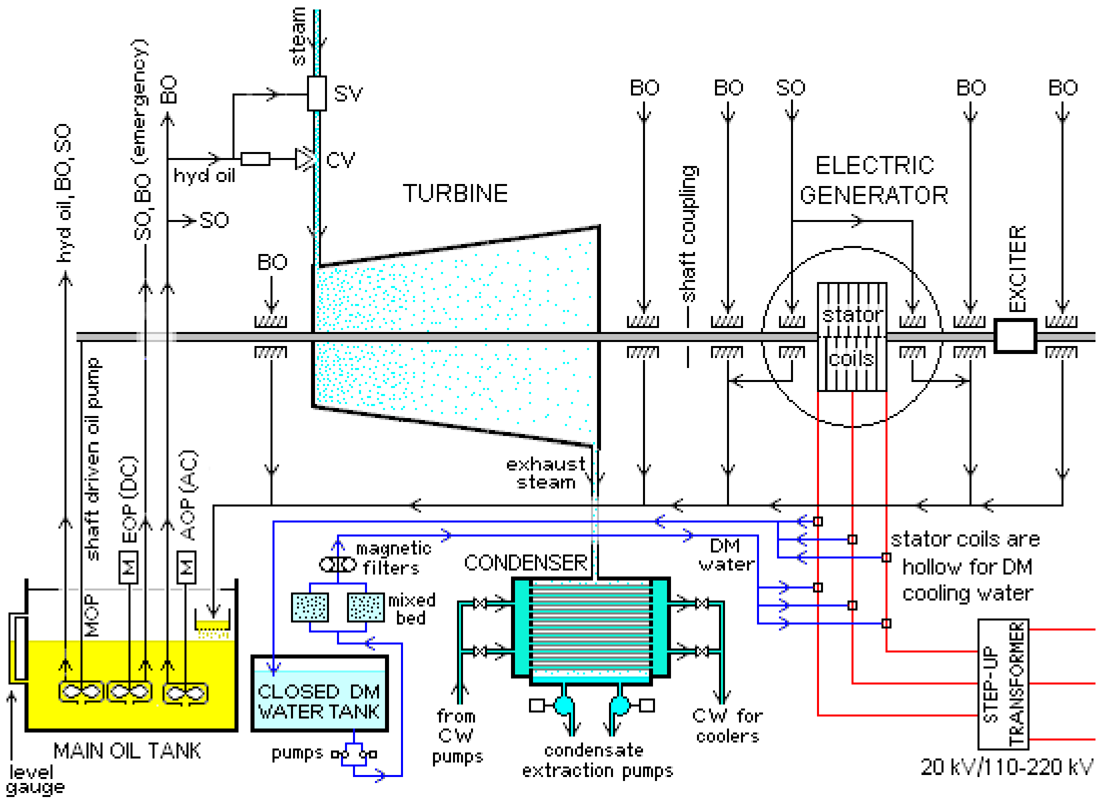
Maintenance requirements of modern steam turbines are simple and incur low costs (typically around $0.005 per kWh); their operational life often exceeds 50 years.

Speed regulation

The control of a turbine with a governor is essential, as turbines need to be run up slowly to prevent damage and some applications (such as the generation of alternating current electricity) require precise speed control. Uncontrolled acceleration of the turbine rotor can lead to an overspeed trip, which causes the nozzle valves that control the flow of steam to the turbine to close. If this fails then the turbine may continue accelerating until it breaks apart, often catastrophically. Turbines are expensive to make, requiring precision manufacture and special quality materials.

During normal operation in synchronization with the electricity network, power plants are governed with a five percent droop speed control. This means the full load speed is 100% and the no-load speed is 105%. This is required for the stable operation of the network without hunting and drop-outs of power plants. Normally the changes in speed are minor. Adjustments in power output are made by slowly raising the droop curve by increasing the spring pressure on a centrifugal governor. Generally this is a basic system requirement for all power plants because the older and newer plants have to be compatible in response to the instantaneous changes in frequency without depending on outside communication.

Turbine generator systems



SO-seal oil; BO-bearing oil; hyd oil-hydraulic oil; SV-stop valve; CV-control valve;
MOP-main oil pump; EOP-emergency oil pump; AOP-auxiliary oil pump; [M] - motor
CW-circulating water; DM-demineralised (water); DC - direct current; AC - alternating current

Marine propulsion

In steam-powered ships, compelling advantages of steam turbines over reciprocating engines are smaller size, lower maintenance, lighter weight, and lower vibration. A steam turbine is only efficient when operating in the thousands of RPM, while the most effective propeller designs are for speeds less than 300 RPM; consequently, precise (thus expensive) reduction gears are usually required, although numerous early ships through World War I, such as Turbinia, had direct drive from the steam turbines to the propeller shafts. Another alternative is turbo-electric transmission, in which an electrical generator run by the high-speed turbine is used to run one or more slow-speed electric motors connected to the propeller shafts; precision gear cutting may be a production bottleneck during wartime. Turbo-electric drive was most used in large US warships designed during World War I and in some fast liners, and was used in some troop transports and mass-production destroyer escorts in World War II. The purchase cost of turbines is offset by much lower fuel and maintenance requirements and the small size of a turbine when compared to a reciprocating engine having an equivalent power. However, from the 1950s diesel engines were capable of greater reliability and higher efficiencies: propulsion steam turbine cycle efficiencies have yet to break 50%, yet diesel engines today routinely exceed 50%, especially in marine applications. Diesel power plants also have lower operating costs since fewer operators are required. Thus, conventional steam power is used in very few new ships.

Nuclear-powered ships and submarines use a nuclear reactor to create steam for turbines. Nuclear power is often chosen where diesel power would be impractical (as in submarine applications) or the logistics of refuelling pose significant problems (for example, icebreakers). It has been estimated that the reactor fuel for the Royal Navy's Vanguard class submarine is sufficient to last 40 circumnavigations of the globe – potentially sufficient for the vessel's entire service life. Nuclear propulsion has only been applied to a very few commercial vessels due to the expense of maintenance and the regulatory controls required on nuclear systems and fuel cycles.

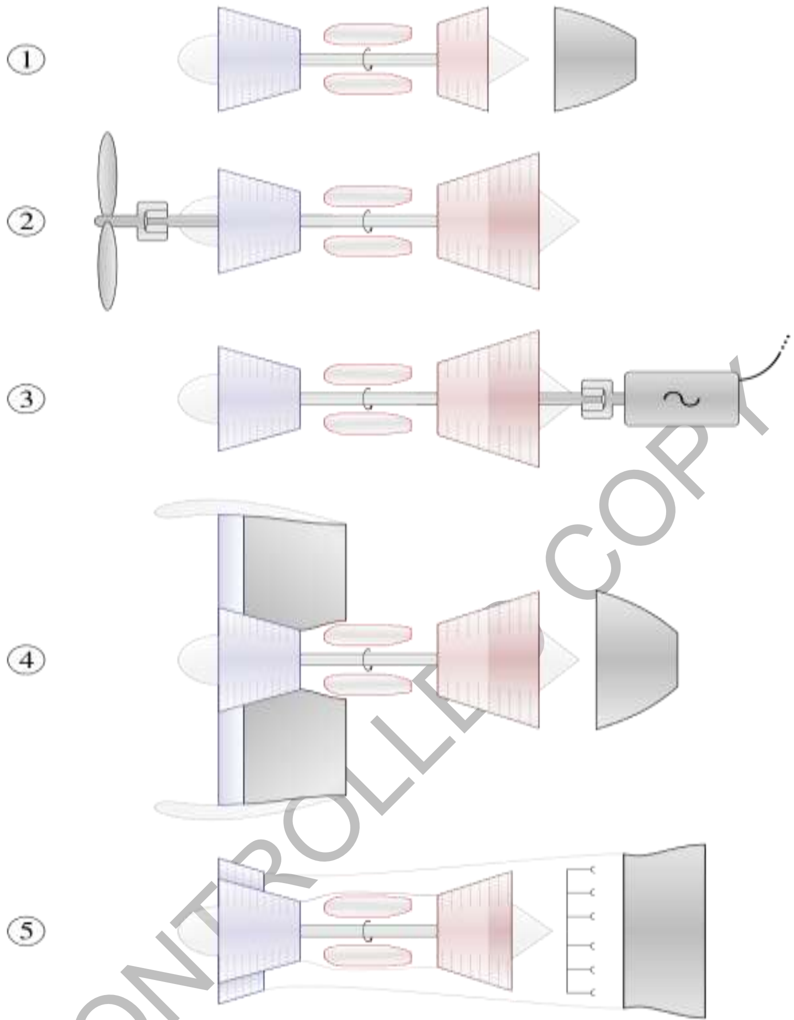
Early development

The development of steam turbine marine propulsion from 1894-1935 was dominated by the need to reconcile the high efficient speed of the turbine with the low efficient speed (less than 300 rpm) of the ship's propeller at an overall cost competitive with reciprocating engines. In 1894, efficient reduction gears were not available for the high powers required by ships, so direct drive was necessary. In the Turbinia, which has direct drive to each propeller shaft, the efficient speed of the turbine was reduced after initial trials by directing the steam flow through all three direct drive turbines (one on each shaft) in series, probably totaling around 200 turbine stages operating in series. Also, there were three propellers on each shaft for operation at high speeds.[24] The high shaft speeds of the era are represented by one of the first US turbine-powered destroyers, USS Smith (DD-17), launched in 1909, which had direct drive turbines and whose three shafts turned at 724 rpm at 28.35 knots.[25] The use of turbines in several casings exhausting steam to each other in series became standard in most subsequent marine propulsion applications, and is a form of cross-compounding. The first turbine was called the high pressure (HP) turbine, the last turbine was the low pressure (LP) turbine, and any turbine in between was an intermediate pressure (IP) turbine. A much later arrangement than Turbinia can be seen on the RMS Queen Mary in Long Beach, California, launched in 1934, in which each shaft is powered by four turbines in series connected to the ends of the two input shafts of a single-reduction gearbox. They are the HP, 1st IP, 2nd IP, and LP turbines.

1.1.3. DESIGN FEATURES AND OPERATIVE MECHANISM OF MARINE GAS TURBINE AND ASSOCIATED AUXILIARIES

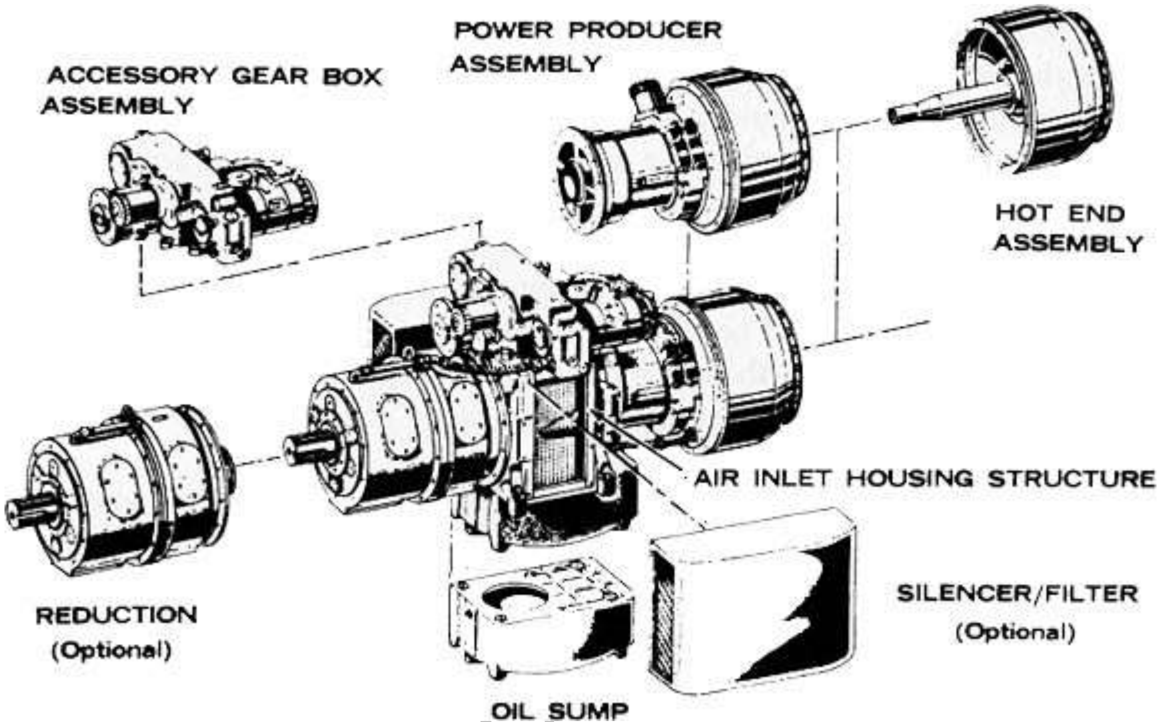
A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in-between.

The basic operation of the gas turbine is similar to that of the steam power plant except that air is used instead of water. Fresh atmospheric air flows through a compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor and other devices such as an electric generator that may be coupled to the shaft. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity. The purpose of the gas turbine determines the design so that the most desirable energy form is maximized. Gas turbines are used to power aircraft, trains, ships, electrical generators, or even tanks.



Examples of gas turbine configurations: (1) turbojet, (2) turboprop, (3) turboshaft (electric generator), (4) high-bypass turbofan, (5) low-bypass afterburning turbofan.

The parts of a gas turbine



Gas turbine engines are, theoretically, extremely simple. Gas turbine have 3 parts:

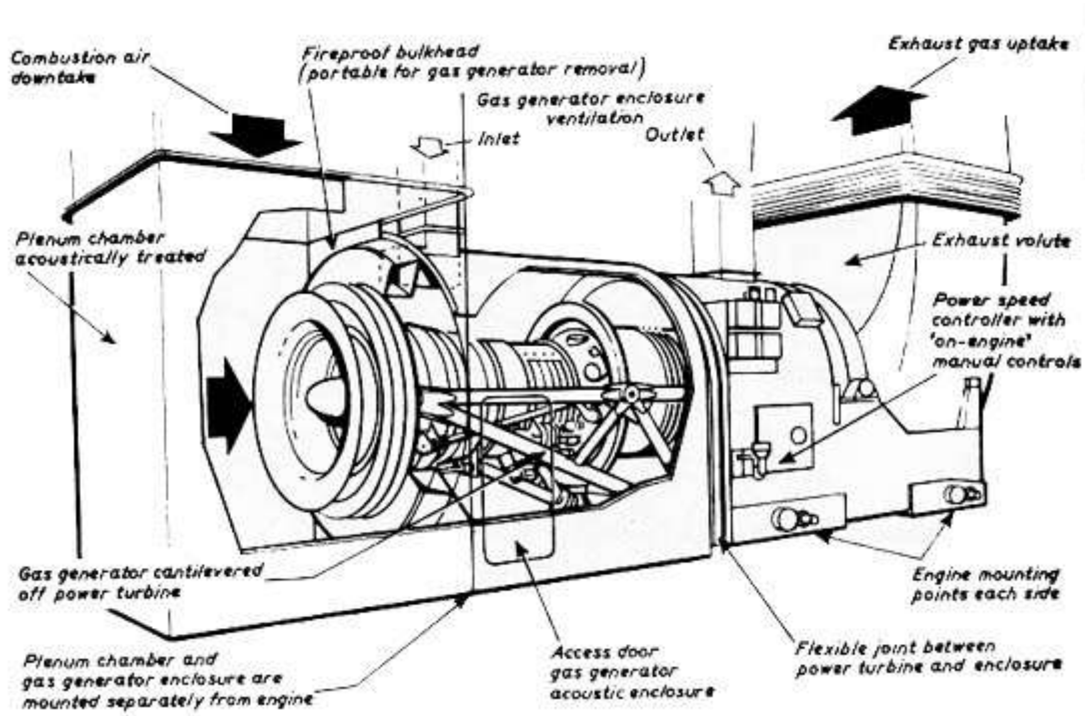
- A compressor to compress the incoming air to high pressure.
- A combustion area to burn the fuel and produce high pressure, high velocity gas.
- A turbine to extract the energy from the high pressure, high velocity gas flowing from the combustion chamber.

Additionally the gas turbine will have these parts:

- An accessory drive gear box, to drive various pumps for fuel, water and oil.
- A reduction gear box, to reduce the high revolutions of the turbine to a more efficient speed for the propeller.

Classifications of Gas Turbines

Gas turbine prime movers are classified in one of two categories: the aero derivative and industrial engine. The aero derivative engine is an aircraft engine adapted to marine service. This is done by changing some components, or even coating them to properly function in the salty air of the marine environment. One example is the General Electric LM2500, weighing in at a thrifty 34,000 lbs (with mounts, enclosures and such) provides one horse power for every 1.5 pounds. In comparison, an industrial gas turbine like the GE MS5000, used in natural gas compression, provides 20,000 hp but weighs in at 200,000 lbs - 10 pounds for every hp. This is due to it's heavier construction. For further comparison; weight and volume of the machinery required by a 20,000 shp ship is about 100 tons for aero derive gas turbine, 400 tons for industrial gas turbine, 700 tons for diesel, and 800 tons for a comparable steam plant.



One benefit of the aero derived engines is the short amount of time for the engine to reach full operating temperature, this is due to the relative small amount of material used in it's construction. As oppose to an industrial turbine, and the more common, diesel engine or steam plant. These must reach proper temperature before being fully loaded, this can take, in some cases, many hours.

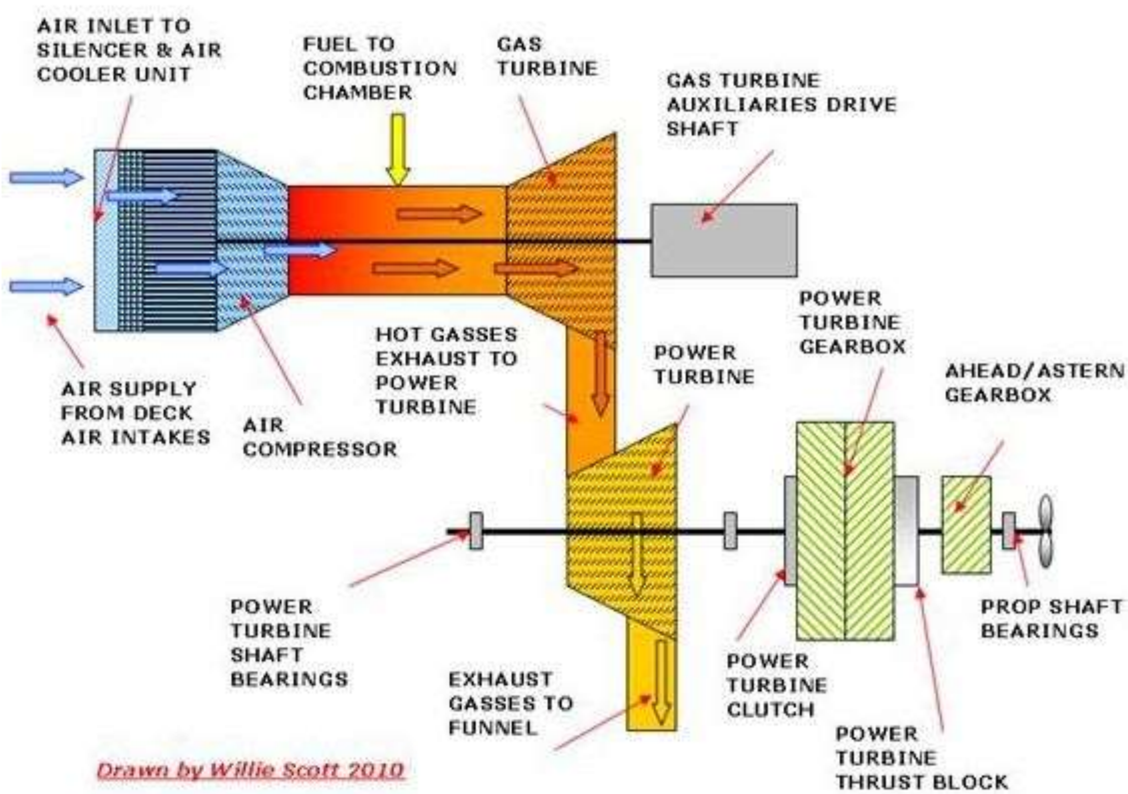
Power Turbine

The power turbine is much slower running than the gas turbine. It has blades and rotors shaped as nozzles similar to that of a normal steam turbine. The power turbine output shaft connects by coupling to the gearbox incorporating a clutch which is used to engage/disengage the drive. The drive shaft exits the gearbox at the revolutions required by either a fixed or variable pitch propeller.

The ship is maneuvered either using the clutch and an ahead/astern gearbox or a variable pitch propeller.

A split shaft gas turbine engine room is much smaller than the normal ship's engine room, but still contains the fuel and lube oil systems with the associated auxiliary pumps, filters and coolers.

One such system is shown below.



1.1.4 DESIGN FEATURES AND OPERATIVE MECHANISM OF MARINE STEAM BOILER AND ASSOCIOATED AUXILIARIES.

General Introduction

A boiler in one form or another will be found on almost every type of ship. Where the main machinery is steam powered, one or more large water-tube boilers will be fitted to produce steam at very high temperatures and pressures. On a diesel main machinery vessel, a smaller (usually firetube type) boiler will be fitted to provide steam for the various ship services. Even within the two basic design types, watertube and firetube, a variety of designs and variations exist.

A boiler is used to heat feedwater in order to produce steam. The energy released by the burning fuel in the boiler furnace is stored (as temperature and pressure) in the steam produced. All boilers have a furnace or combustion chamber where fuel is burnt to release its energy. Air is supplied to the boiler furnace to enable combustion of the fuel to take place. A large surface area between the combustion chamber and the water enables the energy of combustion, in the form of heat, to be transferred to the water.

A drum must be provided where steam and water can separate. There must also be a variety of fittings and controls to ensure that fuel oil, air and feedwater supplies are matched to the demand for steam. Finally there must be a number of fittings or mountings which ensure the safe operation of the boiler.

In the steam generation process the feedwater enters the boiler where it is heated and becomes steam. The feedwater circulates from the steam drum to the tubes surrounding the furnace, i.e. waterwall and floor tubes, where it is heated and returned to the steam drum. Large-bore downcomer tubes are used to circulate feedwater between the drums. The downcomer tubes pass outside of the furnace and join the steam and water drums. The steam is produced in a steam drum and may be drawn off for use from here. It is known as 'wet' or saturated steam in this condition because it will contain small quantities of water. Alternatively the steam may pass to a superheater which is located within the boiler. Here steam is further heated and 'dried' i.e. all traces of water are converted into steam. This superheated steam then leaves the boiler for use in the system. The temperature of superheated steam will be above that of the steam in the drum. An 'attemperator', i.e. a steam cooler, may be fitted in the system to control the superheated steam temperature.

The hot gases produced in the furnace are used to heat the feedwater to produce steam and also to superheat the steam from the coiler drum. The gases then pass over an economiser through which the feedwater passes before it enters the coiler. The exhaust gases may also pass over an air heater which warms the combustion air before it enters the furnace. In this way a large proportion of the heat energy from the hot gases is used before they are exhausted from the funnel. Two basically different types of feedwater is passed through the tubes and the hot gases pass over them. In the firetube boiler the hot gases pass through the tubes and the feedwater surrounds them.

Boiler Types

Introduction

The watertube boiler is employed for high-pressure, high-temperature, high-capacity steam applications, e.g. providing steam for main propulsion turbines, turbo alternators or cargo pump turbines. Firetube boilers are used for auxiliary purposes to provide smaller quantities of low-pressure steam on diesel engine powered ships.

Watertube Boilers

The construction of watertube boilers, which use small-diameter tubes and have a small drum, enable the generation or production of steam at high temperatures and pressures. The weight of the boiler is much less than an equivalent firetube boiler and the steam raising process is much quicker. Design arrangements are flexible, efficiency is high and the feedwater has a good natural circulation. These are some of the many reasons why the watertube boiler has replaced the firetube boiler as the major steam producer.

Modern D-type boilers have generating, superheating, feed and air heating surfaces in percentage areas and position in the boilers to suit the required operating conditions.

In the middle sixties practically all new vessels were propelled by diesel machinery. Reliable slow speed diesel engines were available which, burning heavy fuel, were economical, and being less complicated than a corresponding steam plant, were more easily automated.

The closure of the Suez Canal, however, caused tanker owners to consider the economies of transporting crude oil in greater bulk and this resulted in the design of 200,000 dwt tankers requiring 20,000 k W for propulsion. Such powers were higher than normally available from the oil engines of that period, and presented a great opportunity for the revival of steam propulsion. Boiler and turbine designers took advantage of the situation with the result that steam was once more adopted for the higher powers.

In the constant quest for lower overall costs, including initial and operating costs, turbine machinery installations have been designed with a single boiler for propulsion purposes. This generally being supplemented by some form of auxiliary power as a ‘get you home’ device, in the event of complete boiler failure.

The single boilers of such installation have, of necessity, to be as reliable as possible, and at the same time, must be capable of operating for long periods between shut downs for cleaning operations, etc.

The single boilers of such installation have, of necessity, to be as reliable as possible, and at the same time, must be capable of operating for long periods between shut downs for cleaning operations, etc.

Features embodied in boilers for this service include:

(a) Large furnaces with conservative heat release rates and ample flame clearances.

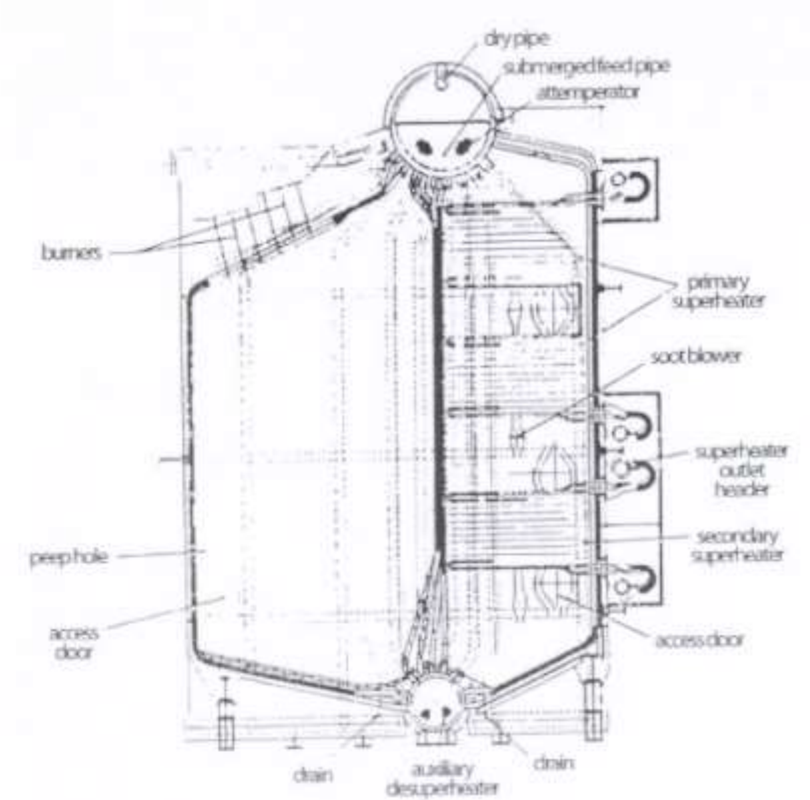
(b) Furnaces completely water-walled either with membrane-type walls or closely pitched tubes to cut down brickwork maintenance.

(c) Roof firing to give a more uniform heat release and improved gas flow through the boiler.

(d) Superheaters in lower temperature gas zones shielded from the furnace.

(e) Improved forms and materials for superheater supports.
(f) Improved methods of superheat control.
(g) Improved soot blowing arrangements.

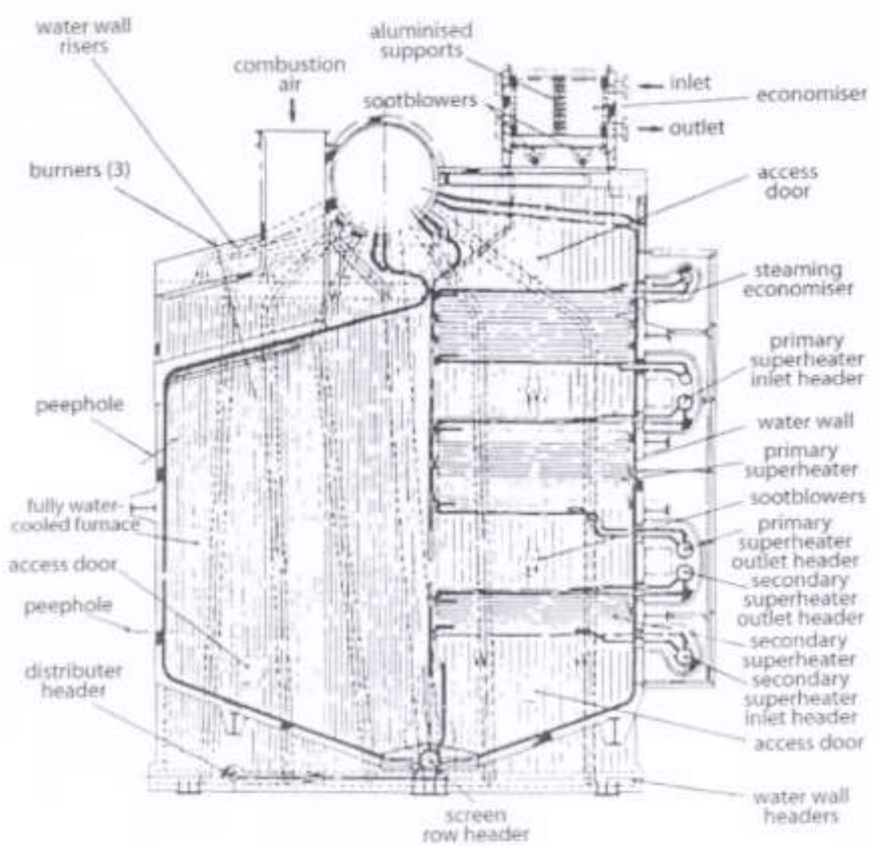
An early development in watertube boilers was bent tube design. This boiler has two drums, an integral furnace and is often referred to as the 'D' type because of its shape . The furnace is at the side of the two drums and is surrounded on all sides by walls of tubes. These waterwall tubes are connected either to upper and lower headers or a lower header and the steam drum. Upper headers are connected by return tubes to the steam drum. Between the steam drum and the smaller water drum below, large numbers of smaller-diameter generating tubes are fitted.



These provided the main heat transfer surfaces for steam generation. Large-bore pips or downcomers are fitted between the steam and water drum to ensure good natural circulation of the water. In the arrangement shown, the superheater is located between the drums, protected from the very hot furnace gases by several rows of screen tubes. Refractory material or brickwork is used on the furnace floor, the burner wall and also behind the waterwalls. The doubling casing of the boiler provides a passage for the combustion air to the air control or register surrounding the burner.

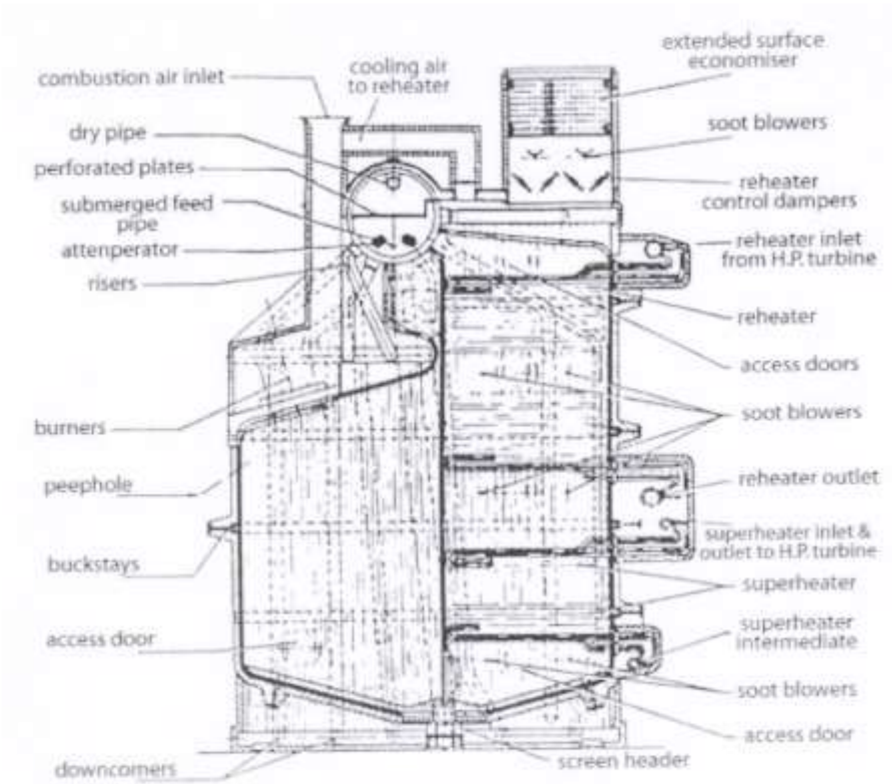
The early version of the D-type boiler were an important advance in their time but changes in refining methods and crude from various sources produced residual type fuel oils which began to reveal their shortcomings. The furnaces, being small and employing large amounts of refractory, operated at very high temperature. Flame impingement was not unknown and conditions generally for the refractories were severe and resulted in high maintenance.

Refractories broke down requiring replacement. They were frequently covered in glass-like deposits, and on the furnace floor thick vitreous accumulation often required the use of road drill for removal.



In the superheater zone the products of combustion were still at high temperature and deposits from impurities in the fuel condensed out on the tubes, reducing heat transfer and steam temperature. Eventually, gas passages between the tubes would become so badly blocked that the forced draught fans would be unable to supply sufficient air to the burners, combustion became impaired and the fouling conditions accelerated. Sodium and vanadium compounds present in the deposits proved very corrosive to superheater tubes causing frequent repeated failure. Due to the fouled condition there was a loss of efficiency and expensive time-consuming cleaning routines were required.

The need for a wider range of superheated steam temperature control led to other boiler arrangements being used. The original External Superheater 'D' (ESD) type of boiler used a primary and secondary superheater located after the main generating tube bank. An attemperator located in the combustion air path was used to control the steam temperature.

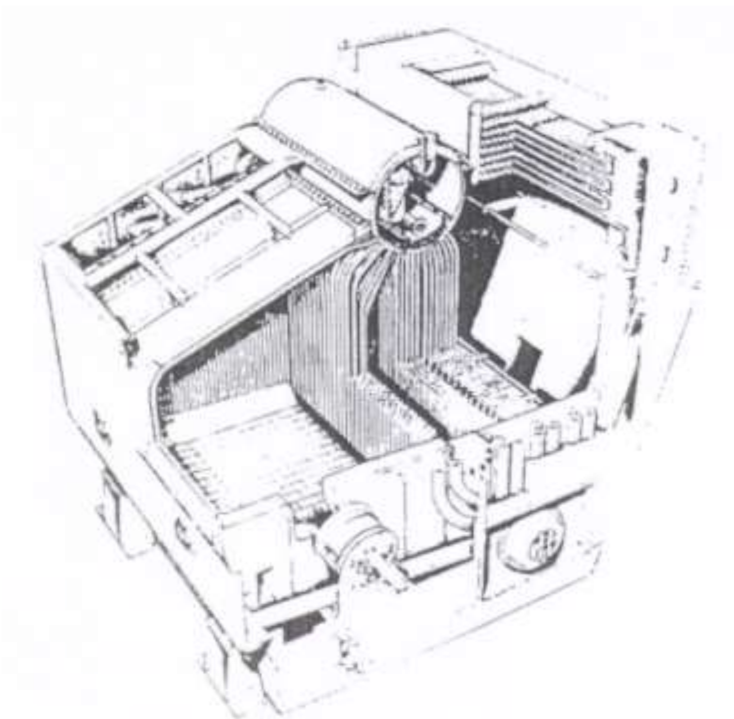


sectional elevation

The later ESD II type boiler was similar in construction to the ESD I but used a control unit (an additional economiser) between the primary and secondary superheaters. Linked dampers directed the hot gases over the control unit or the superheater depending upon the superheat temperature required. The control unit provided a bypass path for the gases when less superheating was required.

In the ESD II boiler the burners are located in the furnace roof, which provides a long flame path and even heat transfer throughout the furnace. In the boiler shown above, the furnace is fully water-cooled and of monowall construction, it is produced from finned tubes welded together to form a gastight casing. With monowall construction no refractory material is necessary in the furnace.

The furnace side, floor and roof tubes are welded into the steam and water drums. The front and rear walls are connected at either end to upper and lower water-wall headers. The lower water-wall headers are connected by external downcomers from the steam drum and the upper water-wall headers are connected to the steam drum by riser tubes.



The gases leaving the furnace pass through screen tubes which are arranged to permit flow between them. The large number of tubes results in considerable heat transfer before the gases reach the secondary superheater. The gases then flow over the primary superheater and the economiser before passing to exhaust. The dry pipe is located in the steam drum to obtain reasonably dry saturated steam from the boiler. This is then passed to the primary superheater and then to the secondary superheater. Steam temperature control is achieved by the use of an attemperator. Located in the steam drum, operating between the primary and secondary superheaters.

Radiant-type boilers are a more recent development, in which the radiant heat of combustion is required to raise steam being transmitted by infra-red radiation. This usually required roof firing and a considerable height in order to function efficiently. The ESD IV boiler, shown above, is of the radiant type. Both the furnace and the outer chamber are fully watercooled. There is no conventional bank of generating tubes. The hot gases leave the furnace through an opening at the lower end of the screen wall and pass to the outer chamber. The outer chamber contains the convection heating surfaces which include the primary and secondary superheaters. Superheat temperature control is by means of an attemperator in the steam drum. The hot gases, after leaving the primary superheater, pass over a steaming economiser. This is a heat exchanger in which the steam-water mixture is flowing parallel to the gas. The furnace gases finally pass over a conventional economiser on their way to the funnel.

Reheat boilers are used with reheat arranged turbine systems. Steam after expansion in the high-pressure turbine is returned to a reheater in the boiler. Here the steam energy content is raised before it is supplied to the low-pressure turbine. Reheat boilers are based on boiler designs such as the 'D' type or the radiant type.

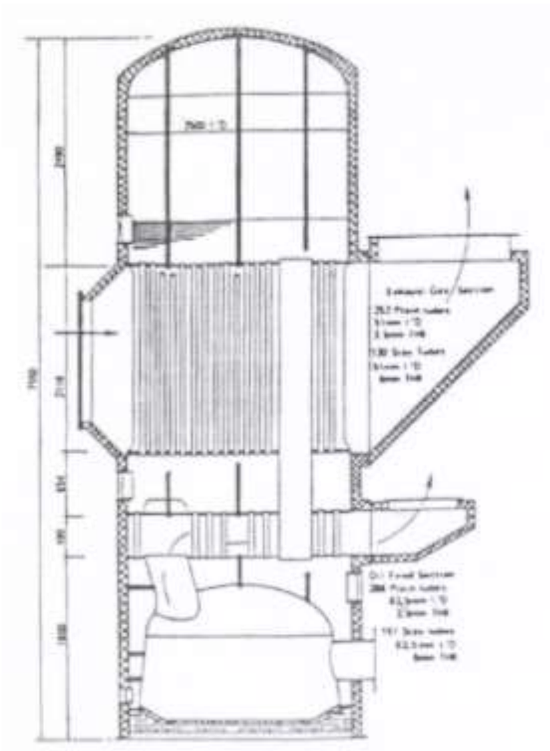
Auxiliary Boilers

Apart from water tube boilers used for main propulsion purposes, there are a number of designs at sea which are used for a variety of auxiliary purposes including, in some cases, emergency propulsion.

Whereas in the past Scotch boilers were commonly used for this purpose, their weight and space requirements have given way to the lighter and more compact water tuber boilers, especially in tankers where there is a heavy steam demand for pumping, heating and other auxiliary services.

Many auxiliary boilers are found on motor ships, where they may not always receive care and attention to the degree that would be expected on a steam ship. For this reason, and also due to the relatively short periods for which they may be fired, these boilers are of simple and robust construction, usually of the bi-drum integral furnace type with simple tube shapes such as the Foster Wheeler D4 or the Babcock. These boilers may be required to deliver saturated steam or a superposed superheater in the uptake allows for a small degree of superheat.

Due to the intermittent operating routine to which these boilers are subjected, and due to the fact that returning condensate may bring particulate matter and/or oil from the steam consumers, feed and boiler water conditions may not always reach appropriate standards of quality and internal deposits followed by tube failure can result. Vigilance, and proper maintenance of filters and steam systems can minimise these risks, but some owners have avoided them by adopting the indirect fired or double evaporation system. In this the boiler consists of two parts; a high pressure portion and a low pressure portion. The former is similar to the D4 or M11 and is direct fired, operating on a closed cycle on the water side. Once filled with high quality water it only needs occasional topping up to replace any slight leakage which may occur. The steam produced is led to the low pressure portion which is supported above the fired boiler. It consists of a pressure vessel containing a tube bundle through which the steam generated by the high pressure stream generates steam at a lower pressure from the water surrounding the tube bundle, within the low pressure vessel. The low pressure steam is used to supply the auxiliary services may be dirty because the worst that can happen is that the secondary tube bundle becomes fouled and the production of low pressure steam is reduced. Risk of tube failure is virtually eliminated since the highly heated tubes in the combustion zone are only exposed to the high quality closed circuit water.



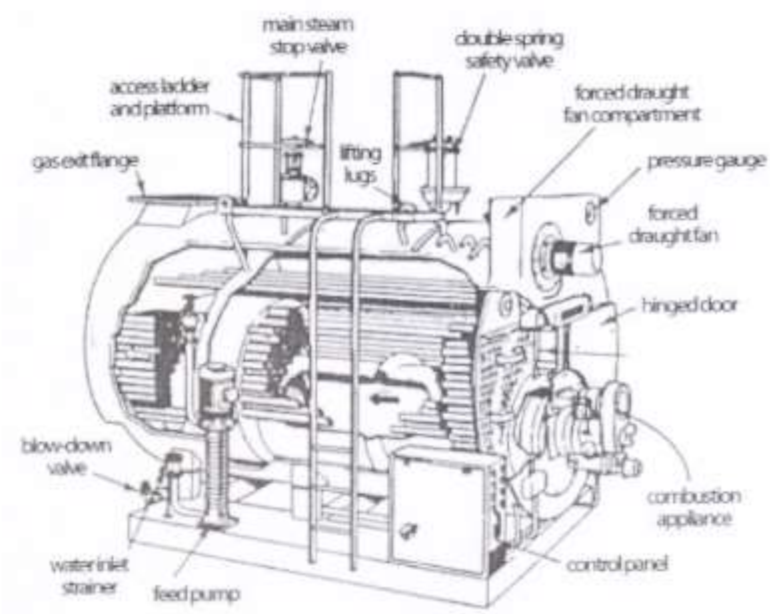
Boiler units of the double pressure or double evaporation type are available from many suppliers worldwide, one typical design being the Aalborg AT4 above. This shows the secondary or low pressure section arranged above the primary high pressure section and connected thereto by welded steam and condensate pipes. The tube bundle within is connected to inlet and outlet headers which are welded into the drumhead. The primary high pressure section is of bi-drum (D-type) construction and is fired by a simple rotary cup burner. Products of combustion leave from the side of the furnace at floor level and pass in a generally longitudinal fashion over tabular generating surface connected between upper and lower drums. Beyond the generating surface the combustion gases transit a superheater arranged in the uptake. The low pressure steam is thereby superheated to some degree before delivery to the auxiliary consumer and this is very useful in ensuring that wet conditions do not exist when steam is passing to machinery remote from the boiler.

With the advent of single main boiler steam ships, notably VLCCs, the auxiliary boilers had the role of emergency propulsion. So that this unit should have the same standard of construction as the all welded radiant boilers then used for main propulsion, welded construction and use of membrane tube panel enclosure walls was adopted.

This could be roof fired or front fired with steam atomising burners, and could deliver saturated steam or superheated steam up to about 350°C from a superheater, and could operate at steam pressure up to the same level as the main boiler as necessary. Auxiliary boilers of this type could also be fitted with heating coils in the lower drum accepting bled steam or desuperheated steam. These boilers could be sized to generate low pressure steam for auxiliary duties at sea or could be smaller, sufficient to maintain, the boiler at 1 bar or so pressure ready for instant firing. In either case, the boiler would be in readiness to supply emergency propulsion steam with a minimum delay. Such emergency steam connected to a suitable stage of the main turbine provides get-u-home power in the event of loss of the main boiler, and prompt supply of the power would be needed if the emergency occurred with the vessel in close company with others, or in bad weather in restricted waters. Obviously, when using a boiler in this way to supply low pressure auxiliary steam great care would be needed to maintain water side cleanliness, since on occasion it would also be directly fired.

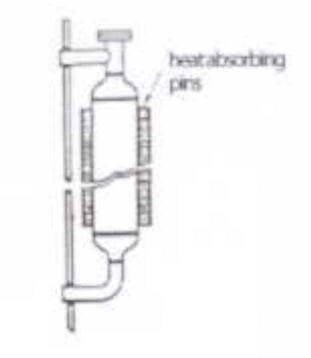
Firetube Boilers

The firetube boilers is usually chosen for low-pressure steam production on vessels requiring steam for auxiliary purposes and in these cases water tube boilers can improve uneconomic. Operation is simple and feedwater of medium quality may be employed. The name ‘tank boiler’ is sometimes used for firetube boilers because of their large water capacity. The terms ‘smoke tube’ and ‘donkey boiler’ are also in use.



Of the variety proprietary designs of firetube or tank type boiler, many are composite, including sections for diesel exhaust gas heat recovery as well as for direct firing. In the Cochran boiler (above), the products of combustion and exhaust gases pass through separate sets of tubes immersed in the boiler water. These tubes are expanded into tube plates which form part of the boiler pressure shells. With the Aalborg AQ5 the gas streams pass horizontally over the outside of vertical tubes expanded into tube plates forming part of the boiler pressure vessel, in such a way that boiler water flows upwards throughout the tubes. Large downcomer tubes complete the circulation system.

A G Weser produced a boiler unit where the products of combustion pass through tubes surrounded by boiler water whilst diesel exhaust passes over tubes through which boiler water passes . A design similar in principle came from Howaldtswerke.

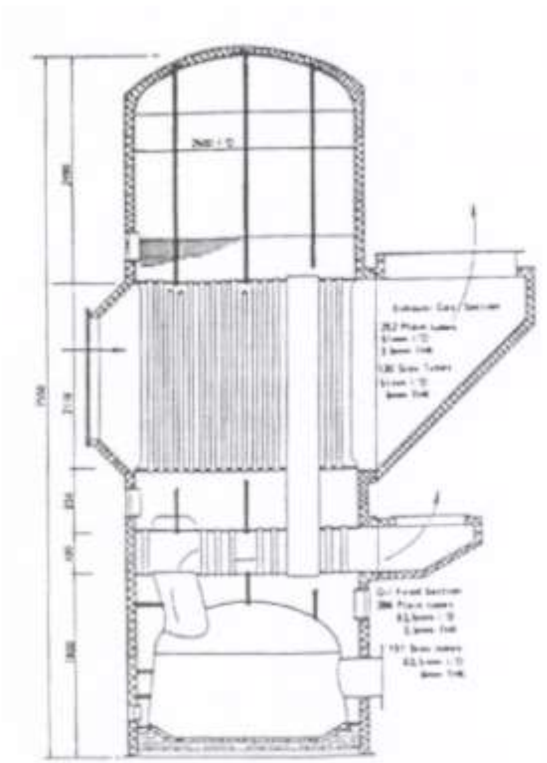


the sunrod patent element

The Sunrod oil fired boiler combines a firetube and a watertube by arranging the latter inside the former. The watertube surface is extended by having steel pins electric resistance welded on its outer surface. The furnace is arranged either as a water cooled shell with a refractory floor or as a completely water cooled shell. In the largest sizes the furnace walls are of watertube construction. In each case a number of firetubes of large diameter extend upwards from the furnace top to a tube plate forming the top pressure shell. Inside each of these is arranged a watertube with extended surface. The top and bottom of each is connected through the wall of its firetube into the water space of the boiler.

Package Boilers

Most firetube boilers are now supplied as a completely packaged unit. This will include the oil burner, fuel pump, forced-draught fan, feed pumps and automatic controls for the system. The boiler will be fitted with all the appropriate boiler mountings.



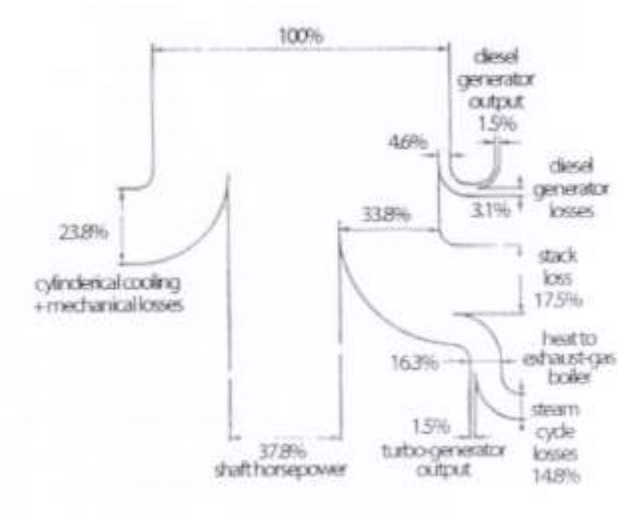
A single-furnace three-pass design is shown in above. The first pass is through the partly corrugated furnace and into the cylindrical wetback combustion chamber. The second pass is back over the furnace through small-bore smoke tubes and then the flow divides at the front central smoke box. The third pass is through outer smoke tubes to the gas exit at the back of the boiler.

There is no combustion chamber refractory lining other than a lining to the combustion chamber access door and the primary and secondary quarl.

Fully automatic controls are provided and located in a control panel at the side of the boiler.

Exhaust Gas Heat Recovery

In the quest for higher efficiency, the designers of marine machinery installations are constantly endeavouring to extract the maximum amount of energy from the fuel within the limits dictated by practical and economic considerations. In all forms of marine propulsion plant, a great deal of energy is wasted, principally by way of the exhaust gases to the atmosphere but also through the cooling water systems, to the sea. It is this waste-heat energy which is potentially recoverable. Continually rising fuel costs and the fact that world reserves of primary energy are not inexhaustible make efficient use of such wasted energy increasingly attractive.



The figure above is a typical heat balance diagram for the main heavy oil engine of a large modern vessel. It will be noted that not more than 40% of the fuel consumed is converted into useful work through the main engine. Of the remaining energy liberated from the fuel, some 34%, the equivalent of about 90% of the mechanical power output, is contained in the exhaust gases. The temperatures of these exhaust gases range from 280°C to 340°C in the case of slow speed 2-stroke engines and from 370°C to 410°C for medium speed 4-stroke engines but it should be remembered that the volume of gas available from a 4-stroke engine is about half of that available from a similarly rated 2-stroke engine. Thus, the apparent increased amount of heat available from the 4-stroke engine is not as pronounce as appears from reference to the exhaust gas temperatures.

When consideration is given to the large volumes of exhaust gases available at these temperatures and when it is recalled that the corresponding temperature of steam at a pressure of 7 bar is 170°C, it readily becomes apparent that the conversion of waste-heat from the exhaust gases of large marine heavy oil engines into useful energy in the form of low pressure steam presents a very convenient method of increasing the machinery's overall efficiency.

There are a number of special factors that require to be considered in designating a waste-heat recovery system which are not common to a fired power plant. In the design of a fired boiler, the required output is known and the designer has to determine the size of the boiler and corresponding fuel input. In the case of a waste-heat boiler, the problem is approached from the opposite direction. Here, the heat input from the exhaust gases is the known factor and the amount of energy that can be recovered, from a practical point of view, in the form of steam is the quantity to be determined, from a practical point of view, in the form of steam is the quantity to be determined. In addition, of course, it is necessary to decide by what method the resultant energy can best be utilised within the machinery installation.

In order to limit the size of waste-heat units practicable proportions, a terminal temperature difference of about 16°C is normally considered to be a minimum figure. Since the mean temperature difference between exhaust gas and the water boiling within the boiler tubes is low, large amounts of heating surface are needed. To minimise the bulk and weight of the boiler arranged above the engine, extended surfaces are used, the heat exchanger taking on the appearance of an economiser used for final heat recovery on fired boilers. Indeed the suppliers for economisers also supply the heat recovery equipment. The usual arrangement has a bank, or banks, of sinuous tubes connected at each end to headers, the whole arranged within an insulated casing. The type of extended heating surface used varies with the manufacturer. An exception to the use of extended surface is seen in the exhaust gas unit of La Mont design which uses a stack of closely pitched spirally wound plain tubes connected to vertical inlet and outlet headers.

In addition, the maximum utilisation of the energy in the exhaust gases is greatly restricted by the danger of low temperature corrosion on the gas side of waste-heat units. The exhaust from a heavy oil engine contain about 10% of water and when an engine is operating on fuels of high vanadium or sulphur content conditions are ideal for the formation of sulphuric acid on the gas side of the waste-heat unit if the temperature of the heating surfaces falls below the acidic dew point which, for practical purposes, may be taken as 140°C. To avoid this danger, a designed gas outlet temperature of not less than 180°C is usually recommended.

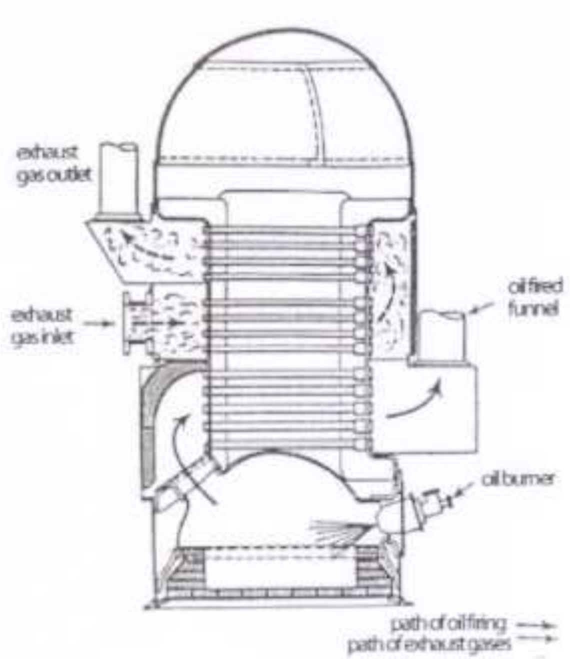
It will be clear from the above therefore, that to arrange for waste-heat boilers to operate at pressures in excess of 7 bar may result in the available waste-heat energy not being used to the best of advantage. On the other hand, generating steam at pressures below 5 bar with a view to extracting a maximum amount of waste-heat may lead to unacceptable maintenance costs due to rapid corrosion of gas side heating surfaces. For these reasons, only about one fifth of the waste-heat in the exhaust gases, representing between 5% and 10% of the output of the main engine is available for conversion into useful work.

Utilisation of waste-heat in the lower temperature ranges is achieved, to a small extent, in many modern systems, by means of exhaust gas feed water heaters or economisers having heating surfaces protected by corrosion resisting material. Similarly, it is worthy of note that the heat carried away in the cooling system of main engines has been successfully used for feed water heating purposes.

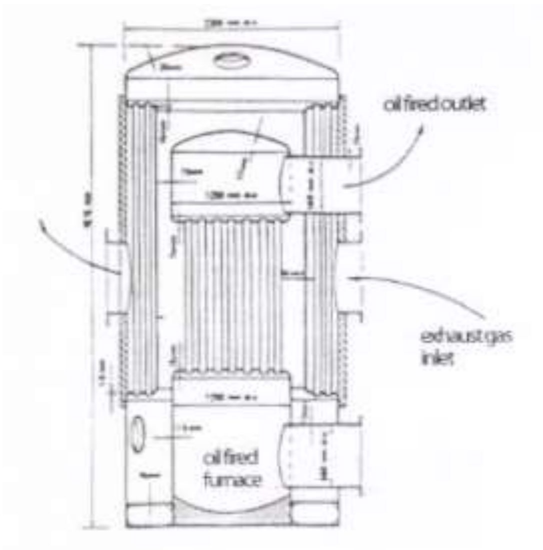
To make the most efficient use of the waste-heat contained in the exhaust gases of a heavy oil engine, machinery installation should be so designed that there is a sufficient demand for steam when the ship is at sea so as to utilise most of the waste-heat available when the main engine is developing about 80% of full power. At the same time, a waste-heat system should incorporate means of raising and maintaining steam for all needs, not only when the ship is at sea under full power conditions, but also when operating at reduced speeds and when in port.

Nowadays, most motorships operate on high viscosity fuels which require to be heated at all times and it is, therefore, essential that adequate supplies of steam are always available if the inconvenient and uneconomic practice of manoeuvring the main engine on a light diesel oil is to be avoided.

In the case of ships having machinery in the lower power ranges, there may only be sufficient waste-heat available to generate steam for main engine fuel and domestic heating purposes. For ships having machinery in the higher power ranges, however, it becomes most attractive, in the interests of economy, to install comprehensive waste-heat systems which are designed to supply sufficient steam to generate all the electrical load at sea as well as steam for heating. In some high powered vessels, the waste-heat potential substantially exceeds that necessary for electrical power generation and heating, and proposals are being studied for utilising this excess energy to supplement main engine propulsion.



The heat recovery unit may be supplied with a steam and water drum when arranged as an independent unit for forced circulation, or sometimes for natural circulation. The most common arrangement is to have the unit circulated by a pump and connected to a separate oil fired boiler. The circulating pump draws water from this, and the steam/water mixture leaving the heat exchangers is separated in the drum of the oil fired boiler, and the steam taken from the drum. At sea the main engine exhaust is used to generated steam, which at the same time keeps the oil fired boiler warm having a preservative effect. In harbour when the main engine is shut down, the oil fired boiler is flashed up to produce steam as required. If, at sea, the steam generated from the diesel exhaust is insufficient to meet demand, then the supply can be supplemented by firing the auxiliary boiler (above). Similar arrangements are possible when the oil fired boiler is of the double evaporation type, the exhaust gas heat recovery unit then being circulated from the LP section (below). It is not normally necessary to make any attempt to control the generated, the pressure in the system will rise. This reduces the mean temperature difference between gas and water in the tubes so reducing heat transfer and the rate of steam generation. It is, however, a simple matter to fit a gas bypass so that, should pressure tend to rise too much, a damper opens, allowing gas to bypass the heating surfaces.



Such heat recovery and auxiliary steam systems can be very simple or very sophisticated depending upon the nature of the vessel and the steam demand on board. Improvements in the overall efficiency of the main engine have led to a decline in the temperature of the exhaust gases so that more complicated arrangements are made in order to extract the maximum amount of heat.
Heat recovery systems may be found to include superheaters, steam separators, dual pressure generating sections, feedheating, steam to steam generation and dump condensers for additional control.

Evaporators

Introduction

There are various means of producing fresh water from sea water, such as ion-exchange and electro-dialysis, but for most marine purposes evaporation provides the most economically viable method.

This basically uses heat from some convenient source to boil the sea water. The vapour driven off leaves its dissolved solids behind in the water remaining in the evaporator. This water is usually referred to as brine. The problem then arises that as the quantity of these dissolved solids building up in the brine, they begin to deposit as scale so reducing the efficiency of the heat transfer process. In addition the increased density leads to foaming at the water level, so giving a greater possibility of the carry-over of water droplets along with the vapour leaving the evaporator thus reducing the purity of the fresh water produced.
By operating the evaporator at low pressure and temperatures, and by maintaining reasonably low densities these problems can be greatly reduced. The level of the brine density is controlled by blowing down; this removes both the salts still in solution together with suspended particles of sludge. In general the density of the brine should not exceed 64,000

ppm, with a normal operating density of around 48,000 ppm. The lower the density the smaller the amount of scale depositing but the greater the amount of blow down required, with consequently a greater consumption of heating steam. In practice this means compromise must be reached between the reduction in cleaning and the increase in fuel consumption. Deposits of scale can often be removed from the heating surfaces by thermal shock when the evaporator is operating, and by mechanical or chemical means when it is shut down.

Small amounts of suitable chemicals added to the evaporator feed are beneficial in reducing the amount of scale formed, or ensuring that only soft scales are deposited.

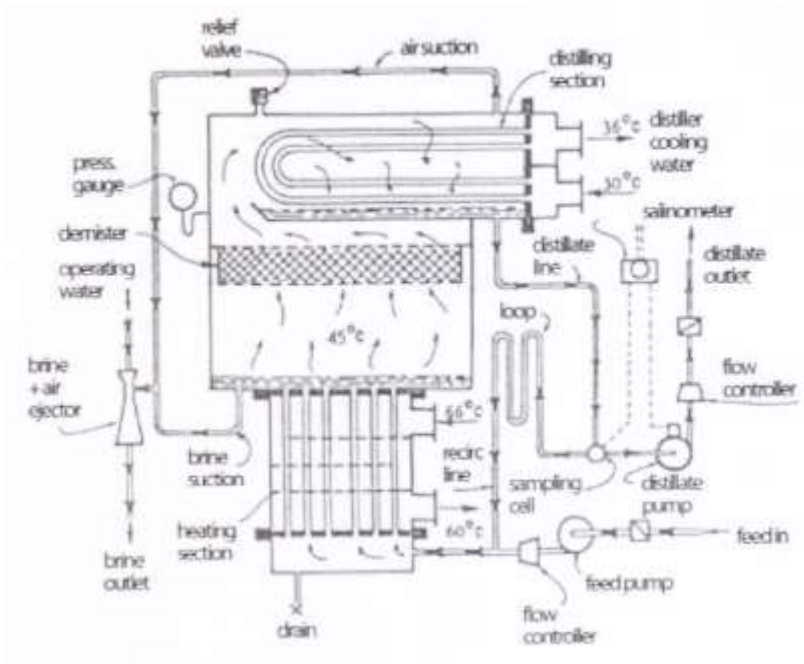
The fresh water produced can be used to provide make-up feed for the boilers, or for domestic purposes. In this latter case it is referred to as potable water, and the vapour must be passed through a suitable distilling plant and also be sterilised before use.

The evaporator feed can consist of fresh water obtained from shore supplies, or sea water. A separate feed pump may be used, but in many cases the feed is obtained from a suitable main, such as sea water cooling line. When chemicals are injected into the sea water cooling lines to protect them from corrosion or fouling, care must be taken that the evaporator does not become contaminated. This is especially important when the production of potable water is involved, and in this case, a separate untreated sea water supply line will be required for the evaporator.

Many types of evaporators are used at sea, the variations in design usually being to give a more economical use of the heating medium, and (or) to reduce cleaning, rather than to improve the purity of the water produced. This usually has a density of less than 4 ppm and, in the case of modern combined evaporators-distillers working under vacuum conditions, less than 1 ppm.

The make-up requirements of high pressure watertube boilers often demand densities consistently below 0.5ppm and this may be achieved by double evaporation, consisting of two evaporators placed in series, the feed of the second being the water produced by the first. Alternatively, using fresh water feed in a single evaporator can give similar results. In other cases the make up feed is passed through a demineraliser which, unlike the previous methods, also enables the dissolved carbon dioxide content of the make-up water to be reduced.

Single Effect Evaporators



These form simple compact units suitable for small to medium outputs. Supplying live steam to the heating section can provide a high mean temperature difference enabling a small heating surface to be utilised for a given output. This however is thermodynamically uneconomical, and in many cases use is made of bled steam or waste heat, for example the jacket cooling water from a diesel engine. In general this will increase the size of the plant.

Submerged Tube High Vacuum Type

This consists of a two part shell, fabricated from mild steel, with its internal surfaces protected against corrosion by a bonded rubber coating. The lower evaporating section contains a vertical tube stack which consists of plain aluminium brass tubes expanded into tube plates at both ends. The upper vapour shell contains the distilling condenser consisting of aluminium brass hairpin tubes expanded into a single tube plate and placed horizontally above a water catchment tray. To reduce carry-over to a minimum, the vapour entering the distilling section has to pass through a mesh type demister. This consists of layers of knitted monel metal wire. Alternatively polypropylene mesh may be fitted.

The evaporator feed, after passing through a strainer, flow indicator, and flow controller, enters at the bottom of the evaporator. It then passes up through the vertical heating tubes where its temperature is raised by steam or hot water passing over the outside of the tubes.

Sufficient heat is provided for the water to boil under the vacuum conditions existing in the shell, the resulting vapour rising to pass through the demister. The vapour can pass freely through this but any water particle impinge onto the wire mesh, where they accumulate and ultimately coalesce into water droplets large enough to break free, dropping down against the vapour flow, to fall back into the brine. Compared to vane type baffles or flat plate deflectors, this mesh type demister greatly improves the purity of the distillate produced.

Vapour leaving the demister then enters the distilling condenser, where its latent heat is removed by cooling water circulating through the tubes of the distiller. The resulting droplets of condensate are collected in the catchment tray, from where it flows via a salinometer which measures the density of the distillate. When this is acceptable the distillate pump discharges it through a flow controller and non-return valve to the storage tanks. If the density is unacceptable the salinometer provides a signal which stops the pump. This allows the unacceptable distillate to pass over the double loop to re-enter the evaporator feed line for re-distillation. As an alternative arrangement the salinometer may be used to operate a series of diverter valves which achieve a similar object.

The brine density is controlled by fitting flow controllers in the feed and distillate lines, these being set to admit 2.75 times as much feed water as the amount of distillate produced, the excess being pumped out by the water operated ejector. This both provides a continuous blow down of brine so as to maintain the density low enough to prevent scale forming, and also removes air and other non-condensible gases released during the evaporation process, from the upper part of the vapour shell. The necessary vacuum for the proper operation of the plant is thus achieved.

About thirty times as much operating water is supplied to the ejector as the amount of brine it removes and this so dilutes the brine that no undue build up of deposits should occur in the discharge lines.

Another factor involved in maintaining the correct brine density is that when newly cleaned the unit can often produce more distillate than its normal rated output. If this is allowed to occur it would reduce the feed to distillate ratio and so lead to an unduly high brine density. The flow controller in the distillate line prevents this by keeping the discharge rate constant, so that any excess distillate returns over the loop to the evaporator, so diluting the brine to its normal density.

Heat for evaporation can be provided by a direct steam supply, by bled steam, or by waste heat such as jacket cooling water from a diesel engine.

The cooling water for the distilling condenser can consist of feed water from a turbine feed system, or of sea water. In the latter case, some of the sea water coolant may be bled off to serve as evaporator feed.

It is to be used as a potable water, then the distillate must be passed through a suitable filter and sterilising unit, before entering the storage tank.

If the feed supply is interrupted, then in order to avoid an undue build up on density the distillate pump should be stopped until the feed supply has been restored.

The salinometer probe should be cleaned at every available opportunity, while at least once every six months or more frequently if required, the plant should be shut down and cleaned. Any sludge which may have accumulated at the bottom of the shell is washed out and, if necessary, any deposits removed from the heating tubes by acid cleaning. This is done by circulating a 10% solution of hydrochloric or sulphamic acid through the heating section, pumping it in through the feed inlet connection and out through the brine outlet connection in the shell.

Flash Evaporator

As the majority of scale formation occurs only when the water actually boils, this type of evaporator separates the heating and boiling processes to different sections of the plant, the basic layout of which is shown.

The incoming sea water feed is first heated to some temperature below its boiling point in tubular heat exchangers. This is done in two stages, in the first formed by the distilling condenser the feed is heated by the outgoing vapour which gives up its latent heat, and in the second stage by steam or hot water. The heated feed water is then released into the flash chamber where the pressure is maintained low enough to ensure that the corresponding saturation temperature is below that of the incoming hot water. The water cannot remain in this super-saturated state, so some of its mass flashes off into steam, leaving its dissolved solids behind in the water remaining in the flash chamber. The released steam then passes to the distilling condenser, from where the resulting distillate is pumped to the storage tanks via a potable filter and steriliser if necessary. The density of the distillate is measured by a salinometer and if it reaches to too high a value, the distillate pump is stopped and the unacceptable water passes over a loop to the brine pump suction from where it is discharged along with the outgoing brine. This is removed from the flash chamber and pumped overboard, being diluted with sea water if necessary to prevent an undue build up of deposits in the discharge line.

By avoiding boiling in the heating sections, scale deposits on the heat exchange surfaces are largely avoided, final water temperatures above 80°C being recommended to keep deposits to a minimum. If necessary chemicals may be added to assist in this, being essential if water temperatures above 80°C are used in the heaters. Any deposits forming in the flash chamber do not interfere with the heat transfer and so do not effect the operation of the plant.

A water operated ejector is used to remove air and other non-condensible gases from the vapour chamber and so maintain the necessary vacuum conditions.

The vapour chamber is fabricated from mild steel, with a bonded rubber coating as a protection against corrosion. Aluminium brass tubes expanded at both ends into tube plated of rolled admiralty brass, form the heat exchange surfaces. The usual mounting for the proper working of the evaporator are fitted.

Automatic control is necessary to ensure satisfactory operation of the plant, as it is sensitive both to changes in sea temperature and to the water level in flash off commences, the second stage heater has to supply all the necessary heat. This can be done either by supplying additional heating steam, or by restricting the flow of feed into the evaporator.

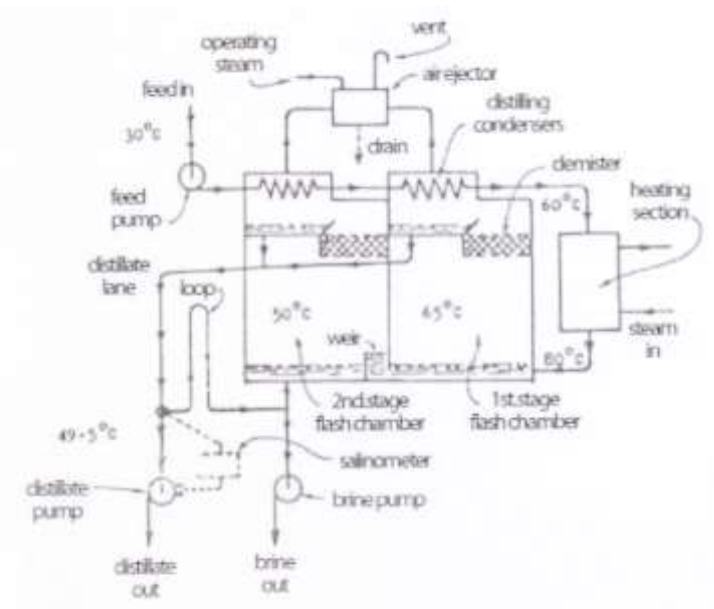
Multiple Effect Evaporation

As an evaporator does no mechanical work its performance cannot be measured in terms of efficiency and instead a performance ratio of distillate output to the heat input, often termed the gain ratio, is used.

To increase the gain ratio the evaporating process may be carried out in a number of pressure stages, or effects. This is achieved by arranging a number of evaporators in series, each being operated at a progressively lower pressure and using the vapour or water from the previous

stage to provide the heat for the evaporation process. Both submerged coil and flash evaporators can be arranged in this way.
The larger the number of effects the greater the saving in steam but at the cost of increased complexity, capital cost, and volume occupied by the plant. Thus the low of diminishing returns applies, and where relatively small outputs are involved single stage evaporation is often preferred, as these provide simple compact units. Economy is improved if desired by using bled steam or waste heat, however for larger outputs economy becomes increasingly important and so warrants the increased cost and complexity of multiple effect plants. For marine use however, except in a few special cases, they are normally limited to double effect flash evaporation plant.

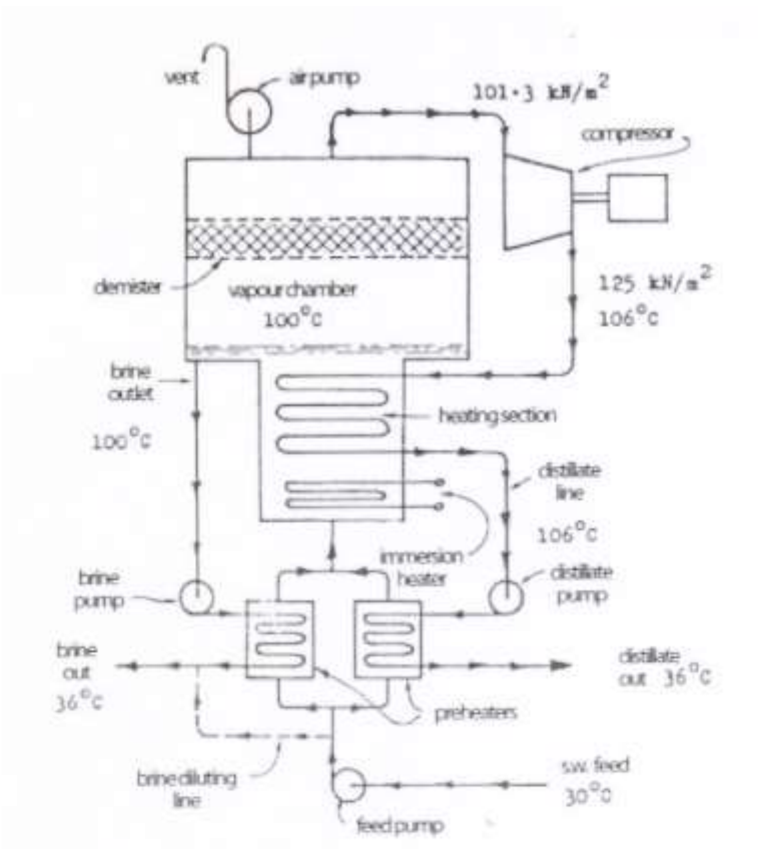
Double Effect Flash Evaporator



As shown previously the incoming feed is preheated as it passes through the distilling condensers of the successive stages and then raises to 80°C in an external heater. The hot water then enters the first stage chamber where flash off occurs. The released vapour passes through the demister to enter the distilling condenser where it gives its latent heat to the incoming feed. The brine meanwhile flows through to the second vapour chamber which is maintained at a lower pressure than the first, so that further flash off can take place. A weir is fitted to maintain a water seal between the two stages.
Distillate formed in the two vapour condensers is collected in the catchment trays, from where it flows to the distillate pump via salinometer probe. If the density proves to be too high, the pump stops and the unacceptable water passes over the loop to the brine pump suction where it is discharged with the outgoing brine.
The vapour shells are fabricated from mild steel with a bonded rubber coating although this tends to increase the size of the unit. Although tolerable for a different form of construction is then used. This usually takes the form of a specially fabricated steel structure, protected

against corrosion by the application of a special paint. Some form of ejector will be fitted to remove air and other non-condensable gases from the vapour shells. The usual mounting for the proper operation of the plant are also fitted.
Automatic control will again be necessary for efficient working of the plant.

Vapour Compression Evaporator



Another method of achieving steam economy is by means of vapour recompression. This process can give gain ratios in the order of 8 to 1, as compared to 0.9 to 1 for single submerged tube, and 1.5 to 1 for double effect flash evaporation. The basic layout of a vapour compression type evaporator is shown above.
The vapour is generated in the evaporator shell at atmospheric pressure and then passes through the demister to the compressor suction. Work is now done on the vapour so that it leaves the compressor at a higher pressure and temperature. This compressed vapour passes to the heat exchange section where it gives up its latent heat so raising the temperature of the incoming feed to its boiling point. The vapour produced then repeats this cycle.
The distillate leaving the heat exchange section is pumped to the storage tanks via the usual salinometer probe, so that in the event of the density being too high the salinometer can send a signal to a series to solenoid operated valves causing the unacceptable water to be dumped. Meanwhile brine is pumped out of the vapour shell and discharged overboard. Water bled

off from the evaporator feed line is used to dilute this water to prevent deposits from choking the pipes and valves.
To conserve heat the outgoing distillate and brine are passed through heat exchangers, where they give up sensible heat to preheat the incoming sea water feed.
A mechanical or thermo compressor can be used. The latter consists of a steam jet ejector, while the former can be either a high speed centrifugal compressor or a low speed rotary lobe type blower. Provided an effective demister is fitted to prevent carry over of water droplets which would otherwise cause serious erosion of the lobes, the slow speed blower type is to be preferred.
The vapour shell is fabricated from mild steel with a bonded rubber lining. This consists of a 3mm thick layer of hard rubber known as ebonite, which is applied to a steel surface which has been shot blasted prior to the application of bonding compound. The rubber coating is then rolled to squeeze out any air bubbles and then cured by steam heat.
This layer provides protection against both the brine and any cleaning acids used. The heat exchange surfaces consist of aluminium brass tubes expanded into rolled Admiralty brass tube plates.
For starting up, a separate heat source must be used to provide sufficient vapour to commence the cycle of events; in the plant considered an immersion heater is fitted for this purpose. An air pump is also fitted to remove air from the shell when starting up. This type of plant is normally automated, the programmed start up and shut down procedures being initiated by a single switch. This allows feed to enter the evaporator where the immersion heater raises it to boiling point. As the vapour pressure builds up it causes the air pump which has been removing air from the shell to cut out. The compressor then starts, followed by the brine and distillate pumps. Automatic control is carried out to maintain a constant pressure in the vapour shell.
Vapour compression plant when fitted with a mechanical compressor can operate with an electrical input only and so can be used where no steam supply is available.
Due to the fact that evaporation in this type of plant occurs at atmospheric pressure, it is essential that some form of chemical feed treatment be applied. Heat exchange surfaces must be kept clear of deposits and should be cleaned at least once every six months, or more frequently if found to be necessary. Acid cleaning may be required to remove the deposits formed.

Boiler Components

Boiler Mountings / Components

Certain fittings are necessary on a boiler to ensure safe operation. They are usually referred to as boiler mountings. The mountings usually found on a boiler are:

Safety valves

These are mounted in pairs to protect against over pressure. Once the valve lifting pressure is set in the presence of a Surveyor it is locked and cannot be changed. The valve is arranged to open automatically at the pre-set blow off pressure.

Main steam stop valve

This valve is fitted in the main steam supply line, and is usually of the non-return type.

Feed check or control valve

A pair of valves are fitted: one is the main valve, the other the auxiliary or standby. They are non-return valves and must give an indication of their open and closed position.

Water level gauge

Water level gauge of ‘gauge glasses’ are fitted in pairs. The construction of the level gauge depends upon the boiler pressure.

Pressure gauge connection

Where necessary on the boiler drum, superheater, etc, pressure gauges are fitted to provide pressure readings.

Air release cock

These are fitted in the headers, boiler drum etc, to release air when filling the boiler or raising steam.

Sampling connection

A water outlet cock and cooling arrangement is provided for the sampling and analysis of feed water. A provision may also be made for injecting water treatment chemicals.

Blow down valve

This valve enables water to be blown down or emptied from the boilers. It may be used when partially or completely emptying the boiler.

Scum valve

A shallow dish positioned at the normal water level is connected to the scum valve. This enables the blowing down or removal of scum and impurities from the water surface.

Whistle stop valve

This is a small bore non-return valve which supplies the whistle with steam straight from the boiler drum.

Watertube boilers

Because of their smaller water content in relation to their steam raising capacity, require certain additional mountings.

Automatic feed water regulator

Fitted in the feed line prior to the main check valve, this device is essential to ensure the correct water level in the boiler during all load conditions. Boilers with a high evaporation rate will use a multiple-element feed water control system.

Low level alarm

A device to provide audible warning of low water level conditions.

Superheater circulating valves

Acting also as air vents, these fitted ensure a flow of steam when initially warming through and raising steam in the boiler.

Soot blowers

Operated by steam or compressed air, they act to blow away soot and the products or combustion from the tube surfaces.

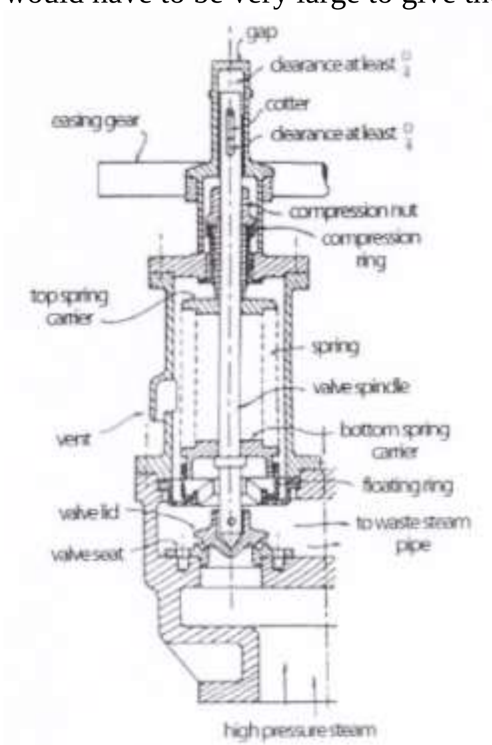
Safety Valves

These are fitted to protect the boiler from the effects of overpressure. The DOT demand that at least two safety valves are fitted to each boiler, but in practice it is usual to fit three safety valves-two on the steam drum, and one on the superheater outlet header. This latter valve must be set to lift before the drum safety valves so as to ensure a flow of steam through the superheater under blow off conditions. It is normally of the same basic type fitted on the drum.

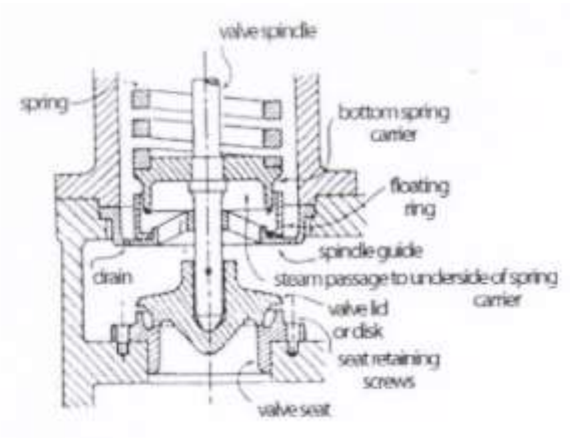
Although the MCA demand a minimum of two safety valves to each boiler, these may be fitted in the same valve chest with a single connection to the boiler, the safety valves must be capable of releasing the maximum amount of steam the boiler can evaporate, while still keeping within the 10 percent accumulation of pressure rule. The accumulation of pressure must not exceed 10% of the working pressure.

ALL BOILER SAFETY VALVES SHOULD LIFT AT 10%

The rule is necessary because, having calculated the cross sectional area of the valve bore, the valve lid must be able to lift at least ¼ of the valve bore in order to provide full steam flow. However, as the valve lifts, the force to compress the spring also increases, and so higher the valve lifts the greater the increase in boiler pressure. The DOT limit this accumulation of pressure to 10 percent of the maximum allowable working pressure for the boiler. This means that the lift of an ordinary spring-loaded mitre valve, although mechanically able to lift ¼D, would be very limited under these conditions, and the valve would have to be very large to give the required throughput.



Various designs have been developed to increase this working lift, and the improved high lift safety valve is a very suitable one for low and medium pressure boilers.
These valves increase their lift over that of a simple spring-loaded mitre valve in two ways. One is the specially shaped valve seat, the other being to use the lower spring carrier in the fashion of a piston, which acted upon by the pressure of the waste steam helps to compress the spring.



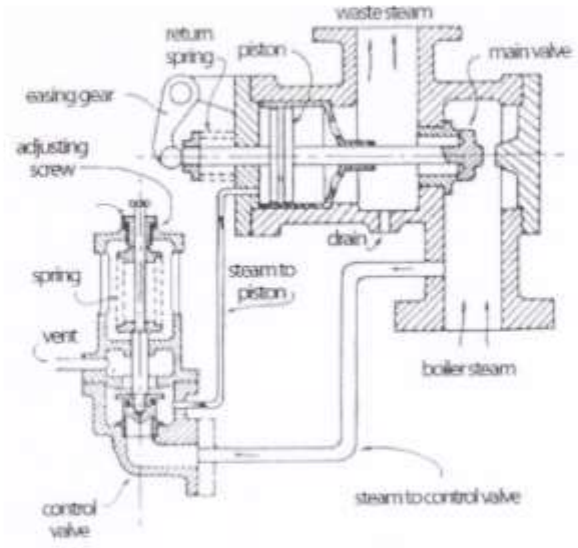
Adjustment of the valve is carried out by means of a compression nut screwing down onto the top spring plate. A compression ring is fitted after final adjustment to ensure no further movement takes place. A cap is then placed over this compression nut and top of the valve spindle, and a cotter is passed through and padlocked to prevent tampering by unauthorised persons. Clearances between this cap, the valve spindle and the cotter are such as to prevent the valve being held down externally, whether by accident or design.

A hexagon on top of the cap enables it to be turned, this motion being transmitted through the cotter and the valve securing pin to the valve lid, turning it upon the seat. With saturated steam this action is often effective in stopping the valve feathering and allowing it to seat firmly.

Easing gear is fitted so that in the event of an emergency, the valve can be opened by hand to full lift of ¼D to release the boiler pressure.

Conventional spring-loaded safety valves present problems when called upon to deal with steam at high pressure and temperatures. These include distortion of the spring and valve seats, and the difficulty of getting the valve to close smartly at these extreme conditions. The latter is necessary in order to prevent feathering; this is the name given to a condition where a thin film of steam blows across between the valve faces and leading to loss of steam. This is especially the case when the steam is superheated.

One type of valve designed to deal with these problems is the full bore type safety valve. This consists of main and pilot control valves; both being in direct communication with the boiler pressure.



Each safety valve is operated by its own control valve, the latter consisting of a small spring-loaded valve set to operate at the boiler blow off pressure. As it lifts its blanks off ports leading to the atmosphere, and allows steam pressure to build up and act upon the operating piston attached to the main valve spindle. This piston has about twice the area of the main valve, and the forces set up cause the main safety valve to open ¼ of it diameter, so giving full bore conditions for the escape of the boiler steam to the atmosphere through the waste pipe. The throughput is approximately 4 times the discharge capacity of an ordinary safety valve.

When the excess boiler pressure has been relieved the pilot valve closes, so opening the ports and allowing the operating steam to vent to the atmosphere; this releases the pressure acting on the piston. The escaping steam helped by the valve return spring, closes the valve.

The main valve is kept closed by the boiler pressure acting upon it. As there is no spring to oppose this force, the higher the boiler pressure the greater the closing load, this being the opposite case to a direct spring-loaded valve.

When this type of valve is fitted to the superheater, trouble due to the high temperatures involved, can be greatly reduced by mounting the control valve on the steam drum so that it operates with saturated steam. In this way both the control valve spring and the operating piston are protected from the superheated steam.

Other advantages for this type of valve are that the main valve has no heavy spring to be affected by the high temperature steam. The light return spring, being at the other end of the chest away from the escaping steam, is of relatively little importance.

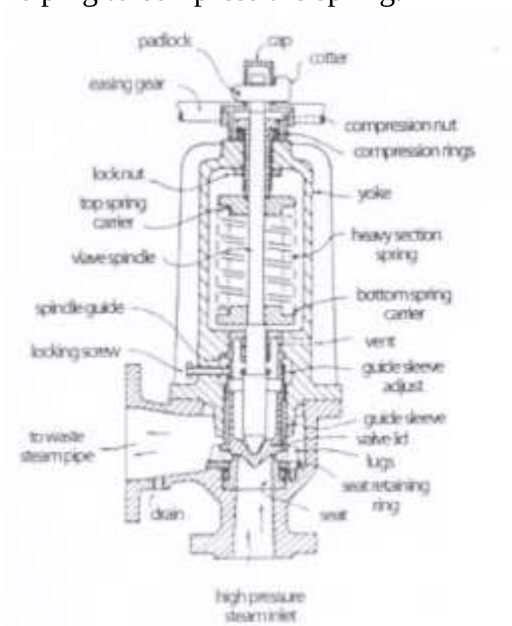
The control valve seat is small and so is less liable to distortion than larger seats and this, coupled with the use of saturated steam helps to ensure that it closes tightly, thus giving a positive closing action to the main valve. The boiler pressure acting upon this enables it to seat tightly, even against slight distortion of the main valve seat.

Adjustment of the blow off pressure is carried out by changing the compression on the control valve spring; this is done by means of an adjusting nut fitted to the control valve.

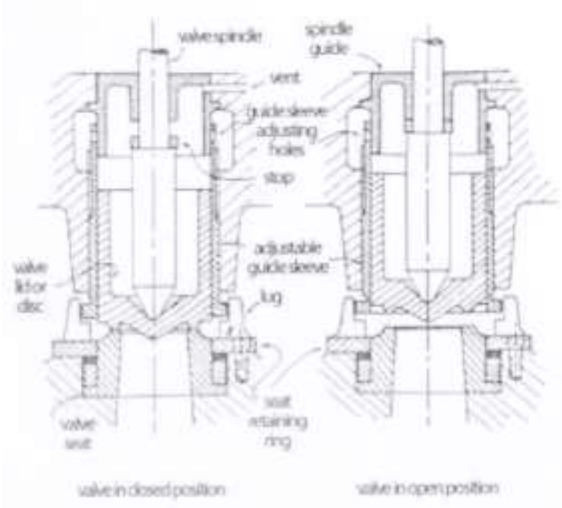
Easing gear is fitted to act directly upon the main valve in order to open it in case of emergency. In addition a hand easing lever is also fitted to the control valve, enabling steam to be admitted to the operating piston of the main valve.

A number of direct spring-loaded disc type safety valves obtain a full lift of ¼ of their diameter within the 10 percent Accumulation of Pressure rule by allowing the valve disc to lift within a sleeve so that, acted upon by the water steam pressure, it performs in the manner of a piston helping to compress the spring. Further assistance being provided by reaction forces set up when the escaping steam is deflected by a specially shaped valve seat and disc face.

When this valve first lifts in response to a condition of overpressure, it allows the escaping steam to act upon the full area of the enlarged face of the valve disc, lifting it up into the fixed guide sleeve. This prevents waste steam pressure acting on top of the valve, and a vent is provided to keep the space between the valve disc and the spindle guide at atmospheric pressure. Thus the waste steam pressure acting upon the face of the valve disc lifts its, so helping to compress the spring.



When the valve fully enters the guide sleeve, it causes some of the escaping steam to be deflected downwards by the bottom edge of the guide sleeve, the resulting reaction set up assisting the waste steam pressure to lift the valve to its full open ¼D position. It is claimed that this, together with the nozzles shaped inlet to the valve seat, gives full flow conditions for the escaping steam.



When the boiler overpressure has been relieved, the valve begins to close, and as the face of the valve disc emerges from the guide sleeve the reaction effect ceases, and the valve now closes cleanly and sharply. This helps to prevent feathering.

The spring is isolated form the main body of the valve, and this together with its heavy cross section enabling it to be made shorter and more resilient, reduces the chances of distortion. In addition the light sheet metal guard protecting the spring allows a good circulation of air over the spring, so helping to cool it.

Adjustment to the valve blow off pressure is made by means of a compression nut screwing down onto the top spring plate. After final adjustment has been carried out a compression ring is inserted, and the lock nut tightened to prevent further movement. The compression ring is in two halves so it can be placed in position without disturbing the compression nut. The protective cap is then fitted over the nut and ring, and padlocked in place.

A further adjustment can be carried out on this type of valve to give the desired discharge and blow down characteristics.

The term blow down is used with reference to the fall below blow off pressure that occurs before the valve finally closes. This leads to a waste of steam and should be avoided as much as possible, and many high capacity safety valves are provided with some form of blow down control. The Hylif valve makes use of the guide sleeve to do this. The throttling effect obtained by adjusting the vertical position of the guide sleeve effectively controlling the speed at which the valve closes and thus the amount of blow down.

This adjustment is carried out by trial and error to give the best valve performance for prevailing conditions. A locking screw is then fitted and a guard plate locked in place to prevent tampering.

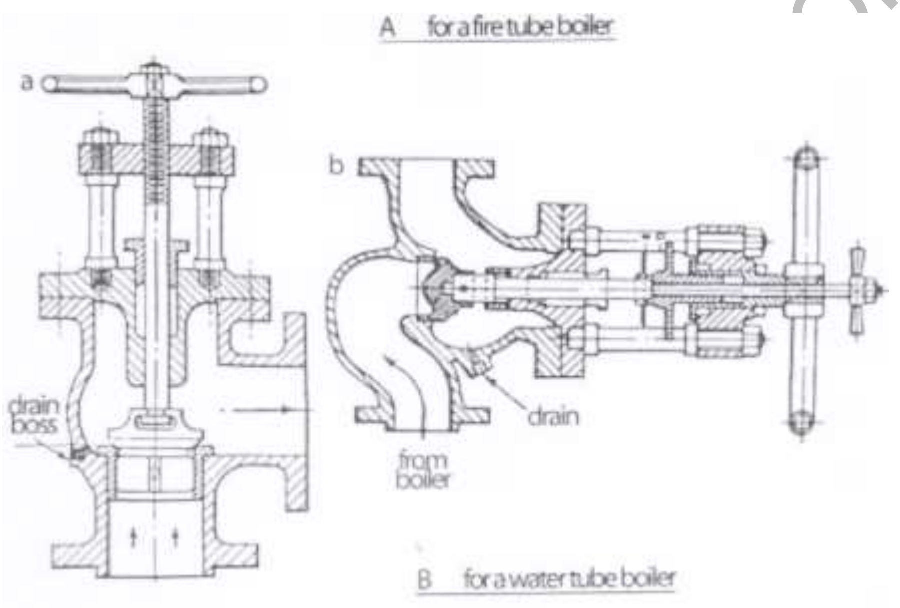
Stepped lugs on the valve seat prevent the sleeve being screwed down too far and restricting the flow of escaping steam.

Easing gear is fitted to enable the valve to be opened by hand in case of emergency; this is arranged so that it cannot be used to hold the valve closed.

An open-ended drain must be fitted to the waste pipe to prevent any build-up of water in the pipe causing a head of water to form over the valve lid so increasing the blow off pressure. Also in very cold conditions this water could freeze in the upper parts of the waste pipe with possibly disastrous results.

Main Stop Valve

This is mounted on the superheater outlet header, and enables the boiler to be isolated from the steam line. If two or more boilers are fitted supplying steam to a common line, the stop valve on each boiler must be a screw down, non-return type. This is to prevent steam from the other boilers flowing into a damaged boiler in the event of a loss of pressure due to a burst tube. In some cases the main stop valve incorporates an automatic closing device, designed to operate in emergency conditions, to shut off steam from the main turbines.



Auxiliary Stop Valves

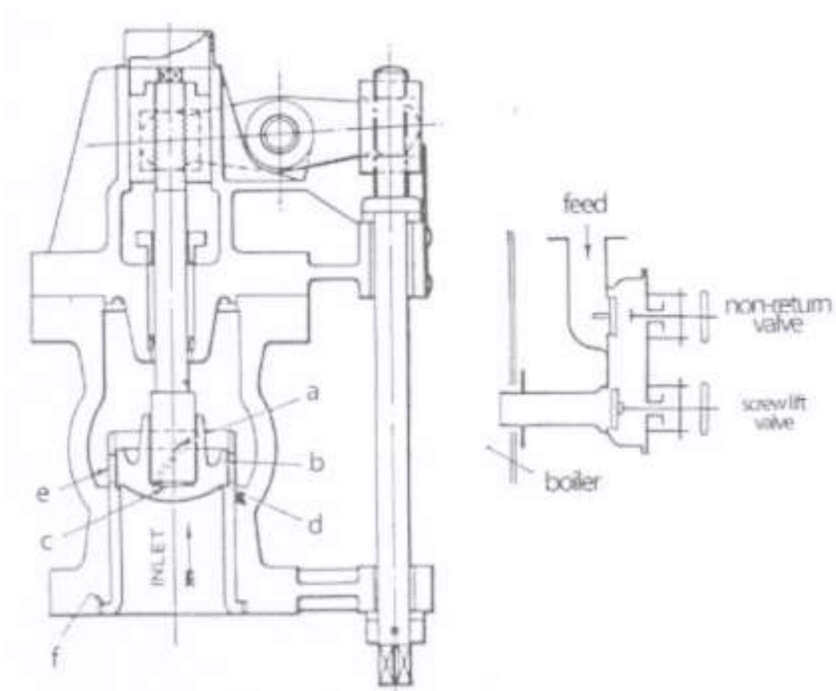
This is basically a smaller version of the main stop, fitted for the purpose of isolating the boiler from the auxiliary steam lines. Again these must be screw down, non-return type valves if necessary to prevent steam flowing back into the boiler in the event of damage. The valve will be mounted on the superheater outlet header; a de-superheater can be used to reduce the steam temperature as required.

Feed Check Valves

These are fitted to give final control over the entry of feed water into the boiler. They must be screw down, non-return valve so that, in the event of a loss of feed pressure, the boiler water cannot blow back in the feed line.

Main and auxiliary feed checks are fitted. The main check is often fitted to the economiser inlet header; if not, like the auxiliary check, it will be mounted directly on the steam drum.

Extended spindles are usually fitted so the checks can be operated from a convenient position. Care must be taken to ensure the valve can be operated easily and quickly, and that a positive indication of the open and closed positions for the valve is given.



Boiler Feed Water Regulator

The water level is a boiler is critical. If it is too low, damage may result from overheating; too high and priming can occur with resultant carry-over of water and dissolved solids into superheaters, steam lines, etc.

Automatic feed regulators are therefore fitted to control the flow of water into the boiler and maintain the water level at its desired value.

They are fitted in the feed line, before the main feed check. In most cases they use a float or thermal means of operation and thus must have a direct connection to the steam and water spaces as required. The regulator can be attached directly to the boiler shell, or alternatively mounted in an external chamber with balance connection to the steam drum, or boiler shell.

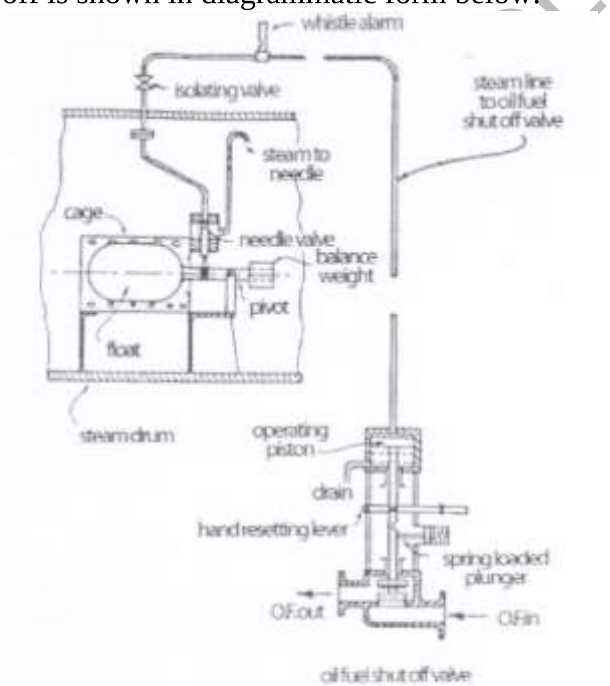
In the case of watertube boilers with their high evaporation rate and small reserve of water the control of the water level is so critical that the classification societies demand that some form of automatic feed regulator must be fitted.

Water Level Indicators

The DOT demand that at least two water level indicators must be fitted to each boiler. In practice the usual arrangement consists of two direct reading water level gauges mounted on the steam drum, and a remote reading indicator placed at a convenient control position.

Low Water Alarms

The classification societies demand that these should be fitted to reduce the risk of damage in the event of a loss of water in the boiler due to burst tube or failure of the feed supply.
In some cases they are mounted inside the steam drum, but many are mounted externally. Various types are available, either steam or electrically operated. Various types are available, either steam or electrically operated. Some versions also incorporate high water level alarms.
If the water level in a watertube boiler disappears from the bottom of the water level gauge glass, immediate action must be taken, the boiler being put out of service.
Due to the high evaporation rate and small reserve of water in a watertube boilers, for various reasons such as malfunction of the feed water regulator, or feed pump, or by a burst tube within the boiler itself, this loss of water can happen very rapidly. The classification societies therefore demand the fitting of a low water protection device. This must both sound an alarm and cut off the fuel oil to the boiler.
Many different types may be fitted; a typical steam operated low water alarm and fuel oil cut off is shown in diagrammatic form below.



The device consists basically of an operating mechanism in the form of a float controlled needle valve, and alarm whistle, and a fuel cut off valve. When the water level falls below a

certain predetermined value the float drops – so opening the needle valve. This allows steam to pass to the whistle alarm and to the actuator of the fuel oil shut off value.
When the steam pressure acts on the actuator piston if pushes it downwards, so closing the shut off valve. When the valve closes, a spring loaded plunger moves into a slot in the valve spindle and holds the valve in the closed position until it can be reset by hands. This is to prevent some transient event, such as the water surging in the drum due to heavy weather conditions, causing the fuel oil shut off valve to first close and extinguish the furnace flame. If this valve were then allowed to reopen automatically immediately the water level is re-established, it could result in large quantities of unburnt oil being sprayed into the hot furnace leading to a possible gas side explosion causing damage or starting an uptake fire.
In addition to this resetting device, an anti-surge will be fitted to the operating mechanism. In the type being considered it takes the form of a cage placed around the float. Holes in this case are such that if, during heavy weather, the water level drops momentarily below the minimum level allowed, it will have surged back before the water in the cage has time to drain out enough to operate the mechanism.
Another refinement which may be fitted is the internal steam supply pipe. This prevents deposits forming around the needle valve seat in the event of leakage, i.e. as might occur if the chamber were left open to the boiler water.
In many versions the operating mechanism is mounted in an external chamber, and connected to the drum by steam and water balance connections. This gives the advantages that maintenance can be carried out on the operating mechanism without shutting down the boiler.
The low water alarm should be tested at frequent intervals and be part of the planned maintenance system, and as soon as practicable after any work or adjustments have been carried out on it. If for any reason the device has to be shut off a notice should be displayed on the starting platform, or in the control room, informing the watch-keeping Engineers of the fact. The device should be returned to service as soon as possible.

Blow Down Valves

These are fitted to the water drum to enable water to be blown from the boiler in order to reduce the density. When the boiler is shut down these valves can be used to drain it. The usually consist of two valves mounted in series, arranged so that the first valve must be full open before the second can be cracked open; i.e. sufficient to give the required rate of blow down. In this way the seating of the first valve is protected from damage, so reducing the risk of leakage when the blow down valves are closed.
These blow down valves discharge into a blow down line heading to a ship-side discharge valve.

Scum Valve

These should be fitted when there is a possibility of oil contamination of the boiler. They are mounted on the steam drum, having an internal fitting in the form of a shallow pan situated just below the normal water level, with which to remove oil or scum, from the surfaces of the water in the drum. These valves discharge into the blow down line.

Drain Valves

These are fitted to headers, etc, so enabling the boiler to be completely drained. They must not be used to blow down, only being opened when the boiler is shut down.

Air Vents

These are fitted to the upper parts of the boiler as required to release air from drums and headers, either when filling the boiler, or raising steam.

Superheater Circulating Valves

These are fitted so that when raising steam they can first release air from the superheater, and then provide enough circulation to prevent superheating by allowing sufficient steam to blow off to the atmosphere or a suitable drain system. They should only be closed when there is enough demand for superheated steam to provide the minimum circulation of steam required to prevent overheating.

Chemical Dosing Valves

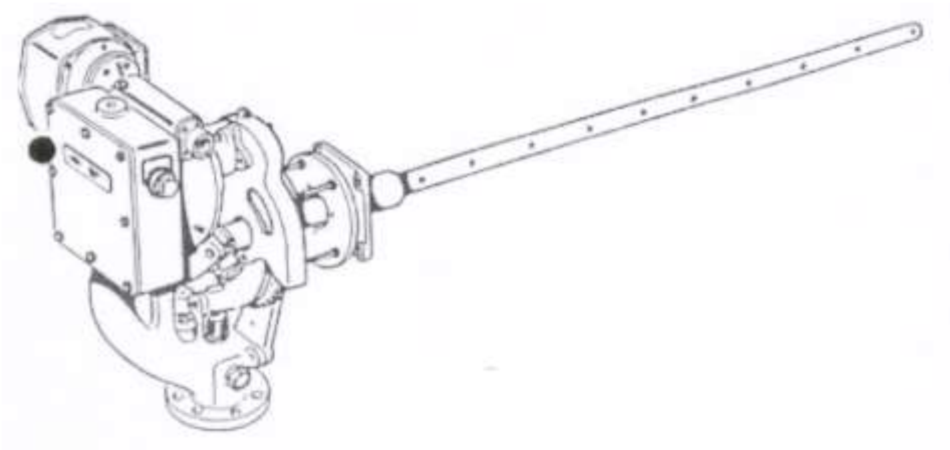
These are fitted to the steam drum to enable feed treatment chemicals to be injected directly into the boiler. Chemicals can also be added to the system via the hot well.

Salinometer Valves

These are fitted to the water drum to enable samples of boiler water to be drawn off so that the tests required for the control of the feed treatment can be carried out. At high pressures it is necessary to provide some means of preventing flash off taking place as the pressure over the sample is reduced to atmospheric. This is usually done by passing the water from the salinometer valve through a cooling coil which reduces its temperature to a value below 100°C.

Soot Blower Master Steam Valves

These are usually mounted on the superheater outlet header to ensure that superheater is not starved of steam while blowing tubes.
In some cases two valves are fitted in series, with a drain valve between them in order to prevent steam leaking into the soot blower steam supply line when these are not in use.



Pressure Gauge Connections

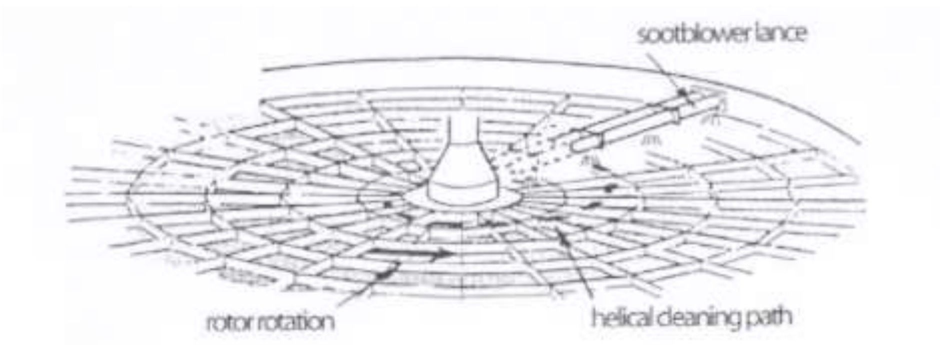
Fitted as required to steam drum, superheater outlet header, etc, to provide the necessary pressure readings. In addition suitable connections must be provided for the pressure sensing points required for automatic combustion control systems etc.

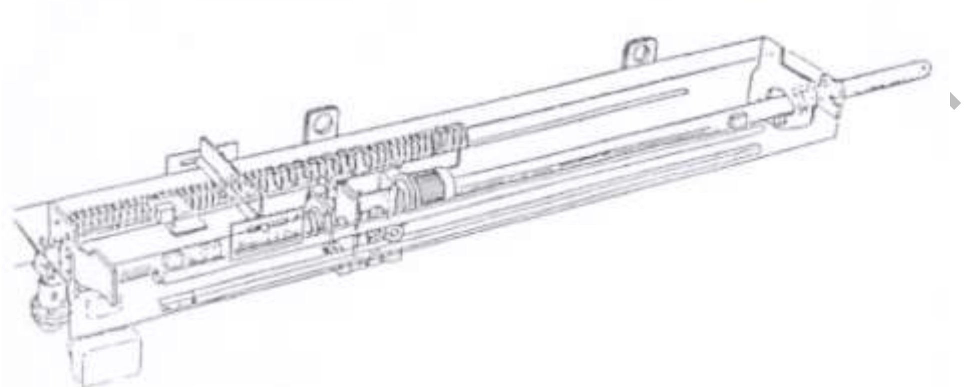
Thermometers

Pockets must be provided in superheater headers, etc, for the fitting of either direct or remote reading thermometers.

Sootblowers

Cleanliness is all important in the operation of heat exchangers including boilers and all the ancillaries described. For boilers, economisers and gas/air heaters which are exposed to products of combustion some form of on loading cleaning is necessary. The most common method involved the regular use of sootblowers in which superheated steam is discharged onto the heating surfaces, driving off any deposits. It will be appreciated that part of the sootblower is itself exposed to the products of combustion and this must be taken into account when choosing the sootblower type and materials of construction.
In its simplest form a steam sootblower consists of a headpiece, including a valve, mounted external to heat exchanger. Extending from this into the gas passage is a tube or lance fitted with nozzles through which the steam discharges. An electric or pneumatic motor attached to the headpiece causes the lance to rotate and when the nozzles come into a position where the discharge of steam will impinge on the area to be cleaned a cam operated valve opens in the head to admit steam from the sootblowers steam piping system. As the lance continues to rotate, bringing the nozzles clear of the heating surfaces, the cam allows the steam valve to close. In such a sootblower the lance is permanently in the gas passage and, apart from a small quantity of purge air admitted to prevent combustion products from entering the head, is uncooled when not in operation (below).



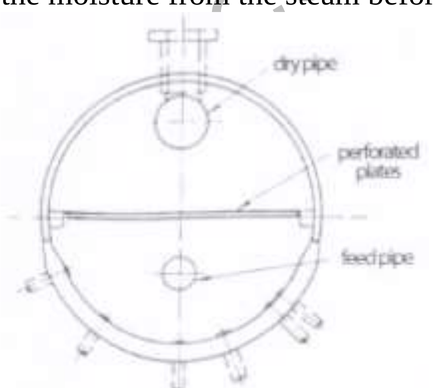


In early D-type convection bank boilers such sootblowers fitted in the superheater zone experienced a very short life due to the ravages of temperature and corrosion. As a result the superheater area suffered severely from fouling and blockage of the gas passages making it necessary to use high pressure water washing off load. To alleviate these difficulties superheaters were arranged when not in operation so that the lance is only exposed to hot gases whilst a cooling flow of steam is passing through. These sootblowers possess a more powerful cleaning action, better able to deal with the deposits which the chemistry of the fuel ash at high temperature causes to be bonded to the heating surfaces and is more difficult to remove than dusty, sooty, deposits found elsewhere. In operation the lance revolves and traverses across the gas passage whilst the steam jets pointing sideways at the end of the lance clean a spiral path. When fully inserted the lance withdraws after making a half turn so that the outward spiral cleaned is out of phase with the inward enabling the whole area to be exposed to the cleaning effect of the steam jet (above). The head of the sootblowers is supported on steel work outside the boilers and the lance is traversed along a rack with the steam being supplied through a telescopic tube (over). Retractable or rack type sootblowers, so called because of the rack traversing mechanism, have proved extremely successful in hot gas zones due to their improved life span and superior cleaning effect. They are naturally more expensive than the simple, fixed head, rotating element blowers and they occupy a good deal of space outside the boiler. For these reasons their use is confined to those areas where the simpler type has not proved satisfactory and that is basically in areas where the gas temperature exceeds 750°C.

At lower temperatures, and by choosing suitable materials for the lance, fixed head rotating elements sootblowers can give good service. The arrangement of nozzles along the length of the lance is chosen to suit the location of the lance in relation to the heat exchanger tubes. If the lance is aligned normal to the tubes cross the tube bank and is in close proximity to them multijet nozzles are pitched to correspond with every third lane or so between these tubes whereas if the lance runs parallel to and in line with the tube axes it can be located at a distance where the tube bank subtends as arc 90° to the lance and fewer nozzles can be used. Since all fresh water used aboard ship has to be made, and that supplied for makeup to the boiler must be further treated with chemicals to ensure a high degree of purity, the use of steam for sootblowers can prove expensive. In the past, use has been made of sootblowing systems where the operating and cleaning medium was compressed air. In modern ships, and with the residual type fuels currently available, steam is now universal. All of the sootblowers provided for a boiler unit, including its final heat recovery system, are connected to a permanent system of pipework outside the boiler. This pipework is normally isolated and is put under steam only when the sootblowers are to be operated. This will be at a frequency dictated by operating conditions; typically once every watch. It is necessary, therefore to carefully warm through the piping system prior to operating the blowers, ensuring that all condensate is fully drained. Control system are now common which will cause the sootblowers to operate sequentially and as necessary the operator can programme the control to omit some blowers from the sequence or to repeat some as local conditions may required.

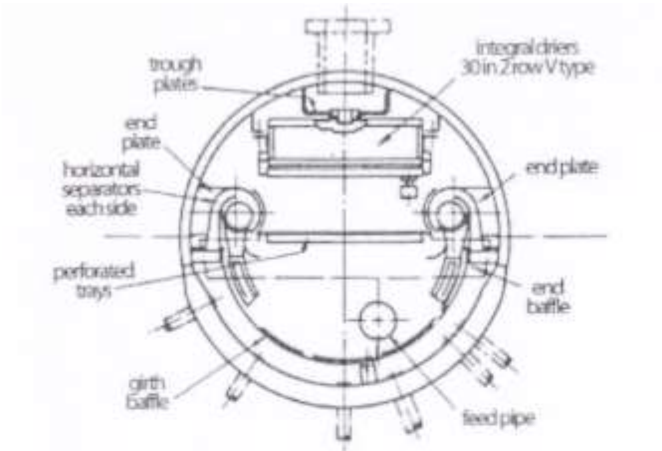
Boiler Drum Internals

It is obviously an essential requirement for any boiler that steam supplied to the range or to the superheater should be free of water particles. In boilers having a high volume to generating capacity ratio, such as the older tank type boilers, no special provision is necessary to achieve this. The large steam space coupled with the low turbulence on the surface of the water is adequate to ensure that sufficient water particles gravitate out, for practical purposes, before the steam exists through the boiler stop valve.
In most water tube boiler installations, however, a better quality of steam is demanded and due to the high turbulence present on the surfaces of the water in the steam drum and comparatively small steam space available, some form of steam drying is required to extract the moisture from the steam before it passes to superheaters.



In low rated installations this drying may be achieved by fitting simple perforated plates immediately above the normal working level of the water in the steam drum in conjunction with a steam collecting pipe which is usually slotted to provide further separation.

For the more highly rated boilers which often include relatively small diameter steam drums, a more complicated arrangement is required. One arrangement is show above. This arrangement consists of a series of girth baffles which direct the steam/water mixture leaving the tubes into horizontal separators. Here, by centrifugal action, most of the water content of the steam is extracted.



The final stage in this system takes the form of chevron driers, a series of perforated plates in 'V' form, where the last droplets of moisture are removed. This arrangement has the disadvantage that considerable dismantling requires to be done before a thorough inspection of the internal surfaces of the steam drum can be made.

Water Gauges

Water Gauges

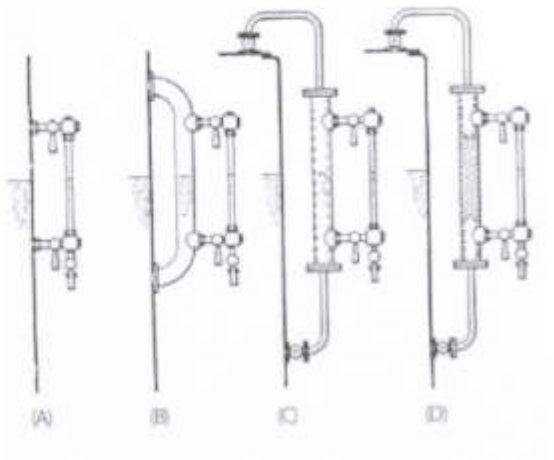
Water gauges play an important part in the safety of boiler operation. Every boiler must have at lest two independent means of indicating the water level. These indicators must be placed in a position where they can be easily and clearly seen by the operator. Scotch boilers must have the two indicators placed one to each side.

Some small, vertical low-pressure boilers may have three test cocks, placed vertically one above the other in way of the normal water level, together with one gauge glass. However no boiler whose working pressure is about 8.2 bar, or with a diameter in excess of 1.8m, is allowed to use test cocks as a means of indicating water level.

In most cases marine boilers make use of two indicators in which the water level is clearly visible.

For boiler pressure up to about 17.5 bar it is normal practice to use round glass tubes suitably connected to the boiler by means of cocks and pipes, for indicating the working level of the water. Above 17.5 bar the glass tube is replaced by what is in effect a built-up rectangular-section box having a thick plate glass front and back.

Tank-type boilers, coming in the lower range of pressures, are invariably fitted with round glass-tube gauges, these being connected to the boiler in one of the following ways:



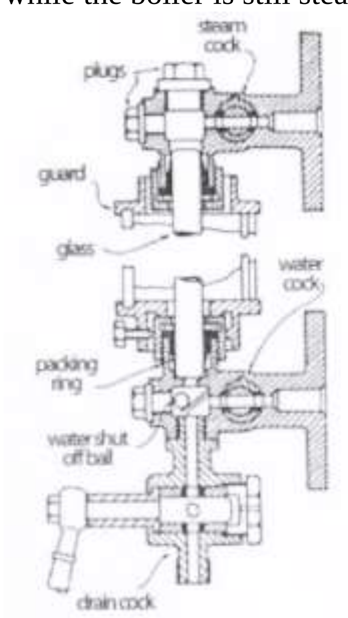
(a) Fitted directly to the boiler;

(b) Fitted to a large-bore bent pipe, one end of which communicates with the steam space and the other with the water space;

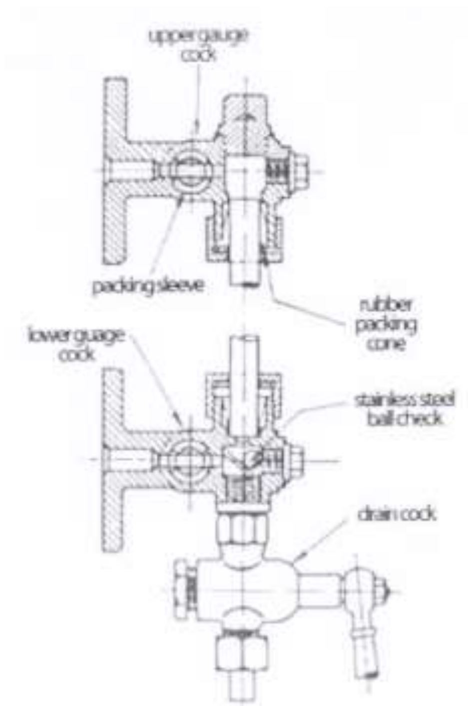
(c) Mounted on a hollow column, the ends of which are connected by pipes to shut-off cocks on the top and bottom of the boiler;

(d) Mounted on a column as in (c), but the centre part of the column is solid, the ends again being connected by pipes to shut off cocks on the top and bottom of the boiler.

Isolating cocks or valves, fitted where these pipes are attached to the shell, give the advantage of a double shut off. This enables maintenance to be carried out on the gauge glass cocks while the boiler is still steaming.



The general arrangement of a tubular gauge glass is shown above. It consists of two gun-metal bodies, the glass tube fitted between them, being held in place and sealed at each end by nuts tightened onto soft, tapered sealing rings.



Isolating cocks are fitted to the steam and water connections, while a drain cock fitted at the lower end allows for blowing through the glass to test it. In come cases, gun-metal cocks having tapered plugs stemmed with asbestos are used. These are not only difficult to keep tight, but also are liable to seize up, and in most cases the more efficient asbestos sleeve type cocks are used.

A ball valve is fitted to the lower end of the gauge in order to shut off the water in the event of the glass fracturing. Otherwise, as water is blow out, the reduction in pressure causes it to flash off in large volumes of scalding steam, with possible injury to boiler-room personnel. Although steam will escape at the other end, it will not be subject to this great increase in volume, and thus the mass of steam blowing out is limited. However, in some cases restricting orifices are fitted in the steam end, only allowing a greatly reduced quantity of steam to blow out in the event of failure – just sufficient to indicate fracture.

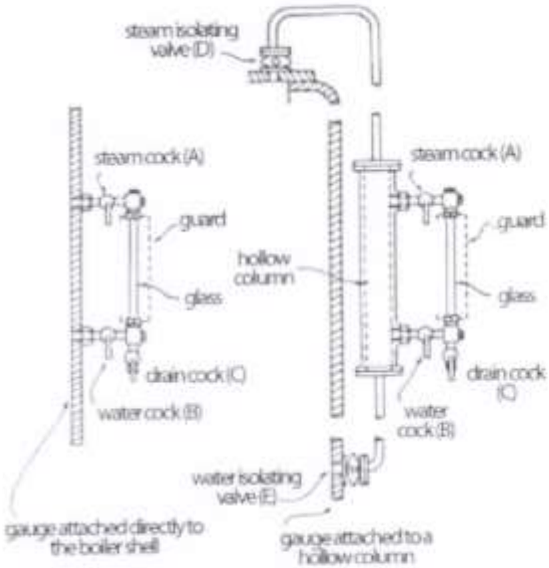
Plugs are fitted in the gun-metal bodies to allow for the renewal of the glass tube, and for cleaning the various passages.

Plate-glass guards should be fitted to prevent injury in the event of the glass tube shattering, especially when blowing through.

Difficulty is often experienced with this type of glass in ascertaining whether it shows completely empty or completely full of water. It is good practice to place a board, painted with diagonal black and white stripes, behind the glass. If it is full of water, refraction will cause the stripes to appear bent to the opposite angle. If no board is fitted, a pencil, or similar object can be sued to the same effect.

Finally the handles of the steam and water cocks must lie vertically downwards when in the full open position, while the drain cock handle must be in thus position when closed. This is to prevent vibration, etc, causing the cocks to move to such a position that a false indication of the water level could result.

In any doubt exists about the accuracy of the reading indicated by a water level gauge it should be tested by blowing through in the correct manner. It should be noted that, when testing, it is not usually possible to determine whether steam or water is issuing from the drain, but a strong blow will indicate unobstructed passages.



The figure above shows some common means of attaching water level gauges to the boiler. The following test procedure should be carried out on gauge glasses attached directly to the boiler shell:

Close the water cock (B), and open drain cock (C). A strong blow will indicate the steam cock (A) is clear. Then closing cock (A), open cock (B); a strong blow now indicates the cock (B) is clear.

A similar procedure can be carried out for gauges attached to the boiler by means of an external pipe, or by means of a solid column. In this latter case, the isolating cocks on the pipes leading to the column many also be chocked. The advantage of the hollow column-type fitting shown in the figure, is that in the event of chokage it is possible by blowing to determine which of the four cocks is chocked.

To do this first carry out the test procedure previously described using cocks (A) and (B) together with drain cocks (C). In both cases a strong blow through the drain indicates these cocks are clear. Then to check the isolating cocks (D) and (E) together with the hollow column itself, use a procedure known as cross blowing. For this close cocks (A) and (E), a strong blow through the drain now indicates cocks (D) and (B) and the respective passages are clear. Then close (D) and (B) and open cocks (A) and (E), where again a strong blow shows these cocks and passages to be clear. If however, during these operations only a weak blow, or a no blow occurs, it indicates an obstruction is present in whichever passage is open at the time, and a simple process of elimination will show where the fault lies.

If the steam cock is choked, a vacuum forms in the upper part of the glass causing the water to rise until it completely fills the glass.

If the water cock is choked, the water level will rise slowly, condensation in the steam space gradually filling the glass.

Similar results, although to a lesser extent, can be caused by partially choked cocks and passages. This chokage is generally brought about by a build-up of deposits left behind by boiler water evaporating away due to leakage in way of cocks, etc.

Another reason for obstruction is the cock handle being twisted; so causing the plug to be closed although the handle is in the open position. This can occur due to tapered plugs, stemmed with asbestos, being nipped up too tight in an attempt to stop them leaking. This type of fault is unlikely with asbestos sleeve-type cocks, provided reasonable care is taken when inserting a new sleeve. A locating rib on the side of the sleeve ensures correct alignment. Also ensure the cock handle is correctly attached to the spindle.

It should be noted that the handles on the steam and water cocks should always point vertically downwards when in the open position as another fault can rise if they are left pointing upwards, i.e. vibration causing a loose plug to move around to a closed or partially closed position.

The glass tube itself can cause trouble. If it is too short it may result in the packing sleeve being squeezed over the ends of the glass, so blocking the opening. This is most likely to happed at the top steam end of the glass. Again too long a glass projecting up into the top crock body can obstruct the steam passage.

A dirty or salted glass can prevent the water level being easily seen.

Where water level gauges are fitted to the boiler indirectly by means of a solid or hollow column, as shown above, the isolating cocks on the boiler can become choked. This again causes the water level in the glass to read too high – for similar reasons to those stated for the steam and water cocks. Additional care must be taken with hollow column-type mountings in that blowing through by means of steam and water cocks on the gauge itself, and not using the isolating cocks on the boiler, will not indicate if either of the latter is choked.

Gauges fitted to the boiler by either of the above methods should be checked on a new boiler, or after a refit, to ensure that no distortion has taken place of bends formed in which condensation can collect; these may cause possible false readings.

It should also be noted that the water cools down in the relatively long pipes connecting the columns to the boiler; this changes its density, resulting in a level in the glass slightly below that in the boiler. Immediately after blowing, the level in the glass will appear slightly higher – now corresponding to that in the boiler – until the water again cools down.

Having checked that all cocks and passages are clear, and with the steam and water cocks closed, and drain open, a tubular-type water level gauge should be put back into service as follows:

Close the drain, and open water cock (B) very slowly. If the water level in the boiler is above the passage to this cock, it will enter the glass and rise slowly to the top. Now open the steam cock (A), and the correct water level in the boiler will be indicated, this should be between one quarter to three quarter of the glass.

If the level drops from the glass when the steam cock is opened, it indicates the water level in the boilers lies somewhere between the water passage to the gauge and the bottom of the glass. In a Scotch boiler the bottom passage lies at least 100mm above the top of the combustion chamber; the boiler is still in a safe condition, but feed water should be added, or the supply increased immediately. On the other hand if the water remains at the top of the glass, it indicates too much water in the boiler, and the feed supply should be reduced, or stopped in necessary, to prevent priming.

If no water appears in the glass when the water cock (B) is opened, the level of water in the boiler must be below the gauge water passage and the boiler is in a potentially dangerous condition. Reduce boiler load and rate of firing and, as long as the water covers the combustion chamber tops, the feed supply should be increased, and if necessary the stand-by feed pump and auxiliary feed checks put into operation. But if the water level does not reappear quickly, or if any doubt exists about the water covering the combustion chamber tops, take the boiler out of operation. Shut off the fuel and, if it is suspected that overheating has occurred, operate the easing gear on the safety valves to release the boiler pressure.

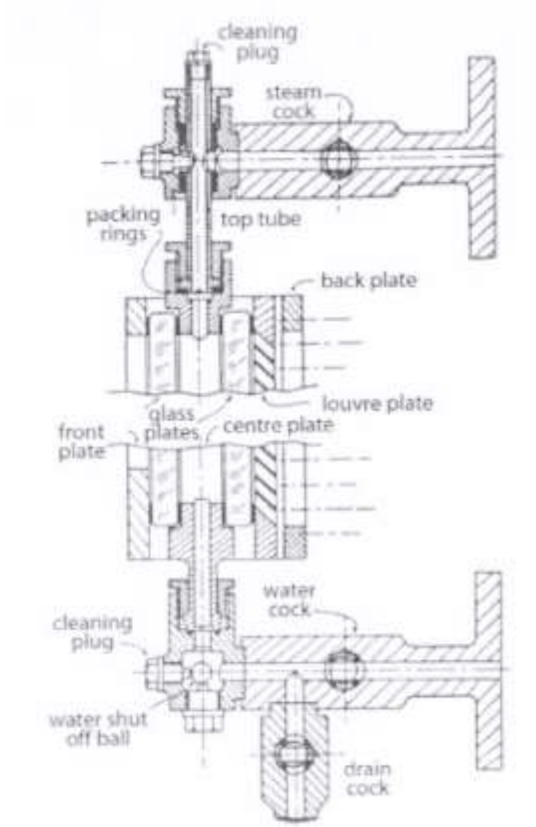
When the boiler has cooled down it should be examined, and only returned to service when considered to be in a safe condition.

The water level gauge should always be kept clean, well it, and is in good order. All passages and cocks liable to chokage should be inspected, and cleaned if necessary when the boiler is shut down.

The water level gauges should be tested at frequent intervals, and always if any doubt arises about the accuracy of the water level indicated. Any obstruction must be cleared as soon as possible.

Steam and water cocks and passages in the gauge can be cleared while the boiler is still steaming. To do this, shut the steam and water cocks, and open the drain. Remove the cleaning plug opposite the obstruction. If this still cannot be cleared, screw in a pug with a small hole, about 5mm diameter, drilled through it in place of the cleaning plug. Insert into this hole a rod of such a size that, held by a gloved hand, it can be moved easily without being slack. Then open the choked cock and push the rod through to clear the blockage. When clear, the open drain will prevent a build-up of pressure, and only a small amount of steam will blow past the rod, the glove protecting the operator from injury. Then close the cock and replace the normal cleaning plug. The gauge glass can now be tested and, if satisfactory, returned to service.

DO NOT CARRY OUT THIS OPERATION ON A PLATE-TYPE GLASS ON A HIGH PRESSURE BOILER.



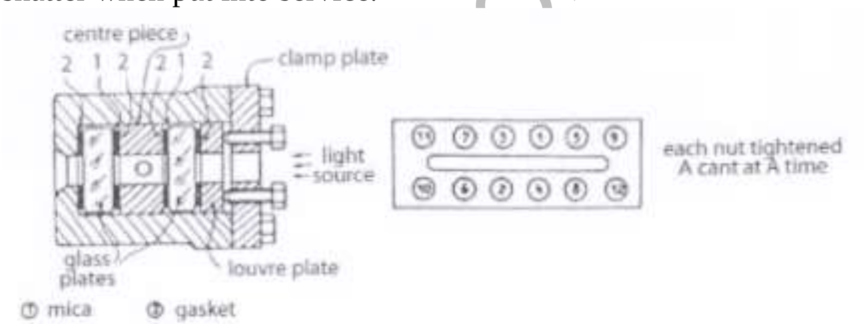
Although plate-type water level gauges can be used for low pressure, in view of their greater cost, usually only come into general use of pressure above a value of about 17.5 bar. The reflex glass shown below is an example of a type of water level indicator suitable for boilers working at a medium pressure range between about 17-30 bar.
These gauges are supplied with gun-metal bodies up to pressures of 17.5 bar while for higher pressures forged steel bodies are used.
The gauge is normally fitted directly to the boiler shell or steam drum. The isolating cocks in the steam and water connections, together with the drain cock, are of the asbestos sleeve type. In many cases these cocks can be operated by extended rods, or chains, to prevent injury in the event of the glass shattering when blowing through the glass. However, the glass plates are so strong that this form of failure does not occur often, and even then the pieces of glass frequently remain in position, thus the fitting of an external guard is not necessary.
The single-sided glass ingeniously make us of the refraction of light so that, when illuminated from the front, the series of ribs at the back of the glass plate cause the light rays to be reflected back from the steam space and absorbed in the water space. This gives a bright silvery appearance to the former, while the latter shows dark. The strong contrast between the two enables the operator to see immediately the position of the water level. It also make it possible to tell at a glance whether the glass shows completely empty or completely full of water – a condition which causes some confusion with many other types of gauge glass.

A ball valve is normally fitted to the lower end of the gauge to shut off the water in the event of glass plate shattering and blowing out. The ball valve thus prevents the escape of water, with the resulting flash-off of large amounts of steam, making it difficult to shut off the gauge, and possible causing injury.

Another problem arises at higher pressures to the fact that hot distilled water at high pressure erodes the glass away. This effect is even more pronounced if alkaline feed additives are being used. To resist this a special borosilicate glass is used for the higher pressure, but can only give limited protection. For pressures above 34 bar some means must be used to prevent the water from coming into direct contact with surface of the glass. This is usually done by placing a sheet of mica between them. Due to the ribbed glass, the reflex-type gauge cannot make use of this form of protection, and so is not suitable for use with high pressure boilers. In the case of high pressure watertube boilers working at values above 34 bar, water gauges usually take the form of double-sided, plate glass type water level indicators, with mica protection for the glass plates.

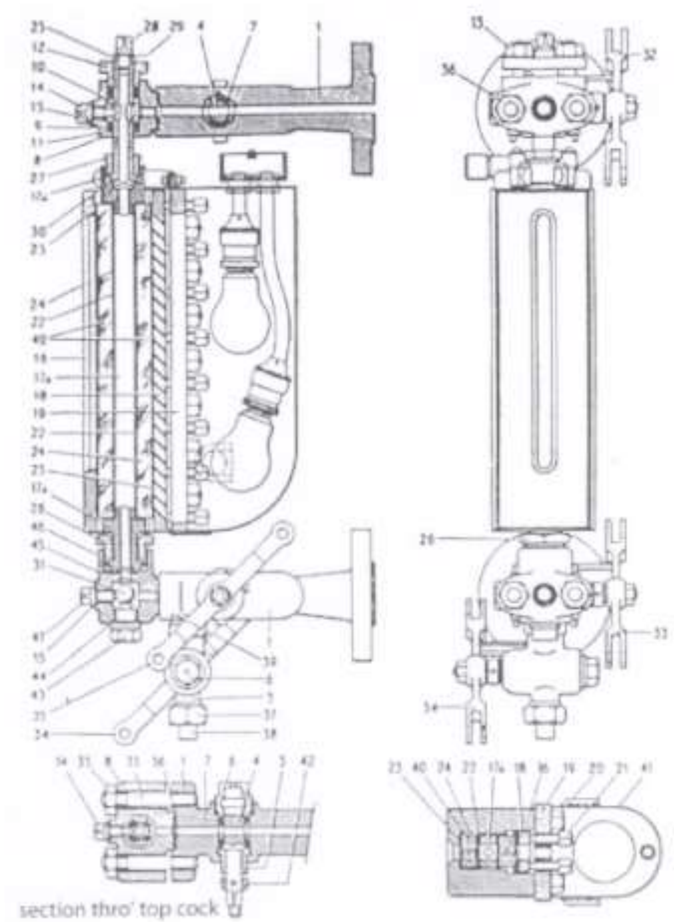
This protection is necessary as at high pressures hot distilled water erodes the glass away and unless a sheet mica is placed between the glass and the water, attack takes place quickly, indeed at the higher pressure ranges the glass will burst within a few hours if this protection is omitted.

The general arrangement of a typical double-pate water level gauge is shown over. It consists basically of a hollow centre piece with flats machined on each side to take the two plates of toughened glass. These are held firmly in place by means of a clamp plate. Care must be taken during assembly to prevent undue stress being set up which sill cause the glass plate to shatter when put into service.



Thus the following procedures should be carried out. Strip down the gauge. Discard the used glass plates, mica sheets, and joints. Make sure all joint faces are scrupulously clean. Check frame and cover plates for flatness; any warping can cause the glass to shatter. Build up the gauge, inserting the new joints, together with the mica sheets, in their correct sequence. This is indicated below. Bolt the clamp plate onto the outer case. The clamping bolts should be pulled finger tight onto the louver plate. Then starting from the centre, tighten these nuts in the order indicated below. Do not overtighten, and pull up evenly, preferably using a torque spanner.

A ball valve is fitted at the lower end of the gauge to shut off the water in the event of the glass plates shattering. It should be noted that some form of double plate gauge glasses can be placed on the boiler upside down. This places the ball valve at the top of the gauge, where it rolls down and obstructs the steam passage, so causing a false reading. It is thus advisable to mark this type of fitting so as to clearly identify the top and bottom ends of the gauge.



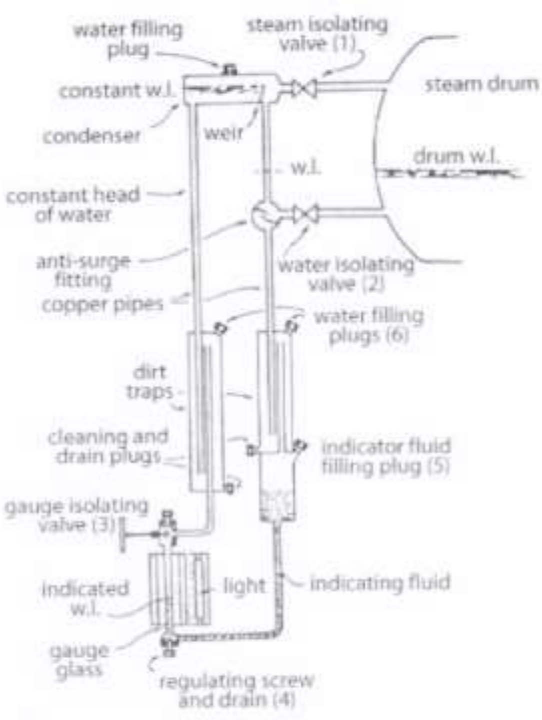
1	Top cock body	17A	Gauge centre piece	33	Bottom cock handle
2	Bottom cock body	18	Gauge louver plate	34	Drain cock handle
3	Drain cock body	19	Gauge back plate	35	Studs and nuts
4	Plug	20	Gauge nuts and studs	36	Joint washer
5	Neck bush	21	Gauge setscrews	37	Union nut
6	Tightening nut	22	Gauge glass gasket	38	Tail pipe
7	Packing sleeve	23	Gauge glass strip	39	Joint washer
8	Stuffing box head	24	Gauge mica-strip	40	Glass plate
9	Packing ring	25	Gauge tube	41	Reflector
10	Lantern bush	26	Split nut	42	Retaining collar
11	Bottoming ring	27	Gauge-tube cap	43	Stuffing-box plug
12	Gland	28	Tube cleaning plug	44	Washer for above
13	Gland studs and nuts	29	Tube plug washer	45	Joint washer
14	Cleaning plug	30	Gauge-tube washer	46	Stuffing-box head
15	Washer	31	Shut-off ball	47	Cleaning plug

16 Gauge front piece 32 Top cock handle

When installing a new gauge glass, first shut the steam and water cocks, and open the drain. Remove the defective unit and fit the new gauge. Leave it in this condition, with the steam and water cocks shut and drain open, to heat up for some hours. Then just crack open the steam cock. After about twenty minutes follow up the clamp nuts in the correct sequence, preferably using a torque spanner. Then close the drain, and fully open the steam and water cocks, to put the gauge into operation. Do not stand directly in front of the gauge during these operations in case the glass shatters.
Strip down and rebuild the defective unit as soon as possible and place it in a rack close to the boiler.
The shut off and drain cocks are asbestos sleeve type, and can be operated at some safe distance from the gauge.
Two of these gauges are normally fitted directly onto each boiler steam drum, usually to one of the end plates, but in some cases to the side of the drum – one at each end.

Remote Water Level Indicators

Difficulty is often experienced in observing the water level as indicated by the direct reading water level gauges mounted on the steam drums of watertube boilers. Thus it is usually considered necessary to provide an additional means of indicting the water level at some point convenient to the starting platform or control room. This can be done by a remote indicator such as the (Igema) gauge shown below.



This consists basically of a U-tube, the two legs connected to the steam drum as shown. Red indicating fluid, which is insoluble in water, fills the lower end and remains there since its density is greater than that of the water.

Above this fluid the two legs of the U-tube are filled with water; one being kept filled to a constant head by means of steam condensing in the unlagged condenser. The level in the other leg corresponds to that in the steam drum. Thus the heads supported by the indicating fluid vary. As the water level in the drum rises so it tends to balance the constant head, and the indicating fluid rises in the glass. The opposite happens when the drum water level falls, the level of the indicating fluid in the glass also falling.

The sharp contrast between the red indicating fluid and the water enables the operator to see the indicated water level at a glance. A completely empty or full glass is immediately obvious.

When taking the boiler out of service, shut off the remote indicator by first closing the gauge isolating valve (3), then the steam isolating valve (1), and finally the water isolating valve (2).

When opening up, first open the steam valve (1), then the water valve (2), and finally the gauge isolating valve (3).

If the remote indicator is connected to the same balance connections as one of the direct reading waterleel gauges, it is important that the remote indicator is isolated before the water level gauge is blown through. Otherwise water may be drawn out of the legs of the U-tube so causing a false water level to be indicated by the remote reading gauge.

After cleaning, etc, the following procedure should be carried out to refill the indicator. First close the isolating valves (1) and (2) on the boiler, and the regulating screw (4). Remove all filling plugs. Then pour in the indicating fluid through the indicator filling plug (5) until the lower part of the U-tube is completely filled, fluid overflowing at the filling plug.

Close the gauge isolating valve (3) and replace the filling plug (5). Then slowly pour distilled water into the water filling plugs (6) on top of the dirt trap until it overflows. Replace the filling plugs. Finally pour water into the top filling plug (7), until again it overflows, the plug is then replaced.

The remote reading gauge glass should now show completely red. Leave it in this condition until full boiler pressure has been raised.

When the boiler is under steam open the steam valve (1), then the water valve (2) followed by the gauge isolating valve (3). Leave for about 15 minutes to settle down, then crack open the regulating screw (4) and slowing bleed off excess indicating fluid, dropping the level about 6mm at a time, with about fifteen minute between, until finally the level of indicating fluid at the centre of the glass corresponds to the water level at the centre of the direct reading water level gauge glass.

Although subjected to boiler pressure, the remote indicator glass is not at high temperature and very rarely gives trouble. However, the apparatus should be cleaned out about once every six months. The indicator should be isolated, drained, and flushed through with clean water. The indicator must never under any circumstances be blown through either with steam or water.

The glass is illuminated from behind, access to these lights being obtained by removing the sheet metal casing at the back of the gauge.

Boiler Operation

Boiler Operation

Boilers of all types are subject to extremely hazardous conditions involving very high temperatures, abrasive and chemically aggressive fuel constituents and the ever present risk of lax operating procedures brought about by over confidence engendered by the inherent robustness and reliability of the plant. Vigilance is essential at all times and the prime consideration is cleanliness of both gas and water sides of the various sections of the boiler plant so that the boiler operates efficiently and with low maintenance.

A high efficiency is obtained when heat losses are low. A major heat loss occurs in the products of combustion exhausted to atmosphere via the funnel. This is minimised by keeping heating surfaces clean and operating with a minimum of excess air so that the temperature and quantity of the exhaust gases is as low as possible.

Complete combustion must not be confused with perfect combustion – complete combustion can readily be obtained by supply excess air, but when this is done, it must not be forgotten that the greater the amount of excess air admitted into the furnace, the greater will be the amount of nitrogen present. This nitrogen is an inert gas and absorbs heat, carrying it away to the uptake. It will readily understood, therefore, that if perfect combustion and maximum efficiency are to be obtained, a close control on the air supply must be maintained.

Excess air or, in other words, excess oxygen and nitrogen, are the chief source of heat loss in combustion. On the other hand, when insufficient air is supplied for complete combustion, the loss due to the presence of the inert nitrogen is small compared to that resulting from incomplete combustion.

In practice, excess air is necessary.The excess air is the mechanical means of obtaining more intimate contact between the oxygen of the air and the fuel.

Combustion efficiency is the relationship between the amount of air actually supplied for combustion and the amount theoretically required. The amount of excess air required for the efficient combustion of coal is a very variable quantity as, with hand firing, the amount and thickness of fuel, also the condition of the firebars, etc, vary from one fire to another. Oil, on the other hand, finely atomised and intimately mixed with air, can be burnt under more stable conditions, the excess air required being about 10-30%.

A smokeless funnel accompanied by a high carbon dioxide (CO_2) percentage, low oxygen (O_2) percentage and without carbon monoxide (CO) is the ideal.

In the absence of gas-analysis apparatus, assuming all burners are clean and oil is at the correct temperature, it is considered good practice to reduce the excess air from the smokeless funnel state until a light-brown haze is obtained.

A further loss is due to the latent heat of moisture formed during combustion from the hydrogen in the fuel but there is little of practical value to be achieved by the operator. Finally there are radiation and unburned loses. The former may be contained by keeping all insulation in good order and the outside surface of the boiler unit as clean and bright as possible.

Unburnt losses can be kept to a small value by proper maintenance and care in operation of the combustion equipment.

The necessary care begins with receipt of the fuel on board. The fuel must reach the point of combustion in good condition. For oil fuel, settling tanks provide a ready use quantity of oil which may be kept at a suitable pumping temperature for a sufficient time, for any water or other residue to settle out. From here it is taken through suction strainers by the pumping and heating unit, which is arranged in duplex form so that 100% standby pumping and heating capacity exists.

Steam heating is used in service, although a separate small capacity electric heater and pump is used for lighting up form cold. From the pumping and heating unit, the fuel oil is further filtered before entering the pipework leading to the firing front. This pipework is arranged in a complete loop back to the suction side of the pumping and heating unit, to enable the whole system to be brought up to working temperature by circulating hot oil before attempting light off. Connections from this pipework to the individual burners and their control valves must be short as possible to minimise the amount of cold oil injected into the furnace during the first attempt at ignition. The arrangement of the pipework should be such that no dead legs or loops occur where sludge deposits may accumulate, and their heating of the oil should be closely controlled at all times. It is customary to exercise this control so that the viscosity at the burners is at an optimum value for the particular type of atomiser in use. This may be done by temperature, knowing the temperature-viscosity characteristics of the fuel, or directly by means of a viscometer.

Combustion equipment needs special care since inadequate combustion conditions caused by badly serviced combustion equipment can lead to serious long term difficulties downstream. With oil firing, regular cleaning and inspection of the atomiser tips is an essential safeguard. Poor atomisation occurs with dirty, partially blocked or misshapen orifices. As soon as wear is detected, the sprayer tips should be replaced with new and old discarded. This should apply to all burners of a group, which should all have sprayers of equal size and quality at all times. The burner barrel must be set up correctly within the air register i.e. centrally disposed and with the atomiser in the correct axial location. The swirler or impeller should be firmly attached to the burner carrier tube and in its correct axial location. The air register doors should be free to operate and provide unrestricted passage when open. The correct settings for the combustion equipment should be clearly specified by the manufacturer.

The air supply arrangements must also be in order. The suction of the forced draught fan should not be impeded, and the trunking should be clear, particularly following any maintenance which may have disturbed those parts. The closely pitched heating surfaces of a steam air heater can also be blocked easily, and should be inspected for cleanliness at intervals and cleaned as soon as necessary. Any dampers in the forced draught air trunking should be checked to ensure that they are in the correct position and that the blades and spindles have not parted company. Sometimes, baffles are used in the windbox to obtain the correct, even air distribution between the several registers, and an occasional check that these have not shifted is worthwhile.

Secondary air systems involve high pressure secondary air fans, which may taken their suction from the hot forced draught air trunking, and deliver to a duct system encompassing the front and rear to the furnace, ending in a number of branches to the individual secondary air nozzles which pierce the furnace wall. Distribution of secondary air in this duct system may be adjusted by means of dampers which should be correctly set.

Assuming that good combustion conditions with a minimum excess of air are achieved, there should be no tendency for severe fouling to occur. Fuels used will, however, vary within a certain range, and contain many undesirable impurities, certain combinations of which will increase the tendency to fouling which must be countered by regular use of sootblowing equipment. For this to be successful the sootblowers by regular use of sootblowing equipment. For this to be successful the sootblowers must themselves be maintained in correct working order, and any deterioration corrected before it leads to problems within the boiler. This involves checking the condition of the lances and steam nozzles and ensuring that the blowing arc during which steam is admitted is correctly aligned with the heating surfaces. The air purging arrangements should be checked to avoid corrosion due to ingress of combustion products when not in use. Further, a check should be made that the sootblower lance is obtaining steam at the appropriate pressure as specified by the designer. This will be adjustable at each sootblower head. At intervals, when the plant is shut down for maintenance and survey, the cleanliness of all gas side surfaces can be inspected and, if necessary, water washing carried out. Very high pressure water washing equipment is available for this task, and, if embarked upon, it should be carried through to a conclusion which leaves all surfaces clean and deposit free. If this is not done, small amount of deposit remaining, now devoid of any soluble matter, will be baked on during subsequent operational periods and will need severe mechanical attack for removal.

If left on it provides a good key for a further rapid build up of new deposit. This is particularly so in high temperature zones and the extra care and effort necessary to achieve a good result will be repaid.

Water side cleanliness is no less important to a good service life from a boiler as it has been observed that even very think layers of scale inside heated tubes soon lead to temperatures which can cause tube failure. It is therefore most important to ensure that water conditions within the boiler are adjusted by the addition of water treatment chemicals, avoiding scale formation and promoting corrosion free conditions within the whole boiler, steam and condensate systems. Feed water entering the boiler should pass through a fine microfilter to remove particles which may have been picked up in the pre-boiler system. After several years operation, or more frequently should there be any accident or interruption in proper treatment, it may become necessary to clean the water side of the boiler. With modern all welded designs, the use of chemical cleaning has come into vogue. This must be approached with caution and the services of a properly qualified chemical cleaning team should be used. Since cleaning is accomplished by circulating weak acids around the affected parts it is essential that thorough flushing and subsequent passivation procedures follow the cleaning stage. Passivation ensures that the water side surfaces receive a protective layer of magnetite, and follows all water side cleaning operations, even those occurring prior to commissioning when the task is to remove millscale and other small debris resulting from construction. The actual treatment used for boiler water condition varies with operating pressure since, in general terms, the higher the pressure the greater the degree of water purity required. For the highest pressures, volatile treatments are used, limiting the amount of dissolved solids in the boiler water and avoiding the need to continuously blow down a small quantity of water from the boiler drum to control the solids content of the water. Care is needed to avoid a build up of small particles in the lower parts of the boiler which, if left unchecked, could impede circulation. To avoid this it is customary, on shutting down and after extinguishing burners, to briefly operated manually the bow down valves from the lower headers.

Raising Steam

In the case of new boilers or boilers which have been out of service for survey or repairs, there are a number of general points to note before starting to raise steam.
Serious accidents have occurred through this procedure being casually carried out, under divided responsibility – especially in the case of new installations – and it is important therefore that the procedure is the responsibility of an experienced qualified engineer.
Prior to filling the boiler, a thorough examination should be made, both internally and externally.
Internally

(a) All tubes should be proved clear – oily waste and tube cleaning gear have on occasions been left in tubes.
(b) Apertures in drum ends leading to water gauges, etc, should be examined – tools have been found obstructing these passages.
(c) Internal surfaces should be free from scale and oil – this also includes oil from tube expanders, if these have been used.
(d) Internal fittings should be secure i.e. perforated plates, feed pipes, internal steam pipes, baffles, etc.
The header handhole plugs and lower manhole doors are now replaced.

Externally

(e) All refractory should be in good order – particularly any protecting drum surfaces.
(f) All valve, safety valves and cocks should be in good operable condition and shut.
(g) Manhole and handhole door joints should be in good condition and properly tightened.
(h) Superheat control valves (dependant on arrangement) should be correctly set to ensure that all initially generated steam flows through the superheaters.

Check the gas side of the boiler is clean and in good order. Make sure that sootblowers are correctly fitted, and operate over their correct traverse. Operate any gas or air control dampers fitted to ensure they move freely for their full travel. Leave them closed or in mid-position as necessary. The boiler casing doors are now replaced.
Open the direct reading water level gauge isolating cocks, together with all boiler vents, alarm and pressure gauge connections. The superheater drains are also opened. Check that all other drains and blow down valves are closed.
Commence to fill the boiler with hot deaerated water. At this stage the initial dose of chemical treatment can be added through the top manhole doors which are then replaced.
Continue to fill to a level just above that which causes the low water level oil fuel cut out to operate. Close any header vents as water issues.
Remove the funnel cover, and ensure that all air checks operate correctly and that the forced draught fans are in working order. If gas heaters are fitted they should be by-passed.

Check the fuel oil system to ascertain it is in good order. Start up the fuel oil service pumps and check for leaks. The boiler is now ready to commence raising steam.

Heat the fuel oil to the required temperature, using the recirculating line to get the heated oil through the system. If no heat is available for this, use gas oil until sufficient steam is available to heat the residual fuel oil normally used.

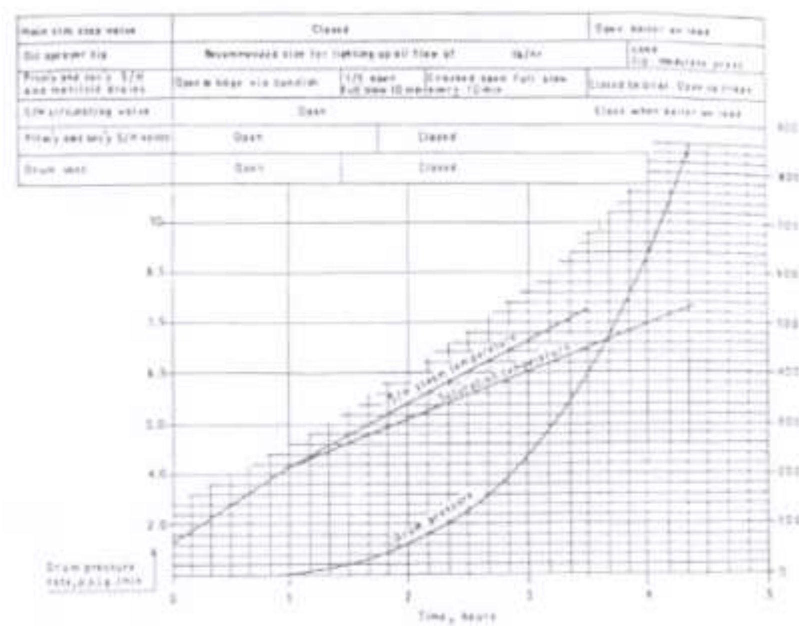
Start the forced draught fan, and with all the air checks full open purge the boiler, making sure any gas control dampers are in mid-position so giving a clear air passage.

Carry out a final check to make sure water level gauge cocks are open, water is showing in the glass, and that steam drum and superheater vents are open.

Now close all the air checks except for the burner to be flashed up, this being done by means of ignition equipment or a paraffin torch. The following few seconds is a trial for ignition period, during which the burner should ignite and a signal received by the flame scanning device. Should light up not occur during this period the burner is secured and the sequence restarted with a further air purge. With the first burner safely firing use the lowest possible firing rate. Adjust the air supply so as to obtain the best combustion and check that, as the boiler heats up, the water level in the glass begins to rise.

At this stage the boiler stop valve is closed, the drum and superheater vents are open, the superheater and steam range drains are open and the superheater circulating valve is open. This last is found in small bore pipe leading from the superheater outlet to atmosphere, its purpose being to permit a cooling flow of steam through the superheater until the boiler goes on load. The pressure raising period is a hazardous one for the superheater and requires that the firing rate be limited, so that, with the small steam flow allowed, the superheater tubes do not become overheated. Pressure should begin to rise after the first hour or so and until this point no steam is available to cool the superheater, so during this initial period great care is taken not to overfire. Thereafter, with a steady firing rate, usually specified by the designer, the pressure will rise so that the saturation temperature in the boiler increase at the rate of 1°C per minute, so avoiding any risk of stresses induced by any substantial temperature differential in any area of the boiler pressure parts. The typical lighting up chart (below) shows how the pressure will increase at a faster rate as time passes until full boiler pressure, in this case 62 bar, is reached in a little over 4 hours.

This chart also indicates the status of the various vent and drain valves during the lighting up period.



Steam temperature should also be monitored so that the circulating valve is not needlessly left wide open, but is trimmed in to conserve water and aid pressure raising. This valve is finally closed when the boiler takes load.

When the steam pressure has reached a value of about 3 bar blow through the water level gauges to ensure they are working correctly. The isolating valves on the remote reading water level indicator can now be opened, and the indicator placed in service.

With the steam pressure at about 10 bar follow up the nuts on all new boiler joints.

At a pressure of about 11 bar open the drains on the auxiliary steam lines, crack open the auxiliary stop valve and warm the auxiliary line through. Now close the drains and fully open the auxiliary stop valve.

When the main engine is ready to take steam, open the main steam line drains, and crack open the main stop valve and warm through the main steam line. Then close the drains and fully open the main stop valve. The remaining burners are ignited. Thereafter the fuel oil pressure is varied, causing the firing rate to match the steam demand by maintaining constant boiler steam pressure.

The procedure from flashing up to coupling up at full working pressure should take about four to six hours. Only in emergency should it be carried out more rapidly. If new refractory material has been installed carryout the procedure more slowly.

At all times during the raising of steam the superheaters must be circulated with steam to prevent them overheating. It the temperature of the superheaters goes above the permitted value for the boiler reduce the rate of firing.

On modern plant, burner management and boiler control is achieved with automatic devices and it is only necessary for the operator to satisfy himself that this equipment, the built in alarms and safety cut out are operational, and to engage the system according to the maker’s instructions. The automatic controls will take care of all manoeuvring situations and steady load operations at sea, during which it is only necessary for regular checks to be made on safety devices such as low water level alarms and low level trips, which extinguish the burners when water reaches a dangerously low level. There is an established routine for blowing down water gauge glasses, and it is as well to extend this to include a check on all alarm and safety cut out devices since such equipment, if seldom called into play, has been known to fail to operate when an emergency arises. If, during any emergency, steam pressure falls back well below the set point, care is needed, following resolution of the problem, not to regain pressure too quickly. For safety of the superheater, fuel flow and steam flow should be in balance. When regaining pressure, fuel flow must be greater than needed for the existing steam flow. This excess firing rate will elevate the superheater tube temperature and must therefore be limited. It will be satisfactory if the rate of regained pressure does not exceed the rate of pressure rise existing at the end of the lighting up period, as shown on the lighting up chart.

Fires

Cleanliness of the heat recovery surfaces after the boiler can often be judged by observing the gas pressure differential above and below. Any significant rise in this value should be attended to. Whilst good combustion conditions will minimise the risk, deposits allowed to accumulate in this area are a fire risk and, should fire take hold undetected, it can prove impossible to control and can wreck the heat exchanger, or even the whole boiler. There is plenty of evidence of soot fires leading on to hydrogen fires.

Soot Fires

The ignition of an accumulation of soot, rich in carbon, caused by poor combustion either in ort or when operating at low power for prolonged periods, can when supplied with the necessary oxygen be the source of a fire sufficiently intense to melt and burn steel. Air heaters, with their thin steel plates or air tubes and an abundance of oxygen, can, unless kept clean, be very susceptible to this kind of damage.

Hydrogen Fires

Instances have occurred in which the tubes of watertube boilers, superheaters, economisers and exhaust gas heat exchangers have, as a result of an intense fire, literally melted and run away in streams. Sometimes in the case of vertical tubes, they have melted and flowed back into their headers to solidify. According to the engineers who investigated these cases, the fires were subsequent to the overheating of tubes which were short of water or steam.
How then does a ‘hydrogen’ fire occur in a watertube boiler or exhaust gas heat exchanger? In the watertube boiler the importance of always ensuring an adequate steam circulation through superheaters has already been mentioned, and cannot be overstressed. Additionally, the firing rate, actual location of the superheater in the boiler, the inner and outer surface cleanliness and condition of the superheater tubes, and possible maladjustment of the burner equipment causing ‘flaming through’ screen tubes, can all influence the likelihood of severe overheating of these tubes.

When overheating of a superheater due to insufficient steam circulation is very severe, the tube material may ignite at about 700°C and, burning in the steam, produce free hydrogen. The iron will continue burning independently of any supply of oxygen from the air, and the hydrogen produced by the reaction will burn on coming into contact with air. This means that once such a fire has started there are likely to be two fires burning simultaneously, one, iron burning in steam and the other, hydrogen burning in air, the combined fire being self supporting and probably lasting until the supply of steam is exhausted.
The conditions necessary for the initiation of a hydrogen fire fortunately rare are generally accepted to be as follows:

1. Tube metal temperatures of over 705°C.
2. Tubes with some steam content (usually quiescent or of poor circulation).
3. The presence of a catalyst in the form of a carbon ash.

The extreme importance of adequate steam circulation was vividly demonstrated in one case where one of the two D type main boilers of a VLCC burnt out. In this incident, subsequent to a tube burst and reduction of steam pressure in one boiler, the NR stop valve shut and, before low water level shut off the fuel, a hydrogen fire started in its steam starved superheater. This white hot fire spread throughout the boiler melting and burning most of the tubes, and also initiated soot fire in the air heater. Waterwall and screen tube headers were subsequently found to be blocked solid with plugs of steel which had formed when the molten boiler tubes and run back into their holes.
In the foregoing incidents with water tube boilers the source of heat responsible for the overheating has been the boiler burners. Such fires do, however, occur in finned tube exhaust gas heat exchangers and boiler economisers, where the source of heat is flue gas with a temperature much too perchance during a soot fire; the unit concerned is not being circulated, the intense heat of the soot fire, rich in carbon, may initiate a hydrogen fire and that this, as in the case of boiler superheater fires, once started, is self-supporting until al steam is exhausted.
It is important, therefore, that boiler economisers and exhaust gas heat exchangers are kept clean on the gas side to prevent soot fires, and that if defective are either bypassed on the gas side, or if not bypassed have their defective sections properly blanked off, drained and vented. Sometimes, due to tube failure in an economiser if the individual tube cannot be isolated, or if the failures are of a multiple nature, it becomes necessary to make an emergency bypass of the economiser on the water side. Ordinarily, the gas temperature in this zone will not be sufficiently high to cause any distress to the metal parts, but there will be a fire risk due to the overheating of any deposits on the tubes. Sootblowers should therefore be operated prior to operation with the economiser bypassed, a suitable reduced firing rate should be established and the gas temperature into and out of the bypassed unit monitored, the plant being shut down at the first sign of untoward readings. Such events are also known to have occurred in diesel exhaust gas boilers and, apart from keeping them clean, a sensible precaution with this equipment is to leave the circulating pump running, after the engine is shut down, to cool down the unit and to ensure that air is not admitted until cooler conditions prevail. The only cure is prevention.

Furnace Explosions

Furnace explosions or on a lesser scale 'blow backs' generally occur when volumes of oily vapour and air, present in a furnace in explosive proportions, are ignited, although sudden admission of air to a fuel-rich burner flame may well produce the same result. These explosions should not occur in boilers fitted with automatic sequential controls, as these, apart from controlling the fuel to air ratio also ensure adequate purging before ignition.
Even in the best designed system, however, automatic light-up failures do occur, and it is then, when going over to manual control, often in a hurry that the wrong action is sometimes taken, resulting in an explosion. Failure to obtain ignition at the first attempt must be followed by adequate purging.
Explosions in watertube boilers with their large capacity furnaces can, be a serious occurrence, often involving the loss of lives. These explosions usually occur when steaming conditions are not stabilised, as for instance during a vessel's fitting-out period when steam is intermittently required for testing auxiliaries. At such times the operation of the boiler is sometimes a divided responsibility, and may well be under manual control without all its safety devices completely installed.
Boiler operation should always be the responsibility of one qualified engineer who full appreciates, from the furnace explosion aspect, the vital necessity of adequate pre-ignition purging, and who is aware of the possibility; especially with membrane walled boilers, of a serious furnace explosion pulling tubes out of drums and disgorging the boiler contents into the engine room.

Laying-up Boilers

During idle periods precautions have to be taken to protect boiler internal surfaces against corrosion. Two methods are in common use dependant on the length of lay-up.
For short periods up to say a maximum of one month, the boiler, superheater desuperheater and economiser, with all valves and cocks shut, are completely filled with hot distilled de-aerated alkaline water – daily checks subsequently being made to ensure that fullness and alkalinity are maintained.
In the second methods, used when longer lay-ups are envisaged, the boiler, superheater, desuperheater and economiser are completely dried out using heating stoves in the drums and hot air through the tubes. When dry valves and cocks are shut tight, all doors replaced (using new joints) and the boiler hermetically sealed – trays of a drying agent such as 'silica gel'; usually being inserted before sealing up.
In the case of auxiliary boilers which operate under intermittent steaming condition corrosive conditions are likely to occur both internally and externally unless precautions are taken during their off periods.
A method frequently used, always assuming steam is available from another source is to embody simmering coils in their water drums. The use of such coils enables a slight pressure to be maintained in the off duty auxiliary boiler, thus eliminating the risk of air ingress, and the gas side is kept warm and dry.

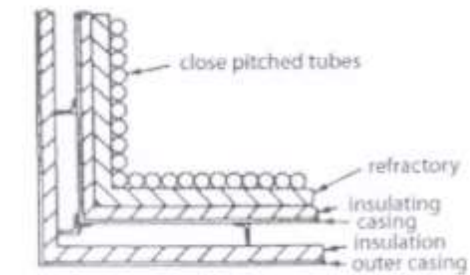
Boiler Tubing

Tube Failures

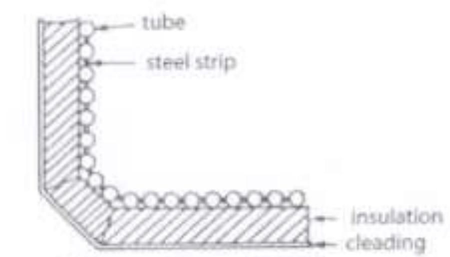
Tube failures can occur at very inopportune moments, renewals are costly and a ship may be delayed; it is of the utmost importance, therefore, when active pitting at present, that its cause is established and obviated. In most cases, having established the cause and satisfied oneself regarding the internal condition of the tubes, it is an advantage to chemically clean the boiler so that any oxide scabs covering pits are removed, prior to re-steaming the boiler under corrected water treatment conditions.

While examining steam drums internally attention should be paid to the condition and fastenings of any fittings not removed for access purposes – internal pipes to desuperheaters, internal feed pipes, low-water pipes, low-water alarms and in particular steam driers.

The problems associated with furnace refractory materials, particularly on vertical walls, have resulted in two water-wall arrangements without exposed refractory. These are known as ‘tangent tube’ and ‘monowall’ or ‘membrane wall’.

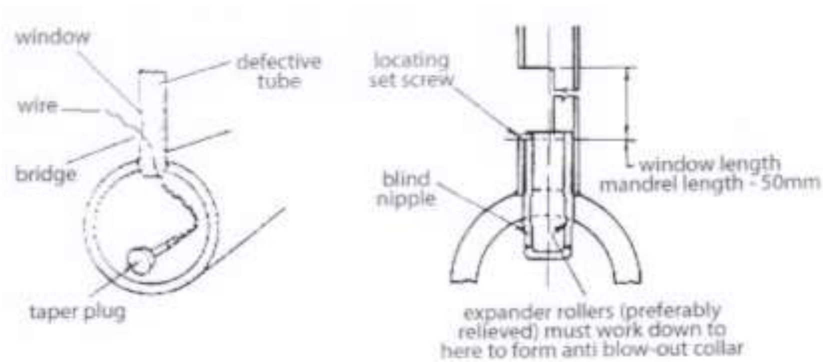


(a) tangent tube arrangement



(b) monowall arrangement

In the tangent tube arrangement closely pitched tubes are backed by refractory, insulation and the boiler casing. In the monowall or membrane wall arrangement the tubes have a steel strip welded between them to form a completely gas-tight enclosure. Only a layer of insulation and cladding is required on the outside of this construction.



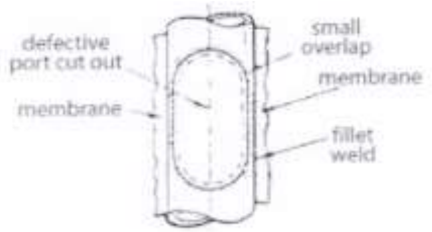
The monowall construction eliminates the problems of refractory and expanded joints. However, in the event of tube failure, a welded repair must be carried out. Alternatively the tube can be plugged at either end, but refractory materials must be placed over the failed tube to protect the insulation behind it. With tangent tube construction a failed tube can be plugged and the boiler operated normally without further attention.
Sometimes it is difficult to find the failed tube, in an exhaust gas boiler with closely fitted finned tubes for example, a method, which has found success, is ultrasonic detection.
Equipment required is a microphone pickup, connected to an oscilloscope.

- Pressurise the tube stack and headers with air.
- Enter the gas space with the microphone pick up.
- Go round the tube stack with the microphone.
- The maximum air hiss will give the maximum deflection on the oscilloscope.

The leaking tube will be in that area.

Temporary Repairs To Membrane Or Monowalls At Sea (Ships' Personnel)

The method of tube repair used in an emergency at sea would depend principally on whether a competent welder and machine are available. If not, the suitable plugs or expandable blind nipples for each of the failed tubes, should be available and also a supply of protective refractory to prevent subsequent burning through of the casing in way of the blanked-off tube.
(a) Welded repairs. Welded repairs are usually of a patch nature and have the advantage that as the tube remains in use it is not necessary to protect it with refractory. A butt welded patch is preferable, but as this, and also any internally fitted patch, are liable, in the hands of an inexperienced welder, to result in weld splatter entering the tube bore, it is safer for a quick temporary repair to rely on an external fillet welded patch. For repairs of this nature the defective part of the failed tube is cut back to sound material and then a patch piece, preferably cut from a tube having bore equal to the outside diameter of the failed tube, is filet welded over the removed section of the failed tube – the overlap being kept small to prevent subsequent overheating when in service. Subject to a satisfactory hydraulic test on completion such a repair should allow the vessel to reach a port where permanent repairs can be effected (see below).



(b) Mechanical repairs. If a welded repair is impracticable the tube may be plugged at both ends providing the tube is subsequently protected by refractory to prevent local burning of tubes and possible the boiler casing.
Various mechanical plugging methods have been devised by the boiler designers, but lack of internal access and the high temperatures appertaining at shut down can make this an extremely unpleasant and/or lengthy operation. Two methods are described below:

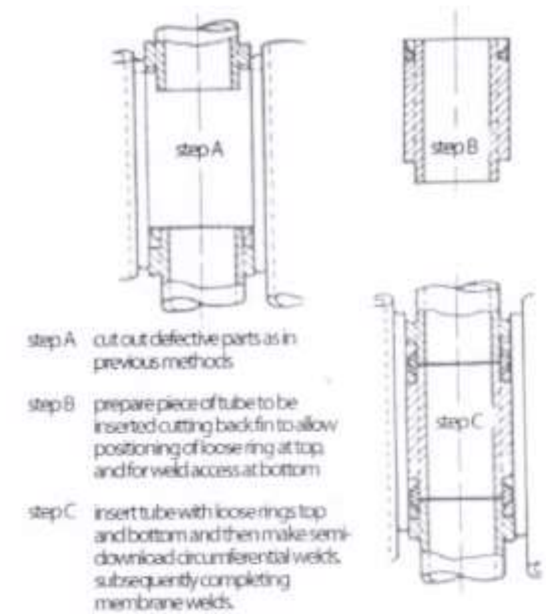
Method 1. Windows are cut in the tube about 62mm from its extremities through which wires with taper plugs attached can be pulled the taper plugs having been inserted into the headers via the inspection doors. The plugs are pulled into position through pieces inserted across the windows, and are then pulled up solids by nuts.
After both ends of the tube have been plugged in this manner the whole length of the defective tube and the boiler casing behind it are shielded from the furnace heat during subsequent steaming by a thick shield of plastic refractory.
Method 2. Again windows are cut at each end of the tube through which blind nipples are inserted and subsequently expanded.
It will be appreciated that in this method boiler pressure tends to blow the plugs out whereas in Method 1 boiler pressure tightens the plugs in the hole. It is important to ensure therefore that with this method the expander rollers project down the bore of the nipple beyond the header or drum thickness so that an internal anti blow-out 'collar' is formed on the nipple during expanding; as a double precaution special 'stepped' roller can be used to form this collar.
As in Method 1, the whole length of the failed tube has subsequently to be shielded from the furnace heat.

Repairs To Membrane Or Monowalls In Port

The type of repair whether accepted as permanent or semi-permanent will depend largely on the availability of welders skilled in this type of work.

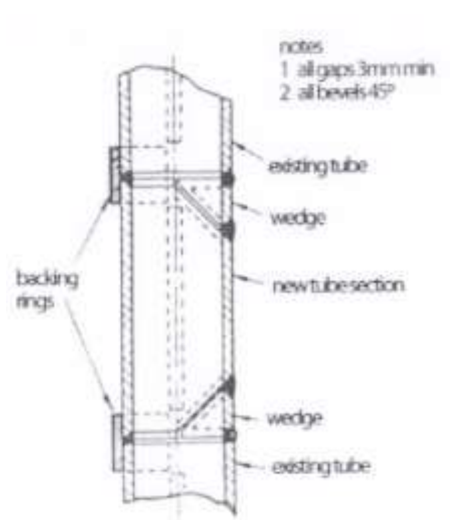
Inserting a new section

The obvious and most straightforward permanent repair consists of cutting out the defective length of tube along with part of its adjoining membranes and butt welding in a new section. This repair entails the services of skilled welders, the removal of casing and refractory in way of the repair, and accurate weld preparation.



It is important to note that unless welders skilled in the type of repair are available, the surveyor should insist that the welders being employed do a preliminary procedure test to his satisfaction.

Fish mouth tube replacement method

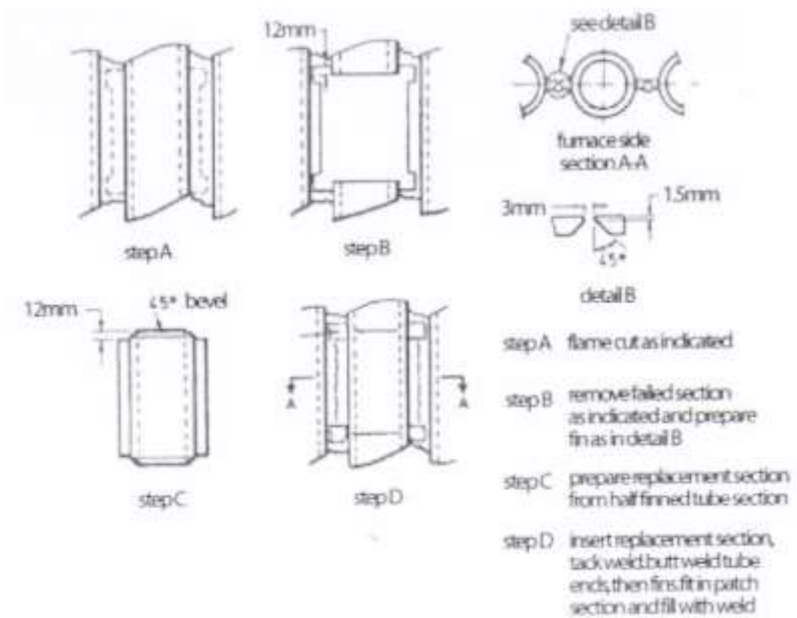


This method, when carefully executed, is also acceptable as a permanent repair and has the advantage that as all welding is done from the furnace it is not necessary to disturb the boiler casing and refractory.

The defective part of the tube along with part of its adjoining membranes are burnt out, as in the previous method. The replacement piece of tube is prepared with its top and bottom ends cut off at 45° to give access when the replacement is in position for welding, from the furnace, the rear part of the two circumferential butt welds.

When these rear parts of the circumferential welds have been satisfactory completed, wedge-shaped pieces of tube are welded into the two windows, and the circumferential butt weld then complete working from the outside. The membranes are subsequently closed by welding as in the previous method.
The configuration of the wedge pieces can be varied to suit tube diameter and access required and, if necessary, backing rings may be used.

The loose ring method



In ports where it is doubtful whether the experience of the welders justifies their employment on the previous two methods of repair, it is possible by this 'loose ring' method, to make an acceptable repair of a semi-permanent nature using down hand welding.
In this method access has to be made all around the tube and loose rings with cupped upper surfaces are slid into position in way of the butts to be welded, so that an inexperienced welder has a better chance of making a butt cum fillet joint. In all other aspects the repair is as in the previous two cases.
In view of the extra metal thickness in way of the rings and possible build up of weld metal this repair could subsequently be the subject of overheating in service, and on that account the repair should only be regarded as semi-permanent.

Testing

On completion of any of the foregoing repairs whether temporary or permanent, the boiler should be subjected to a working pressure hydraulic test. In the case of the repairs effected in port the welds should be crack detected and, if possible, X-ray detection equipment should be used.

1.1.5 DESIGN FEATURES AND OPERATIVE MECHANISM OF PROPELLER SHAFT AND ASSOCIATED ANCILLARIES.

Main propulsion shafting is supported by bearings which maintain the shafting in proper alignment. These bearings divide themselves naturally into two groups; those with bearings inside the watertight boundary of the hull and those bearings which are outside the hull watertight boundary.

The requirements imposed upon main shaft bearings are extremely severe. The bearings are required to operate at speeds ranging from 0.1 rpm, when on turning gear, to 100 or more rpm, in either direction of rotation. Unlike some applications, the bearing loads do not vary with rpm but are essentially constant of all speeds. Reliability is heavily emphasised in the design of bearings because there is no redundancy for bearings and a single bearing failure may incapacitate the propulsion system.

Therefore it is advisable to have one spare shaft bearing shell held on board at all times.

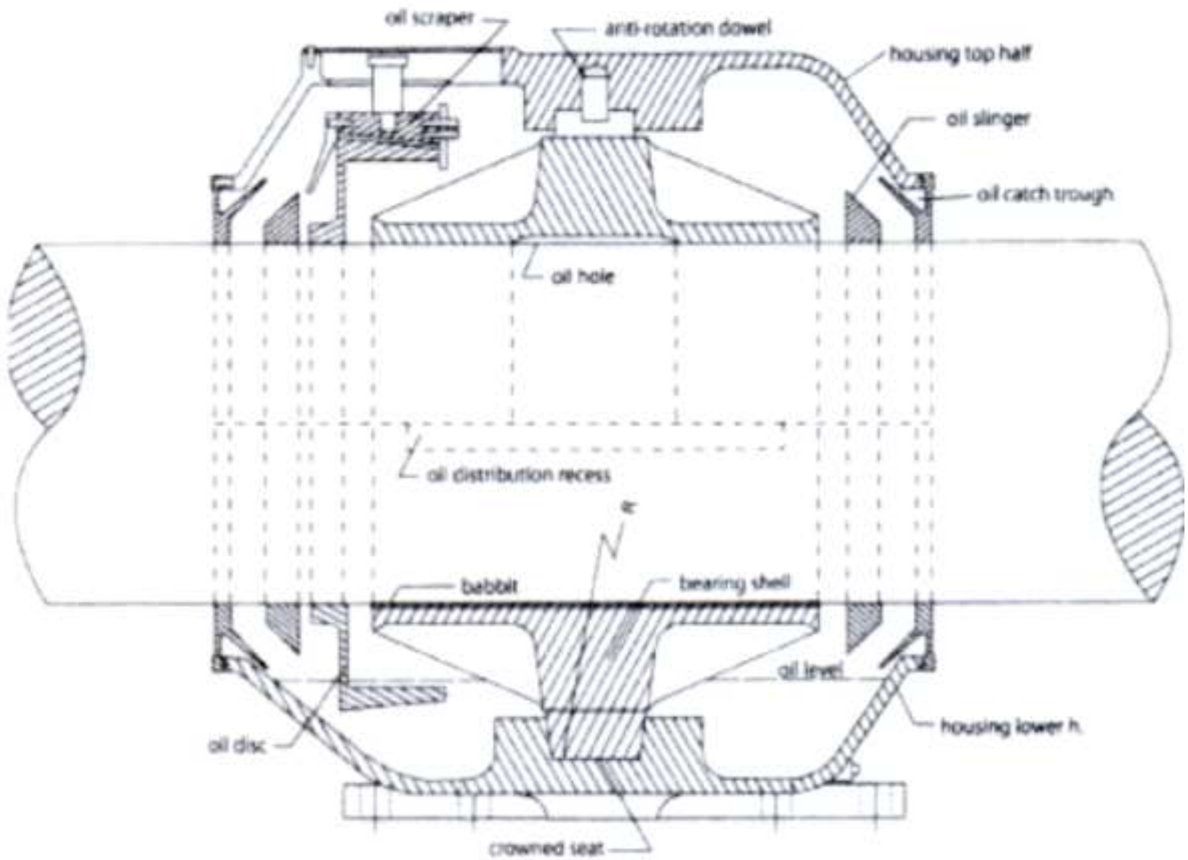
In addition to the radial bearings which support the main shafting, there is located inside the ship a main thrust bearing which transmits the propeller thrust from the shafting to the hull structure.

Shaft Support Bearings

Bearings located inside the ship's watertight boundary are called line shaft bearings, although they are sometimes referred to as steady or spring bearings. Almost without exception, these bearings are ruggedly constructed, conservatively designed, Babbitt lined, and oil lubricated. Except in special cases, the bearings are self-lubricated by rings or disks arranged in such a manner that lubrication is effected by the rotation of the shaft. Roller bearings have been used in smaller shaft sizes, but the advantages of lighted weight and lower friction have in general not been sufficient to offset the higher reliability and lower maintenance costs of the babbitt lined type.

When shaft bearings are opened up for inspection or survey, it is important that the oil spaces and running surfaces are protected from the ingress of foreign materials, e.g. blasting grit. On assembly, the position of the oil thrower ring must be checked.

Line shaft bearing housings are made of steel castings or fabricated of steel plates welded together. Completely satisfactory bearing housings are obtained by either method, and manufacturing costs govern the construction method used. Since rigidity is more of concern than strength, low carbon steel is used as the material for bearing housings with the exception of bearings for naval combatant vessels, in which case high-impact shock requirements may necessitate the use of high-strength steel. Bearing housings are split horizontally at the shaft centreline. The bottom half of the bearing must be very ruggedly designed since it carries the vertical shaft load and any side load that exists.



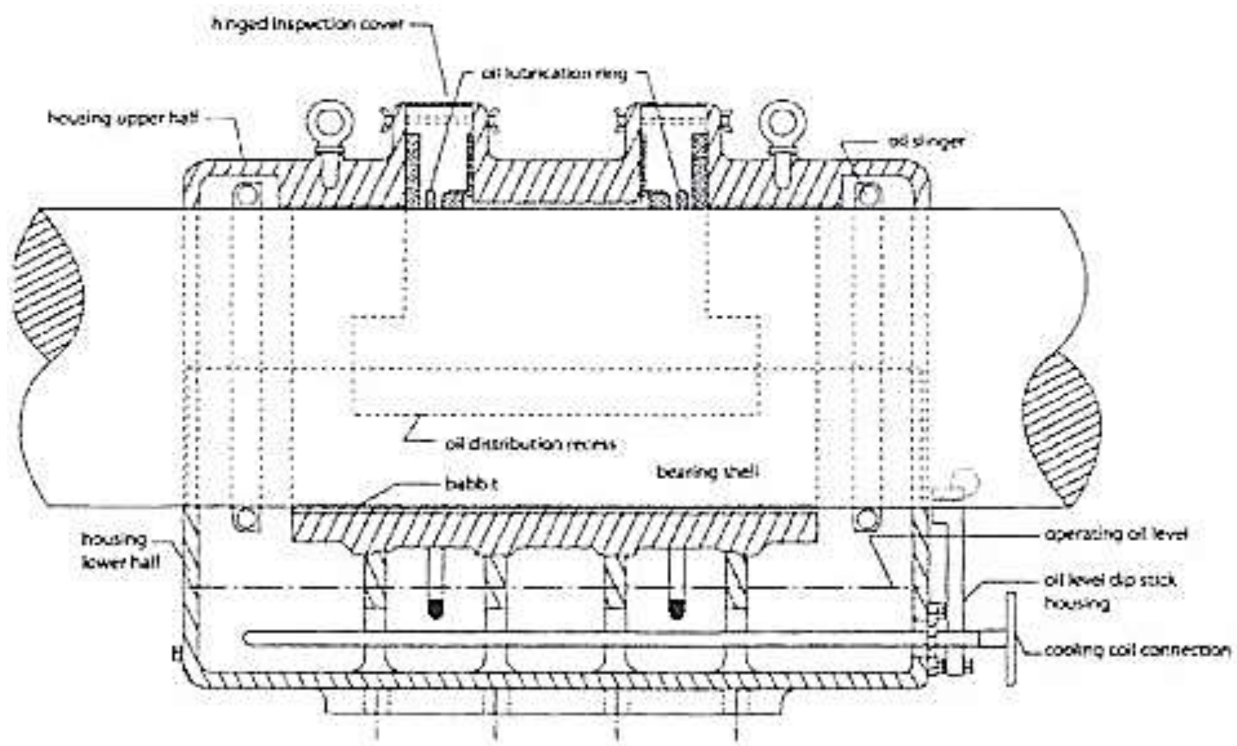
SELF - ALIGNING LINE SHAFT BEARING WITH OIL DISK LUBRICATION

Shaft Alignment

General Considerations

Hog and sag effects due to state of loading and draught, effects of waves, etc, can quite easily be as much 1mm per 1 m or ship length and even more.

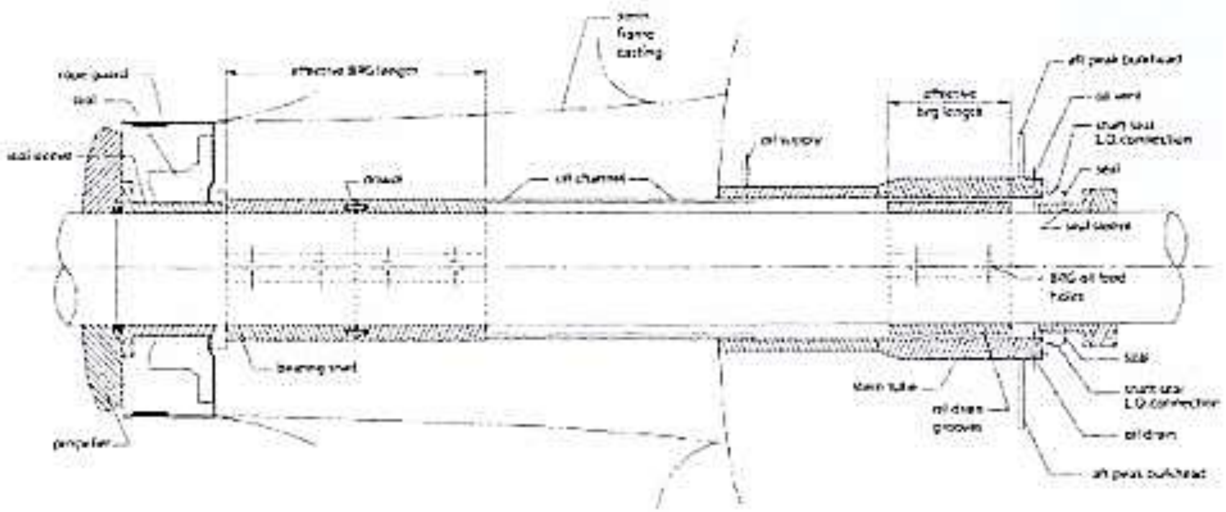
The effect of waves and sea action are mainly indeterminate over the bedplate length (say 16m) is ignored. However, this indeterminate influence gives a realisation of how difficult it is to put a heavy engine and shafting, in perfect alignment, on a flexible beam form of a ship under the action of sea influences, such realisation must show that some amount of reasonable flexing and allowances for same must always be accepted.



NON-SELF-ALIGNING LINE SHAFT BEARING WITH OIL RING LUBRICATION

Stiffening of tank tops and engine supports, together with use of rigid bedplates, can reduce central deflection to a maximum of about 13mm over the engine room length and less, and to about 2mm maximum over the bedplate from the no load to the full load condition. Invariably the bedplate has a sag from when light ship of say 1mm and a hog form when fully loaded to say 1mm. The curves for average conditions. An engine crankshaft set true at light ship could when hogged 2mm introduce static bending stresses of say 90 MN/m2. Most engine builders have their own records and experiences for dealing with this problem.

Oil Lubricated Stern Tube



TYPICAL OIL-LUBRICATED STERN TUBE BEARING

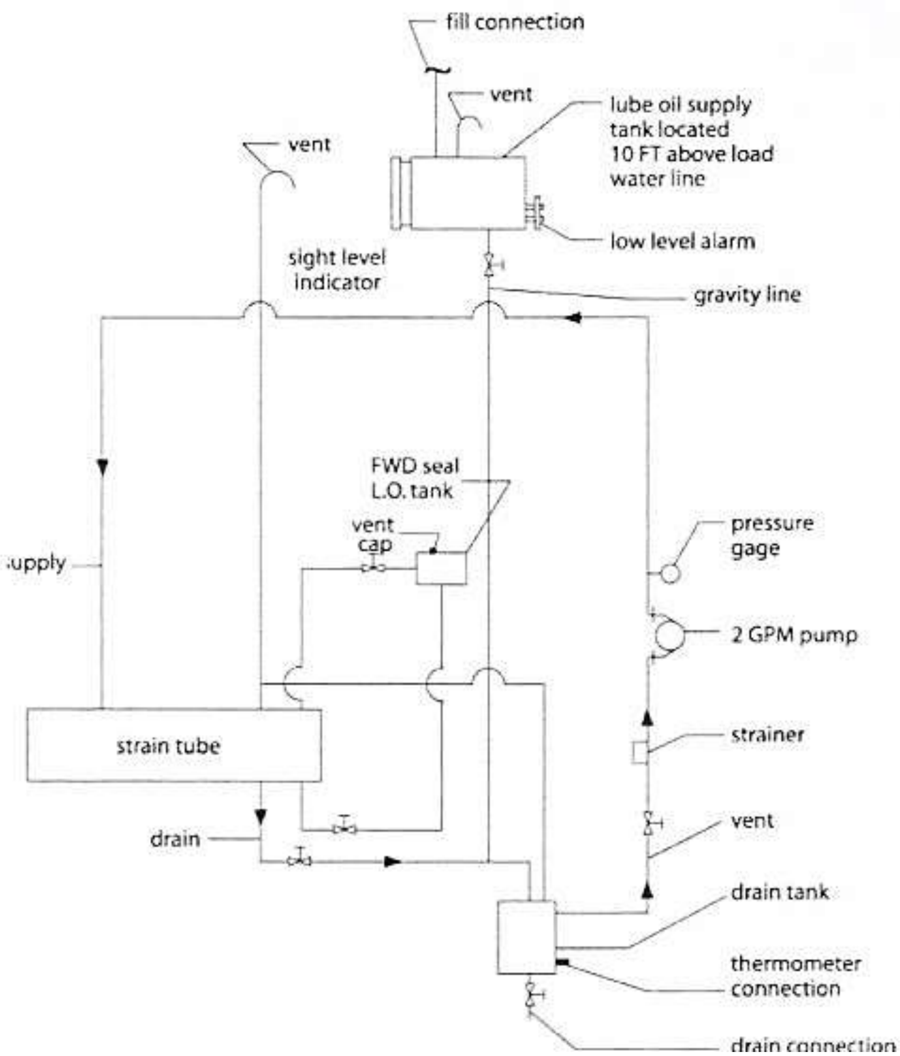
This stern tuber has been in use for many years. Various designs are available but the same principle is apparent – seal the ends of the tube with a glands and supply oil under pressure. Water should be regularly drained off and in port they should be emptied and drained. A typical oil tube is as sketched in the drawing. Weardown for the white metal should not normally exceed 2mm to avoid hammering out and the period between inspections is about six years. A highly resilient reinforced plastic material is often used in place of white metal. It is claimed to have superior load carrying capacity, high resistance to fatigue and shock loading, with good lubrication properties. Stern tube seals, with oil lubrication, have also 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. In these designs four seal rings are usually located in the support housing aft with oil pressure supply to the middle chamber. Two similar ring seals, with oil feed between, are arranged in a floating housing at the forward end. Ceramic coated liners can also be used.

Stern Tube Lubrication Oil Systems

Oil lubrication stern tube bearings are totally submerged in oil, and seals on the aft and forward ends of the tube prevent the ingress of seawater and the leakage of oil into the ship, respectively. The pressure of the oil in the stern tube is maintained above that of the ambient seawater by means of a head tank which is located about 3 metres above the full load waterline.

During service, if the stern tube starts to leak externally, adding high viscosity oil to the system, e.g. “Vickers Hydrox”, can cure this.

Ships which have large draft changes may require two head tanks; one for the full draft operation and one for ballast operation.

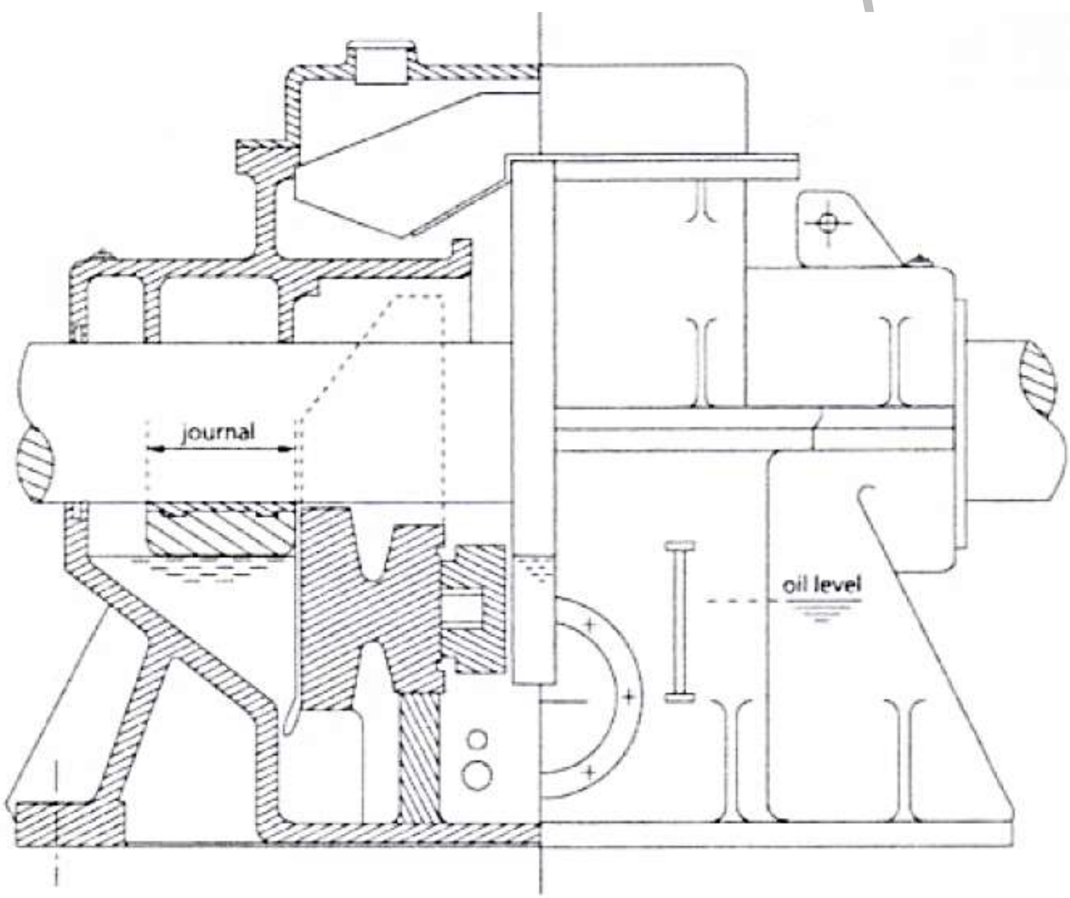


The drawing illustrates a typical tube oil diagram for an oil lubricated stern tube bearing. A small pump is usually installed as shown to force oil circulation through the stern tube. The oil flow is such that oil is circulated through both bearings. Many variations of this system have been used including filters, heaters, coolers, and coalescers to condition the oil as it passes through the circuit.

Thrust Blocks

Modern types are of the Mitchell principle. The thrust of the collar is transmitted through the oil film and pads to the casing. The white metal surface would be more likely to yield than the oil film at pressures as high as 500 bar (compressive yield of white metal say 560 bar = 56 MN/m^2).

The oil scraper bears on the outer periphery of the thrust collar and delivers oil to the reservoir-stop from where it cascades on to the pads and bearings. The pads fit radially in the inverted horse show castings, pads being secured circumferentially by the stop. The castings back on to liners so ensuring location in fore and aft direction and fixing the clearance, which can be adjusted. The radial pivot line on the pad back vary from half to two thirds of the pad width from the leading edge.
The lower half castings act as an oil reservoir sump, being provided with oil level gauge glass and a cooling coil. The total oil clearance is approximately 1mm for say 500m diameter shaft. The wedges at base have a slow taper of about 20 mm/m and act to relieve the holding down bolts of shear. The floors in the double bottom tank below the thrust stool are closely pitched. Clearance are measured using wedges or hydraulic ram movement.



Ship Side Valves

Valves and cocks on the shipside control the entrance of sea water into the pipe systems for the purpose of circulating the condensers, coolers and distillers, filling the ballast tanks and other uses. Inlet valves are, of course, submerged below the light –load line, and water enters on the underside of the valve so that it will not cease to operate even if the spindle is broken.

The entrance to both valves and cocks is covered with an external grid to prevent debris being taken in. The main inlet valves are the ballast injection and the main circulating pump valve – the main injection. In rivers and shallow waters sand may be drawn into the main injection valve, which is often placed above the bilge keel, and a second valve, the high injection, is sometimes provided and used in shallow waters with the main injection shut down.

Discharge valves are required to prevent flooding of the vessel if a piping system should break down with the discharge submerged. Shipside valves are always of the non return design. Generally, valves will be of a type where the closing device consists of a circular disc with some arrangement of wings, or a centrally located guide rod on the base of the disc. The wings, or the guide rod, guide the disc in its up and down motion in the valve seat bush fitted in the body of the valve. The disc is sometimes referred to as the valve lid, or the clack, and is the closing device that prevents flow through the valve.

Valves may be operated manually or by opening and closing devices known as valve actuators. Manually operated valves have a screw and handwheel to open or close the valve. The thread of this type of valve is usually a single start thread as this gives a rapid enough opening or closing speed when the valve wheel is turned. The lid travel of this type of valve from shut to open is approximately one quarter of the lid diameter, although some valve designed to have less flow resistance may have a larger amount of opening.

As valves have become larger and ships machinery has become more automated than formerly, actuators are increasingly being used to operate valves. This requirement is brought about in some cases because the forces required to open and close large valves are beyond the limits for manual operation. The use of actuators also make it possible to control valve from some central location such as the cargo control room in a tanker or the control space covering propulsion and auxiliary machinery.

Valve actuators come in various forms. One is as a piston working within a cylinder, arranged to operate on the double acting principle. That is to supply power on to the piston so that the valve may be operated in either direction without the aid of springs. In other cases a ram and spring are used to enable the valve to be operated in two directions. Actuators may also be of a form referred to as a servomotor. This type of actuator is used where a rotation of approximately 90° is required, such as in a ball valve. Another type of actuator uses a double acting piston to obtain an up or down motion. At the bottom of the piston rod a small shaft is fitted which passes through the piston rod, but at 90° to it. The small shaft moves up and down following the motion of the piston. The piston and rod are prevented from rotating by making the small shaft reciprocate within a fixed vertical slot. Within the portion of the actuator carrying the vertical slot a sleeve is fitted. The sleeve is held between two ball thrust bearings, allowing it to revolve, but restricting any vertical motion. A double helix is cut in the inner sleeve and the small shaft moves up and down in the helices. This vertical movement gives the inner sleeve angular movement, allowing it to open and close a ball valve or a butterfly valve.

Valve actuators are powered by either compressed air or hydraulic fluid supplied under pressure. Where large amounts of power are required to operate valve actuators, hydraulic powered equipment is generally less demanding on space than pneumatic equipment. Generally pneumatic equipment is faster in action. Electric motors are also used as actuators to open and close valve operated by threaded valve spindles.

Damage to the valve is prevented by limit switches fitted to prevent the motor overriding the fully open or fully closed positions of the valve.

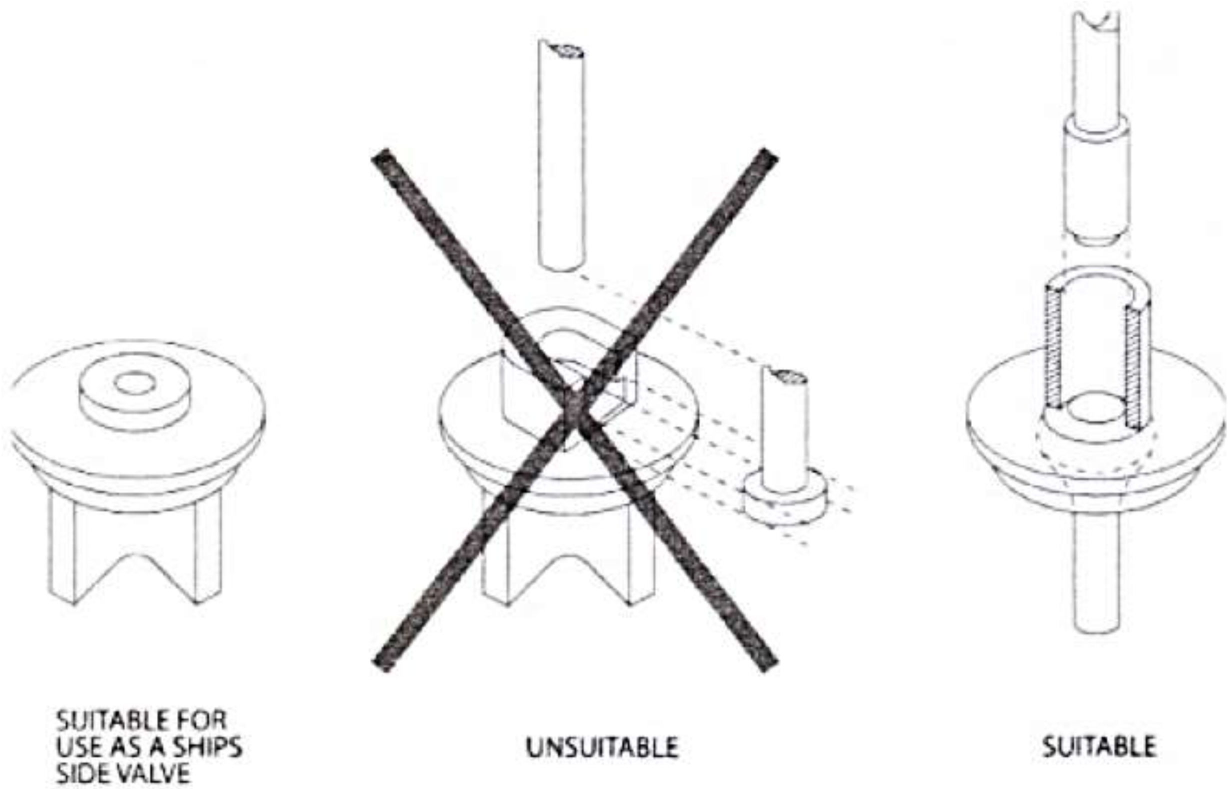
If indicators are required to show whether valves are open, partially open or closed, pointers showing the position of the valve are fitted and connected up mechanically with the actuator. This is often accomplished by electrical means using a form of feed back if required. This is accomplished by electrical resistance. In some cases it is only necessary to know whether a valve is open or closed. In such cases the valve position indicator may be operated by limit switches covering movement of the actuator. In some cases feedback from the valve actuator may be used to activate the limit switches.

The indicator may be a pair of coloured lamps.

Ship side valves are required to allow flow in only one direction. To prevent flow in the opposite direction non-return or check valves are fitted in the piping system. These may be in the form of a globe valve fitted with or without a normal valve spindle. When fitted with a valve spindle, the valve may be held in a closed position when the spindle is screwed down onto the valve lid, or allowed to open when the spindle is screwed away from the valve lid and the pressure balance is correct.

The lid, or clack, is opened when the downstream pressure under the valve is greater than the upstream pressure above the valve. If the pressure difference is revered, the valve closes, and flow in the wrong direction is prevented. When check, or non-return valves are fitted with a spindle used to hold the valve closed, they are refered to as screw down, non-return valves, or screw-down check valves. If a check valve has been removed for overhaul, great care must be taken when it is re-assembled in the pipeline to ensure fluid flow is only allowed in the correct direction.

The shipside valves should be greased and exercised on a regular basis, say, on a monthly interval.



Care Of Valves

Valve Leakage

Valve leakage is generally caused the by the disc and the seat not making a tight joint.

This may be the result of scale or dirt lodged on the seat , and if the obstructing substance cannot be blow through, the valve must be opened and cleaned. There may be scores on the seat or disc, due to erosion or to attempting to close the valve on scale; the valve must then be made tight by grinding, or if the damage is extensive by re-seating and grinding.

Stuffing-box Leakage

Leakage at the stuffing-box can be remedied by tightening up the gland nuts, or repacking the stuffing-box if necessary (but not so tightly that the stem sticks). Persistent leakage at the stuffing-box is usually caused by a bent or scored valve-stem.

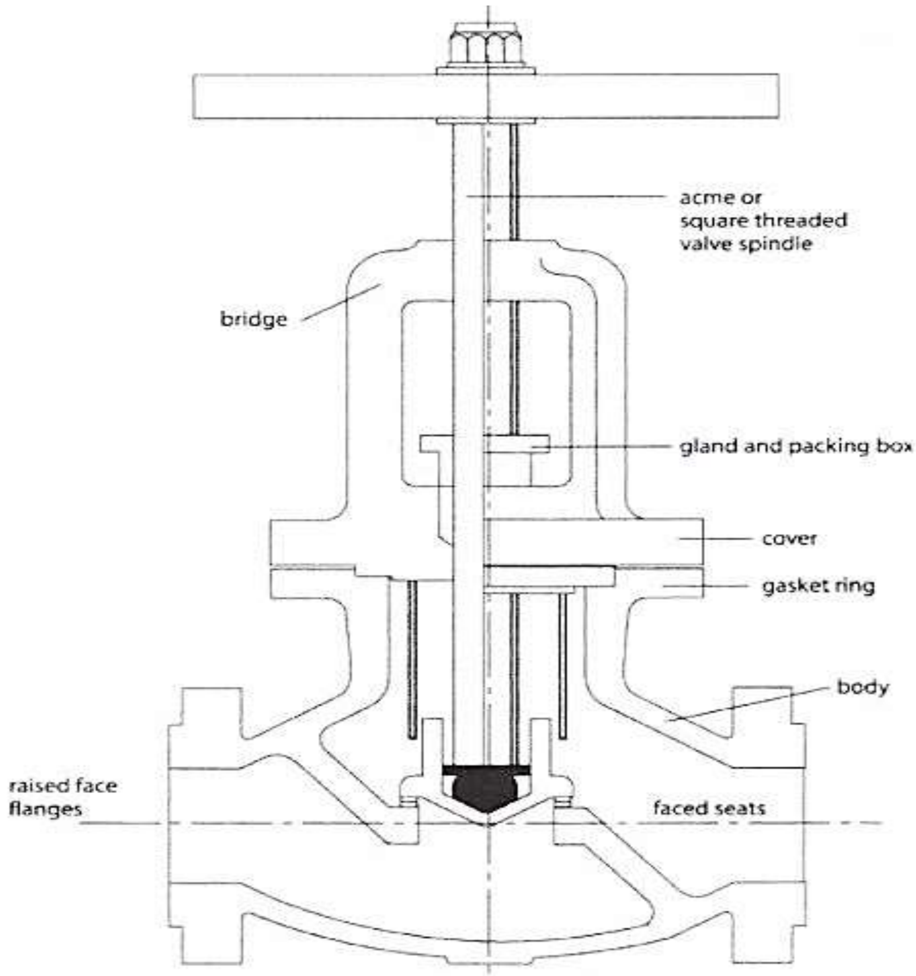
Sticking of Valve-stem

This is caused by too tight packing of the stuffing-box, by paint or rust on the valvestem, or by a bent valve-stem. If the valve is shut firmly while hot, the subsequent cooling causes contraction which bonds the disc tightly to the seat. If the valve is jammed open while cold, subsequent heating and expansion binds the valve open; it can usually be shut by means of a wrench, however, although care must be taken not to damage the valve-stem. If the stem is turned very slightly in the closing direction, after opening a valve wide, any danger of binding will be eliminated. A serious condition which may be caused by rough handling is damaging of the threads of the stem and sticking in the yoke or bonnet threads.

If the damage is seen before the stem becomes stuck, the threads can be dressed smooth with a file, but once the stem is stuck a new stem will probably be necessary.

Re-facing and Grinding

If the seat and disc are scored badly they should be re-faced, the seat with a re-seating machine and disc in a lathe. After re-facing, the seat and disc are ground together with an abrasive. The disc is turned back and forth on the seat, the seat and disc are ground together with an abrasive. The disc is turned back and forth on the seat, and occasionally lifted from its seat and its position shifted slightly. The grinding is continued until a bearing all round is obtained.



1.2. PLAN AND SCHEDULE OPERATIONS

1.2.1. THERMODYNAMICS AND HEAT TRANSMISSION

THERMODYNAMICS AND HEAT TRANSFER:

Thermodynamics is concerned with the amount of heat transfer as a system undergoes a process from one equilibrium state to another, and it gives no indication about how long the process will take. A thermodynamic analysis simply tells us how much heat must be transferred to realize a specified change of state to satisfy the conservation of energy principle.

In practice, we are concerned with the rate of heat transfer (heat transfer per unit time) than we are with the amount of heat transfer. For example, we can determine the amount of heat transferred from a thermos flask as the hot milk inside cools from 95oC to 85oC by a thermodynamic analysis alone. But, a designer of the thermos flask is primarily interested in how long it will be before the hot milk inside cools to 85oC, and a thermodynamic analysis cannot answer this question. Determining the rates of heat transfer to or from a system and thus the time of cooling or heating, as well as the variation of temperature, is the subject of heat transfer.

Thermodynamics deals with equilibrium states and changes from one equilibrium state to another. Heat transfer, on the other hand, deals with systems that lack thermal equilibrium, and thus it is a non-equilibrium phenomenon. Therefore, the study of heat transfer cannot be based on the principles of thermodynamics alone. However, the laws of thermodynamics lay the framework for the science of heat transfer. The first law requires that the rate of energy transfer into a system be equal to the rate of increase of the energy of that system. The second law requires that heat be transferred in the direction of decreasing temperature. It is analogous to the electric current flowing in the direction of decreasing voltage or the fluid flowing in the direction of decreasing pressure.

Heat transfer is energy in transit due to temperature difference. Whenever there exists a temperature difference in a medium or between media, heat transfer must occur. The basic requirement for heat transfer is the presence of temperature difference. There can be no net heat transfer between two mediums that are at the same temperature. The temperature difference is the driving force for heat transfer, just as the voltage difference is the driving force for electric current flow and pressure difference is the driving force for fluid flow. The rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction. The larger the temperature gradient, the higher the rate of heat transfer.

1. Gas cycles/engine analysis

<u>Gas power cycles</u>

Deal with systems that produce power in which the working fluid remains a gas throughout the cycle (in other words, there is no change in phase).

Spark Ignition (gasoline) engines, Compression ignition (diesel) engines and conventional gas turbine engines (generally refer to as Internal Combustion engines or IC Engines) are some examples of engines that operate on gas cycles.

Air standard cycles

Internal combustion engines: Combustion of fuel is non-cyclic process. Working fluid, air-fuel mixture undergoes permanent chemical change due to combustion Products are thrown out of the engine & Fresh charge is taken in.

Hence, the working fluid doesn't undergo a thermodynamic cycle. In order to analyze this complex gas power cycles, air standard cycles are conceived.

In air standard cycle a certain mass of air operates in a complete thermodynamic cycle where the heat is added and rejected using external reservoirs, and all the processes in the cycle are reversible.

Summary of assumptions made during such analysis: The working fluid, air behaves like an ideal gas (and specific heats are assumed to be constant)

Combustion process is replaced by heat addition and exhaust process by heat rejection

All the processes are reversible.

Internal combustion engines

There are two types of reciprocating engines:

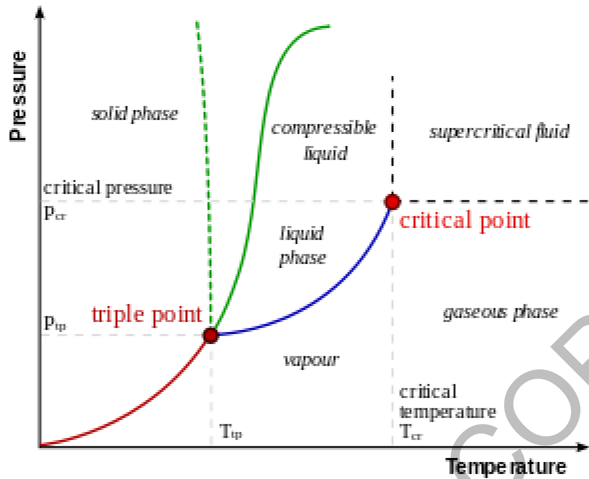
- Spark Ignition- Otto cycle
- Compression Ignition-Diesel cycle

2. Properties of vapours

Vapor refers to a gas phase at a temperature where the same substance can also exist in the liquid or solid state, below the critical temperature of the substance. (For example, water has a critical temperature of 374 °C (647 K), which is the highest temperature at which liquid water can exist.) If the vapor is in contact with a liquid or solid phase, the two phases will be in a state of equilibrium. The term gas refers to a compressible fluid phase. Fixed gases are gases for which no liquid or solid can form at the temperature of the gas, such as air at typical ambient temperatures. A liquid or solid does not have to boil to release a vapor.

Vapor is responsible for the familiar processes of cloud formation and condensation. It is commonly employed to carry out the physical processes of distillation and headspace extraction from a liquid sample prior to gas chromatography.

The constituent molecules of a vapor possess vibrational, rotational, and translational motion. These motions are considered in the kinetic theory of gases.



The vapor-liquid critical point in a pressure-temperature phase diagram is at the high-temperature extreme of the liquid-gas phase boundary.

3. Steam cycles

Historically, the first functioning power cycle is the steam cycle, which commonly is working with water vapor (steam). The Rankine cycle is an ideal case from the common steam cycle.

Steam power plants constitutes around 80% of the world's electric power generation.

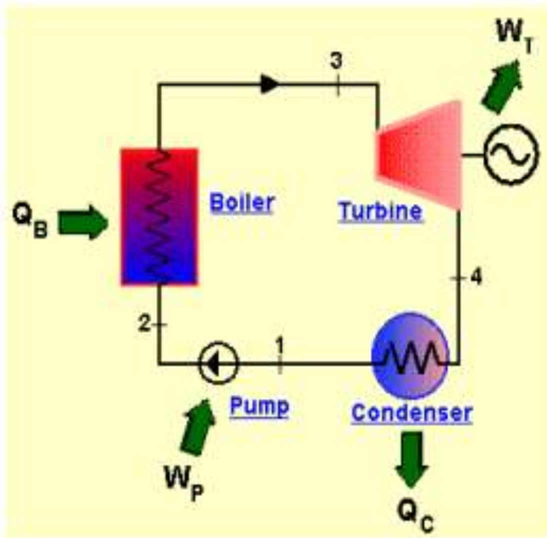
A steam cycle, (or vapor cycle), is a cycle in which the working fluid is compressed,

vaporized, expanded and condensed; thereafter the cycle repeats.

Components of a Basic Steam Cycle

- Liquid water is compressed to a high pressure by a pump.
- The pressurized water is heated and vaporized in a boiler, which is fuelled by coal, oil, gas, biomass or nuclear fission.
- Hot and compressed water vapor has high energy content, which is utilized by the turbine generating work.

- After expansion in the turbine the vapor enters a condenser, which brings the vapor to liquid form.



4. Refrigeration

Thermodynamic heat pump cycles or refrigeration cycles are the conceptual and mathematical models for heat pumps and refrigerators. A heat pump is a machine or device that moves heat from one location (the 'source') at a lower temperature to another location (the 'sink' or 'heat sink') at a higher temperature using mechanical work or a high-temperature heat source. Thus a heat pump may be thought of as a "heater" if the objective is to warm the heat sink (as when warming the inside of a home on a cold day), or a "refrigerator" if the objective is to cool the heat source (as in the normal operation of a freezer). In either case, the operating principles are identical. Heat is moved from a cold place to a warm place.

1.2.2 MECHANICS AND HYDRODYNAMICS.

Bombas

Las bombas e la altura de bombeo).

El tercer tipo debe su nombre a un elemento rotativo, llamado rodete, que comunica velocidad al líquido y genera presión. La carcaza exterior, el eje y el motor completan la unidad de bombeo.

En su forma usual, la bomba de émbolo alternativo consiste en un pistón que tiene un movimiento de vaivén dentro de un cilindro.

Un adecuado juego de válvulas permite que el líquido sea aspirado en una embolada y lanzado a la turbina de impulsión en la siguiente.

Bombas centrífugas

Una bomba es una máquina capaz de transformar energía mecánica en hidráulica. Un tipo de bombas son las centrífugas que se caracterizan por llevar a cabo dicha transformación de energía por medio de un elemento móvil denominado impulsor, rodete o turbina, que gira dentro de otro elemento estático denominado cuerpo o carcasa de la bomba. Ambos disponen de un orificio anular para la entrada del líquido. Cuando el impulsor gira, comunica al líquido una velocidad y una presión que se añade a la que tenía a la entrada. La relación entre presiones y velocidades es $h= V2/2g$ siendo h la altura en metros de columna de líquido, V la velocidad del líquido y $g= 9.81\ m/s2$ (aceleración de la gravedad).

Dentro del campo normal de aplicación, las propiedades de una bomba centrífuga son:

a.- Caudal uniforme, sin pulsaciones.

b.- La presión o altura de elevación disminuye a medida que aumenta el caudal. En general, a partir del punto de funcionamiento, cuando se cierra la válvula de regulación de la tubería de impulsión aumenta la presión y se reduce la potencia. Sin embargo, las bombas de alta velocidad específica (impulsor semi-axial o hélice) no cumplen esta norma general.

c.- La altura, medida en metros de columna de líquido, a la que eleva una bomba es independiente de la naturaleza del líquido y, por tanto, la altura a la que impele una bomba es la misma, prescindiendo de la influencia que ejerce la viscosidad.

d.- La potencia absorbida por la bomba es proporcional al peso específico del líquido elevado.

e.- El par requerido para el arranque de una bomba centrífuga es pequeño y la potencia absorbida durante su funcionamiento de régimen es continua y libre de sobrecargas, cuando la altura no varía y no hay perturbaciones ajenas a la bomba en la aspiración.

Bomba Centrífuga como elevador de presión

Como ya se ha dicho, la bomba comunica al líquido una energía que equivale a una altura o presión y ésta se añade a la que tenía en la entrada, es decir, que si a una bomba, que comunica una velocidad equivalente a una altura de 20 metros, le llega el líquido a una presión de 10 metros, la altura total que tendríamos a la salida de la bomba sería de 30 metros. Por eso si hay que elevar a gran altura se pueden colocar varias bombas, de modo que la salida de una de ellas sea la entrada de la siguiente, así la altura alcanzada será la suma de las alturas de todas las bombas.

Análogamente se puede disponer una bomba con varios impulsores, de modo que la salida de cada uno de ellos se conecte a la entrada del siguiente y con una sola bomba podremos subir el líquido a una altura igual a la alcanzada por la suma de los distintos impulsores. Este es el funcionamiento de las bombas multicelulares de alta presión.

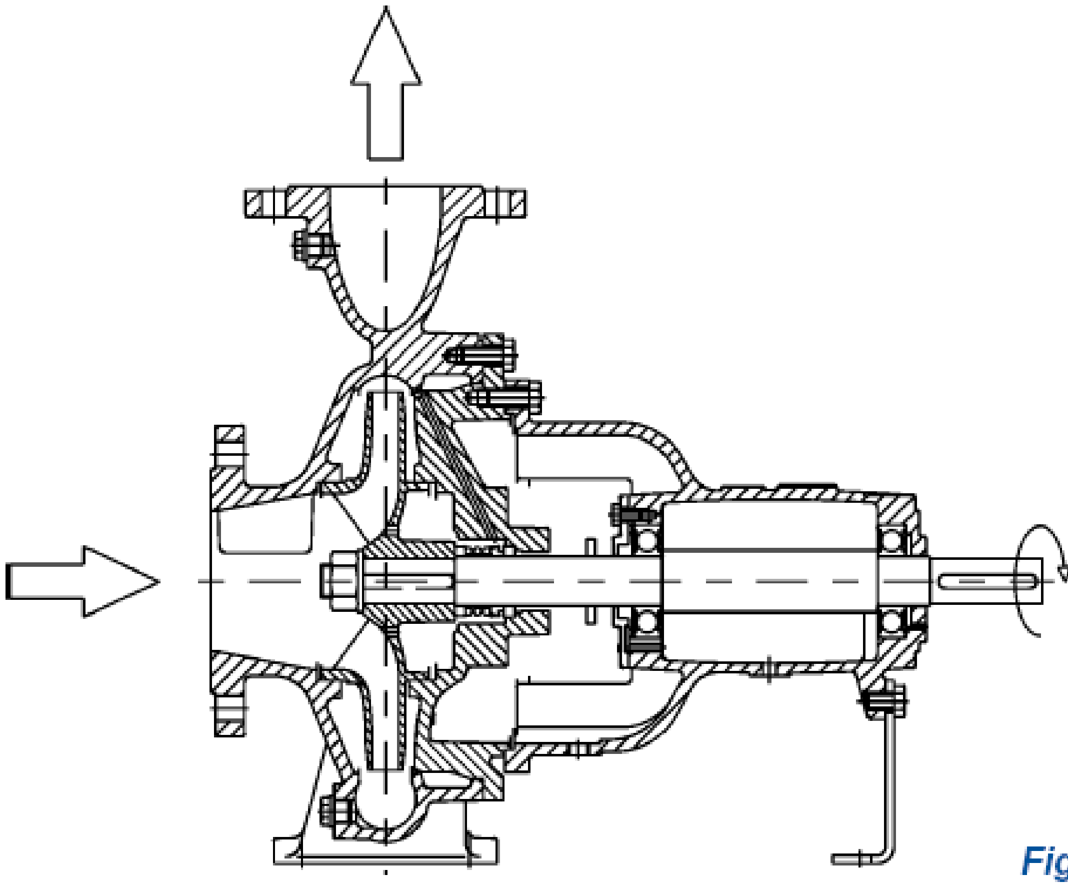


Fig. 1

DIFERENTES TIPOS DE BOMBAS CENTRÍFUGAS

BOMBAS CENTRIFUGAS
Baja y Media Presión
3500 RPM

CATALOGO

- Modelo 3 · 1½" x 1½"
- Modelo 4 · 2" x 1½"
- Modelo 5 · 2" x 1½"
- Modelo 6 · 3" x 2"
- Modelo 7 · 3" x 3"
- Modelo 8 · 4" x 4"

Bombas centrífugas con succión frontal de un paso, impulsor cerrado, sello mecánico, 3500 RPM. Tanto la Bomba como el impulsor están construídos en fierro gris, pero se pueden surtir en otros materiales bajo pedido.

Todos los modelos se pueden acoplar a motor eléctrico o de combustión interna, ya sea acoplado directamente o por transmisión universal con soporte de baleros, cople flexible o bandas y poleas.

Modelo 3
1½" x 1½"

litros por minuto a metros de columna de agua

Modelo	c.f.	5	10	15	20	25	30	35	40	45	P máx
3 - 150	1½			250	240	180	114				34
3 - 200	2				300	260	220	125			38
3 - 300	3					260	230	180	130		46

Modelo 4
2" x 1½"

litros por minuto a metros de columna de agua

Modelo	c.f.	5	10	15	20	25	30	35	40	45	P máx
4 - 50	½	270	145								12
4 - 75	¾	340	250								14
4 - 100	1		285	120							17
4 - 150	1½		420	320	170						21
4 - 200	2			410	310	130					26

Modelo 8
4" x 4"

litros por minuto a metros de columna de agua

Modelo	c.f.	5	10	15	20	25	30	35	40	45	P máx
8 - 500	5	1800	1620	1080							18
8 - 750	7½		1920	1680	1260						25
8 - 1000	10			1980	1650	1200					31
8 - 1500	15					1860	1500	1110	660		44

Bombas de tornillo

Las bombas de tornillo son un tipo especial de bombas rotatorias de desplazamiento positivo, en el cual el flujo a través de los elementos de bombeo es verdaderamente axial. El líquido se transporta entre las cuerdas de tornillo de uno o más rotores y se desplaza axialmente a medida que giran engranados. La aplicación de las bombas de tornillo cubren una gama de mercados diferentes, tales como en la armada, en la marina y en el servicio de aceites combustibles, carga marítima, quemadores industriales de aceite, servicio de lubricación de aceite, procesos químicos, industria de petróleo y del aceite crudo, hidráulica de potencia para la armada y las máquinas - herramientas y muchos otros.

La bomba de tornillo puede manejar líquidos en una gama de viscosidad como la melaza hasta la gasolina, así como los líquidos sintéticos en una gama de presiones de 50 a 5.000 $lb/pulg^2$ y los flujos hasta de 5.000 gpm.

Debido a la relativamente baja inercia de sus partes en rotación, las bombas de tornillo son capaces de operar a mayores velocidades que otras bombas rotatorias o alternativas de desplazamiento comparable.

Algunas bombas de lubricación de aceite de turbina adjunta operan a 10.000 rpm y aún mayores. Las bombas de tornillo, como otras bombas rotatorias de desplazamiento positivo son de autocebado y tienen una característica de flujo que es esencialmente independiente de la presión.

La bomba de tornillo simple existe sólo en número limitado de configuraciones. La rosca es excéntrica con respecto al eje de rotación y engrana con las roscas internas del estator (alojamiento del rotor o cuerpo).

Alternativamente el estator está hecho para balancearse a lo largo de la línea de centros de la bomba.

Las bombas de tornillos múltiples se encuentran en una gran variedad de configuraciones y diseños. Todos emplean un rotor conducido engranado con uno o más rotores de sellado. Varios fabricantes cuentan con dos configuraciones básicas disponibles, la construcción de extremo simple o doble, de las cuales la última es la más conocida.

Como cualquier otra bomba, hay ciertas ventajas y desventajas en las características de diseño de tornillo. Estos deben de reconocerse al seleccionar la mejor bomba para una aplicación particular.

Entre algunas ventajas de este tipo tenemos:

1. Amplia gama de flujos y presiones.

2. Amplia gama de líquidos y viscosidad.
3. Posibilidad de altas velocidades, permitiendo la libertad de seleccionar la unidad motriz.
4. Bajas velocidades internas.
5. Baja vibración mecánica, flujo libre de pulsaciones y operaciones suaves.
6. Diseño sólido y compacto, fácil de instalar y mantener.
7. Alta tolerancia a la contaminación en comparación con otras bombas rotatorias.

Entre algunas desventajas de este tipo tenemos:

1. Costo relativamente alto debido a las cerradas tolerancias y claros de operación.
2. Características de comportamiento sensibles a los cambios de viscosidad.
3. La capacidad para las altas presiones requiere de una gran longitud de los elementos de bombeo.

Bombas Tornillo - Estator

CÓDIGO 425x a 429x / 526x a 529x

Bomba vertical para desagote de tambores

Principio de funcionamiento simple y efectivo, permite bombear productos viscosos y/o densos, se suma su cualidad de autoaspirante. No dispone de válvulas que se atasquen por partículas en suspensión.

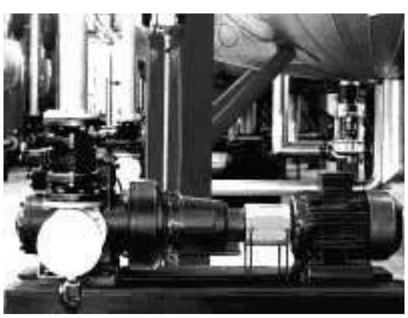
- Los materiales en contacto con el producto son de acero AISI 304 ó 316, elastómeros o materiales sanitarios.
- El compartimiento de bombeo está completamente separado del cojinete, para impedir la contaminación del producto.
- Diseñadas para cumplir con las más estrictas normas sanitarias, de desarme rápido.
- Eficaz sello mecánico rotativo con la pista de rozamiento de grafito y cerámica lapidada o metálico.
- Viscosidad máxima normal 20.000 cp.
- Tamaño de partículas, según modelos, hasta 16 mm.
- Temperatura máxima 70ºC.

Bombas Tornillo - Estator

CÓDIGO 425 a 729 - S145 a 5195

Esta sencilla bomba autocebante se utiliza para productos lsólida construcción en inoxidable, de fácil desarme y utilización confiable la hacen aptas para la industria procesadora de alimentos, fármacos, cosmética y química.

- Materiales en contacto con el producto, INOX AISI 304-316, elastómeros y otros sanitarios.
- Compartimiento de bombeo separado del soporte cojinetes.
- Diseño sanitario y desarme rápido sin herramientas.
- Tolva alimentadora a pedido.
- Sello mecánico sanitario.
- Porta sello, opcional retirable.
- Giro indistinto o reversible.
- Viscosidad máx. normal 50.000 cp.
- Tamaño partículas s/modelo 32 mm.
- Temperatura máx. normal 90ºC.



Bombas de tres tornillos

rangos: autoaspirantes, horizontal, vertical, bombas sumergibles, bombas magnéticas
fluidos: lubricación, sin o malos lubricadores
applicaciones: incendio, hidraulicas, construcciones de maquinaria, quimicas, petroquimicas, marina, costa afuear, procesos, energía, apliacaciones de la industria en general
Rango de capacidades: caudal hasta 5300 l/min, presiones hasta 280 bar

Bombas de tornillo eccéntricas

rangos: autoaspirantes, simple o multi estado, horizontal, vertical, bombas tipo bloque
fluidos: liquidos de alta viscosidad, pastosos, neutros or agresivos, puros o abrasivos, gaseosos, con fibras y solidos
applicationes: aguas servidas, químicas, petroquímicas, alimantos, bebidas, papeles y pulpa, marina y costa afuera
Rango de capacidades: caudal hasta 720 m3/hora, presiones hasta 25 Bar

La más completa gama de bombas de tornillo helicoidal con calidad alemana.

Gama industrial para caudales hasta 300 m3/h y presiones hasta 72 bar.

Todo tipo de aplicaciones y versiones

Bombas axiales

Este tipo de bomba es muy adecuado cuando hay que elevar un gran caudal a pequeña altura.

Por esto, sus principales campos de empleo son los regadíos, el drenaje de terrenos y la manipulación de aguas residuales.

El rendimiento de esta bomba es comparable al de la centrífuga. Por su mayor velocidad relativa permite que la unidad motriz y la de bombeo sean más pequeñas y por tanto más baratas.

La altura máxima de funcionamiento oscila entre 30 y 40 pies. Sin embargo, es posible conseguir mayores cotas mediante 2 ó 3 escalonamientos, pero este procedimiento raramente resulta económico. Para grandes bombas se adopta generalmente el montaje vertical, pasando el eje por el centro de la tubería de salida.

El rodete es de tipo abierto, sin tapas, y su forma es análoga a la de una hélice naval.

El agua entra axialmente y los álabes le imprimen una componente rotacional, con lo que el camino por cada partícula es una hélice circular.

La cota se genera por la acción impulsora o de elevación de los álabes, sin que intervenga el efecto centrífugo.

La misión de los álabes fijos divergentes o álabes directores es volver a dirigir el flujo en dirección axial y transformar la cota cinemática en cota de presión.

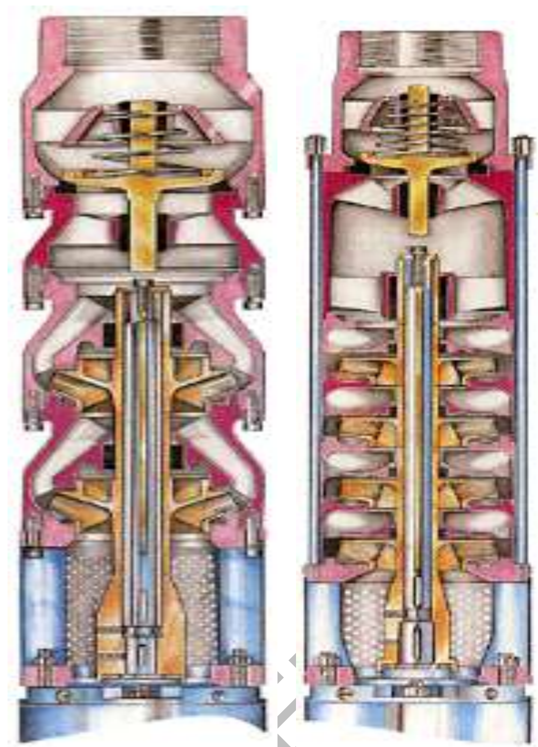
Para evitar la creación de condiciones favorables al destructivo fenómeno de Cavitación, la bomba de flujo axial se ha de proyectar para poca altura de aspiración.

De hecho, es preferible adoptar en la que el rodete permanezca siempre sumergido, ya que así la bomba estará siempre cebada y lista para comenzar a funcionar.

El objeto del sifón es evitar el riesgo de que se averíe la válvula de retención, que de otro modo tendría lugar una inversión del flujo en la tubería, con lo que la bomba funcionaría como una turbina.

La acción sinfónica se interrumpe mediante una válvula de mariposa.

Esta válvula está en ligero equilibrio hacia la posición de abierta y en el instante en que cesa el bombeo, la válvula se abre y entra el aire, con lo que se evita la inversión del flujo. La estación de bombeo puede automatizarse por medio de electrodos inmersos en el pozo de aspiración para controlar el funcionamiento de la bomba.



bombas de tipo axial

Bomba axial de tipo mixto

La bomba de flujo mixto ocupa una posición intermedia entre la centrífuga y la de flujo axial.

El flujo es en parte radial y en parte axial, siendo la forma del rodete acorde con ello.

La trayectoria de una partícula de fluido es una hélice cónica. La cota que se consigue puede ser hasta de 80 pies por rodete, teniendo la ventaja sobre la bomba axial de que la potencia que ha de suministrar el motor es casi constante aunque se produzcan variaciones considerables de cota.

La recuperación de la cota de presión se consigue mediante un difusor, un caracol o una combinación de ambos.

Bomba axial tipo tornillo

Las bombas de tornillo son un tipo especial de bombas rotatorias de desplazamiento positivo, en el cual el flujo a través de los elementos de bombeo es verdaderamente axial.

El líquido se transporta entre las cuerdas de tornillo de uno o más rotores y se desplaza axialmente a medida que giran engranados.

La aplicación de las bombas de tornillo cubren una gama de mercados diferentes, tales como en la armada, en la marina y en el servicio de aceites combustibles, carga marítima, quemadores industriales de aceite, servicio de lubricación de aceite, procesos químicos, industria de petróleo y del aceite crudo, hidráulica de potencia para la armada y las máquinas - herramientas y muchos otros.

La bomba de tornillo puede manejar líquidos en una gama de viscosidad como la melaza hasta la gasolina, así como los líquidos sintéticos en una gama de presiones de 50 a 5.000 lb/pulg^2 y los flujos hasta de 5.000 gpm.

Debido a la relativamente baja inercia de sus partes en rotación, las bombas de tornillo son capaces de operar a mayores velocidades que otras bombas rotatorias o alternativas de desplazamiento comparable.

Algunas bombas de lubricación de aceite de turbina adjunta operan a 10.000 rpm y aún mayores. Las bombas de tornillo, como otras bombas rotatorias de desplazamiento positivo son de auto cebado y tienen una característica de flujo que es esencialmente independiente de la presión.

La bomba de tornillo simple existe sólo en número limitado de configuraciones. La rosca es excéntrica con respecto al eje de rotación y engrana con las roscas internas del estator (alojamiento del rotor o cuerpo).

Alternativamente el estator está hecho para balancearse a lo largo de la línea de centros de la bomba.

Las bombas de tornillos múltiples se encuentran en una gran variedad de configuraciones y diseños. Todos emplean un rotor conducido engranado con uno o más rotores de sellado. Varios fabricantes cuentan con dos configuraciones básicas disponibles, la construcción de extremo simple o doble, de las cuales la última es la más conocida.

Bombas de flujo axial

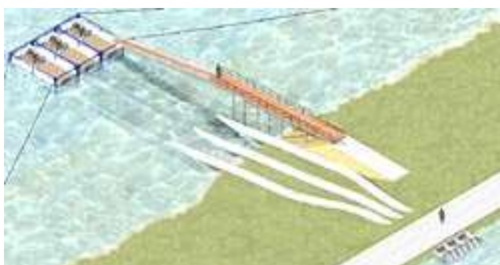
Equipo de bombeo axial de bombas estacionarias

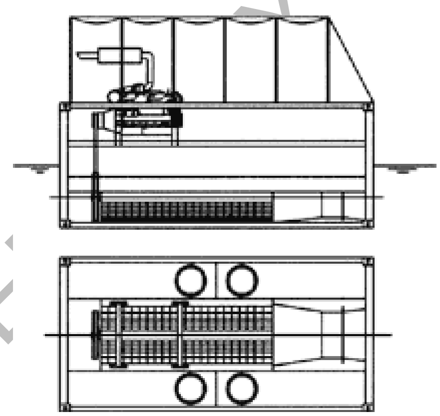
Debido a la extensa experiencia de **ETEC** implementando sistemas de bombeo para la Acuacultura, donde la operación de los equipos es constante, con agua salada, y bajo condiciones altamente corrosivas y extremas, **ETEC** ha incorporado en su diseño de Bombas Axiales altos estándares de resistencia, y niveles de eficiencia incomparables, con aplicación en otras industrias.

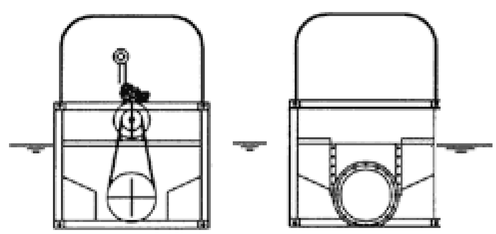
bombas axiales tipo flotante

Los elementos hidráulicos están construidos en Acero Naval, bajo normas ASME. Estos elementos están empernados a la estructura flotante, permitiendo ser retirados para mantenimientos.

Los elementos hidráulicos de la bomba, y el sistema de flotación, conforman una unidad completa, construida toda bajo la forma de un contenedor de 20'







- Información técnica relacionada con bombas, Internet www.lesker.com, www.finishthompson.com

1.2.3 PROPULSIVE CHARACTERISTICS OF DIESEL ENGINES, STEAM AND GAS TURBINES, INCLUDING SPEED, OUTPUT AND FUEL CONSUMPTION

Diesel engines

Engines using the Diesel cycle are usually more efficient, although the Diesel cycle itself is less efficient at equal compression ratios. Since diesel engines use much higher compression ratios (the heat of compression is used to ignite the slow-burning diesel fuel), that higher ratio more than compensates for the lower intrinsic cycle efficiency, and allows the diesel engine to be more efficient. The most efficient type, direct injection Diesels, are able to reach an efficiency of about 40% in the engine speed range of idle to about 1,800 rpm. Beyond this speed, efficiency begins to decline due to air pumping losses within the engine. Modern turbo-diesel engines are using electronically controlled, common-rail fuel injection,that increases the efficiency up to 50% with the help of geometrically variable turbo-charging system; this also increases the engines' torque at low engine speeds (1200-1800RPM).

Gas turbine

The gas turbine is most efficient at maximum power output in the same way reciprocating engines are most efficient at maximum load. The difference is that at lower rotational speed the pressure of the compressed air drops and thus thermal and fuel efficiency drop dramatically. Efficiency declines steadily with reduced power output and is very poor in the low power range - the same is true in reciprocating engines, the friction losses at 3000 RPM are almost the same whether the engine is under 10% load or not having any useful output on the driveshaft. The inertia of high speed gas turbine together with the low air pressure under low speed cause it to have a significant lag which many drivers are unwilling to cope with. Today the gas turbine is not used for automobiles and trucks because the usage patterns dictate varying loads, including idling speeds. General Motors at one time manufactured a bus powered by a gas turbine, but due to the economy where crude oil prices rose exponentially (1970's) this concept was abandoned, Chrysler and Ford also built prototypes of turbine powered cars, Chrysler building a short prototype series of them. Driving comfort was good, but overall economy lacked due to reasons mentioned above. This is also why gas turbines can be used for permanent and peak power electric plants. In this application they are only run at or close to full power where they are efficient or shut down when not needed.

Gas turbines do have advantage in power density - gas turbines are used as the engines in heavy armored vehicles and armored tanks and in power generators in jet fighters.

One other factor negatively affecting the gas turbine efficiency is the ambient air temperature. With increasing temperature, intake air becomes less dense and therefore the gas turbine experiences power loss proportional to the increase in ambient air temperature.

Steam engine

Steam engines are external combustion engines, where the working fluid is separate from the combustion products. Non-combustion heat sources such as solar power, nuclear power or geothermal energy may be used. The ideal thermodynamic cycle used to analyze this process is called the Rankine cycle. In the cycle, water is heated and transforms into steam within a boiler operating at a high pressure. When expanded through pistons or turbines, mechanical work is done. The reduced-pressure steam is then condensed and pumped back into the boiler.

In general usage, the term steam engine can refer to either the integrated steam plants (including boilers etc.) such as railway steam locomotives and portable engines, or may refer to the piston or turbine machinery alone, as in the beam engine and stationary steam engine. Specialized devices such as steam hammers and steam pile drivers are dependent on steam supplied from a separate boiler. Reciprocating piston type steam engines remained the dominant source of power until the early 20th century, when advances in the design of electric motors and internal combustion engines gradually resulted in the replacement of reciprocating (piston) steam engines in commercial usage, and the ascendancy of steam turbines in power generation. Considering that the great majority of worldwide electric generation is produced by turbine type steam engines, the "steam age" is continuing with energy levels far beyond those of the turn of the 19th century.

Choice of a suitable power plant depends on:

- size of the ship
- speed (type of cargo)
- length, duration of voyage
- cost (operational expenses)
- fuel

CHARACTERISTICS

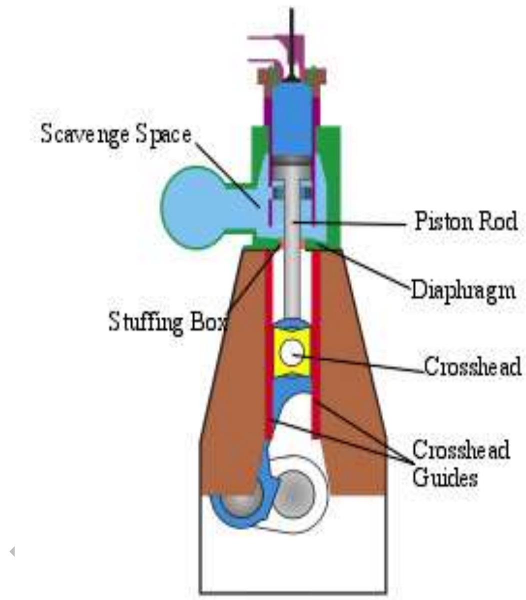
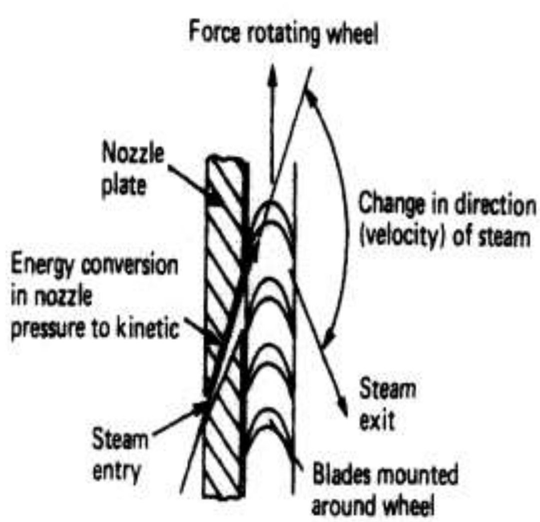
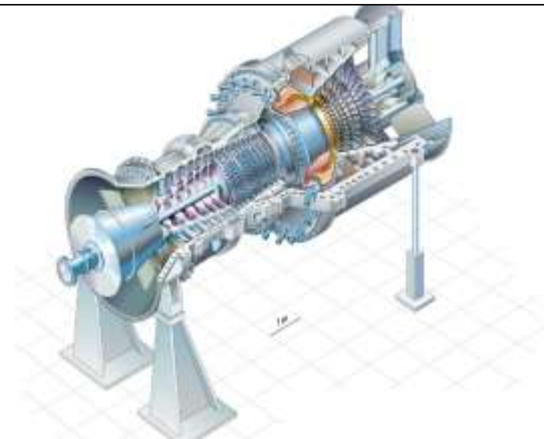
<table>
<tr><th colspan="2">Diesel Engine</th></tr>
<tr><td>In 1892 Rudolph Diesel invented the compression ignition engine
The most widely used propulsion.
Two-stroke (large engines).
Four-stroke (auxiliary e.).
PROS:
- most efficient prime mover
- lower fuel consumption
- less bunker space.
CONS:
- more expensive to build and maintain
- more noise and vibration heavier</td><td>
</td></tr>
<tr><th colspan="2">Steam Turbine</th></tr>
<tr><td>- Marine steam turbine was developed by Sir Charles Algernon Parsons
- Low noise, low weight, low maintenance costs, more space obtained (power /weight ratio raised)
- BUT higher fuel consumption
- Most new-build ships with steam turbines are specialist vessels such as nuclear-powered vessels, and certain merchant vessels (LNG, coal carriers) where cargo can be used as bunker fuel.</td><td>

Figure 3.1 Energy conversion in a steam turbine</td></tr>
</table>

Gas turbine	
- A compressor draws in and compresses atmospheric air. - A combustion system where fuel is injected, mixed with compressed air and burned. - Power turbine to the shaft. - Poor thermal efficiency at low power.	

1.2.4 HEAT CYCLE, THERMAL EFFICIENCY AND HEAT BALANCE OF THE FOLLOWING.

Thermodynamics is concerned with the amount of heat transfer as a system undergoes a process from one equilibrium state to another, and it gives no indication about how long the process will take. A thermodynamic analysis simply tells us how much heat must be transferred to realize a specified change of state to satisfy the conservation of energy principle.

In practice, we are concerned with the rate of heat transfer (heat transfer per unit time) than we are with the amount of heat transfer. For example, we can determine the amount of heat transferred from a thermos flask as the hot milk inside cools from 95oC to 85oC by a thermodynamic analysis alone. But, a designer of the thermos flask is primarily interested in how long it will be before the hot milk inside cools to 85oC, and a thermodynamic analysis cannot answer this question. Determining the rates of heat transfer to or from a system and thus the time of cooling or heating, as well as the variation of temperature, is the subject of heat transfer.

Thermodynamics deals with equilibrium states and changes from one equilibrium state to another. Heat transfer, on the other hand, deals with systems that lack thermal equilibrium, and thus it is a non-equilibrium phenomenon. Therefore, the study of heat transfer cannot be based on the principles of thermodynamics alone. However, the laws of thermodynamics lay the framework for the science of heat transfer. The first law requires that the rate of energy transfer into a system be equal to the rate of increase of the energy of that system. The second law requires that heat be transferred in the direction of decreasing temperature. It is analogous to the electric current flowing in the direction of decreasing voltage or the fluid flowing in the direction of decreasing pressure.

Heat transfer is energy in transit due to temperature difference. Whenever there exists a temperature difference in a medium or between media, heat transfer must occur. The basic requirement for heat transfer is the presence of temperature difference. There can be no net heat transfer between two mediums that are at the same temperature. The temperature difference is the driving force for heat transfer, just as the voltage difference is the driving force for electric current flow and pressure difference is the driving force for fluid flow. The rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction. The larger the temperature gradient, the higher the rate of heat transfer.

Gas cycles/engine analysis

Gas power cycles

Deal with systems that produce power in which the working fluid remains a gas throughout the cycle (in other words, there is no change in phase).

Spark Ignition (gasoline) engines, Compression ignition (diesel) engines and conventional gas turbine engines (generally refer to as Internal Combustion engines or IC Engines) are some examples of engines that operate on gas cycles.

Air standard cycles

Internal combustion engines: Combustion of fuel is non-cyclic process. Working fluid, air-fuel mixture undergoes permanent chemical change due to combustion Products are thrown out of the engine & Fresh charge is taken in.

Hence, the working fluid doesn't undergo a thermodynamic cycle. In order to analyze this complex gas power cycles, air standard cycles are conceived.

In air standard cycle a certain mass of air operates in a complete thermodynamic cycle where the heat is added and rejected using external reservoirs, and all the processes in the cycle are reversible.

Summary of assumptions made during such analysis: The working fluid, air behaves like an ideal gas (and specific heats are assumed to be constant)

Combustion process is replaced by heat addition and exhaust process by heat rejection

All the processes are reversible.

Internal combustion engines

There are two types of reciprocating engines:

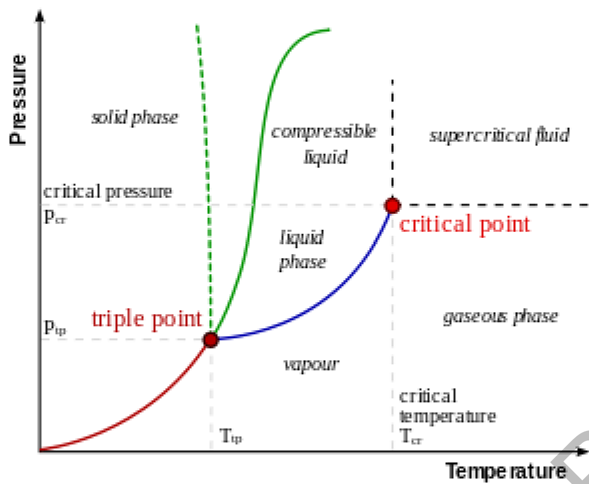
- Spark Ignition- Otto cycle
- Compression Ignition-Diesel cycle

Properties of vapours

Vapor refers to a gas phase at a temperature where the same substance can also exist in the liquid or solid state, below the critical temperature of the substance. (For example, water has a critical temperature of 374 °C (647 K), which is the highest temperature at which liquid water can exist.) If the vapor is in contact with a liquid or solid phase, the two phases will be in a state of equilibrium. The term gas refers to a compressible fluid phase. Fixed gases are gases for which no liquid or solid can form at the temperature of the gas, such as air at typical ambient temperatures. A liquid or solid does not have to boil to release a vapor.

Vapor is responsible for the familiar processes of cloud formation and condensation. It is commonly employed to carry out the physical processes of distillation and headspace extraction from a liquid sample prior to gas chromatography.

The constituent molecules of a vapor possess vibrational, rotational, and translational motion. These motions are considered in the kinetic theory of gases.



The vapor-liquid critical point in a pressure-temperature phase diagram is at the high-temperature extreme of the liquid-gas phase boundary.

Steam cycles

Historically, the first functioning power cycle is the steam cycle, which commonly is working with water vapor (steam). The Rankine cycle is an ideal case from the common steam cycle.

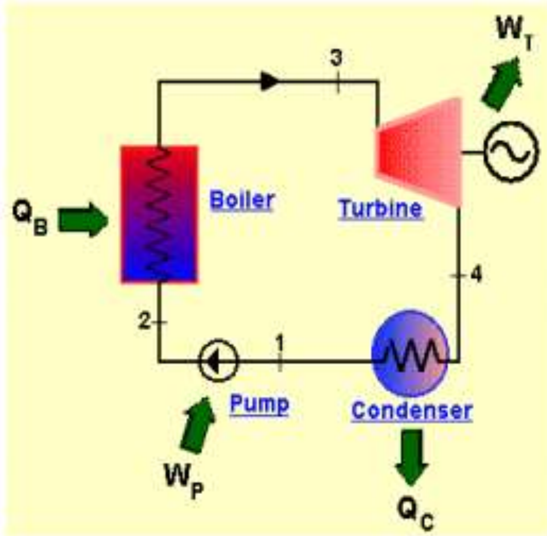
Steam power plants constitutes around 80% of the world's electric power generation.

A steam cycle, (or vapor cycle), is a cycle in which the working fluid is compressed,

vaporized, expanded and condensed; thereafter the cycle repeats.

Components of a Basic Steam Cycle

- Liquid water is compressed to a high pressure by a pump.
- The pressurized water is heated and vaporized in a boiler, which is fuelled by coal, oil, gas, biomass or nuclear fission.
- Hot and compressed water vapor has high energy content, which is utilized by the turbine generating work.
- After expansion in the turbine the vapor enters a condenser, which brings the vapor to liquid form.



1.2.5 REFRIGERATORS AND REFRIGERATION CYCLE.

Refrigeration and air conditioning system design, operation and maintenance.

Thermodynamic heat pump cycles or refrigeration cycles are the conceptual and mathematical models for heat pumps and refrigerators. A heat pump is a machine or device that moves heat from one location (the 'source') at a lower temperature to another location (the 'sink' or 'heat sink') at a higher temperature using mechanical work or a high-temperature heat source. Thus a heat pump may be thought of as a "heater" if the objective is to warm the heat sink (as when warming the inside of a home on a cold day), or a "refrigerator" if the objective is to cool the heat source (as in the normal operation of a freezer). In either case, the operating principles are identical. Heat is moved from a cold place to a warm place.

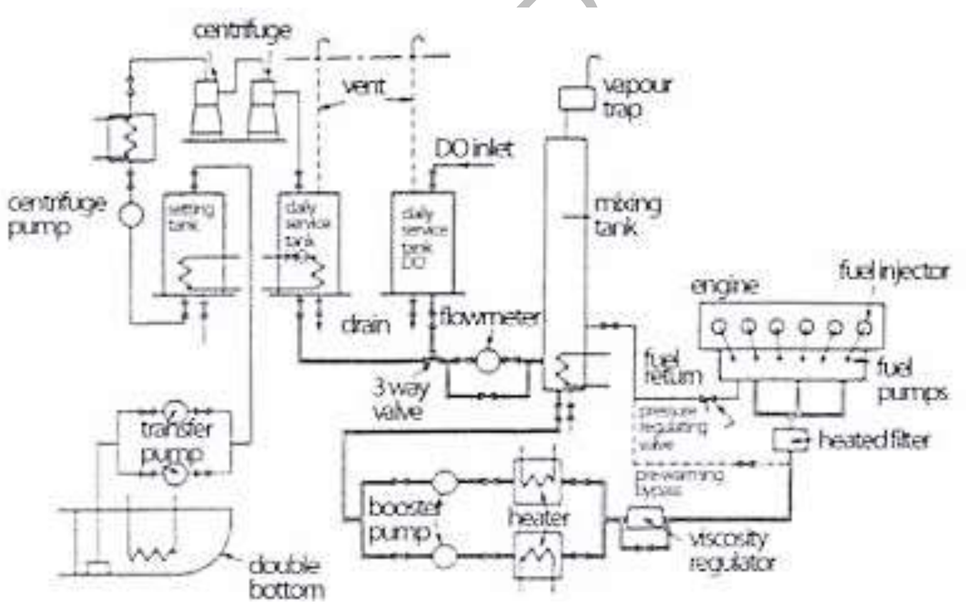
1.2.6 PHYSICAL AND CHEMICAL PROPERTIES OF FUELS AND LUBRICANTS

- FUEL SYSTEMS

The fuel oil system for a diesel engine can be considered in two parts – the fuel supply and the fuel injection systems. Fuel supply deals with the provision of fuel oil suitable for use by the injection system.

Fuel Oil Supply

A diesel engine is usually arranged to operate continuously on heavy fuel and have available, a diesel oil supply for manoeuvring conditions or for operating in an emergency situation, for example, no fuel heating due to a boiler failure or poor quality fuel related problems.



In the system shown above the oil is stored in tanks in the double bottom from which it is pumped to a settling tank and heated.

After passing through centrifuges the cleaned, heated oil is pumped to a daily servicetank. From the daily service tank the oil flows through a three-way valve to a mixing tank. A flow meter is fitted into the system to indicate fuel consumption. Booster pumps are used to pump the oil through heaters and a viscosity regulator to the engine-driven fuel pumps. The fuel pumps will discharge high-pressure fuel to their respective injectors.

The viscosity regulator controls the fuel oil temperature in order to provide the correct viscosity for combustion. A pressure-regulating valve ensures a constant-pressure supply to the engine-driven pumps, and a pre-warming bypass is used to heat up the fuel before starting the engine. A diesel oil daily service tank may be installed and is connected to the system via a three-way valve. The engine can be started up and manoeuvred on diesel oil even on a blend of diesel and heavy fuel oil. The mixing tank is used to collect recirculated oil and also acts as a buffer or reserve tank as it will supply fuel when the daily service tank is empty.

The system includes various devices such as low-level alarms and remotely operated tank outlet valves which can be closed in the event of fire.

Filter banks are fitted before the booster pumps, auto clean, basket type or cartridge, it is important that a clean set of filters are installed in the standby bank at all times.

Fuel Injection

The function of the fuel injection system is to provide the right amount of fuel at the right moment and in a suitable condition for the combustion process. There must therefore be some form of measured fuel supply, a means of timing the delivery and the atomisation of the fuel. The injection of the fuel is achieved by the location of cams on a camshaft. This camshaft rotates at engine speed for a two-stroke engine and at half engine speed for a four-stroke. There are two basic systems in use, each of which employs a combination of mechanical and hydraulic operations. The most common system is the jerk pump: the other is the common rail.

Fuel Oil

Today, fuel constitutes not only the single highest cost factor in operating a ship but also the source of the most potent operating problems. The reason for this is that new refining techniques, introduced as a result of political developments in the Middle East in 1973-1974, have meant that fluid catalytic cracking and vis breaking has produced a more concentrated residual fuel of very poor quality. This residual fuel is the heavy fuel oil traditionally supplied to ships as bunkers and used in the majority of motor ships of a reasonable size for the main engine. The high cost of even these poor quality residual fuels means that owners generally have no alternative but to burn them, though some still prefer to use even more expensive intermediate grade produced as a result of mixing residual fuel oil with distillate.

Marine engines must operate successfully on heavy residual fuel oils which may vary in quality and analysis depending upon the source of their crude and the refinery processes. Fuels from different sources may be incompatible and not mix successfully: it is therefore advisable to store ships’ bunkers from different ports in separate tanks to avoid the risk of stratification and formation of heavy sludges.

The problem referred to above have an effect on the engine in terms of wear and tear and corrosion from harmful components in the fuel. It is the duty of the ship's engineer to be aware of these harmful constituents, their effects on the operation of his engines and the remedies offered to counter the harmful properties.

Problems With Heavy Fuels

The problems of present and future heavy residual fuels are mainly categorised as:

1. Storage and handling.
2. Combustion quality and burnability.
3. Contaminants, resulting in corrosion and/or damage to engine components, for example, burnt out exhaust valves.

Effects of Heavy Fuels

roperties	Present H.O.	Future H.O.	Effect on Engine
'iscosity (Red 1 at 37°C Heating 'emp) pumping entrifuging njection	3500 50 95 110-120	5200 65 98 115-130	Increased fuel heating required.
)ensity at 15°C	0.98	0.99	Water elimination becomes more difficult.
'our point °C loxious elements :arbon residue %	30 6-12	30 15-22	Fouling risk of components. Increased combustion delay .
sphaltenes %	4-8	10-13	Hard asphaltene producing hard particles. Soft asphaltene giving sticky deposits at low output. Increased combustion delay with defective combustion and pressure gradient increases.
:etane number	30-55	25-40	High pressure gradients and starting problems.
ulphur %	2-4	5	Wear of components due to corrosion below dew point of sulphuric acid (about 150°C)
'roperties	Present H.O.	Future H.O.	Effect on Engine
'anadium ppm odium ppm	100-400 18-25	120-500 35-80	Burning of exhaust valves at about 500°C. Lower temp. in case of high Na content.
ilicon and aluminium			Wear of liners, piston grooves, rings, fuel pump and injectors.

Fuel Oil Storage Problems

The problems of storage in tanks of bunker fuel is one of a build-up in sludge leading to problems in handling. The reason for the increase in sludge build-up is because heavy fuels are generally blended from a cracked heavy residual using a lighter cutter stock resulting in a problem of incompatibility. This occurs when the asphaltene or high molecular weight compound suspended in the fuel is precipitated by the addition of the cutter stock or other diluents. The sludge which settles in the bunker tanks or finds its way to the fuel lines tends to overload the fuel separators with a resultant loss of burnable fuel, and perhaps problems with fuel injectors and wear of the engine through abrasive particles.

To minimise the problems of sludging, the ship operator has a number of options. He may ask the fuel supplier to perform stability checks on the fuel that he is providing. Bunkers of different origins should be kept segregated wherever possible and watercont mination kept to a minimum. Proper operation of the settling tanks and fuel treatment plant is essential to prevent sludge from entering the engine itself. A detergent-type chemical additive can be used to reduce the formation of sludge in the bunker tanks.

14.7 Water in the Fuel

Water has always been a problem because it finds its way into the fuel during transport and storage on the ship. Free water can seriously damage fuel injection equipment, cause poor combustion and lead to excessive cylinder liner wear. If it happens to be seawater, it contains sodium which will contribute to corrosion when combined with vanadium and sulphur during combustion.

Apart from the watchkeeping operation of draining, or "sludging" tanks, water can normally be removed from the bunkers by proper operation of separators of the fuel is the same or greater than the water, removal of the water is difficult – or indeed not possible – and for this reason the maximum specific gravity of the fuel supplied for ship's bunkers has generally been set at 0.99

Properties of Fuel Oils

The quality of fuel oil is generally determined by a number of specific parameters or proportions of metals or impurities in a given sample of the particular fuel. Such parameters are: viscosity, specific gravity; flash point; Conradson carbon; asphaltenes content; sulphur content; water content; vanadium content; sodium content, and so on. Two parameters of traditional important have been the calorific value and viscosity. Viscosity, once the best points to a fuel's quality or degree of heaviness, now considered as being only partially a major quality criterion because of the possible effects of constituents of a fuel.

The calorific value or heat of combustion of a fuel oil is a measure of the amount of at released during complete combustion of a unit mass of the fuel, expressed KJ/kg.

Viscosity

The viscosity of a fuel is its resistance to flow and is a measure of the work done in moving a given mass of the fuel. Viscosity decreases rapidly with an increase in temperature, and thus, in order to handle today' heavy fuels of high viscosity, heating is necessary to thin the oil.

The viscosity value of an oil has no significance unless it is stated at a given temperature. Viscosity is usually measured in seconds Redwood or degrees Engler from measurement using standard apparatus in which a given quantity of the oil is run through a standard orifice at a given temperature. For example, 200 seconds Redwood No. 1 at 37°C is the time for 50 ml of the oil to run through a standard orifice at 37°C.

Cetane Number

The cetane number of a fuel is a measure of the ignition quality of the oil under the conditions in a diesel engine. The higher the cetane number, the shorter the time between fuel injection and rapid pressure rise.

Conradson Carbon Value

This is the measure of the percentage of carbon residue after evaporation of the fuel in a closed space under control. The Conradson or coke value is a measure of the carbonforming propensity and thus an indication of the tendency to deposit carbon on fuel injection nozzles. The Ramsbottom methods has largely replaced the Conradson method of carbon residue testing, but it gives roughly the same results.

Ash Content

The ash content is a measure of inorganic impurities in the fuel. These typically are sand, nickel, aluminium, silicon, sodium and vanadium. The most troublesome are sodium and vanadium, which form a mixture of sodium sulphate and vanadium pentoxide, which melt an adhere to engine components, particularly exhaust valves.

Sulphur Content

This has no influence on combustion but high sulphur levels can be dangerous because of acid formation. In recent years there has been a tendency to equate sulphur content with cylinder liner wear, but opinion differ on this matter.

Water Content

This is the amount of water in a given sample of the oil and is usually determined by centrifuging or distillation.

Cloud Point

The cloud point of an oil is the temperature at which crystallisation of paraffin wax begins to be observed when the oil is being cooled down.

Pour Point

This is the lowest temperature at which an oil remains fluid and thus is important to know for handling on board purposes. An alternative is the solidifying point or the highest temperature at which the oil remains solid. It usually lies some 3°C below the pour point.

Flash Point

The flash point is defined as the lowest temperature at which an oil gives combustible vapours, or the point at which air/oil vapour mixture can be ignited by a flame or spark.

Specific Gravity

This is normally expressed in kg/m3 at 15°C. As the density of the fuels depends upon the density of the individual components, fuels can have identical densities but widely varying individual component densities. Apart from being an indicator of the 'heaviness' of fuel, when measured by a hydrometer the specific gravity can be used to calculate the quantity of fuel by weight in a tank of given dimensions.

Typical Values For Standard Fuels

Fuel	SG(g/cm^2)	Flash Point (°C)	Lower CV (kJ/kg)
Gas Oil	0.82-0.86	65-85	44 000 – 45 000
Diesel Oil	0.85	65	44 000
Heavy Fuel	0.9-0.99	65	40 000 – 42 000
(200 secs Redwood No. 1 – 3500 secs Redwood No. 1)			

The following is a fuel oil specification of a leading slow-speed diesel engine manufacturer. These properties are considered the worst in each case that can be burnt in the particular engine.

Maximum viscosity 6000 secs Redwood No. 1
Specific Gravity 0.990

Flash point 60°C
Maximum Conradson carbon 18% by weight
Maximum asphaltenes 14% by weight
Maximum sulphur 5% by weight
Maximum water 1.0% by weight
Maximum ash 0.2% by weight
Maximum vanadium 550 ppm
Maximum sodium 30% of vanadium content

- **LUBRICANTS**

Manufacturing of Lubricating Oil

Lubricating oil base stocks are obtained by fractional distillation of crude oil in vacuum distillation plant.
Crude oils are roughly classified into Paraffin base, which has a high lubrication oil content with a high pour point and high viscosity index and Asphalt base, which has a low lubricating oil content with a low pour point and subjected to various treatments to improve their properties, and they would be blended to produce a wide range of lubricating oils.

Compound Oil

From 5% to 15% of a non-mineral animal or vegetable oil may be added to a mineral (or mineral blend) oil to produce a compounded oil.

Oils which have to lubricate in the presence of water or steam are usually compounds of fatty animal oil and mineral oil, they tend to form a stable emulsion which adheres strongly to the metal surfaces. Fatty oils have a high load carrying capacity and if sulphurised they have extreme pressure (EP) property; used for cutting oils and running in of gearing.

It must be remembered that British Standard recommend that mineral oil only should be used for the lubrication of steam machinery as fatty oils contain acids which can cause corrosion in feed systems and boilers.

Terms Used In Lubricating

The important lubricant properties will now be examined.

Viscosity has already been mentioned with respect to fuel oils, but it is also an important property of lubricating oils. Viscosity index is also used, which is the rate of change of viscosity with temperature.

The **Total Base Number** (TBN) is an indication of the quantity of alkali, i.e. base, which is available in a lubricating oil to neutralise acids.

The **acidity** of an oil must be monitored to avoid machinery damage and neutralization number is used as the unit of measurement.

The **oxidation resistance** of a lubricant can also be measured by neutralization number. When excessively oxidised, an oil must be discarded.

The **carbon-forming tendency** of a lubricating oil must be known, particularly for oils exposed to heat. A carbon residue test is usually performed to obtain a percentage value.

The **demulsibility** of an oil refers to its ability to mix with water and then release the water in a centrifuge. This property is also related to the tendency to form sludge.

Corrosion inhibition relates to the oil's ability to protect a surface when water is present in the oil. This is important where oils can be contaminated by fresh or salt water leaks.

The modern lubricant must be capable of performing numerous duties. This is achieved through blending and additives. It must prevent metal-to-metal contact and reduce friction and wear of moving parts. The oil must be stable and not breakdown or form carbon when exposed to high temperatures, such as where oil cooling is used.

Any contaminants, such as acidic products of combustion, must be neutralised by alkaline additives; any carbon build up on surface must be washed away by detergent additives and held in suspension by a dispersant additive. The oil must also be able to absorb water and then release it during purification, but meanwhile still protect the metal parts from corrosion.

Scuffing

Breakdown of the oil film between surfaces causes instantaneous microscopic tack welding of a surface asperity nature. Further movement causes tearing out of the materials and the resultant condition is known as scuffing. Most liable to be found when the lubrication film is difficult to maintain, for example on turbine gear teeth and in IC engine cylinder liners.

Extreme Pressure Lubricant

Special additives to the oil to maintain oil film under most severe load conditions and where film is difficult to maintain. Molybdenum disulphide (moly slip) additive is often used. Such lubricants are used to prevent scuffing.

Pitting

More a fatigue or a corrosion fatigue phenomena, usually the result of too high contact pressures giving minute cracking at contact surfaces.

Emulsion

Oil which is contaminated or had deteriorated in service will not separate easily from water and may cause an emulsion, in whole or in part Emulsification is associated with precipitation of sludge at an increasing rate, such as sludges are formed from accretion or resins and ashphaltenes. The oil should have a good demulsibility when new and should retain this in service.

Oxidation

A bearing oil subject to oxidation due to a high ‘heat load’ on the oil in circulation forms products in the oil which include polar compounds, for example the fatty acids such as oleic in which the acidic group is polar. Severe shaft and bearing corrosion can result. Polar substances have a molecular structure such that one part of the molecule is electrically negative with respect to the other part. This polar form tends to disperse one fluid in the other and stabilise the emulsion and tends to favour orientation at interfaces. Oxidation and corrosion products such as oxides of iron etc, stabilize emulsions. Anti-oxidation additives or inhibitors restrict polar molecule formation.

Pure mineral oils normally have a high resistance to oxidation.

Typical Bearing Pressures

Crankpin bearings 91 bar (max)
Top end bearings 138 bar (max)
Guide shoes 5 bar (max)
Michell thrust bearing 30 bar (max)
Note that fluid film lubrication applies for most bearings of high speed engines but a guide shoe is a case of boundary lubrication.

Lacquering

Oxidation and corrosion products plus contamination products lead to deposit. On high temperature regions hard deposits form thin layers on pistons or heavier deposits for example on upper piston skirts. On cooler surfaces sludge of a softer nature is more reliable to be deposited.

Lubricating Oil Additives

These are chemical compounds which are added for various reasons, mainly they would be added to give improved protection to the machinery and increased life to the oil by (a) giving the oil properties it does not have (b) replacing desirable properties that may have been removed during refining and improving those naturally found in the oil.

Among the additives used could be:

1. Anti-oxidant

Reduces the oxidation rate of the oil. Oxidation rate doubles for approximately every 7°C rise in temperature and at temperatures above 80°C approximately oxidation rapidly reduces the life of the oil. Viscosity usually increases due to oxidation products and some of the products can help to stabilise foam, which prevents the formation of a good hydrodynamic layer of lubricant between the surfaces in a bearing and reducing the load carrying capacity. Oxidation products cause lacquering on hot metal surfaces, they form sludge and possibly organic acids which can corrode bearings.

2. Corrosion Inhibitor

An alkaline additive is used to neutralise acidity formed in the oil and in the case of cylinder lubricants for diesel engines to neutralise sulphuric acids formed from fuel combustion.

3. Detergents

These keep metal surfaces clean by solubilising oil degradation products and coating metal surfaces, due to their polar nature, thus hindering the formation of deposits. They also neutralise acids.

4. Dispersants

These are high molecular weight organic molecules which stick to possible deposit making products and keep them in fine suspension by preventing small particles forming larger ones. At low temperatures they are more effective than detergents.

5. Pout Point Depressant

Added to keep oil fluid at low temperatures. The additive coats wax crystals as they form when temperature is reduced preventing the formation of larger crystals.

6. Anti-forming Additive

When air is entrained into the oil, this could be due to low supply head or return lines not running full, etc, foaming could result which can lead to breakdown of the load carrying oil film in bearings.

7. Viscosity Index Improver

This is added to help maintain the viscosity of the oil as near constant with temperature variations as possible.

8. Oiliness and Extreme Pressure Additives

These reduce friction and wear. They may form chemically with the metal reaching welding temperature, a film which has a lower shear strength than the base metal, hence welding and tearing of the metal is prevented. These additives would be important during the running in of gearing.

Other additives could include emulsifying and de-mulsifying agents, tackiness agents and metal de-activators.

Lubrication Fundamentals

A lubricant will reduce friction and wear, it will keep metal surfaces clean by carrying away possible deposits and providing a seal to keep out dirt. A lubricating oil will carry away the heat generated in bearings and gears, etc, preventing overheating seizure and possible breakdown.

Bearing Lubrication

The addition of the slightest trace of lubricant to a bearing modifies the friction force appreciably. The two most important properties of a lubricant would be oiliness and viscosity. Oiliness is a form of bond between molecules of lubricant and material surface in which the lubricant is adsorbed by the material. The absorbed film is very thin and once formed is very difficult to remove, which is most advantageous, in this respect colloidal suspension graphite is a very successful additive. If a layer of finite thickness lubricant exists without material contact, then friction is determined by viscosity, if the layer is only a few molecules thick then oiliness is the main factor.

Boundary friction is the condition between contact high spots (of a microscopic nature) while the low areas between are separated by a finite lubricant layer. In this state the thickness of the oil film is so small that oiliness becomes the predominant factor. This lubrication condition could be said to exist in some top end bearings, guides, etc.

Film lubrication, or hydrodynamic lubrication, is the condition whereby the bearing surfaces are completely separated by an oil layer. The load is taken completely by the oil film, the film thickness is greater at inlet (initial point in direction of rotation) than at outlet, the pressure at inlet increases quickly, remains fairly steady having a maximum value a little to the outlet side of bearing centre line, and then decreases quickly to zero at outlet. This form of lubrication is ideal but can only be satisfied in certain types of bearings, simple examples such as high speed journal bearings, as turbine bearings, or plane surfaces that can pivot and allow a wedge oil film to allow for load, speed, viscosity, etc, effects, as in Michell bearings.

Factors Affecting Hydrodynamic Lubrication

1. Viscosity of the Lubricant

The higher the viscosity the greater the tendency towards hydrodynamic lubrication. Obviously, the type of lubricant – oil, water or grease – and the temperature are important. Temperature can be increased by insufficient lubricant circulating to remove the heat generated in a bearing – this could be caused by clearances being too small and/or insufficient supply of oil.

2. Relative Speed of the Surfaces

The higher the relative speed the greater the tendency toward hydrodynamic lubrication.

Increasing a journal or crankpin diameter and retaining the same rotational speed as before will increase relative speed.

In reciprocating engines the oscillatory motion of the crosshead and guide-shoe means that there is a tendency in these units towards boundary lubrication as the relative speed goes from a maximum to zero. This is one of the reasons why crosshead lubrication may be a problem.

3. Bearing Clearance

If this is too large the bearing ‘knocks’. This impulsive loading increases pressure between the surfaces and can cause boundary lubrication. If the clearance is too small, overheating of the oil, boundary lubrication and possible seizure could result.

4. Pressure, i.e. Bearing Load per Unit Area

If this is high it can lead to boundary lubrication. If peak loads are high in the cylinder of a diesel, due to incorrect fuel injection timing or other reason, bearing pressure will increase.

Lubricating Oils

Extensive demands are made on oils for lubricating systems and their specifications may differ according to the type of engine and the fuel used. In addition to lubricating and cooling the bearings, the same oil may be required to lubricate piston rings and cylinder liners, and neutralise acids entering the crankcase in trunk piston engines. It may be required to act as the cooling medium for hot surfaces within pistons, and must tolerate high pressures in gear or chain drives and cams, and even high-speed bearings in turbochargers. The oil may be used as a hydraulic fluid in exhaust valve actuators, pressure control systems and servomotors.

System oils must inevitably contain additives to improve their properties and prolong their life. Additives are chemical compounds which mix with the oil's molecular structure so that they do not separate out during storage, use or treatment in purifiers and filters. Their properties will be depleted with use, however, and to minimise this it is necessary to limit maximum temperatures, thermal cycling and contamination in the system. Topping-up with fresh oil to replace that consumed will help to maintain a stable crankcase oil condition.

Oil for engines operating on residual fuels must be alkaline. For crosshead engines 10 to 15 TBN (SEA 30) oils should be adequate, but for trunk piston engines up to 40 TBN (SAE 40) is used depending upon the sulphur content of the fuel.

Besides correct alkalinity and viscosity, oils require rust and oxidation inhibitors, a high viscosity index, detergent/dispersant properties, water repellents, and must resist foaming and emulsification.

To monitor its condition, oil samples must be taken from the working system at regular intervals and sent to an oil laboratory for detailed analysis, which will give information on oil condition and depletion of additives. It may also assist in diagnosing engine faults and advise on any remedial measures may be given. General trends I condition are important, but any sudden changes or losses must be investigated immediately.

A number of simple oil condition tests may be carried out on board ship with portable equipment. A flashpoint test will warn of possible fuel oil contamination. Colour titration tests can indicate loss in alkalinity. A variety of viscosity tests are available.

Water presence can be detected, but special equipment is required if actual percentages are to be measured. Inspection of the sludge/water discharge at the purifier will give a good indication of condition. In blotter tests the slow migration of a drop of oil on blotting paper will indicate the oxidation, carbon present and dispersive properties when compared with similar drops of fresh oil. Bacteria in the oil can be checked with culture slides, certain bacteria will attack the bearings white metal.

Cylinder Lubrication

Cylinder lubrication is difficult under any circumstances, but the problem has been increased markedly by the use of low quality, high sulphur content, viscous, residual fuels, in place of distillate or semi-distillate fuels. Furthermore, all modern crosshead engines are of the 2-stroke type, so that there is no non-working stroke during which the oil film on the walls can be reformed at moderate pressures and temperatures.

Again, all modern engines are fitted with diaphragm plates and piston rod glands which effectively separate the cylinder from the crankcase. There is, therefore, no cooling effect of crankcase oil on the piston; cylinder lubrication being entirely dependent upon oil, supplied by mechanical lubricators, to a number of oil feed points located around the periphery of the liner.

At first glance it would appear that no lubricant, mineral or synthetic, could withstand the temperatures common in diesel engines at the top of the stroke. Gas temperatures exceeding 1,700°C are encountered at the beginning of the firing stroke, and local temperatures may be appreciably higher if combustion is poor, resulting in flame impingement on the cylinder walls. It has been emphasised that accurate surface, or skin temperatures, of all parts of the combustion chamber and the ring zone are most difficult to obtain by any form of equipment currently in use, such as thermocouples, fusible plugs, or templugs. The temperature of the water-cooled liner at the upper limit of travel of the top compression ring, measured just below the surface, is in the order of 180 – 220°C, depending upon the design, while the temperatures just below the surface of the piston top ring groove vary from about 100 to 200°C, again depending upon engine design and the exact point of measurement.

The temperature of the cylinder liner at its lower end varied appreciably, depending upon the length of the cooling water jacket. In cross-scavenged engines, as would be expected, the temperatures around the exhaust ports at the lower end are relatively high, so that the mean surface temperatures of the liner are higher than in uniflowscavenged engines. In recent high output engines, temperatures have been reduced by effective cooling of the bars between the exhaust ports. Reliable figures of nearsurface temperatures at the lower limit of travel of the top ring are difficult to obtain, but they are probably in the order of 90 to 120°C.

The fire point of a good quality mineral oil suitable for use as a diesel cylinder oil is in the region of 250°C and thermal cracking commences about 300 to 350°C. Rapid oxidation of mineral oils, with the subsequent formation of solid or semi-solid products of decomposition, occurs well below this figure.

Two important considerations, apart from the quality of the lubricant, make it possible for an effective oil film to exist. Firstly, the oil film is subjected to the maximum gas temperatures for only a fraction of a second before it is renewed on the return stroke of the piston, and secondly, modern lubricants, with their improved oxidation resistance can maintain an oil film on the liner even at these temperatures, within the working range of the stroke.

From the mechanical point of view, working conditions are about the worst possible for the establishment of hydrodynamic lubrication. The piston reaches its maximum velocity about mid-stroke, then slows to rest before reversing direction on the return stroke. Thus, at TDC where temperatures are at their maximum and also the radial pressure of the rings on the walls is highest, the piston is stationary before accelerating to maximum speed, then de-celerating again towards BDC.

Under such extreme conditions it is impossible for hydrodynamic conditions to exist in a diesel engine cylinder, except perhaps about mid-stroke. At TDC, providing that the oil used can withstand the very high temperatures, squeeze film or elastohydrodynamic lubrication limits the degree of boundary lubrication and thus metal-to-metal contact.

Shipboard Lubricating Oil Tests

Qualitative oil tests carried out on board ship do not give a complete and accurate picture of the condition of the oil, this could only be obtained in a laboratory.

However, they do give good enough indication of the condition of the oil to enable the user to decide when the oil should be replaced, or if some alteration in the cleaning procedure is considered necessary. Tests for alkalinity (or acidity), dispersiveness, contamination, water, bacteria and viscosity are usual.

Samples of oil for analysis should be taken from the main supply line just before entry into the engine since it is the condition of the oil being supplied to the engine that is of the greatest importance.

Alkalinity Test

A drop of indicator solution is placed on to blotting paper and this is followed by a drop of sample oil placed at the centre of the drop of absorbed indicator. A colour change takes place in the area surrounding the oil spot, if it is red-acid, if blue/greenalkaline, if yellow/green-neutral.

Dispersiveness, Contamination and Water

A drop of oil is placed on to blotting paper and the shape colour and distribution of colour of the spot gives indication of oil condition. An irregular shape indicates water is present.

A uniform distribution of contaminants indicates good dispersiveness. If they are concentrated at the centre of the oil spot, dispersiveness is poor. If the colour of the spot is black, heavy contamination is the cause.

Viscosity Test

Four equal sized drops of oil, one used, one of the same grade unused, one with viscosity higher than and one with viscosity lower than the unused oil are placed in a line along the edge of an aluminium plate.

When sufficient time has elapsed so that they are all at room temperature the plate is inclined from the horizontal and when one of the oils has run down about 7.5 cm the plate is returned to the horizontal.
By comparing the distances travelled by the sample of used oil with the three reference oils an estimate of viscosity is possible. Obviously, if the distances travelled by used and unused oils of the same grade are equal there is no change in viscosity.
If the viscosity is reduced this could be due to dilution by distillate fuel. Heavy contamination due to carbon and oxidation would cause the viscosity to increase, as would contamination by heavy fuel oil. If variations in viscosity of 30% from initial viscosity are encountered the oil should be renewed.
A simple viscosity test of a similar nature to that described above known as the 'Mobil Flowstick' test uses equal quantities of used and unused oils of the same grade in a testing device. Equal capacity reservoirs are filled with the oils which are allowed to reach room temperature, then the device is tilted from the horizontal and the oils flow down parallel channels.
When the reference oil reaches a reference mark, the device is quickly returned to the horizontal and the distance travelled by the used oil in comparison to the unused oil gives a measure of viscosity.

Crackle Test for Water in Oil

If a sample of oil in a test tube is heated, any water droplets in the sample will cause a crackling noise due to the formation of steam bubbles – this test gives indication of small amounts of water being present. A simple settling test would be sufficient to detect large quantities of water in the oil.

Microbial Degradation of Oil

Microbial degradation is the possible infection of an oil system by micro-organisms.

These live by consuming hydrocarbons in the base oil together with nitrogen, sulphur and phosphorous from additives. If water is present they will multiply rapidly in the warm, agitated conditions in the oil system. Contamination may occur from cooling water leaks, condensation in humid climates or accidental entry of dirt and water during overhaul.

Infection by micro-organisms will form organic acids and more water while depleting the additives. This will cause corrosion and wear of metal surfaces (particularly bearing metals), and will create sludge ands lime that choke oil filters. The oil may be prone to emulsification and saponification.
Tests of microbial infection make use of a special gel which is either dipped in the oil or has oil poured over it and is then incubated to develop a growth or culture. The appearance of this culture is then compared visually with a standard coloured chart, to indicate the degree of contamination if any. If the oil does not wet the gel, it may be necessary to mix the sample with a small quantity of sterile water.
Contamination does not commonly occur if cleanliness and care are exercised and water is eliminated from the system. Recommendations are that a maximum of 0.2% of water content must not be exceeded when using detergent oils.

Remedy and Preventional

1. Burn oil (extreme case), clean out and disinfect system.
2. If oil is just beginning to show water separation difficulty, heat it in a tank for about two hours at 80 to 90°C in order to sterilise.
3. Prevent water entry into the oil.
4. Keep system and engine room clean, use disinfectants wash for tank tops and bilges, etc.
5. Treat piston and jacket water with biocide.
6. Use piston and jacket water additives which do not feed the microbes (Nitrogen and Phosphorous are, apparently, nutrients).
7. Use biocide in the oil.
8. Test lubricating oil and piston and jacket water with prepared dip slides for the presence of bacteria.

Oil Maintenance

The types of contaminants which should be removed rapidly and completely are:

a. Water, possibly the most common contaminant. In diesel engines, especially when burning residual fuel, aqueous mineral or organic acids.
b. Dirt, dust and foreign matter, including rust and scale, weld spatter, core sane, silica from the atmosphere, wear particles from bearings, cylinders and gears, paint and jointing compounds, fibrous material etc.
c. Carbonaceous compounds and sludge from incomplete combustion of fuel and lubricating oil.
d. Bacteria.

Filtration Equipment

a. Simple settling out of contaminant under static conditions.

b. Centrifugal separators commonly described as centrifuges.
c. Mechanical strainers and filters, coarse and fine.
d. Adsorbent and absorbent filters.
e. Chemically active filters.

In general, the coarser the filter, in terms of particle size which can pass through, the greater the throughput. Conversely, the finer the degree of filtration the smaller the oil throughput, or alternatively, for a given throughput, select the filter required.

1.2.7 TECHNOLOGY OF MATERIAL

Manufacture of iron

Iron ore is obtained from the earth and consists of iron oxide with impurities. The impurities, which vary in quantity with different ores, are Silica, Alumina, Calcium, Manganese, Phosphorus and Sulphur.

The ore is converted to pig iron in a blast furnace. The furnace is charged with alternate layers of coke, ore and limestone and air at about 1000°F and 15-20 lb/sq in blown through. When the furnace is working normally there is a gradual increase in temperature from top to bottom. Oxygen is removed from the ore and at about 2400°F the metal becomes incandescent and starts to absorb carbon. This lowers the melting point of the metal which now melts rapidly and runs downwards over glowing coke, absorbing more carbon, to the bottom of the furnace where it is tapped off and run into "pigs" or taken directly to the steel making plant. The limestone which is a flux forms a slag which absorbs some of the impurities. The slag lies on top of the molten metal and is tapped off from time to time. Phosphorus and manganese contents are unchanged by slagging.

The pig iron produced contains from 3½% to 4½% of carbon and quantities of Silicon, Sulphur, Phosphorus and Manganese, depending on the quality of the ore.

Manufacture of Steel - Acid and Basic Processes

Steel is essentially an alloy of iron and carbon and is produced by the removal oxidation of the impurities from molten pig iron or from a molten mixture of pig iron and scrap metal. The presence of these impurities makes the metal weak and brittle.

The principal processes of manufacture are:

i. Bessemer Converters
ii. Open Hearth Furnaces
iii. Electric Furnaces

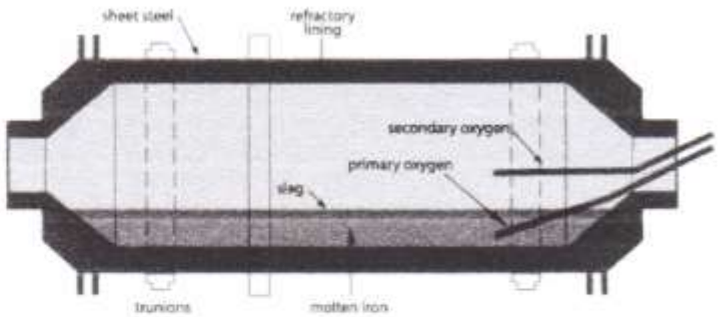
Bessemer Converters and Open Hearth Furnaces are generally employed but for high grade alloy steels the Electric Furnace may be used. The terms "acid" and "basic" refer to the furnace linings used and the nature of the slag produced. If the pig iron has a low phosphorus content an acid lining - silica can be used and in this case the phosphorus content will not alter. To remove phosphorus lime is added to the charge and a basic slag is formed. This slag would react with an acid furnace lining so a basic lining magnesite or dolomite is used.
When the charge in the steel making furnace is ready the steel is in an oxidised condition and deoxidation is necessary before pouring into ingot moulds. This is achieved by adding manganese which has a strong affinity for oxygen. The manganese oxide formed is insoluble and mainly floats out as slag, any remaining within the ingot being in the form of harmless inclusions. Prior to pouring into the ingot moulds, additions of carbon, silicon and manganese are made to give the steel the required composition.

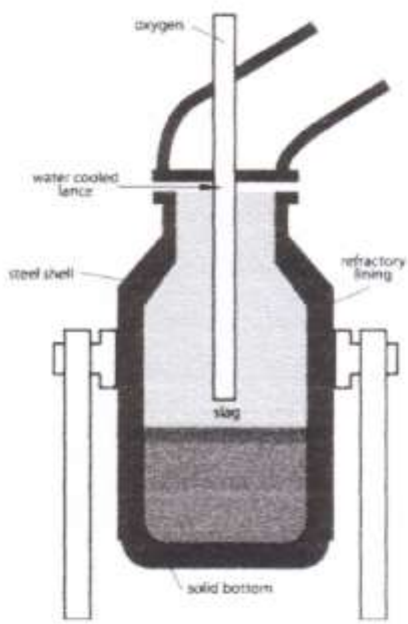
Bessemer Process

The molten iron is run into the converter, the blast air turned on and converter tipped to the upright position. The impurities are oxidised in the order shown in the above graph. Phosphorus when oxidised will not form a stable phosphate unless there is an excess of lime. Under these conditions, the phosphorus is not removed. To remove the phosphorus, lime must be added to the charge and a basic lining used as previously stated. The stable phosphate formed is removed with the slag. When the manganese, silicon and carbon are reduced to a low percentage, as indicated by the colour of the flame, the converter is tapped. By the addition of an alloy of manganese are obtained and harmful oxides eliminated as far as possible.

Basic Oxygen Process

Basic oxygen plant has lower installation costs and increased production compared with open hearth furnaces and the development of such process represents a major technological advance in the art of steel making. Several different types of furnace are being used in different parts of the world; however, the two illustrated in Figure below are typical. Both the Linz Donawitz* (L-D) and the Rotor converter have certain similarities in that (1) they consist of steel shells lined with high-grade basic refractories, (2) they take charges consisting of steel scrap, molten pig iron and limestone, and (3) they both employ oxygen blasts to remove the impurities by oxidation.





However, while the L-D converter remains upright during its working cycle and used oxygen blown on to the surface of the charge, the Rotor converter is mounted horizontally and slowly rotated while oxygen is blown both into and on top of the molten charge.
The furnace reactions are similar to those of the open hearth furnace, but the whole process is much faster and no external heating is required because of the strongly exothermic nature of some of the reactions. Very high-grade steel is produced quite inexpensively by this process.

Open Hearth Process

Molten metals or pig and scrap iron is charged into the furnace. The air and gas are turned and flux added. Since the gas and air are controlled the process can be slow the extent required.
This allows the taking of samples to observe progress. The flap doors are switched about 30 minute intervals to make use of the regenerative chambers. The required deoxiders and carbon are added as in the Bessemer processes.

The slow rate of cooling which takes place in the ingot moulds, gives rise to a course grain structure and consequently the steel is weak and brittle. Refinement of the grain structure is accomplished by hot working.

Electric Furnaces

The main advantage offered by the electric furnace is the neutral nature of the heat source. The most common type of electric furnace is the direct-arc type where heat comes from arcing between the long graphite electrodes and molten charge. It is the efficient method and modern steel plants use this method.

Plain Carbon Steels

When iron is heated within the solid states, it exhibits several distinct changes . The temperature at which these changes take place, are termed arrest points. Two of these points are due to changes in the atom pattern and the temperatures at which the changes occur are termed upper and lower critical temperatures. Above upper critical temperature carbon is completely soluble in solid iron and below lower critical temperature carbon is insoluble in solid iron. Lower critical temperature is constant 723°C but upper critical temperature depends on the carbon content of the steel.
The structures found in slowly cooled carbon steel are:

Austenite

A solid solution of carbon and iron, i.e. the metal is homogenize and

Ferrite

May be regarded as pure iron. This material is soft and ductile.

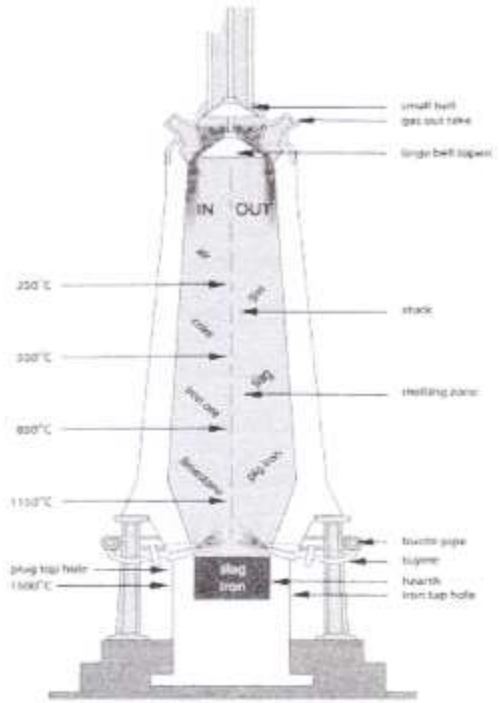
Cementite

Iron-carbide compound which is hard and brittle.

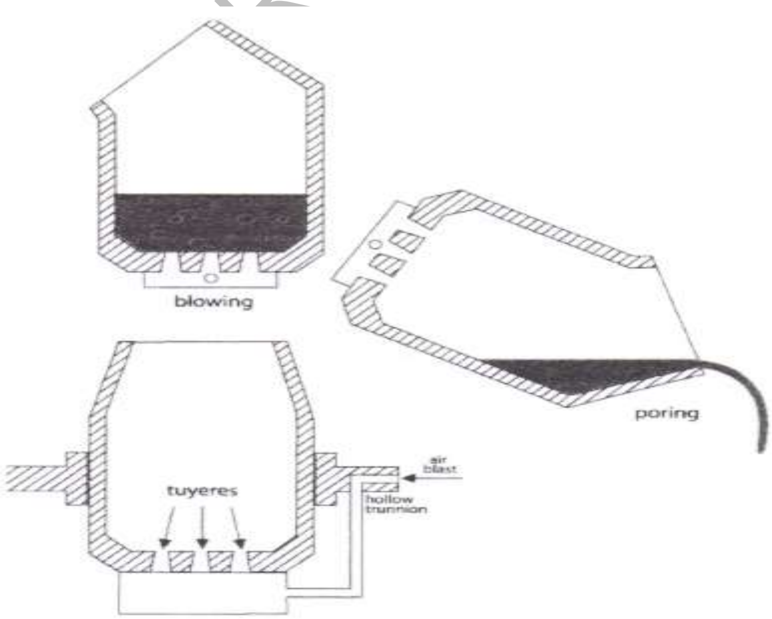
Pearlite

A structure in which the grains are composed of layers of ferrite and cementite and which is formed from austenite of 0.83% carbon content

Detail Of Blast Furnace

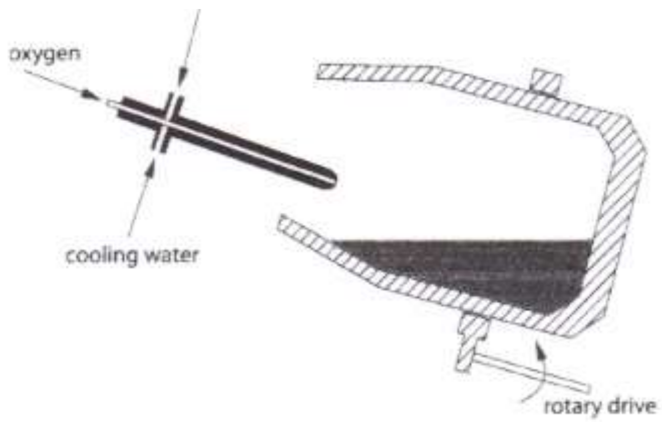


The Bessemer Converter



THE BESSEMER CONVERTER

Basic Open Hearth Process



Consider specimens of steel, containing 0.4%C, 0.83%C and 1.2%C being slowly cooled from the austenitic state. Refer to figure above.
Iron with 0.4%C: At X ferrite of compositions X1 begins to precipitate making remaining austenite richer in carbon until carbon content becomes 0.83% at 723°C and transformation from austenite to pearlite takes place. The final structure is composed of graining of ferrite and grains of pearlite. Iron with 0.83%C: Transformation of austenite to pearlite begins and ends at 723°C.
Final structure is all pearlite.
iron with 1.25C: At Y cementite is precipitated at austenite grain boundaries making the remaining austenite less rich in carbon until its carbon content consists of pearlite with cementite at the grain boundaries.
The mechanical properties of slowly cooled plain carob steels depend upon the proportions of ferrite, pearlite and cementite in the final structure. Figure 2 shows the relationship between carbon content, mechanical properties, structure and uses of plain carbon steel in the normalised condition.
Effects of other elements present in plain carbon steels
(These elements being residual from the refining process)
Manganese - up to 1%
Silicon - up to 0.3%
Sulphur - up to 0.05%
Phosphorus - up to 0.05%
Manganese is an essential constituent since it deoxidises the steel, ensures freedom from blowholes and combines with sulphur present. See Sulphur, Silicon has little effect on mechanical properties in low carbon steels but should not exceed 0.2% in high carbon steels since it tends to break down cementite into graphite or ferrite.
Sulphur may exists as ferrous sulphide or manganese sulphide. Ferrous sulphide appears at grain boundaries and is hard and brittle at low temperatures and has a low melting point,

giving rise to crumbling during hot working. Manganese sulphide exits as soft inclusions, which produce no harmful effects. Phosphorus is soluble in steel and results in the appearance of a hard, brittle constituent. For this reason, the phosphorus of steel should not be allowed to exceed 0.05%.
The mechanical properties of plain carbon steel can be varied considerably by heat treatment. There are three basic methods:

1. Hardening
2. Tempering
3. Annealing and Normalising

Hardening involves heating the steel until it is 30-50°C above upper critical temperatures followed by quenching. If the rate of cooling is rapid enough insufficient time is available for the structural changes from austenite to ferrite, pearlite and cementite to take place and an extremely hard and brittle constituent known as Martensite is formed. Less rapid cooling results in an intermediate structure called Troostite. The extent to which hardening can be carried out depends on section thickness. This is called mass effect.
Tempering is employed to relieve quenching stresses and to toughen the steel. The steel is heated to 200°C-400°C below the lower critical temperature followed by cooling. The higher the tempering temperature the more closely will the structure revert to the slowly cooled state.

Annealing

a. Process or sub critical annealing is carried out on cold worked low carbon steel to relieve internal stress and to soften the material. The steel is heated to about 50°C below lower critical temperature and then allowed to cool.
b. Full annealing is employed on steel casting and hot worked steels to obtain grain refinement and ductility. The steel is heated to about 50°C above upper critical temperature and then allowed to cool slowly in the furnace.
c. Normalising differs from full annealing in that the metal is allowed to cool in still air. Tensile strength and impact values are higher than the figures obtained by annealing.
d. Spheroidising annealing is used for softening high carbon steel to facilitate machining. The steel is heated to just below lower critical temperature. Due to surface tension effects, the cementite assumes globular form while the remainder reverts to ferrite. After shaping, the pearlite-cementite structure can be restored by heat treatment. The heat treatment ranges for plain carbon steels are shown in figure 3.
e. Case-Hardening - Where an article requires to have a hard wear-resisting surface, together with a tough core, it is necessary to employ a low carbon steel and case harden the surface to obtain this dual structure.

The carbon content at the surface is enriched by surrounding the components in materials rich in carbon, such as a mixture of charcoal and barium carbonate; the pieces to be carbonised are placed into boxes with the carbonising materials and sealed. The boxes are

then placed in a furnace and brought to a temperature around 900°C and held at that temperature for a time dependant on the depth of case required. After six to eight hours, a low carbon steel may have 0.9% carbon to a depth of about 0.040%.
A part which has been carbonised at such a temperature will have a coarse grain structure which must be refined. This is achieved by reheating the parts above the critical point and quenching in oil. This treatment results in refining the structure of the core. If it is desired, the case can be tempered at 150°C. The case is then hardened, i.e. heated to 770° then quenched in water. It can then be tempered, i.e. heated to 200°C depending on hardness required.

Cyanide Hardening

This method of hardening is as follows:
The components are immersed in a bath of Sodium Cyanide at a temperature just over 900°C. Cyanide contains carbon and nitrogen both of which are active carbonising agents. In a very short time, the components can be removed from the bath and quenched and a reasonably thick hard case will be present. In two hours, a case of about 0.222" can be formed, at a temperature of 900°C. The treatment is complete after quenching in oil or water. The advantages of this method are:

1. Speed at which hardening can be carried out.
2. Distortion can be kept to a minimum (work suspended or in basket).
3. The bright finish of the parts is maintained.

Disadvantages - Expensive, dangerous fumes, salt clings to parts causes splitting during quench, require gloves and goggles, salt contaminated quench bath.

Induction Hardening

This process is carried out by heating the surface to be hardened by a surrounding induction coil to a temperature of between 750° and 850°C. ~When the temperature has been reached the heating current is switched off and work is quenched by a spray of water.
Advantages

a. Heat can be applied where required for correct length of time.
b. Heat may take only a few seconds therefore small oxidisation.
c. Interior may be cool-minimising distortion.
d. Good for mass production.

Flame Hardening

For steels with a carbon content between 0.3 and 0.5% and medium carbon alloy steels. It consists of heating and surface with one or more acetylene blowpipes and quickly following with special quenching jets.

1. Job fixed - jets move
2. Jets mixed - job moves
3. Job rotates - jets move longitudinally
4. Job heated quickly then blowpipe removed and quenched.

Advantages

a. No distortion
b. High degree of surface hardening
c. Core unchanged (may be heat treated for toughness and ductility first).

Parts should be tempered or stress relieved after quenching. Used for gears, brake drums, tyres, axles.

Gas Carburizing

In this method carbon dioxide and other gases containing carbon are circulated through a furnace chamber into which the parts have been placed. The furnace may be gas fired or electrically heated. This process is quicker than pack carburizing and compared to liquid carburizing may be controlled more in respect of case depths. The main drawback is the high initial cost of the equipment.

Heat Treatment After Carburizing

Case hardening Steels

Both plain carbon and alloy steels are used for case-hardening. The carbon content should not exceed 0.3% if reasonable core toughness is to be maintained. Manganese is added to case hardening steels to aid carburisation and increase depth of hardening but should not exceed 0.9% since it tends to cause quench cracking. Silicon content is kept below 0.3% since it causes graphitisation. Alloy Case-hardening steels usually contain nickel or nickel and chromium. Nickel retards grain growth reducing the need for post-hardening heat treatment. Nickel also increases the strength and toughness of the core. Chromium may be added to increase hardness of the case but small amounts only are used because of the tendency to cause grain growth.

Cast Iron

Generally any material made up primarily of iron with about 2% or more of carbon is considered to be cast iron, with most commercial alloys containing from about 2.5% to 3.8% carbon.
The properties of cast iron are:

1. Low melting point

2. Good fluidity in the mould
3. Rigidity
4. Good water resistance
5. High compressive strength
6. Easily machined if suitable composition is chosen.

White and Grey Cast Iron

The terms 'white' and 'grey' refer to the form in which the carbon content exists. In white cast iron the carbon is combined as cementite and the iron produced is white, hard, brittle and unmachinable. In grey cast iron the carbon is free in the form of graphite flakes and the iron is grey, soft and easily machined. Both cementite and free graphite are present in 'mottled' cast iron. Unless graphitisation is sever, the matrix or background will in every case be pearlite.
The factors affecting the form taken by the carbon are:

1. rate of cooling
2. chemical compositions

Rapid cooling tends to produce cementite and a white iron while slow cooling allows the precipitation of graphite in a grey iron.
Silicon aids the formation of graphite and is used for the purpose of producing a soft iron in the case of thin sections where cooling is accelerated. Sulphur stabilised cementite making the iron hard and brittle but its effect may be suppressed by the addition of manganese. When high fluidity is required phosphorus is used but the iron produced is weak and brittle but is useful for ornamental purposes.

Malleable Cast Irons

Malleable cast iron is made up by annealing white iron castings at a temperature of approximately 900°C for four or five days. The graphite gathers into clusters in a ferrite-pearlite matrix. The disadvantages of this process are the time taken and its limitation to sections of less than 2 inch thick.

Spheroidal Graphite Cast Iron (SG Cast Iron)

Castings with the graphite in globular form can be obtained by adding small amounts of magnesium to the ladle before casting. The metal is then annealed giving a structure consisting of globules of carbon in a ferrite matrix. Such castings can replace steel castings and forgings.

Elements Residual From The Refining Process In Plain Carbon Steels And The Effects Of Theses Elements

Manganese (up to 1%)

Manganese is an essential constituent since it deoxidises the steel, ensures freedom from blowholes and combines with any sulphur present to offset the ill effect of the sulphur (see below).
Note: Steel is not classed as an Alloy Steel unless it contains more than 1% Manganese.

Silicon (up to 0.3%)

Silicon has little effect on mechanical properties in 'low carbon steels' but should not exceed 0.2% in high carbon steels, since it tends to break down 'Cementite' into 'Graphite' or 'Ferrite'.

Sulphur

Sulphur may exist as 'ferrous sulphide' or 'manganese sulphide'. Ferrous Sulphide appears at grain boundaries and is 'hard and brittle' at low temperatures and has a low melting point, giving rise to crumbling during hot working.
Manganese Sulphide exists as soft inclusions, which produce no harmful effects.

Phosphorus (up to 0.5%)

Phosphorus is regarded as a deadly impurity in steel.

The Grain Boundary

Since the 'orientation of the atoms' in each grain is different, the atoms at the 'Grain Boundary' cannot be arranged on a regular space lattice.
Since the grain boundary structure is different from that of the grains, the properties will also be different.
At a relatively 'low temperature' the grain boundaries are 'stronger' than the grains.
At 'elevated temperatures' the grain boundaries are 'weaker' than the grains.
Therefore a 'Fine Grained Structure' will give 'higher' strength and hardness at 'room temperatures'.
At 'higher temperatures' a 'Course Grain' is preferred.
These remarks apply to pure metals and solid solution alloys, but, may not apply to certain alloys with grain boundary impurities.
This type of fracture at room temperature is usually 'Across the Grain' (Transcrystalline). Whereas at the elevated temperatures the fracture may be 'Along the Grain Boundaries' (Intercrystalline).
It can be seen that the properties of a metal will be governed by the amount of grain boundary, i.e. The Grain Size.
The control of the 'Grain Size' is therefore important in the working and heat treatment of metals and alloys.

Recrystallisation

When a certain temperature is reached the distorted grains are replaced by new fine polygonal grains and softening occurs. The phenomenon is known as 'Recrystallisation'.
The recrystallisation temperature for a particular metal or alloy will depend on a number of factors:
(a) The degree of prior cold working
(b) The addition of other elements
(c) The annealing time.

Hot Working

This takes place 'above' the recrystalline temperature (Lower Critical Range for Steel). In Hot-Working, deformation and recrystallisation occur simultaneously so that the rate of softening is greater than the rate of work hardening. The important factor is the finishing temperature. Hot working should be finished at a temperature 'just above' the temperature of recrystallisation so that a 'Fine Grain Size' is obtained.
If the finishing temperature is 'too high' then 'grain growth' will occur whilst the metal is cooling above the recrystallisation temperature.
If the finishing temperature is 'too low' then 'work hardening' will be the result.

Definition Of Hot Working

'Working that does not produce residual stresses' and also as
'Working at a temperature above that of recrystallisation'.
The chief processes of hot-working are hot-rolling, forging and extrusion. In general, simple shapes e.g. sheet, plate, rod, etc., are usually hot rolled whilst more complicated shapes are forged. Non-ferrous sections and tubes are usually made by extrusion.

Cold Working

Cold working destroys the lattice structure with its regular crystal planes along with deformation can readily occur. The metal thus becomes 'harder' and the characteristic 'ductility is lost'. Hardening due to cold-working is referred to as 'working hardening'.

Definition Of Cold Working

'Working that produces residual stresses' and also as
'Working at a temperature below that of recrystallisation'.
Cold working e.g. rolling, drawing or pressing is usually carried out on previously hot-worked metals and alloys. It is frequently the finishing stage in production. The effect of cold working is to break down the crystal structure 'elongating the grains in the direction of working'.

Examples of Work Hardening

Copper piping suffers from continual expansion and contraction which leads to hardness and brittleness (Removed by Annealing).
Shackles, Chains, Lifting Gear, etc., develop surface hardness due to cold working and must be annealed at regular intervals.

Grades Of Mild Steel

Dead Mild Steel

Carbon content 0.07 to 0.15%. It is soft and ductile and is used for hot and cold-rolled strip for pressings, rod and wire for nails, rivets and solid-drawn tubes.
It does not machine well because of its softness, but it welds easily.
It has a Tensile Strength of up to 350 N/mm2 and an Elongation of 32%.

Mild Steel

Carbon content 0.15 to 0.3%. It is harder and less ductile than dead mild steel and most of the steel produced falls into this range. It is used for case hardening steels, boiler and ship's plate, steel structural sections such as joists, channels, angles, bars for machining and forging and for steel castings.
Mild steel welds easily and has good machining properties
It has a Tensile Strength of up to 480 N/mm2 and an Elongation of 25%.

Medium Carbon Steel

Carbon content of 0.3 to 0.6%. It is harder, stronger and less ductile than mild steel and is more difficult to weld and machine.
It is used for components which need good load-bearing qualities and a resistance to abrasion.
Forging for general engineering purposes, connecting rods, axles, gears, crankshafts, fishplates.
It has a Tensile Strength of up to 700 N/mm2 and an Elongation of 12%.

3.2 Alloy

Alloy Steels

Plain carbon steels have the following limitations:

- High tensile strength cannot be combined with good values for toughness and ductility.
- Large sections cannot be effectively hardened due to the 'mass effect'
- Poor resistance to oxidation, corrosion and creep at high temperatures.

To overcome these limitations alloy steels have been developed which are invariably stronger and/or have much greater resistance to oxidation, corrosion, creep and fatigue. Alloy steels are more expensive than plain carbon steels because of the cost of alloying elements and they are often more difficult to manipulate into shape and to machine.
Nickel and chromium are frequently used together since the grain growth tendency of chromium is checked by the grain refinement due to nickel; also, the graphitising effect of nickel is offset by the stabilising effect of chromium. Chromium imports a low rate of oxidation at all temperatures whilst nickel limits grain growth and the brittleness arising there at high temperature. Nickel-chromium alloys are particularly suitable for high temperature work.
(see later note on 'Nimonic Series'.)

Austenitic Steels

Austenitic Steels are a group of alloy steels which consist entirely of austentic FCC crystal structure of iron and alloying elements, even after the steel has been slowly cooled to room temperature. Austenitic steels usually contain a high chromium and nickel content and in such cases are frequently referred to as Austenitic Stainless Steel. Such steels have a low Thermal Conductivity (i.e. therefore used for cryogenic and high temperature valve spindles), very high resistance to corrosion, oxidation and creep - and they also have a very good resistance to Sulphide stress cracking and Hydrogen embracement (i.e. valves used for chemical cargoes etc). Austenitic steels are generally used where strength, corrosion and oxidation resistance are required at high temperature (e.g. exhaust valves, high temperature valve spindles, exhaust turbo-blowers, turbine nozzles and turbine rotor blading), and for low temperature (cryogenic) and chemical cargo operations.
Austenite is relatively soft (e.g. Brinell Hardness approximately 180: Mild Steel 250, High Carbon Steel 800) and ductile and non-magnetic. The stainless steels are unsuitable for welding and suffer from a defect known as 'WELD DECAY' - which causes corrosion brought about by the precipitation of chromium carbides in some part of the structure which then sets up a galvanic cell with the remaining 'stable' structure.

Titanium Alloys

In terms of its occurrence in the Earth's Crust, titanium is a relatively abundant metal and, of the Engineering Metals, only aluminium, iron and magnesium are more plentiful. The amount of titanium ore within the range of mining operations is about 100 times greater than that of copper. However, the very high affinity of titanium for both oxygen and nitrogen makes it difficult to extract whilst the molten metal itself reacts with all known refractories. Thus

titanium is an expensive metal because of its cost of extraction and forming rather than any scarcity of its ores.
High purity titanium has a relatively low tensile strength (216 N/mm2) and a high ductility (50%) but the strength can be raised considerably by alloying with elements such as aluminium carbon, chromium, molybdenum, etc. Titanium is a greyish white metal not unlike steel in appearance and has a strength to weight ration midway between aluminium and steel. It has a very good corrosion resistance.
The relative density of titanium is only 4.5 and suitable alloys based on it have a high specific strength. Moreover creep properties up to 500°C are very satisfactory whilst the fatigue limit is also high. Titanium alloys therefore find application in the compressors of jet engines. In turbine engineering generally titanium alloys, being of low relative density, impose much lower centrifugal stresses on rotors and discs for a given blade size. Titanium alloys are also very resistant to erosion by set steam and other media so that steam turbo generators, gas turbines and heat exchanger plates all make use of these alloys.
Because of the high specific strength, high temperature resistance and good corrosion resistance generally, many titanium alloys find use in supersonic aircraft - including 'Concorde' - as structural forging. Such an allow is IMI Ti690 (11Sm; 2.25A; 4 Mo; 0.2Si) which develops a strength of 1300 N/mm2.
'Nimonic' Services are not strictly speaking steels but contain basically 75% Nickel and 20% Chromium stiffened with small amounts of carbon, titanium, aluminium, cobalt and molybdenum. Used where very high creep strength at elevated temperature is required.
Alloy Steel used up to 1000K (e.g. Steam Turbines)
Nimonic Alloys used up to 1300K (e.g. Gas Turbines)
'Stellite' is the trade name of an alloy consisting of cobalt, chromium, molybdenum, tungsten and iron. Varying proportions of some or all of the metals are used to produce alloys with various characteristics. Stellite is extremely hard, corrosion resistant and has good resistance to loss of strength at high temperature. In diesel engines Stellite is used to surface the face and seats of exhaust poppet valves. Stellite is applied by welding or spray process onto the valve face and seat, which must be preheated.

Alloying Elements

These are added to plain carbon steels to improve their existing properties and also to introduce new properties such as corrosion resistance.

Nickel (1 to 8%)

Increases strength and toughness with little loss of ductility, giving good erosion resistance. Nickel is a 'grain refiner', forming a fine grained material, but fortunately it is also a 'powerful graphitiser'. It is used in amounts up to 5%; as a grain refiner in case-hardened steels. Larger amounts are used in stainless steel and heat resistance steels.

Manganese (1 to 2%)

Reduces the ill effect of Oxygen and Sulphur and 'increases strength'.

Silicon (up to 1%)

Reduces the ill effect of Oxygen and Sulphur and 'increases strength'. Also gives good casting fluidity (up to 0.3%) and used in some heat resisting steels (up to 1%).

Chromium (0.25 to 18%)

Used in small amounts in constructional steels, tools steels, and ball races. Used in large amounts in stainless steels and heat resisting steels. Induces 'hardness', improves resistance to erosion, corrosion and high temperatures. Increases strength with unfortunately increases brittleness due to increasing of grain size.

Molybdenum (0.5 to 1%)

Increase strength, heat and creep resistance at high temperatures. Used for superheater tubes, turbine rotors, etc.

Vanadium (0.2 to 4%)

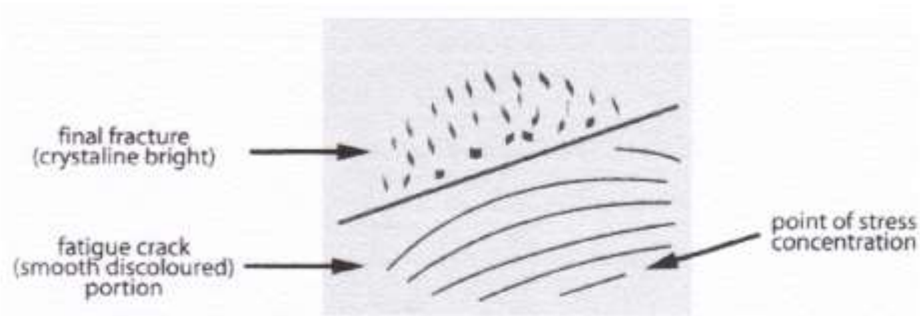
Used in steels required to retain hardness at high temperatures e.g. Hot Forging Dies. Increases strength and fatigue resistance. Used in conjunction with Molybdenum for boiler tube material.

Fatigue

Fatigue failure is caused by 'repeated stress cycles' such as reverse or alternating stresses, repeated stresses and fluctuating stresses:

- Reversal of direction of Bending or Torsion
- Alternating Compressive and Tensile Stresses
- Application and Removal of Stresses
- Variation of the Intensity of Stress

The appearance of the material after a fatigue failure is shown below:



Ductile materials display a smooth zone and a crystalline zone, but these zones are less marked, in the case of brittle materials.

The smooth zone is produced by the gradual progression of the fatigue crack and the rubbing of the surfaces of the crack.

The crystalline zone is produced by the sudden fracture when the remaining sound material can no longer withstand the increased stress caused by the reduction in the area carrying the load.

A fatigue crack starts at some point of stress concentration. If the material is subjected to 'Intermittent Stressing' the surface of the smooth zone will display a number of curved lines.

Factors That Influence Fatigue Strength Of A Component

Grain Size

When a material has a 'coarse grain' it has 'poorer' fatigue resistance than when it has a fine grain.

Component Shape

A fatigue crack often starts some point of stress concentration and so stress rising features such as an abrupt change of section e.g. sharp corners, keyways, etc., should be avoided if possible.

Surface Finish

Tooling marks act as stress raisers and so the fatigue resistance of a component can be improved by polishing etc.

Residual Stresses

Stressed produced by the machining operations will affect the fatigue resistance of a component. Tensile Stresses 'reduce' the resistance. Compressive Stresses 'improve' the resistance.

Corrosion

Corrosion produces a pitted surface and so introduces stress raisers. The fatigue strength of a component is reduced very considerably by corrosion.

Temperature

At high temperature materials tend to lose their strength and also suffer 'grain growth' and so fatigue strength falls when the temperature is high.

Creep

The term 'Creep' is used to describe the 'slow plastic deformation' that occurs under prolonged loading, usually at high temperatures.

Factors That Influence Creep

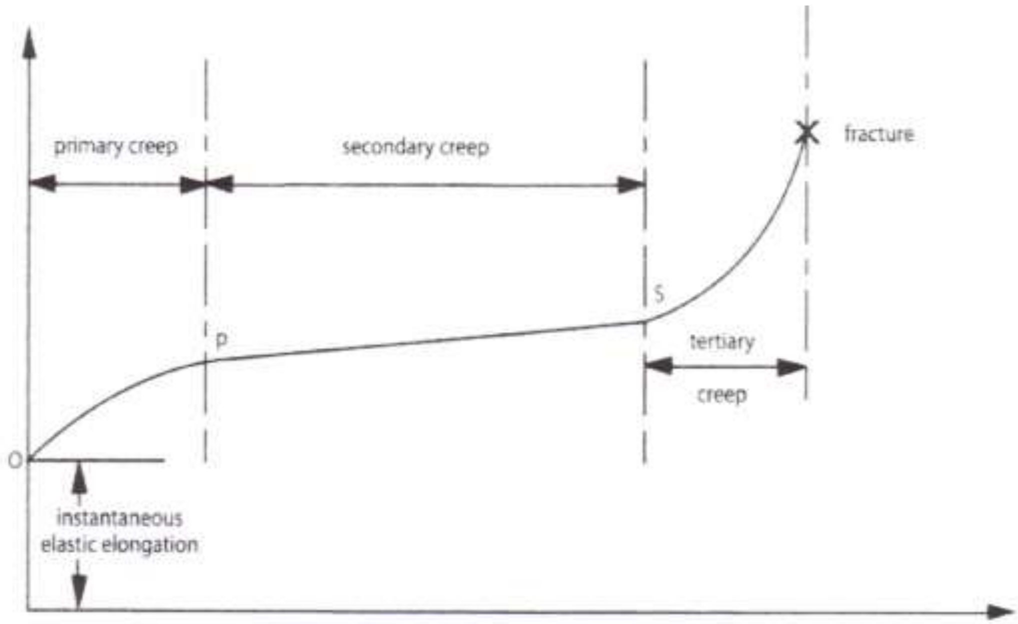
Temperature

The rate of creep increases with temperature

Grain Size

A course grained material has a better creep resistance than one with a fine grain.

Creep is a form of slip which occurs when metal is subjected to a tensile load at high temperature. Creep can be defined as the continuing deformation with the passage of time, in materials subjected to constant stress. This deformation is plastic and occurs even though the acting stress is 'below the yield stress' of material. At low temperatures the rate of creep is very small but at higher temperatures it becomes increasingly important. For this reason creep is commonly regarded as a high temperature phenomenon associated with steam plant, gas-turbine technology and turbo-charger blading.



TIME

Plastic Strain from 0 to X which Occurs in Three Stages:

Primary or Transient Creep (0 to P) beginning at a fairly rapid rate which then decreases with time as strain - hardening sets in.

Secondary or Steady-State Creep (P to S) in which the 'rate' of strain is fairly uniform and at its lowest value.

Tertiary (tershari) Creep (S to X) in which the 'rate' of Creep increases rapidly so that fracture occurs at X. This stage coincides with necking of the material.

During Primary and Secondary Creep, plastic deformation takes place due to slip associated with dislocations movements within the grains. This leads to work hardening which, at high temperatures, is balanced by thermal softening. The dislocations eventually move out of the grains and into the grain boundaries. Tertiary Creep coincides with the initiation of micro-cracks at the 'grain boundaries', which leads to necking and the consequent rapid failure of the material. Hence, at the higher temperatures, fine grained material creep more than course grained material since fine grained material contains more grain boundaries per unit volume.

Cast Irons

Generally any material made up primarily of iron with about 2% or more of carbon is considered to be 'cast iron'.

Most commercial alloys contain from about 2.5% to 3.8% carbon.

The properties of cast iron are:

1. Low melting point
2. Good fluidity in the mould
3. Rigidity
4. Good wear resistance

5. High compressive strength
6. Easily machined if suitable composition is chosen.

Copper Alloys

The alloying elements used have a fair degree of solubility and within this range, the solid solutions formed are soft and ductile and are suitable for cold working. Further additions of the alloying element result in the formation of hard particles, accompanied by an increase in strength and a decrease in ductility. Such alloys are suitable for hot-working and for castings.

Copper - Zinc (Brasses)

Up to 39% zinc - cold working alloys, soft and ductile
39% - 45% zinc - hot working alloys
above 45% - material becomes brittle.

Tin improves corrosion resistance.
Manganese is added for the deoxidisation producing sounder castings and for improving tensile strength.
Aluminium increases tensile strength and corrosion resistance.
Nickel increases corrosion and erosion resistance.

Copper-Tin (Bronzes)

Additions of up to 10% tin are soluble in copper and form soft ductile alloys which can be cold-worked. Further additions of tine result in the appearance of a hard constituent, such alloys being suitable for hot-working and for castings. The cold worked alloys are used mainly for coinage.
Admiralty Gunmetal (88: 10: 2, Cu: Sn: Zn)
Zinc is present as a deoxidiser and increases fluidity. This alloy is used mainly for castings requiring strength and corrosion resistance. An additional of 1% lead may be used to improve pressure tightness. The alloy may be used for bearings.
15% Tin - Bronze Alloy
Cast 15% tin bronze is suitable for bearings.

Phosphor - Bronzes

Phosphorus increases strength and corrosion resistance.

Alloys containing up to 8% and 0.3% phosphorus can be cold worked and are used for instrument springs and steam turbine blading. Cast alloys contain up to 13 tin and up to 18% phosphorus are used mainly for bearings.

Aluminium - Bronzes

Alloys containing up to 9.4% aluminium are soft and ductile and are suitable for hot and cold working. Further additions result in the appearance of a hard constituent and are used for the hot worked condition and for castings. Aluminium bronzes have good mechanical properties, wear, fatigue and corrosion resistance. The 7% aluminium alloy often contains small additions of nickel, iron and manganese and is used for marine condenser tubes.
The 10% alloy with additions of nickel, iron and manganese is used for propellers.

Copper Nickel Alloys (Monel Metals)

Copper and nickel form solid solutions for all proportions. These alloys may be hot or cold worked and have excellent corrosion resistance. The copper-rich alloys are known as cupro-nickels.(70: 30: Cu: Ni) used for condenser tubes (Cupro-Nickel)
(29.5: 68.5: 1: 1, Cu: Ni: Fe: Mn) Monel Metal. This alloy combines good mechanical properties and high corrosion resistance.

Bearing Metals

Alloys used for bearing should have a low co-efficient of friction, be sufficiently hard to resist wear, tough to withstand shock loading, have strength to support the working load, be sufficiently plastic to allow self alignment and have high thermal conductivity to dissipate heat when running. The alloys employed usually consist of hard particles in a soft matrix. The hard particles provide the wear resistance while the matrix provides the mechanical properties.

Copper Base Bearing Alloys

Phosphor - bronzes containing 10-13% tin and 0.3 - 1% phosphorus and tin bronzes containing 10-15% tin are used for bearings where loading is heavy. Lead bronzes are useful in that they have a high resistance to wear and have good thermal conductivity enabling the bearings to remain cool. Sintered bearings are made by heating a compressed powder mixture of 90% copper and 10% tin with an addition of graphite. These bearings being semi-porous retain lubricant.

Yorcalbro - Copper - Zinc Alloy

22% zinc 2% aluminium 0.04% arsenic.

Bearing Metals

Alloys used for bearings should have the following characteristics:

1. Have a low co-efficient of friction
2. Be sufficiently hard to resist wear
3. Be tough to withstand shock loading
4. Have strength to support the working load
5. Be sufficient plastic to allow self alignment
6. Have a high thermal conductivity to dissipate heat when running.

The alloys employed usually consist of hard particles in a soft matrix. The hard particles provide the wear resistance while the matrix provides the mechanical properties.

Copper Base Bearing Alloys

Phosphorous Bronzes containing 10-13% Tin and 0.3-1% Phosphorous and Tim Bronzes containing 10-15% Tin are used for bearings where the loading is heavy.
Lead Bronzes are useful in that they have a high resistance to wear and have good thermal conductivity enabling the bearings to remain cool.
Sluntered bearings are made by heating a compressed powder mixture of 90% copper and 10% tin with an addition of graphite.
These bearings being semi-porous retain lubricant.

Copper

Composition

Nearly Pure
Copper is malleable and ductile either when cold or hot and can be rolled into sheets or drawn out into wire.
When the metal has work expended on it as stated or by hammering, it becomes hard and brittle, rendering it unsuitable for practical purposes. To soften the copper it is heated until it acquires a red appearance when it is quenched in cold water.

Properties

It is soft and ductile. It is easy to shape. It is resistant to ordinary corrosion when in contact with water or steam, but owing to its softness it is unsuitable for use with steam or high pressure and temperature.

As it is a good conductor of heat it is required to be lagged to prevent heat loss. Is good electrical conductor and is widely used in electrical work. Its greatest use is in alloying with non-ferrous metals in the production of bronze, gunmetal, muntz metal, nickel-copper and other alloys.

Copper Base Alloys - Advantages

Good Mechanical Properties
High Electrical and Thermal Conductivity
Very Resistant to Corrosion and Wear
Can be easily Formed and Machined
Can be easily Joined by soldering, brazing, Welding
Can be easily polished and plated
Pressing and Forging Temperatures are lower than Ferrous Metals.

Dezincification Of Brass

This is one of several forms of selective corrosion which affects some alloys. In the case of brass it is the 'removal of the Zinc content' of Brass (a copper zinc-alloy) by the sea water or hot fresh water and leaving behind a 'porous and leaking sponge of copper'.
The characteristic appearance of a 'dezincified brass' is the coppery colour of the affected area and small pit holes.
Single phase brass alloys (70% Cu: 29% Zn: 1% Sn) can be inhibited against dezincification by the addition of a small amount of arsenic.
Duplex alloys such as Muntz Metal i.e. 60/40 Brass (60% Cu: 40% Zn) 'Cannot be inhibited', although the addition of 1% Tin will retard the corrosion.
In general, dezincification will not occur to brasses in which arsenic has been added and whose Zinc content is less than 37%.
Aluminium Brass (75% Cu: 22% An: 2% Al) will eliminate dezincification as a protective film is formed which even if broken will reform itself.

Copper Alloys

The alloying elements used have a fair degree of solubility and within this range, the solid solutions formed are soft and ductile and are suitable for cold working. Further additions of the alloying element result in the formation of hard particles, accompanied by an increase in strength and a decrease in ductility. Such alloys are suitable for hot-working and for castings.

Copper - Zinc (Brasses)

Up to 39% zinc - cold working alloys, soft and ductile
39% - 45% zinc - hot working alloys
above 45% - material becomes brittle.

Tin improves corrosion resistance.
Manganese is added for the deoxidisation producing sounder castings and for improving tensile strength.
Aluminium increases tensile strength and corrosion resistance.
Nickel increases corrosion and erosion resistance.

Copper-Tin (Bronzes)

Additions of up to 10% tin are soluble in copper and form soft ductile alloys which can be cold-worked. Further additions of tine result in the appearance of a hard constituent, such alloys being suitable for hot-working and for castings. The cold worked alloys are used mainly for coinage.
Admiralty Gunmetal (88: 10: 2, Cu: Sn: Zn)
Zinc is present as a deoxidiser and increases fluidity. This alloy is used mainly for castings requiring strength and corrosion resistance. An additional of 1% lead may be used to improve pressure tightness. The alloy may be used for bearings.
15% Tin - Bronze Alloy
Cast 15% tin bronze is suitable for bearings.

Phosphor - Bronzes

Phosphorus increases strength and corrosion resistance.
Alloys containing up to 8% and 0.3% phosphorus can be cold worked and are used for instrument springs and steam turbine blading. Cast alloys contain up to 13 tin and up to 18% phosphorus are used mainly for bearings.

Aluminium - Bronzes

Alloys containing up to 9.4% aluminium are soft and ductile and are suitable for hot and cold working. Further additions result in the appearance of a hard constituent and are used for the hot worked condition and for castings. Aluminium bronzes have good mechanical properties, wear, fatigue and corrosion resistance. The 7% aluminium alloy often contains small additions of nickel, iron and manganese and is used for marine condenser tubes.
The 10% alloy with additions of nickel, iron and manganese is used for propellers.

Copper Nickel Alloys (Monel Metals)

Copper and nickel form solid solutions for all proportions. These alloys may be hot or cold worked and have excellent corrosion resistance. The copper-rich alloys are known as cupro-nickels.(70: 30: Cu: Ni) used for condenser tubes (Cupro-Nickel)
(29.5: 68.5: 1: 1, Cu: Ni: Fe: Mn) Monel Metal. This alloy combines good mechanical properties and high corrosion resistance.

Bearing Metals

Alloys used for bearing should have a low co-efficient of friction, be sufficiently hard to resist wear, tough to withstand shock loading, have strength to support the working load, be sufficiently plastic to allow self alignment and have high thermal conductivity to dissipate heat when running. The alloys employed usually consist of hard particles in a soft matrix. The hard particles provide the wear resistance while the matrix provides the mechanical properties.

Copper Base Bearing Alloys

Phosphor - bronzes containing 10-13% tin and 0.3 - 1% phosphorus and tin bronzes containing 10-15% tin are used for bearings where loading is heavy. Lead bronzes are useful in that they have a high resistance to wear and have good thermal conductivity enabling the bearings to remain cool. Sintered bearings are made by heating a compressed powder mixture of 90% copper and 10% tin with an addition of graphite. These bearings being semi-porous retain lubricant.

Yorcalbro - Copper - Zinc Alloy

22% zinc 2% aluminium 0.04% arsenic.

Bearing Metals

Alloys used for bearings should have the following characteristics:

1. Have a low co-efficient of friction
2. Be sufficiently hard to resist wear
3. Be tough to withstand shock loading
4. Have strength to support the working load
5. Be sufficient plastic to allow self alignment
6. Have a high thermal conductivity to dissipate heat when running.

The alloys employed usually consist of hard particles in a soft matrix. The hard particles provide the wear resistance while the matrix provides the mechanical properties.

3.3 Corrosion and protection

Electro-Chemical Corrosion

This type of corrosion covers all forms of 'Wet Corrosion' i.e. where the metal is in contact with a liquid or even moist atmosphere. In the electro-chemical theory it is assumed that all metals have a tendency to dissolve or corrode, when the metal discharges 'positively-charged' particles called 'ions' into solution. This leaves the metal with a characteristic 'negative charge' or potential. The greater the negative potential, the greater is the tendency of the metal to dissolve or corrode.

The corrosion resistance of metals is governed by their position in the 'Electro-Chemical Series' in which metals are arranged according to their electrode potentially. The results are expressed relative to 'Hydrogen' which is taken as Zero.

The tendency of each individual metal to corrode is relatively small, but is greatly increased when it is in contact with a dissimilar metal in the presence of a conducting liquid, referred to as the 'Electrolyte'. A current will flow between the two metals since they are at different potentially. Corrosion of the one 'higher in the table' (Anode) will be accelerated, whilst the metal 'lower in the table' (Cathode) will be protected.

The rate of corrosion is governed by the relative areas of the Anode and the Cathode. In general for a given area of Anode, the attack increases in severity, the greater the areas of the adjacent Cathode.

For electro-chemical corrosion to occur there must be a Cathode, and Anode and an Electrolyte.

Anodic End (Corroded)

Metal	Electrode Potential Volts
Sodium	-2.71
Magnesium	-2.40
Aluminium	-1.70
Zinc	-0.76
Chromium	-0.56
Iron	-0.44
Cadmium	-0.40
Nickel	-0.23
Tin	-0.14
Lead	-0.12
Hydrogen	0.00
Copper	+ 0.35

Silver	+0.80
Platinum	+1.20
Gold	+1.50

Cathodic End (Protected)

Pitting

Pitting is an example of the differential aeration effect. The initial depression or pit in the surface may be the result of several factors e.g. a break in a protective film or scale, or the solution of a non-metallic inclusion due to electrolytic action.
Once a pit is formed the corrosion proceeds rapidly since the surface of the metal (Cathode) has a greater access to 'oxygen' than the base of the pit (Anode).
Corrosion is accelerated by the fact that the surface area of the Cathode is considerably greater than that of the Anode.
The corrosion products accumulate at the mouth of the pit and assist corrosion by making oxygen diffusion more difficult.

Corrosion Of Metals In Sea Water

With dissimilar metals in sea water, galvanic action results and the more anodic metal corrodes.
Any material in the Table below is anodic to those below it.
i.e. Steel is anodic to bronze in sea water and therefore it will corrode. We can say that the steel has given 'cathodic protection' to the bronze.

Anodic End Of Table (Corroded)

Magnesium

Aluminium

Zinc

Mild Steel

Manganese Steel (without oxide film)

Admiralty Brass

Copper

Aluminium Bronze

Gunmetal

Cupro-Nickel 70/30

Nickel

Stainless Steel (with oxide film)

Monel Metal

Graphite

Titanium

Cathodic End Of Table (Protected)

To minimise galvanic effect:

1. Choose materials close to each other in the series.
2. Make the key or main component of a more noble metal (i.e. cathodic).

Corrosion And Deposition

Most of the metal equipment in marine power plants is made up of steel or copper alloys (brass, copper-nickel, bronze and others). All of these metals will dissolve slowly in water unless the water is properly treated. This is called corrosion.

Some of the most important kinds of corrosion damage which can occur in marine power plant equipment are:

a. Thinning of the tube metal. This is the result of corrosion that is continuous and over a fairly large area of metal. This kind of a damage is also called general corrosion. Thinning can progress to the point at which the metal can no longer contain the internal pressure which may cause the metal to swell and eventually burst.
b. Pitting - when only a small area of metal is corroded the result is a deep hole called a pit. If pitting corrosion is not controlled, some pits may go all the way through the metal. This causes leaks. When these are many pits close together, they may become connected. The effect on the metal is the same as that of general corrosion.

c. Corrosion cracking is another form of corrosion which can effect certain materials. In general, alloys, which are mixtures of metals are most susceptible to cracking. Stainless steel and brass such as Admiralty are particularly susceptible to cracking under certain conditions. cracking is a form of corrosion which occurs along a very narrow band through the metal.
d. Some metal alloys are susceptible to exfoliation or de-alloying. Both of these types of corrosion are associated with the selective reaction of only one of the metals in a metal alloy. Exfoliation generally occurs in feedwater heaters. Nickel is selectively oxidised from the copper-nickel alloy tubing leaving layers of copper metal and nickel oxide. Brasses are mixtures of copper and zinc. When de-alloying occurs, zinc is removed from the metal leaving a spongy mass of copper behind. This is commonly referred to as dezincification.
e. Embrittlement is an effect of corrosion that changes the physical properties of a metal.Some corrosion reactions cause metals to lose their normal strength and ductility and become brittle and weak. Embrittlement cannot be seen by inspecting a boiler tube that has not failed. However, an embrittled tube that has failed will have a crystallized appearance at the edge of the point of failure and usually there will be no evidence of bulging.

In Section II some of the chemical reactions of corrosion were covered. These will help you to understand some other aspects of corrosion which follow.

The study of corrosion considers reactions between a material and its environment. From the standpoint of the power plant water chemist, the study of corrosion also includes suppression of corrosion by altering or controlling the environment to which steam power plant materials are exposed. In order to understand the suppression of corrosion, one must first understand its causes.

The earliest studies of corrosion of iron (steel) showed that practically the only factor which limits the life of iron is oxidation. All of the chemical processes by which iron is corroded, eaten away, or rusted are covered by this term.

Before proceeding the term oxidation and its counterparts reduction should be clearly understood. The word oxidation implies the chemical reaction of a substance with oxygen. This is true, but this is a very specific application of the term. It also has a much broader and more important meaning.

The term reduction is often though of as a reaction that involves the removal of oxygen from a substance. Again, this is true but it is also only a specific application of the term. Reduction also has a much broader and important meaning. The terms are often abbreviated as "REDOX" because they are closely related.

Simply stated oxidation involves the loss of electrons by a substance and reduction of the gain of electrons by a substance. By this definition the element oxygen does not have to be involved in an oxidation-reduction reaction at all. The reason for this close relationship of the terms should also be apparent: If one substance gives up electrons another substance must gain them.

In experiencing oxidation, uncharged iron atoms pass into solution and become iron ions. This change involves the atoms giving up electrons. The oxidation of iron is therefore electric in nature because of the flow of electrons.
Oxidation and corrosion are therefore electrochemical processes. On this basis corrosion can be looked at in a similar fashion to other electrical processes.
The basic nature of corrosion is almost always the same. A Flow of electricity occurs between certain areas of a metal surface through a solution capable of conducting an electric current. This electro-chemical action causes the eating away of metal at areas where the electric current leaves the metal and the metal atoms enter the solution as ions.

Anodes and Cathodes

The presence of a solution which can conduct an electric current, and electrolyte, is one of the first requirements for corrosion. An electrolytic solution is any liquid that contains ions. Remember that ions are electrically charged atoms in solution and that even pure water contains both charged ions and negatively charged hydroxyl ions in equilibrium. Because of this, solutions of salts, acids and alkalis are all good electrolytes.

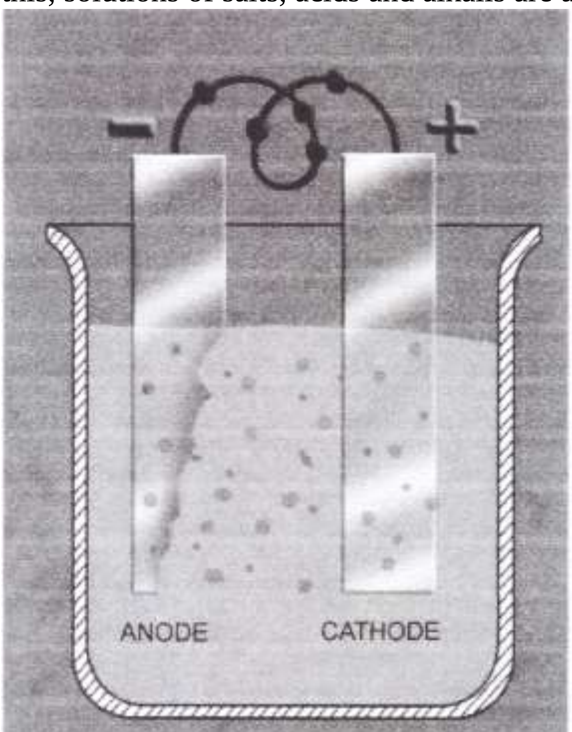
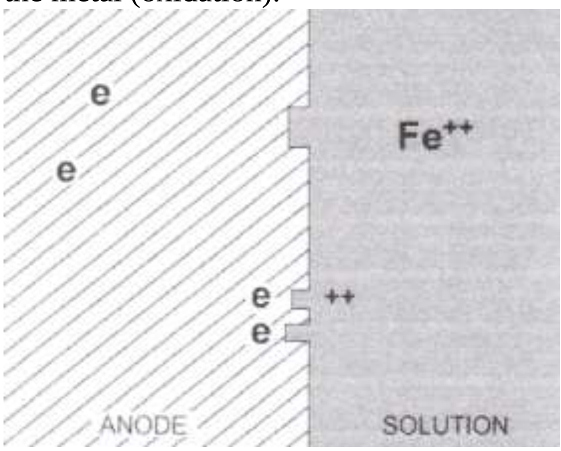


FIG 1.

In addition to an electrolyte, two electrodes - an anode and a cathode - are required for corrosion. The electrodes may consist of two different types of metal or they may be different areas on the same piece of metal. In either case, for corrosion to occur there must be a difference in electrical potential between the two electrodes or areas so that electricity will flow between them. In addition to the portion of the electrical circuit made up of electrolyte, the circuit must be completed by a metallic path between the two electrodes. If they are on the same piece of metal there is an inherent circuit. If they are separate pieces of metal they must be connected in some manner.

What takes place at the anode in a corrosion cell when corrosion occurs?

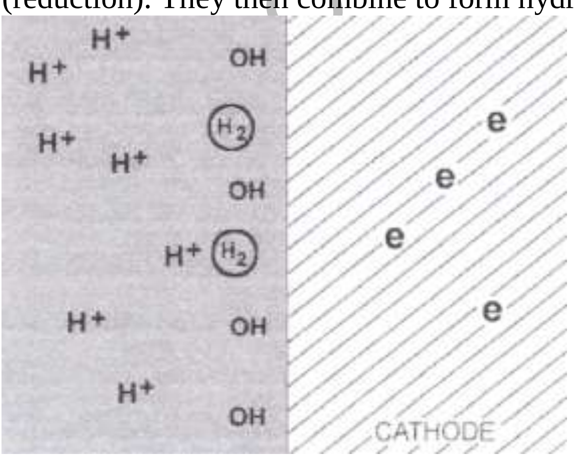
Positively charged atoms of metal detach themselves from the surface and enter into solution as ions, while the corresponding negative charges, in the form of electrons, are left behind in the metal (oxidation).



The detached positive ions bear one or more positive charges. In the corrosion of iron, each atom releases two electrons and becomes an iron ion carrying two positive charges. The released electrons travel through the metal to the cathode area.

What takes place at the cathode?

The electrons reaching the surface of the cathode by passing through the metal circuit meet and neutralize some positively charged hydrogen ions which were present in the electrolyte. In losing their electric charge by gaining electrons the hydrogen ions become neutral atoms (reduction). They then combine to form hydrogen gas.



The conversion of hydrogen ions to hydrogen atoms and then to hydrogen gas results in a decrease in hydrogen ions in the electrolyte. This increases the alkalinity of the electrolyte in the area of the cathode.

The ionic and cationic (REDOX) reactions discussed so far can be written as follows:

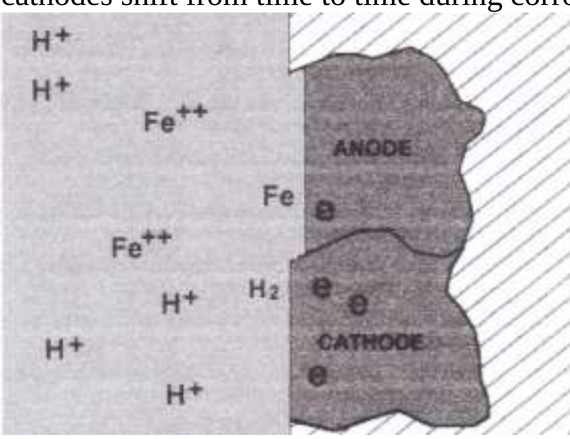
Anodic Reaction - $Fe^{\circ} \rightarrow Fe^{++} + 2e$

Cathodic Reaction - $2e + 2H^{+} \rightarrow 2H^{\circ} \rightarrow 1H_2$

From the above it is easy to see that several environmental factors can be varied to affect corrosion rate. If for instance the hydrogen ion concentration is increased (pH reduced) the rate of corrosion is likely to increase since there are more hydrogen ions to receive electrons at the cathode. Conversely if the solution is made more alkaline (by reducing the H ion concentration - pH increased) the of corrosion can be reduced.

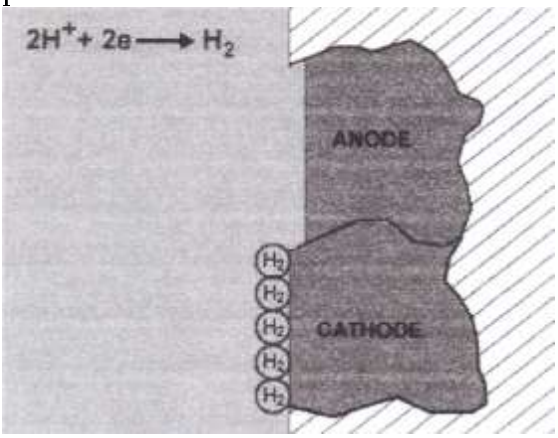
Further by reducing the concentration of dissolved material in the electrolyte the conductivity of the electrolyte is reduced and the resistance is increased. An increase in resistance impedes the flow of current and the corrosion rate of an immersed material can be reduced.

It is important to note that anodes and cathodes can occur randomly on a piece of metal. This can be illustrated by placing a piece of steel in a hydrochloric acid solution. Upon immersion of the piece of steel in the acid solution, the vigorous formation of numerous hydrogen bubbles is observed. Hydrogen is evolved seemingly from the entire surface without the indication of either cathodic or anodic areas. This is, in fact, the case since the anodes and cathodes shift from time to time during corrosion under these conditions.



The development of an anode on a metal surface may result from a variety of microscopic surface conditions including local impurities in the metal, surface imperfection, orientation of grains in the metal, localized stresses and variations in environment. It is important to realize that it is not always possible to define the probable anodic and cathodic areas in a system such as a steam power plant.

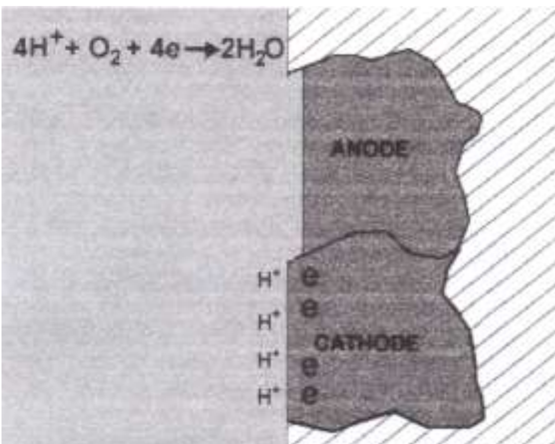
It was stated that the conversion of hydrogen ions to uncharged (neutral) hydrogen atoms which combine to form hydrogen gas is the major cathodic reaction of corrosion. In acid solutions such as hydrochloric acid, corrosion proceeds rapidly because of the high concentration of free hydrogen ions available for the cathodic reaction. In neutral or alkaline solutions, the number of hydrogen ions is greatly reduced and it is possible for a microscopic layer of hydrogen gas to form a film on the cathode. The coating of hydrogen on a cathode slows down the corrosion rate by acting as an insulation and preventing hydrogen ions in the liquid from accepting electrons at the cathode surface. This phenomenon is called cathodic polarization.



If oxygen is present in solution, it can react with hydrogen at the cathode surface forming water by the following reaction:

$4H^+$+02+4e->2H20

When this occurs, corrosion is accelerated since the cathode cannot become polarized and corrosion rates are increased.



The formation of a corrosion product film on the surface of an anode is a form of anodic polarization. In this case, the corrosion product acts as an insulation preventing further reaction and thereby inhibiting corrosion.

1. There are many types of corrosion product films which can form. In steel systems without oxygen present, ferrous ions produced at the anode react with hydroxyl ions in the water forming ferrous hydroxide. This is the first step in the formation of magnetite (Fe30 4) which is a desirable and very protective film. Iron is actually converted into magnetite by the following complex sequence of chemical reactions.
   i. $Fe° + 2H^+ = Fe^{++} + H_2$
   ii. $2Fe° + 6H^+ = 2Fe^{+++} + 3H_2$
   iii. $Fe + 20H^- = Fe(OH)_2$
   iv. $2Fe + 60H^- = 2Fe(OH)_3$

v. $Fe(OH)_2 + 2Fe(OH)_3 = Fe_3O_4 + 4H_2O$

or

$3Fe + 4H_2O = Fe3O_4 + 4H_2$

2. It can be seen from the above reactions that the formation of ferrous hydroxide and magnetite is dependent on the presence of sufficient free hydroxal ions. The of conversion is also affected by temperature. The higher the temperature the more rapid the conversion.
3. In the presence of oxygen, ferrous hydroxide may not be converted to magnetite but may form ferric hydroxide instead. Ferric hydroxide is a typical form of rust. It is not very protective because it is porous and does not adhere tightly to the surface of the anode. As a result, corrosion can progress beneath the ferric hydroxide surface. Ferric oxide (Fe2O3) is another frequent corrosion product formed in the presence of oxygen. Ferric oxide films are not very protective.
4. In copper systems, the desirable protective oxide which can occur at the anode if cuprous oxide (Cu2O). In the presence of oxygen cupric oxide (CuO) which is not as adherent and protective as cuprous oxide can form.
5. The corrosion products of iron and copper can often be identified by their colour. The following is such a list:

Product	Formula	Colour
Ferrous Hydroxide	$Fe(OH)_2$	White
Ferric Hydroxide	FeO(OH)	Yellow or Orange
Ferric Oxide	Fe_2O_3	Red or Brown
Magnetite	Fe_3O_4	Black

Anodic polarization is frequently called passivation. Without the formation of protective oxide films on steel or copper alloy surface, corrosion would be excessive because these metals are very reactive with water. It is therefore one of the water chemist's major goals to maintain water conditions that will achieve and maintain surface passivity of steel and copper equipment.

a. One of the first aspects of corrosion protection is to prevent high hydrogen ion concentrations (low pH). High hydrogen ion concentrations accelerate corrosion because they accelerate the cathodic reaction, the acceptance of electrons by hydrogen ions. Conversely, maintaining suitably high hydroxyl ion concentrations in solution in steel systems helps to achieve anodic polarization by the formation of a protective corrosion product film. Low pH also leads to the formation of soluble corrosion products whereas high pH encourages the formation of insoluble and protective corrosion products.

b. Oxygen should be excluded from power plant systems because it tends to depolarize cathodic areas by reaction with the hydrogen film as well as to impair anodic polarization by leading to the formation of unprotective corrosion products. These are important concepts of corrosion and corrosion prevention.

They have a broad range of application in power plant water management.

What are the causes of Specific Corrosion Reactions that Occur in Steam Power Plants?

The following was a general discussion on the nature and causes of corrosion. The following material covers most of the specific causes of specific corrosion reactions that occur in steam power plants:

Oxygen Corrosion

Oxygen can play a major role in the corrosion of power plant equipment. It is one of the most undesirable contaminants which enter a condensate feedwater-boiler water system. It accelerates corrosion by cathodic depolarization and by destroying the passivity of steel or copper surfaces.
De-aerating feedwater heaters are provided to remove oxygen from feedwater to prevent corrosion. Oxygen scavengers such as hydrazine or sodium sulphite are used to remove the trace amounts of oxygen not removed by the de-aerator. Hydrazine is highly reactive with oxygen. Feedwater treatment with hydrazine prevents oxygen from corroding both the feedwater system and the boiler. Sodium sulphite may be added to boiler water to prevent oxygen corrosion.

Carbon Dioxide Corrosion

Carbon dioxide can cause corrosion. Most of the carob dioxide in power plant water is formed inside the evaporators. Heat causes carbonates and bicarbonates in the brine to "breakdown". Carbon dioxide that is formed in this way leaves the evaporator with the steam and causes corrosion of condensate return lines.
The following reactions show the manner in which CO2 is formed by the decomposition of bicarbonate and carbonate.

$NaHCO_3$	Heat	$NaOH + CO_2$
$Na_2CO_3 + H_2$	Heat	$2NaOH + CO_2$

Carbon dioxide gas causes condensate piping corrosion because it forms an acid in water. The following reactions show how carbon dioxide forms carbonic acid in water.
$CO_2 + H_2O \longrightarrow H_2CO_3$

or

$CO_2 + H_2O \longrightarrow H^+ + HCO_3^-$

Note the formation of free hydrogen irons which define an acid condition.

Carbon dioxide in condensate accelerates corrosion in several ways. First, it reduces the pH of the condensate, thereby accelerating the cathodic reaction. Second, at the anode carbon dioxide has other affects. The reduction in pH by the formation of carbonic acid reduces the hydroxyl ion concentration which impairs the formation of protective ferrous hydroxide and magnetic. It also leads to the formation of ferrous bicarbonate which is a highly soluble compound and has not passivating effect. These effects are similar in copper systems.

Acid Corrosion

Acid corrosion (not resulting from the presence of carbon dioxide) can also occur in boilers. When condenser leakage occurs or boiler feedwater becomes contaminated with carryover from the makeup evaporator, one of the major salts that is introduced to the boiler water is magnesium chloride. The composition of seawater was shown in Section I. Magnesium is the second most plentiful cation in seawater and chlorides are the most plentiful anion.

When magnesium chloride enters high temperature boiler water, the magnesium ions react with the phosphates and hydroxyl ions in the boiler water. Magnesium ions are so reactive with hydroxyl ions at high temperature in boiler water that magnesium hydroxide precipitation will occur until the boiler water pH drops to approximately pH - 4.0. This can be prevented by proper boiler water treatment. When the pH value is not carefully controlled, hydroxyl ion concentrations are reduced to low levels. This results in hydrochloric acid attack to the metal surfaces.

$McCl_2 + 2H_2O$ Heat $Mg(OH)_2 + 2HCI$

and

$Fe^{++} + 2HCl$ Heat $Fe(Cl)_2 + H_2$

The presence of deposits on boiler tube surfaces can lead to concentration of hydrochloric acid underneath the deposits. When this occurs the corrosion rates become extremely high and serious damage can occur in a very short time.

Caustic Corrosion

Caustic corrosion or corrosion resulting from the presence of sodium hydroxide can occur in boilers. It was previously stated that maintaining elevated hydroxyl ion concentrations is desirable for both steel and copper surfaces. This is true, but there is a range of conditions (pH values) above which the presence of free hydroxyl ions can be damaging to these materials.

Sodium hydroxide (NaOH) is one of the major chemical additives used in the treatment of boiler water. The purpose of sodium hydroxide is to maintain the hydroxyl ion concentration in the optimum range for the formation of good protective magnetite on steel surfaces. Its other role is to help in the formation of non-adherent sludge instead of scale when hardness enters the boiler water.

Excessive amounts of sodium hydroxide can, however, lead to corrosion. This is particularly true of ultra-high pressure boilers. If there is too much sodium hydroxide present at a steel surface, this chemical can react with the steel to form a soluble material which can then precipitate as a loose, porous magnetite deposit. The following reactions illustrate the manner in which it can occur:

$Fe+2NaOH — Na_2FeO_2+H_2$

$3Na_2FeO_2+4H_2O — 6NaOH+Fe_3O_4$

The normal concentrations of sodium hydroxide maintained in boilers are not harmful. However, it is possible for sodium hydroxide to concentrate in localized areas of boilers, thereby leading to localized corrosion. This occurs when heavy layers of deposits form on the boiler tubing, causing sodium hydroxide to be concentrated under the deposits at the metal surface.

Caustic corrosion can also occur when boiler tube surfaces become steam blanketed because of either excessive boiling or separation of steam and water in horizontal or inclined tubes.

Excessive boiling can result from very high heat transfer rates which can occur when burners are misaligned in a furnace and the flames impinge on the boiler tubing. In this case, boiler water containing sodium hydroxide can splash onto the steam blanketed surface and as the water boils off the sodium hydroxide concentrations can become excessive.

A similar effect sometimes occurs in horizontal or inclined tubing if there is insufficient mass velocity in the tubing to keep the steam and water well mixed. If the water separates and flows along the bottom of the tube and the steam along the top of the tube, water can splash onto the hot dry upper surface. As the liquid boils from the droplet on the hot upper surface, excessive sodium hydroxide concentrations can occur.

Because caustic corrosion is a very significant problem in ultra-high pressure boilers, the ultra marine program eliminated free hydroxide from the boiler water by using the co-ordinated phosphate method of treatment.

Hydrogen Damage

In addition to the foregoing types of boiler corrosion which result in the localized thinning of boiler tubing, ultra-high pressure boilers are susceptible to a form of attack which damages the internal structure of the metal causing it to become brittle. This type of attack is called hydrogen damage.

Hydrogen damage occurs when there is a very rapid corrosion reaction in ultra-high pressure boilers. Hydrogen atoms formed at a cathode are small enough to enter the boiler metal. When they have entered the metal tubing the hydrogen atoms react with the carbon which is normally present. The reaction product of carbon and hydrogen is methane. Methane is a very large gas molecule and it causes internal pressure to form within the metal of steel tubing. These high methane pressures cause grains of steel to separate and eventually cause cracks in the metal tubing.

$C+4H — CH_4$

Hydrogen damaged boiler tubing has been most frequently found after incidents of acid corrosion resulting from seawater condenser leakage and improper pH control of the boiler water. Hydrogen damage has been observed to occur in a matter of hours when acid corrosion is taking place.
One of the most serious aspects of hydrogen is that affected tubing cannot be detected by any method other than removing tubes for metal-lurgical examination. It is, of course, impossible to inspect all of the tubes in a boiler by this technique and as a result boilers are often left with badly damaged and unreliable tubing after repairs of failed tubes have been made. The remaining tubes often fail a few at a time over an extended period.

Ammonia Corrosion

The preceding types of corrosion were discussed with principal reference to boilers in marine steam power plants. Of these, oxygen corrosion and carbon dioxide corrosion are equally important in the condensate and feedwater systems. It was also stated that oxygen and carbon dioxide corrosion are important with regard to both carbon steel and copper system materials. Another important form of corrosion which can affect the copper tubing in a condenser and in feedwater heaters occurs through the presence of excessive amounts of ammonia and oxygen. It was previously discussed that maintaining an elevated pH or free hydroxyl ions is beneficial in maintaining the passivity of copper and copper alloy surface. It was also stated that there is an optimum range of pH control above which corrosion could occur. In general, the best range of pH control for copper alloys is pH = 8.3-9.0.
Ammonia or other amides are used to maintain the optimum pH conditions in condensate and feedwater systems. This can be done by adding ammonia or other compounds directly or by adding slightly more hydrazine than is needed for oxygen scavenging. You will remember that hydrazine reacts with oxygen as follows:
$N_2H_4 + O_2$ — $2H_2O+N_2$
Excess hydrazine that leaves a boiler drum with the steam will decompose at the high temperatures in a superheater by the following reaction.
Heat
$3N_2H_4$ — $4NH_3+N_2$

When the Steam condenses in the surface condenser, the ammonia gas that has formed by decomposition becomes dissolved in the condensate.
$NH_3 + H_2O$ — NH_4OH
or
$NH_3 + H_2O$ — NH_4^{+}+OH-
From the above reaction it can be seen that ammonia is an alkaline material and that it should have the effect of elevating the pH of a solution because it leads to the formation of free hydroxyl ions. When the ammonia causes the formation of only enough free hydroxyl ions to maintain a pH of from 8.3 to 9.0 there is no problem. However, when both oxygen and excessive amounts of ammonia are present corrosion can occur. Oxygen causes protective cuprous oxides to form cupric oxides. Cupric oxides then react with ammonia, forming

copper-ammonium compounds which are extremely soluble. When the protective oxide is removed from the copper surface, the passivity of the surface is destroyed and corrosion can progress very rapidly.

All copper alloys can be corroded by this reaction. The form of corrosion is one of general wastage of pitting under normal circumstances. However, brasses such as admiralty can be caused to crack as a result of corrosion by the combined effects of oxygen and ammonia.

Mechanical Effects

In addition to the types of corrosion resulting from the presence of various chemicals in water, the process of corrosion can also result in the loss of metal in water systems. Erosion is generally considered a mechanical problem whereby a metal surface is worn away by the effects of liquid velocity or turbulence. In reality the loss of metal by this mechanism in a water system is always related to both corrosion and erosion effects because mechanical and chemical factors are both important.

The formation of protective and non-protective oxides was already discussed. Protective oxides prevent corrosion from progressing by forming an insulating layer on a surface. Non-protective oxide films permit the continued progression of corrosion. Protective oxide films such as magnetite and cuprous oxide cannot be easily removed by mechanical effects such as velocity (erosion), whereas non-protective oxide films can be much more easily swept from the surface. We can now recognize that although erosion is principally the designer's problem it can be alleviated by maintaining the water chemistry conditions that produce the most protective oxides.

It is easy to visualize how the erosion-corrosion process occurs. You have all seen hard tightly inherent back iron oxide on steel surfaces covered with loose rust. Velocity can sweep loose rust from a surface exposing bare metal which will corrode further. It is far more difficult for velocity to remove a tightly adherent black magnetic iron oxide film.

What Types of Deposits Form in Marine Steam Power Plants?

There are three types of matter which can form deposits in Steam Power Plants.

Corrosion products on metal surfaces are a form of deposits. They can be formed and remain in place on metal surfaces and eventually become quite thick.

Corrosion products can also be detached from the metal surface where they were formed and can be carried along by the condensate or feedwater as suspended solids. These corrosion products can redeposit in other locations. Iron oxide and copper oxides formed on and released from the surfaces in a condensate and feedwater system usually form deposits in a boiler. Corrosion products can also be released from steel surfaces within a boiler and can be transported to other locations in the boiler by the circulating boiler water. Almost all corrosion products are insoluble in boiler water.

Deposits of insoluble corrosion products can often be found lying in the bottom of drums and headers. In these locations they usually do not lead to any problems. Corrosion products can also deposit on boiler tubing surfaces where they can act as thermal insulation, retarding heat

transfer and thereby causing the boiler tubing to become overheated. Corrosion product deposits lead to the formation of corrosion sites for caustic or acid attack.
Corrosion product deposits are minimized by proper control of pH, oxygen and carbon dioxide.
Calcium and magnesium (hardness) from seawater can form deposits called scale in a number of locations in power plants. Scale is a deposit of minerals that come out of solution on a metal surface.
Scale deposits can form in makeup evaporators. Evaporator brine is made up of concentrated seawater at relatively high temperature.
Scale can form in boilers when makeup water is not pure or when leaks develop in the surface condenser and contamination of the feedwater with hardness occurs. All of the contaminants present in feedwater enter a boiler where without proper boiler water treatment the elevated temperature conditions in the boiler cause the hardness to precipitate as scale.
The types of scale deposition that are usually found aboard ships include the following:
Calcium carbonate is formed from the reaction of calcium with bicarbonates and carbonates at high temperature and elevated pH in the boiler water.
$Ca(HCO_3)_2$ -----> Heat -----> $CaCO_3$+Co_2 +H_2O

Calcium sulphate is remarkable because the solubility decreases rapidly with increasing temperature. Although it is more soluble than calcium carbonate, it can be deposited as scale if the sulphate concentration in the boiler water is high.
Magnesium hydroxide is also produced by decomposition of bicarbonates or carbonates. Magnesium carbonate is not usually found in boiler scale because it is much more soluble than calcium carbonate or magnesium hydroxide.
$MgCO_3 + H_2O$ ----> Heat ----> $Mg(OH)_2 + CO_2$
Calcium silicate and magnesium silicate can be formed when the boiler water contains dissolved silicate. Many different silicate minerals have been found in boiler scales. It is not practical to discuss all the conditions that cause a particular type of silicate scale to be formed. However, like other kinds of boiler scale, silicate scales can be prevented by properly controlled water treatment.
Sludge deposits are formed in boilers by any type of suspended solids that will adhere to a metal surface. This includes suspended corrosion products which we have already discussed. Sludge deposits can also be made up of suspended solids formed by the reaction of calcium and magnesium and boiler water treatment chemicals. If excessive amounts of calcium and magnesium find their way into a boiler; or, if blowdown is not adequate to remove the suspended particles from a boiler, sludge deposits can form. The reaction that form sludge in boilers are as follows:
$3CaCl_2 + 2Na_3PO4$ — $Ca_3(PO_4) + 6NaCl$
$3MgCl_2 + 2Na_3PO4$ — $Mg_3(PO4) + 6NaCl$
$MgCl_2 + 2NaOH$ — $Mg(OH)_2 + 2NaCl$
$5CaCl_2 + 3Na_2HPO_4$ — $4NaOH\ Ca_5(OH)(PO_4)_3 + 10NaCl + 3H_2O$

It is important to understand that no boiler water treatment program can completely prevent the formation of sludge deposits if excessive amounts of hardness are permitted to enter a

boiler over an extended period. Proper boiler water treatment will prevent the formation of scale, prevent corrosion and minimize the formation of sludge deposits. However, chemical treatment is not a complete solution. When contamination feedwater occurs, the problem must be corrected at its source at the earliest possible time.
The causes of makeup water contamination must be found and corrected. Condenser leaks must be stopped. It is as important to increase blowdown rates when contaminated feedwater enters a boiler (to prevent high concentrations of suspended solids from building up and sludge deposits from forming) as it is to maintain the proper chemical residual in a boiler.
Because deposits can lead to both overheating and corrosion problems, it is necessary to clean boilers. In older type boilers it was possible to mechanically clean (turbine) the tubes. In most modern boilers it is impossible to gain access to all of the tubes with mechanical cleaning equipment and chemical cleaning with acids or other solvents is required.
After grease and oil have been removed by an alkaline boilout, new high pressure boilers are usually cleaned with acid to remove mill scale (iron oxide). Boilers that have become dirty in operation require periodic chemical cleaning to prevent problems. The frequency of cleaning, the choice of solvents and the methods of cleaning are determined by the amount and types of deposits to be removed. This portion of the field of water technology is discussed in detail in a number of pages included in the bibliography.

What is Chemical Hideout?

Chemical hideout is a phenomenon that sometimes occurs in boilers. It is characterized by an abnormally fast loss of phosphate residual from the boiler water during normal steaming and the occurrence of a high phosphate residual when a boiler is shut down or operated at a low steaming rate.
Under normal steaming conditions dissolved phosphates in the boiler water precipitate on heat transfer surfaces depleting the concentration in the boiler water. During shutdown or low steaming periods they redissolve causing high concentrations.
Hideout occurs because of the relatively limited solubility of sodium phosphate compounds at high temperature. When boiler tubing is steam blanketed and boiler water splashes on the hot surface sodium phosphate may deposit as a dry salt as the water boils away. In a dirty boiler the same concerning effect of deposits that causes corrosion by some dissolved compounds causes sodium phosphate to concentrate within and under deposits. If the concentrating effect is great enough when hideout is reduced or removed, this salt dissolves in the boiler water.
Hideout is not a desirable condition because it makes boiler water treatment difficult, but there is no evidence that it leads to any serious boiler problems. It is frequently an indication that a boiler is dirty and should be cleaned.

Cathodic Protection

Cathodic protection has been credited with considerable success in this field. Ships equipped with this type of protection may have some or all of their tanks fitted with a number of sacrificial metal anodes. These anodes consist of magnesium or other suitable metals. To

obtain the best results the tanks containing the anodes have to be cleaned so that the steel work is free of grease and oil residue. After cleaning, clean salt water ballast is pumped into the tank until it is full and the tank is left for several days.
The salt water sets up a galvanic couple. Galvanic current attacking the sacrificial anodes conveys a protective coating from the anode to the steel work around it. The anodes waste away and eventually have to be replaced.
Unfortunately, cathodic protection has a number of drawbacks. It is only effective when the tanks containing the anodes are ballasted for a reasonable period of time. Obviously this is not always possible. In certain trades the ballast passage may be of limited duration and in any case work has to go on, tanks have to be cleaned, dirty ballast changed, and so on. Because of this, some ship-owners and tanker companies only fit cathodic protection in the ballast tanks which fall within one of the vessel's regular ballast patterns. To protect the other tanks alternative measures are taken. Sometimes the interior of the tank is sand blasted or shot blasted to clear the interior surfaces of all scale and the special protective paints are applied.
Another factor that must not be overlooked when considering corrosion in oil tankers, is the effect of relatively high humidity or dampness in empty cargo tanks on the ballast passage. Corrosion from this source is considered to be sufficient to justify the installation of a ventilation system, the purpose of which is to pass warm dry air into the cargo tanks. The reduction in humidity automatically results in the reduction of corrosion. Vessels fitted with this type of system report that it is also an excellent means of keeping empty tanks gas free.

Cathodic Protection Systems

There is a balance in nature, dictated by the laws of chemistry, that determines that the most commonly occurring metals are only obtained in the form of their compounds. In addition, once extracted they are sufficiently reactive so that their reversion to compounds is a major problem.
Outstanding among these metals is iron, the base material of industry and its tendency to oxidise in the presence of water, forming rust. Products of iron and mild steels are prone to rusting and the resulting damage costs industry several hundred million pounds per year.
of course in theory it is possible to protect iron against rusting by covering it with an impervious film of paint. But even when this film is truly impervious and is mechanically intact on first application, the rigours of industrial life almost guarantee that, within a short time, there will be enough flaws to allow the ingress of water, air and carbon dioxide to promote rusting.
Rusting is an electrochemical process and it seems reasonable that a remedy using the same principle should be sought. This, in effect, is what cathodic protection is. In its earliest form, cathodic protection was merely a matter of coating iron with a layer of zinc, by processes known as galvanising or sheradising. In the presence of an electrolyte like water with some contaminants, the zinc dissolves more easily than the iron and is thus preferentially corroded. Protection is afforded by the zinc even when the film is broken thus it is superior to paint finishes.

This is in theory the situation but zinc coating is not as effective in certain circumstances as the chemistry text-books would suggest. Partly, this is due to the uncertain environments that iron and steel structures are expected to withstand and because once mechanical wear has produced a large bare patch on the iron substrate the local bimetallic couple is no longer effective.

Developments in cathodic protection have taken two distinct lines. First, greater use is being made of metals which are much more electronegative than the base material (in the case of iron, aluminium and magnesium have been found to proved better protection that zinc in many cases) and impressed current systems setting up a flow of electricity opposing that naturally generated by the two metals, have been developed.

Metal Corrosion

Each of these systems has its advantages, especially when the full range of metal corrosion is considered. In industry, it is common to find copper pipes leading directly to an iron or steel storage tank or chamber. The presence of an electrolyte, which can simply be rainwater, a very dilute carbonic acid, is enough to start electrolyte action leading to corrosion and subsequent failure of the joint.

In both areas of protection the emphasis has been on developing new materials for the anodes and improving their mechanical characteristics. Among the additional materials that are now being used are, according to Dr D Davies of the appropriately named Cathodic Protection Company, magnesium and aluminium, often with additional Cadmium or silicon to replace zinc sacrificial anodes. There has always been a tendency towards increasing use of magnesium in pipeline protection, where the nature of the installation makes it economic to use a more expensive material if maintenance can be reduced.

Current Systems

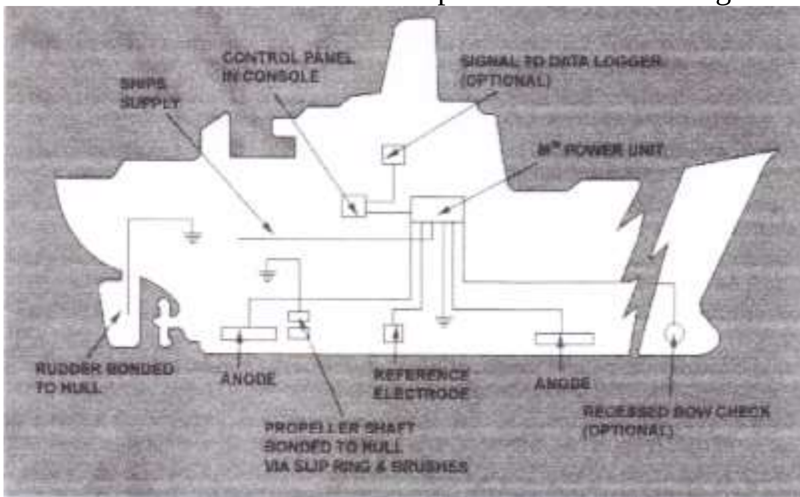
Impressed current systems have been moving gradually towards better materials and increased efficiency. Diodes of silicon have superseded selenium in some applications and although these must be protected against static discharge, the changeover is generally justified in terms of cost. One advantage with these devices, of course, is that they can be used at high temperatures and are therefore, suitable for process plants of different kinds.

Cathodic protection is applied to most major structures where materials (metals) are exposed to adverse conditions where electrolytic action is likely to take place. Although they require a power supply, the demand is low and compared with other methods of protection the maintenance cost is small.

But, there is one potential drawback which follows as a natural corollary of the system and that is, it is as harmful to supply too large a current as it is to supply too little. Changes in temperatures, surface conditions of the metals and conductivity of the electrolyte demand that the current, and therefore the potential difference, should be changed.

It is for this reason that there has been a move towards automation in recent years, where conditions are automatically monitored and the power supply regulated to match them exactly through, for example, thyristor control system.

Automated systems of this kind are particularly applied to ships and power stations and are being used on a modest scale in these fields.
But recently cathodic protection has moved beyond the narrowly defined areas of metal corrosion and has moved into the protection of metals against other forms of attack.



Deposition of dissolved salts in boiler tubes from hard water supplies can now be prevented by using an appropriate electro-chemical treatment rather than the better established ion exchange system. Despite the power supply necessary for these installations, there is little to choose in terms of economy between the two, while an electrolyte system is usually cheaper to install.
Anti-fouling systems, depending on the electrical dispersal of metallic ions in the water around a metallic structure, have also been found to be effective and this principle has also been applied to inhibiting the growth of algae around power station outfalls.

Neglect Of Cathodic Protection Now Rectified

One of the most surprising aspects of cathodic protection is the way in which it has been neglected by industry for so many years. To revert to rusting iron, as far back as 1906, Chambers' Technological and Scientific Dictionary was explaining the phenomenon in terms of electrode potential and it would have seemed reasonable that an electrical solution would have been more eagerly sought and when found adopted.
Fortunately this situation has now been rectified and the technique is now being widely enough used to ensure that there will be even further development of anode materials and construction. In conjunction with these, growing interest in automatic control and a more exact knowledge of corrosion phenomena should continue to reduce the immense damage to industrial installations caused every year by nothing more lethal than water and fresh air.

3.4 Testing

Tensile Testing Machine Tests (Destructive)

The test consists of subjecting a test piece to a tensile pull which is increased until failure occurs. A beam carried a sliding weight. The arm is balanced on a fulcrum by hydraulic pressure. As W is gradually moved out and the beam tends to fall, the hydraulic pressure stabilises it. An extensometer is fitted to a predetermined gauge length on the specimen. As the load increases the extension can be found from the extensometer. Note that the extensometer is usually only used within the elastic limit and the extensometer should be removed before the elastic limit is reached to prevent damage.
The results usually recorded are:-
(i) Ultimate Tensile Strength (UTS) =
Maximum Load
Original C S A
(II) Elongation as a percentage of stated test piece length.
Readings are for comparison purposes only.

Hardness (Brinell)

A hardened steel ball of known diameter is applied to the specimen under a known loading for a period of 1 second.
The diameter of the impression resulting in the specimen is measured with a microscope. Hardness is indicated by the Brinell Number, derived by dividing the applied load in kilogrammes by the spherical area of the impression in square millimetres. The harder the material, the smaller the impression and consequently the higher the Brinell number. To keep the relationship between load P, diameter D and the impression produced within limits, for different materials, different P/D2 ratios are used. The following are approximate Brinell numbers, for the stated material.

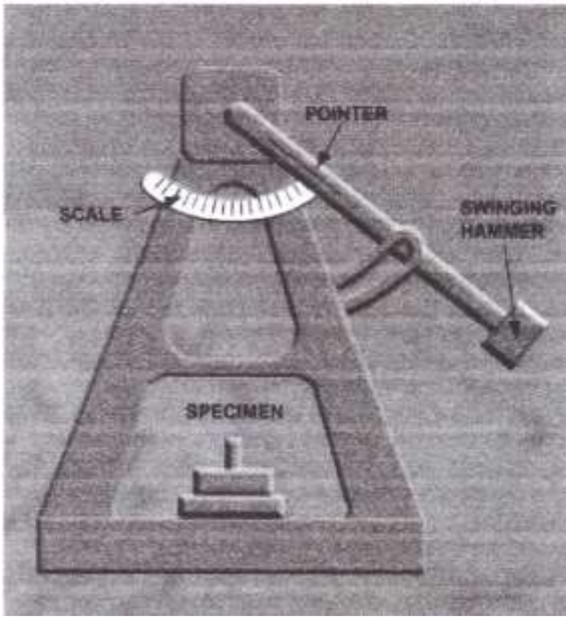
<u>**Material**</u>

<u>**Brinell Hardness Number**</u>

Bronze (Chill Cast)	32
Brass	60
Gunmetal	70 - 75
Mild Steel	110 - 130
Carbon Steel	150 - 200
Cast Iron	400

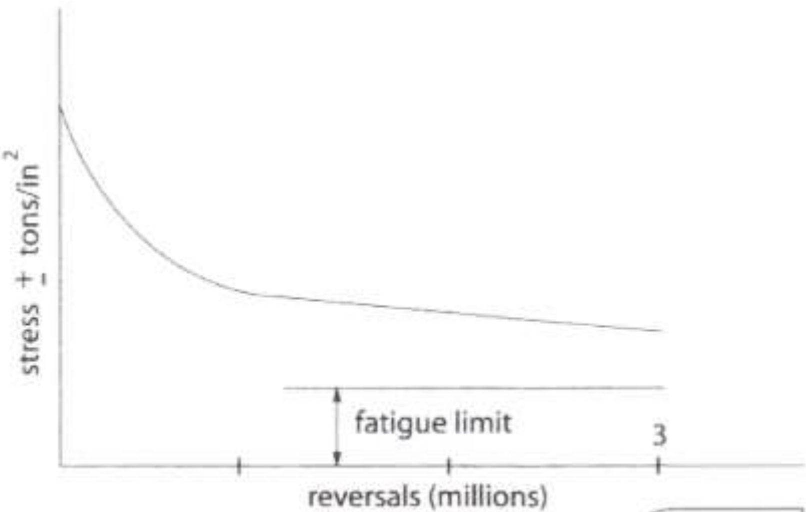
Impact (IZOD)

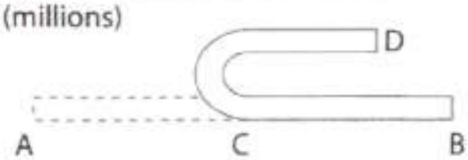
The specimen, which is notched to ensure breakage at the required part, is held in a vice. The swinging weight is released and allowed to break the specimen. Some of the KE of the weight is thus lost as a result of which it does not rise to its original height on the back swing. The difference in height is noted by the slack counter on the scale and read off in ft lbs.



Bend

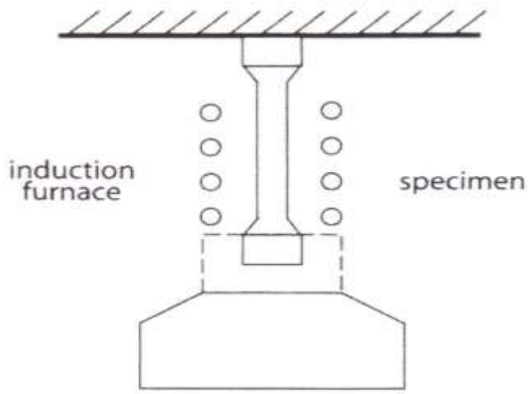
There are variations of bend and reverse bend tests. One of the most popular is the 180° bend test. The specimen Ab is bent by steadily applied pressure through 180° over a former of specified radius till the legs of the test piece are parallel, i.e. A is in position shown by D. The specimen is taken to have passed the test if free from cracks on the convex surface.

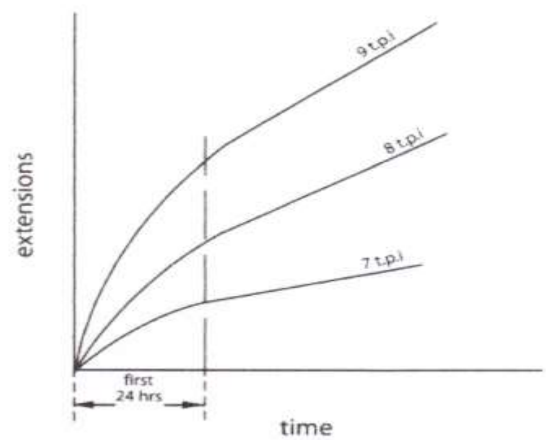




Creep (Barr-Badgett, Bailey)

Creep is the flow plastic deformation of metals under a constant stress. The need to consider this, arises when materials are under load at high temperatures





The specimens are tested in a battery or rigs at the same temperature but under different stresses. From the information obtained graphs are drawn which indicate the performance of the material under working conditions.
The creep value may be given as:

i. percentage elongation for given stress at a given temperature in a given time,
ii. Stress required to cause a maximum permissible creep strain of 0.001 in 100,000 hrs.

(10-8 hour)

Non-Destructive Testing

Several methods of non-destructive testing are now employed fairly extensively in the production of engineering materials. Each test has its own particular value (one test may show a defect which another may not), consequently care has to be taken that the test or tests will show likely defects. The tests will now be briefly explained.

Radiography

(a) X Radiography

In this test rays of electrons from a high voltage source are passed through the specimen and record the intensity of distribution of photographic material in the form of a shadow picture. Defects in the specimen can be seen by inspection of the picture. The required voltage depends on the type and thickness of material and varies from 10KV to 5000KV. A portable 10KV set can be used to inspect steel from about ?" thick to 1½" thick depending on the technique used. The exposure time is approximately two minutes.

(b) Gamma Radiography

In this case the rays from radio-active substance are used in a similar manner to the above. The substances produces from industrial use are cobalt, tantalum and iridium. In general gamma rays are used when the thickness of metal is great or where castings are in any way complicated. The advantages over X rays are that parts of varying thickness may be shown in one radiograph and that the technique is much simpler. The disadvantages are that the time of exposure is greater and that the results produced are generally inferior to those by X ray. Great care must be taken with the radio active source, all non essential personnel cleared from the test area.

Ultrasonics

The specimen under test has sound waves of a frequency well above the audible range introduced into it. A flaw in the material results in the distortion of the sound waves which are transmitted and received in a probe containing a single crystal. The apparatus is most effective when the flow is perpendicular to the plane of transmission of sound waves. Close grained materials such as the result due to forging, rolling, etc., show the most satisfactory result.

Forgings of up to 30' thick can be examined by this method against a maximum of about 10 by X and gamma rays.

Magnetic Testing

Surface defects in materials which can be magnetised, not visible to the eye, may be shown up by this method. The area to be examined, if not smooth is painted a light colour. A magnetic field is set up by means of a permanent or electro magnet. Black magnetic ink is sprayed on and is attracted to any surface crack which then becomes clearly indicated.

Penetrant Methods For Surface Defects

This is a modern variation of the "oil and chalk" test. The material is subjected to a prolonged soaking by a fluorescent oil. The excess oil is cleaned off. The oil contained in any surface crack emerges and is made visible by the discoloration of whitewash applied after cleaning or by illumination by ultraviolet light.

Non magnetic material such as copper, aluminium, etc, can be tested for cracks by using Eddy Currents. This involves the generation of small localised electrical high frequency currents past beneath the surface of the tube or bar. Search coils of copper wire pick up residual eddy currents and compare them with a standard specimen.

3.5 Synthetic Materials

Plastics And Rubbers

It is very difficult to draw a clear-cut distinction between those polymers known as plastics and those known as rubbers. Natural rubber, of course, is very readily distinguished from other polymers because of its distinctive origins and structure. However, many synthetics are known variously as plastics or rubbers. The distinction is clarified to some extent if the concept of an elastomer is introduced. An elastomer is a material that can be repeatedly stretched to at least twice its original length and, upon release, return to its original length. Rubbers, unless highly vulcanised, are elastomeric materials, while that group of polymeric materials termed "plastics" are commonly rigid or semi-rigid in character.

Thermosetting And Thermoplastic Polymers

Plastic materials all soften when first heated, being shaped by one means or another while in this soft state. However, a fundamental distinction can be made on the basis of their behaviour upon cooling and subsequent reheating.
Thermosetting plastics harden quickly while in the soft state, the curing process usually being assisted by pressure. These plastic materials cannot be softened and reworked once this curing process has gone to completion.
Thermoplastics, on the other hand, only set when the temperature is lowered below a certain limit and may be softened and reworked by reheating to a suitable temperature. Thus, thermoplastics are reclaimable while thermosetting plastics are not.

Properties Of Polymers

The following properties are typical of "solid" plastics:

- Low specific gravities
- Good thermal and electrical resistance
- Good surface finish direct from the forming dies
- Availability in a wide colour range or transparent if required
- Low strengths compared to metals
- Unsuitable for service conditions where temperatures in excess of several hundred degrees centigrade exist
- Poor to fair dimensional stability, particularly in moist conditions.

Natural And Synthetic Rubbers

Natural rubber is a polymer of a single material called isoprene and it exists in certain trees and plants as a colloidal dispersion in the milky liquid known as rubber latex. Crude rubber, often called "crepe rubber", is produced when the latex is coagulated by acetic acid, the resulting spongy mass passes through rollers which form the material into a sheet. This crude rubber must be further processed by the addition of fillers, plasticisers and pigments before it is in a form suitable for industry and even then the processed rubber is usually vulcanised before going into service.
Unvulcanised rubber is susceptible to attack by vegetable and mineral oils, petrol, benzene, carbon tetrachloride, nitric acid, strong sulphuric acid and other common industrial solvents. Vulcanised rubber has a greater chemical resistance to all these reagents, such resistance generally increasing with the amount of sulphur added.

Synthetic Rubbers

Because rubber must be imported from distant countries, much time and energy has been expended in the development of synthetic rubbers, several of which are of commercial importance today. While most synthetic rubbers are distinctly inferior to natural rubbers, several are intentionally different, possessing certain important properties which makes them important for specific applications.
The following list includes some of the most important synthetic rubbers:
Neoprene:(polychloroprene), closely related chemically to natural rubber, but possesses superior resistance to oils and greases. It is used for hoses, oil seals and gaskets which are in contact with mineral and vegetable oils or petroleum.
Styrene Rubber:(Buna-S or GR-s), produced by the copolymerization of styrene and butadiene and has similar though somewhat inferior properties to natural rubber. It was developed during World War II and largely replaced natural rubber at that time.
Polyisoprene:appears to have the same molecular structure as natural rubber, consequently possesses similar properties and has similar uses.
Polyurethanes: high resistance to many organic solvents, susceptible to acid and alkali attack and good elastic properties; very suitable for the manufacture of expanded flexible foams.

The Joining of Materials

Welding Processes

Submerged Arc Weldings

This is an arc welding process in which the arc is maintained with a blanket of granulated flux. A consumable filler wire is employed and the arc is maintained between this wire and the parent plate. Around the arc the granulated flux breaks down and provides some gases and a highly protective thermally insulating molten container for the arc. This allows a high

concentration of heat, making the process very efficient and suitable for heavy deposits at fast speeds. After welding the molten metal is protected by a layer of fused flux which together with the unfused flux may be recovered before cooling.
The process is basically only intended for down hand applications and where it is used for single pass welding of any size it is essential to use some form of backing bar because of the comparatively large weld pool obtained. Here the backing bar may be of copper and waste cooled or a flux trough may be provided to form the underbead.

Tungsten Inert Gas Welding (TIG)

In the TIG welding process the arc is drawn between a watercooled non-consumable tungsten electrode and the plate. An inert gas shield is provided to protect the weld metal from the atmosphere and filler metal may be added to the weld pool as required. Ignition of the arc is obtained by means of a high frequency discharge across the gap since it is not advisable to strike an arc on the plate with the tungsten electrode. Normally in Britain the inert gas shield used for welding aluminium and steel is argon. Only plate thickness of less than 6mm would normally be welded by this process, and in particular aluminium sheet, a skilled operator being required for manual work.
Metal Inert Gas Welding (MIG)
This is in effect an extension of TIG welding and electrode in this process becoming a consumable metal wire.
Basically the process consists of a wire feed motor supplying wire via guide rollers through a contact tube in the torch to the arc. An inert gas is supplied to the torch to shield the arc, the electrical connections are made to the content tube and workpiece. Welding is almost always done with a D.C. source and electrode positive for regular metal transfer and when welding aluminium to remove the oxide film by the action of the arc cathode. Although the process may be fully automatic, semi-automatic processes as illustrated with hand gun are now in greater use and are particularly suitable in many cases for application to shipyard work.
Initially aluminium accounted for most of the MIG welding, the argon being used as the inert shielding gas. Much of the welding undertaken on aluminium deckhouses, and liquid methane gas tanks of specialised carriers, has made use of the process. Generally larger wire sizes and heavier current have been employed in this work, metal transfer in the arch being by means of a spray transfer, that is metal droplets being projected at high speed across the arc.
Early work on the welding of mild steel with the metal inert gas process made use of argon as a shielding gas; but as this gas is rather expensive, the satisfactory welding could only be accomplished in the downhand position, an alternative shielding gas was sought. Research in this direction was concentrated on the use of CO_2 as the shielding gas and the MIG/CO_2 process is now widely used for welding mild steel. Using higher current values with thicker steel plate a fine spray transfer of the metal from the electrode across the arc is achieved, with a deep penetration. Wire diameters in excess of 1.6mm are used and currents above about 350 amps are required to obtain this form of transfer. Much of the higher current work

is undertaken with automatic machines, but some semi-automatic torches are available to operate in this range in the hands of skilled welders. Welding is downhand only.

Classification And Coding Of Manual Metal Arch Welding Electrode

In order that the electrodes from different manufacturers may be identified as certain types, a code for classification of electrodes was prepared BS 1719.
The code is made up as follows:

Prefix Letter

This may be either:

- E - Solid Extrusion
- R - Extruded with Re-inforcing
- D - Dipped

and denotes the method of manufacture. If more than one method used the coding is according to the predominant method.

Type of Flux Covering: 1st Digit

This digit, the 'hundreds' digit, indicates the type of coating and therefore gives some idea of the operating characteristics.

1st DIGIT	TYPE OF COVERING
1	High cellulose content
2	High titanium dioxide (titania) producing a fairly viscous slag
3	Appreciable amount of titanium dioxide producing a fluid slag
4	High iron or manganese silicate oxide content producing an inflated slag
5	High iron or manganese silicate oxide content producing a heavy solid slag
6	Based on calcium carbonate and fluoride
9	A covering not based on any of the above

Welding Position: 2nd Digit

This digit, the 'tens' digit, indicates the welding position for which the electrode is suitable.

2nd Digit Welding Positions

0 - F, H, V, D, O
1 - F, H, V, O
2 - F, H
3 - F
4 - F, H (Fillet Weld Only)
9 - Not classified above.

When the electrode is coded as suitable for vertical and overhead positions, it should be understood that sizes larger than 6 S.W.G. (or 8 S.W.G. for iron power electrodes) are not normally used for welding in these positions.
Welding Current and Voltage Conditions: 3rd Digit
This digit, the 'units' digit, indicated the recommended operating characteristics.

Digit Welding Current And Voltage Conditions

0 - D+
1 - D + a90
2 - D - A70
3 - D + A50
4 - D ± A70
5 - D ± A90
6 - D ± A70
7 - D ± A50
9 - Not classified above

Special Characteristics: Suffixes

In the coding of an electrode with special characteristics a suffix letter, as defined below, is used.

Suffix Definition

P - Deep penetration electrodes as specified in BS 5639 'Covered Electrodes for the Metal Arc Welding of Mild Steel'
H - Hydrogen - controlled electrodes
J - Iron power electrodes with a metal recovery of 110 to 130% of the core wire weight
K - Iron powder electrodes with a metal recovery of more than 130% of the core wire weight.

Jointing Types

Compressed Asbestos Fibre

Used for superheated and saturated steam, gases, alkalis, mild acids, oils, solvents and most chemicals.

Nitrile bound Compressed Asbestos Fibre

Used for oils, solvents and petrols. Used in refineries as it is resistant to aromatic hydrocarbons.

Wire Reinforced Compressed Asbestos Fibre usually with a Graphite Surface

Used for areas of sever physical conditions where high temperatures and pressures exist. Suitable for diesel exhaust manifolds and cylinder head joints where vibration can be a problem.

Cork - Rubber Jointing

Hard Types

Used for petroleum fuels, oils and lubricants

Medium Hardness Types

Used for solvents, greases, oils refrigerants, coolants, water and air as well as lubricating and numeral oils.

Soft Types

Used in a wide range of general purpose applications including minor automotive Rocker cover joints

Non Asbestos Compressed Fibre Jointing

This jointing is used where asbestos in any form is acceptable and would be used for sealing against steam, water, oils, gases, dilute acids and alkalis. It can also be provided with a fine steel mesh for applications requiring greater strength.

Spiral Wound Gaskets

These gaskets are built up from a continuous spiral of specially formed stainless steel strip with alternate plus layers of non metallic filler, usually compressed asbestos fibre. Their inherent resilience enables them to maintain a seal at high fluctuating temperatures and pressures and to accommodate slight flange distortions during service.

For pressures over 64 bar it is recommended that stainless steel inner rings should be specified. The inner ring also reduces turbulence in the pipe system, by virtually eliminating the cavity between flange faces and the bore of a standard gasket.

Applications

These gaskets are particularly suitable for use in complex equipment in petroleum gas and chemical industries and also in the marine environment. They may be used with water, steam, oil solvents and the majority of chemicals likely to be encountered in these areas.
They are particularly useful in areas where high temperatures and pressures may be encountered.

P.T.F.E.

The extraordinary characteristics of P.T.F.E. have already been used in many applications. It can replace materials such as asbestos, glass, ceramic and rubber for some applications.
Temperature Range: 240°C to + 315°C
Operating Pressure:- Vacuum to 210 bar.
Factors which affect Sealing Characteristics
To enable a gasket to accommodate unevenness and surface roughness, it needs to be compressible within the contours resolved. At high temperatures not only is there a reduction in the force exerted by the clamping bolts, due to thermal expansion, but also the polymeric binding of the gasket material undergoes a chemical change and the gasket relaxes. These processes must not reduce the pressure between the gasket and the surface to which it is sealing as the gasket can be damaged by the internal pressure. This property of a gasket is determined by the British Standards Relaxation Test.

Flanged Joints

The fitting of flanges to a pipe provide a convenient method of joining two pieces of pipe together. The type of fluid being transported in the pipe and the pressure and temperature of that fluid can vary and the main restriction being materials available.
Flanges also provide a convenient method of making the pipeline more easily repairable by breaking into shorter sections. It is also more easily constructed if it follows a complex route. The size of the flange and number of bolts in the flange are dependent on the pipe diameter and internal pressure of the pipe, although temperature may also have to be considered. The larger the pipe diameter and higher the pressure the greater number of bolts required to hold the flanges together.

Compression Couplings

Compression couplings provide a convenient method of joining relatively small diameter pipes. The olives in the coupling provide the seal by deforming into the pipe under the

compressing load applied to it. There is therefore no need for any other jointing providing sufficient care has been taken with the original installation.
Compression couplings are used in a wide variety of applications from relatively low pressure domestic water systems (3 bar) to high pressure hydraulic systems (200 bar).

Soft Soldering

If two pieces of metal are to be soft soldered together they must first of all be thoroughly cleaned of all scale and dirt and then a suitable flux brushed along the joint. The pieces are then heated and some molten solder is run into the joint by one means or another. In the case of lead-tin solders a copper soldering bit is usually used to heat the work, to melt the solder and then to apply it to the joint. However, solder may also be applied using a heating torch such as those run by propane or other LP gases. All soft solders have the following general properties.
They have melting points considerably lower than those of the metals being joined,
They readily "wet" the surfaces of the joint and then flow freely into the joint by capillary action,
They form a sound and well-attached fill within the joint, and,
They have adequate mechanical strengths.
The structure of the soldered joint will vary depending upon the type of metal being soldered and the composition of the solder itself. However most soldered joints reveal some surface alloying between the film of solder and the metal being joined, the actual amount of such surface alloying depending upon the solubilities of the metals involved. If the surface alloying results in a gradual change in structure and composition from the parent metal into the solder film and then back into the parent metal again the joint will be a strong one.
While the lead-tin solders are most commonly used for soft soldering, lead-antimony solders are also in use; such "antimonial" solders are less expensive than the lead-tin but cannot be used on galvanised iron.

Functions Of Fluxes

Continuity of grain structure across a soldered or welded joint can only be obtained if the metals are brought into atomic contact, and this is not possible if the metals are coated with oxide layers, grease, corrosion products or other surface films. Mechanical cleaning can only remove the bulk of such surface films, some form of chemical cleaning being necessary to complete the cleaning operation. Fluxes perform some or all of the following functions:
They chemically clean the surfaces to be joined,
They prevent the formation of new oxide layers during the heating cycle of the joining process,
They assist the filler metal to run freely into the joint, and
They assist the "wetting" process by which surfaces alloying occurs.

Brazing

Brazing is also know as "hard soldering" since it is done with solders of considerably higher melting points than those of the soft solders and also because the joints formed are harder and stronger than soft soldering joints. The solder, or spelter as it is commonly known, is melted directly into the joint using a propane or oxyacetylene flame.

Brazing Alloys are Classified as:

Silver Solders: Commonly silver-copper-zinc alloys with or without in the range 600-800°C.
Brazing Brasses (or spelters): These are copper-zinc alloys varying from about 50-60% copper and may contain up to 2% tin. They melt in the range 850-900°C.
Phosphorus-bearing Brazing Alloy: These are usually self-fluxing alloys that usually contain at least 75% copper and between 4-8% phosphorous.

Welding

Gas Welding

Oxy-acetylene is most commonly used giving a temperature of 2000 to 2500°C. The oxygen is supplied in "black" cylinders at a pressure of 120 atmospheres. The acetylene is supplied in "red" cylinders at a pressure of 15 atmospheres. The cylinder contains acetone in which acetylene dissolves readily. To ensure even distribution of the acetylene in the acetone a cellular filling is given to the cylinder using KAPOK fibre.
The regulator contains two pressure gauges. The gas passes through the first gauge and shows the pressure in the cylinder, then through a reducing valve, the reduced pressure being shown on the second gauge. The reducing valve is in two stages the first being automatically controlled, the second being hand regulated.
The oxygen hoses are black and all oxygen connections have right hand threads. The acetylene hoses are red and all acetylene connections have left threads.

Flame Cutting

Metals can be flame cut using an oxy-acetylene system and a special cutting torch. The edge of the plate is heated in the normal way to an incandescent state or ignition point. A trigger valve in the torch then introduced a jet of pure oxygen at 25 to 40 lbf/in2. Violent oxidation occurs and a narrow groove is formed, the force of the jet blowing cut the burnt metal in a shower of sparks.

Cast Iron Welding

In the following notes the term 'cast iron' will be taken to mean 'grey cast iron', as this is the type of cast iron most commonly encountered in repair situations.
Cast iron, when welded, is liable to failure by cracking. This is due to its low ductability together with its high coefficient of expansion and contraction. The material has a high

carbon content and a rapid rate of cooling will cause hard brittle structure to form which can also cause cracking and can make subsequent machining of the weld impossible.
Therefore, to reduce the stresses due to expansion and contraction and to overcome the hardening effect, castings, where possible, should be pre-heated and slowly cooled after welding.
Where pre-heating is not possible due to the size or situation of the casting, the heat input to the joint should be kept to a minimum by the use of special welding techniques.

Titanium Alloys

In terms of its occurrence in the Earth's Crust titanium is a relatively abundant metal and, of the engineering metals, only aluminium, iron and magnesium are more plentiful. The amount of titanium ore within the range of mining operations is about one hundred times greater than that of copper. However, the very high affinity of titanium for both oxygen and nitrogen makes it difficult to extract whilst the molten metal itself reacts with all known refractories. Thus titanium is an expensive metal because of its cost of extraction and forming rather than any scarcity of its ores.
High-purity titanium has a relatively low tensile strength (216 N/mm2) and a high ductility (50%) but the strength can be raised considerably by alloying. It is a polymorphic element. The a phase (CPH) transforms on heating to 882.5°C to (BCC) (Fig 11.7 (i)) and this change-point is affected by alloying as is the A3 point in iron. Thus alloying elements which have a greater solubility than it tend to stabilise over a wider range of temperatures (Fig. 11.7 (III) and (iv)).They include the transition metals iron, chromium, molybdenum, etc. Alloys represented by a phase diagram of the type (iv) can be precipitation hardened as might be expected with a diagram of this form (7.5.2.1). A typical titanium-base alloy IMI 700 (6 Al; 5Zr; 3Mo; 1Cu) attains a tensile strength of 1540 N/mm2.

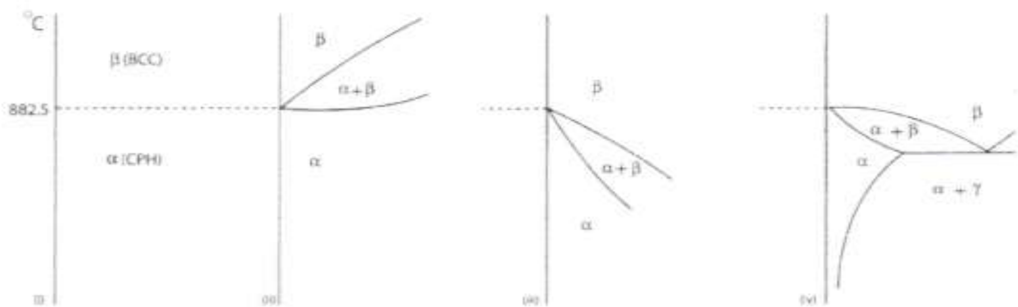


Fig. 11.7 - Effects of alloying on the α ⟷ β transformation temperature in titanium.

Fig 11.7 - Effects of alloying on the α β transformation temperature in titanium.The relative density of titanium is only 4.5 and suitable alloys based on it have a high specific strength. Moreover creep properties up to 500°C are very satisfactory whilst the fatigue limit is also high. Titanium alloys therefore find application in the compressors of jet engines. In turbine engineering generally titanium alloys, being of low relative density, impose much lower centrifugal stresses on rotors and discs for a given blade size. Titanium alloys are also very

resistant to erosion by wet steam and other media so that steam turbo-generators, gas turbines and condenser tubing all make use of these alloys.
Because of the high specific strength, high temperature resistance and good corrosion resistance generally, many titanium alloys find use in supersonic aircraft - including "Concorde" - as structural forgings. Such an alloy is IMI Ti680 (11 Sn; 2.25 al; 4 Mo: 0.2 Si) which develops a strength of 1300 N/mm2.

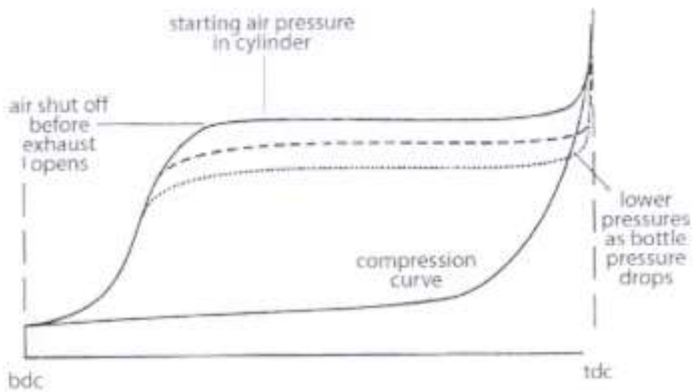
1.3 OPERATION, SURVILLANCE, PERFORMANCE, ASSESMENT AND MAINTENANCE SAFETY OF PROPULSION PLANT AND AUXILIARY MACHINERY. Practical Knowledge

1.3.1 START UP AND SHUT DOWN MAIN AND AUXILIARY MACHINERY, INCLUDING ASSOCIATED SYSTEMS.

.1 Main machinery and associated systems

There are several methods of starting a diesel engine, including manual, electrical and mechanical devices. The techniques used on a particular engine depend largely on its size, design and service requirements. Small diesels, such as those employed in lifeboats etc, may be hand, or perhaps electrically, started. In main propulsion engines, or even diesel generators, such methods are unable to supply the substantial torque required to overcome the inertia of the large masses involved. These engines usually employ a system using the energy stored in compressed air.
Where the main engine is of the direct drive reversible type, it is essential that it is capable of starting in either direction from any position of rest. To achieve this, it is necessary for each cylinder to be fitted with a starting air valve, the opening of which is dictated by a ‘distributor’. This distributor ensures that air is introduced into the relevant cylinder at the correct time to achieve starting in the desired direction from any position of rest. There will be an overlap period during which two cylinders, at the extremities of their air injection periods, will both receive air. This ensures positive starting in the correct direction. (The starting sequence is the same as the firing order for the engine.) The amount of overlap is dependent upon the number of cylinders, the timing of the exhaust opening and so on. (The greater the number of cylinders, the less overlap required.)
Modern practice is to introduce air into the cylinder slightly before Top Dead Centre (tdc). (The alignment of piston rod with con rod at this point is such that little, if any, turning moment is developed.) This allows the air to accumulate in the clearance volume ready to force down the piston once it is over tdc. At the same time, another cylinder will be receiving air (because of the overlap). This unit will be one in which the crank is well past tdc so that it generates an adequate turning moment to carry the above unit over tdc. The first unit, already pressurised, will be able to accelerate the engine up to the ‘fuel initiation’ speed. The useful expansion of the starting air will cease at the opening of the exhaust. To continue air injection any further would be wasteful and futile. This limit is normal to 3-cylinder engines but is unnecessarily long in engines with more than three units.

The starting air pressure is well below the compression pressure of the engine but it will be able to turn the engine over against the compression because the compression pressure is only reached towards the end of the stroke, whereas starting air is introduced for a much longer period of the stroke. The starting air ‘indicator’ diagram, (below) shows that there is a far greater energy release below the starting air curve than that required to achieve the compression. Areas below the curves represent, to scale, the energy involved in the relevant operation.



The momentum built up in the rotating elements of the crankshaft will help in smooth starting once the initial inertia has been overcome.

Reversibility can be achieved by introducing air into a cylinder where the piston is approaching tdc, in the direction of rotation in which it was stopped. Exactly the same concepts as discussed above then apply, but in the reverse firing order. Control can be achieved through the distributor or by varying the position of the starting air cams (sliding camshaft, usually independent of the fuel pump camshaft). Lost motion clutches had some bearing on the distributor on some engines but the advent of constant pressure turbocharging has led to radical simplification in the design of lost motion clutches.

Where the starting air system is concerned, the following features are usually considered desirable:

1. Between the engine and the starting air receiver there should be a robust and effective non-return valve. This valve should be situated as close to the engine manifold as is practically possible, so that any explosion in the starting air manifold is contained in as small a length of piping as possible, and should be prevented from getting back to the air bottles.

2. Locating the valve close to the engine limits the distance travelled and hence the build up in speed of the explosive wave that would otherwise occur as the wave front travels down the pipeline seeking out oxygen and fuel. This high velocity wave front has been responsible in the past for destroying pipelines and valves. It must therefore be contained to as small a range as possible.

3. Between the above non-return valve and the cylinder valves some form of relief should be fitted (to disperse the forces of an explosion as quickly as possible). These devices may take the form of:

(a) an ordinary spring-loaded relief valve(s).

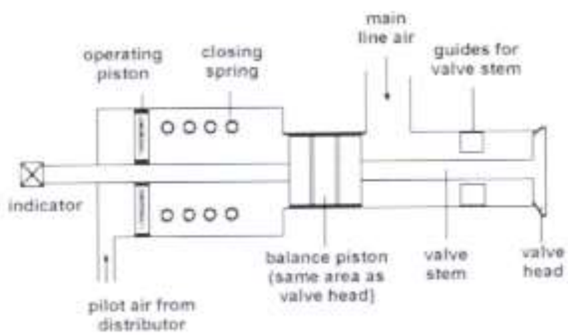
These are open to maltreatment and misjudgement so they may not operate adequately when needed.

(b) bursting disc caps.

These are relatively tamper proof provided that the correct materials and replacement caps are used. They do vent the manifold completely and, unlike the above relief valve, which resets once the pressure has dropped, require some form of blanking off if the engine is to be started again. For this reason, it is usual for several caps to be fitted to the engine (one per unit), unlike the relief valve where one or two valves are the norm.

(c) quick closing valves (air operated).

These are not very common, but are built in such a way that they are rapid in action and virtually tamper proof. They operate on the differential area principle. One side of a piston-like assembly sits against the air manifold; the other end, slightly larger in diameter, is pressurised directly from the air receivers. Should the manifold pressure rise, the 'valve' is blown open and the manifold vented, once the pressure drops the pilot air from the receiver closes the valve again by working on the bigger area. Such an arrangement allows pressure release and then immediate recovery of the air starting system.



4. For each unit there is a cylinder valve, a simplistic design of which is show above. Note the following in the figure:

(a) the 'mushroom' head and balance piston, of the same nominal diameter, so that the main line air simultaneously acting on both faces hold the valve in balance rather than forcing the valve open.

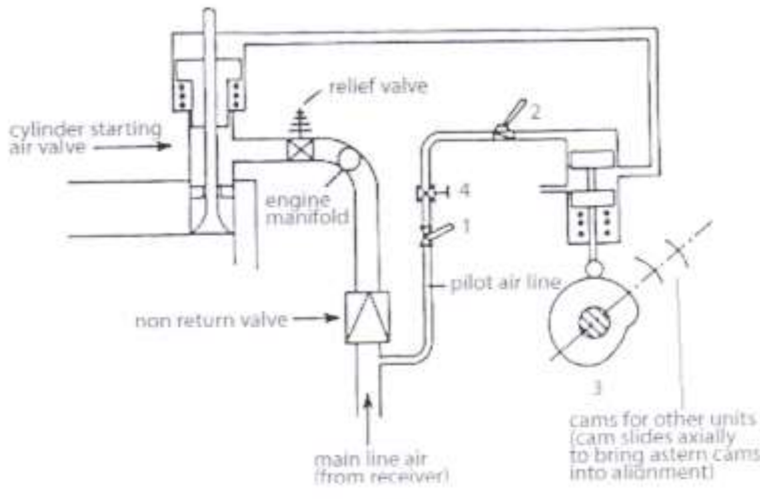
(b) the guide on the stem, which ensures correct alignment and reseating as the valve closes.

(c) The spring incorporated to close and hold closed the valve.

(d) The power piston, of such dimensions that, on the introduction of pilot air, the valve is rapidly opened again spring pressure (and cylinder pressure).

(e) Spindle, which indicates the position of the valve and may be turned to help close a 'sticky' valve.

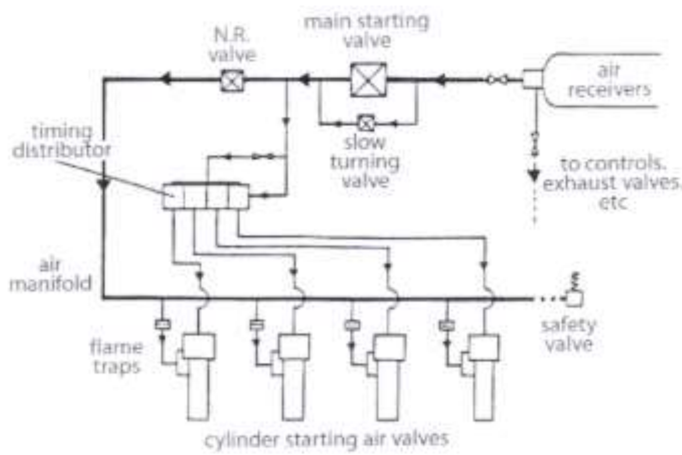
To ensure that the cylinder valves open in the correct sequence, a distributor is required. The distributor provides the air start timing with correct overlap whether going ahead of astern. Distributors may be cylindrical or circular discs both suitably ported, or radially distributed spool type valves aligned above a laterally sliding independent cam shaft. A schematic of a starting air system is shown below.

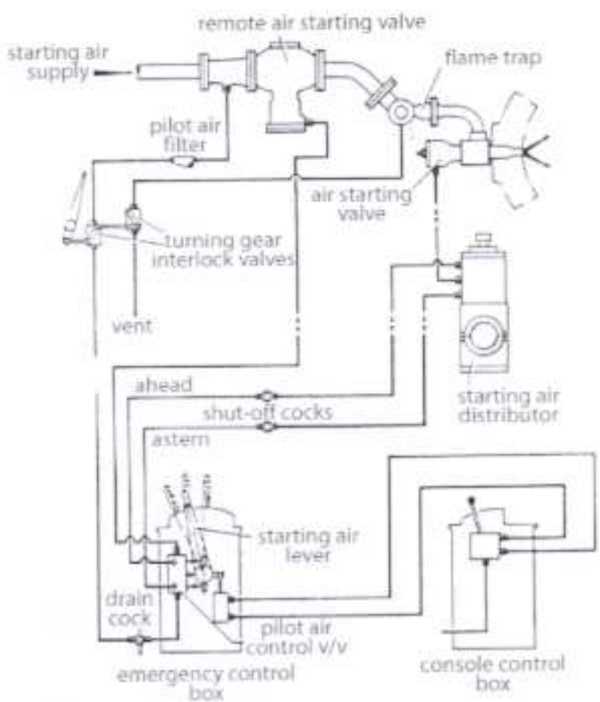


The starting air valves can be tested by closing the air supply to the pilot valves, turning gear disengaged, indicator cocks open, open up the main air to the engine, put the control lever in the start position, check the indicator cocks, any cock emitting starting air indicates that the starting valve for that particular unit is passing and defective.

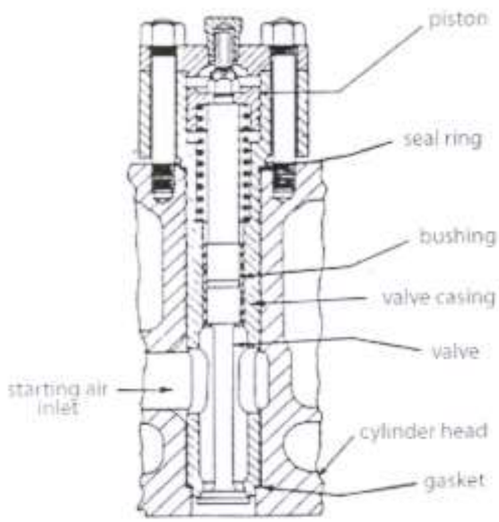
Starting air system

The figures below show starting air systems for a large two-stroke engine. Clean, dry, compressed air at starting pressure (30 bar) is stored and supplied to the system from air receivers. The main starting valve (automatic valve) is operated by a pneumatic actuator, and similar controls are fitted for slow turning and to the distributor or timing valves. The main starting valve can be locked shut and this must be done before the engine turning gear is engaged. When this valve is open, air passes through a non-return valve and flame arrester to the main manifold supplying pressure to the cylinder valves, one of which is fitted to each cylinder of the engine.





The cylinder air start valves are normally held closed by a compression spring together with cylinder pressure acting over the valve lid. Air from the manifold enters these valves where it forms a pressure balance between the undersides of the valve lid. Air from the manifold enters these valves where it forms a pressure balance between the underside of the valve lid and a balance piston of equal area on the valve spindle. Consequently this does not cause the valve to open.



Cylinder valves are opened when operating air, transmitted from the distributor, applies pressure to the larger operating piston on the valve spindle. As the valve is forced open, starting air from the manifold enters the cylinder, applying pressure on the piston and causing the engine to rotate in the corresponding direction. To close the cylinder valves the connection from the distributor is opened to atmosphere, allowing the spring to close the valve and return the operating piston.

Air from the main valve also passes through two connections to the distributor. One depresses each timing valve in the distributor from its free position to engage it with the timing cam. This line can be blocked for test purposes or by safety cutouts. Until air pressure is applied, the timing valves are held clear of the cam by springs.

The second connection supplies air to the operating ports, from which it will pass through any timing valves, which are open, to the corresponding cylinder valves, causing them to open. Air from the manifold will then enter that cylinder to start the engine. The timing valve for each cylinder is synchronised with the engine position and successive valves operate in the firing order.

On large engines a slow-turning valve can bypass the main starting valve and will supply just enough air to rotate the engine slowly. This is used to turn the engine through one revolution while the indicator cocks are kept open, when preparing for sea. At any subsequent time, if the engine has not been used for about half an hour the slow-turning valve should be used to turn engine slowly for one revolution before opening the main valve for a normal start.

Starting air is shut off from the engine as soon as sufficient starting speed has been reached; fuel is then applied and engine speed increased.

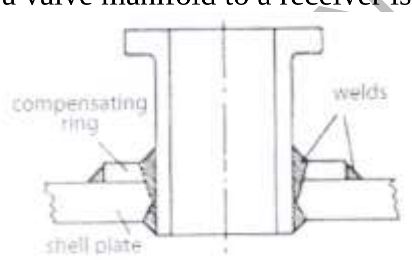
A main engine must be capable of starting from any position and it is normal to have starting valves in each cylinder. Multi-cylinder Vee type engines may only require starting valves to be fitted to one bank of cylinders.

Adequate drains must be fitted to the air start system to keep it free of oil or water. A safety or relief valve is fitted to the main air manifold. Flame arresters or bursting caps or discs

must be fitted to each cylinder valve connection from the manifold in reversible engines. Non-reversing engines require one only, fitted between the non-return valve and the engine. Checks must be made that cylinder starting air valves do not leak. These can be carried out while the engine is running by feeling the temperature of the air pipe adjacent to the valve (see Safety on explosions in air start systems). Tests while the engine is stopped require starting air to be applied and the main valve opened, after first blocking off air to the timing valves.
Pressure will escape into the cylinder of any leaking air valve and this can be detected by listening at the open indicator cock.
Prior to testing the engine, the air start valves should be greased via the grease point, turned by applying a spanner to the square on the spindle end.

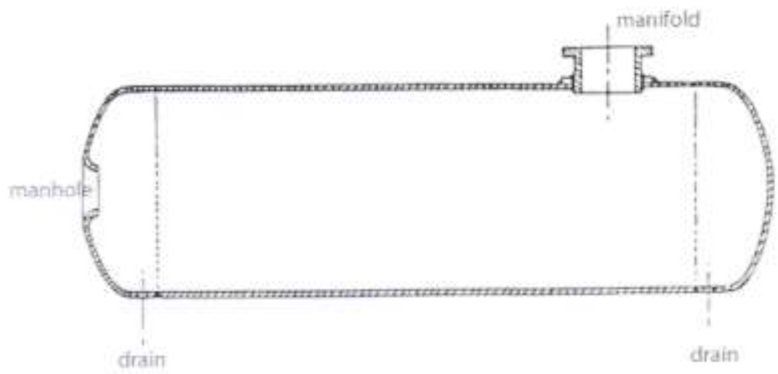
Starting air receivers

Starting air receivers are required to store compressed air for starting and manoeuvring main engines, for starting auxiliary engines, and to supply pneumatic control systems, exhaust valve air springs, air whistle and other auxiliary air pressure systems. Air is normally stored at pressures up to 30 bar for the main engine starting. Reducing pressure valves are fitted to regulate lower pressure for other systems.
Two receivers are fitted and their total capacity must be at least sufficient to obtain the regulation number of engine starts without recharging: 12 starts required for reversible engines, 6 starts for non-reversing engines. Receivers are welded from good quality steel, cylindrical in shape with dished ends. They must meet all regulation and tests for pressure vessels.
Compensating rings are necessary where any openings have been cut. Welds must be stress relieved and subjected to non-destructive testing. An acceptable welded attachment for fitting a valve manifold to a receiver is shown below.



The usual fittings required to a main starting air receiver are: safety valve pressure gauge connection, drain valve, filling valve, discharge to engine air system, pneumatic control system, etc. Although each connection may be made separately to the shell of the receiver, it may be preferred to fit a valve manifold with only one common connection to the shell.
The safety valve must be set to relieve the receiver of excessive pressure rise and must have sufficient area to prevent accumulation of pressure for any reason. The pressure gauge connection must be in direct communication with the internal pressure irrespective of other valves being open or closed. The drain will remove the contents from the lowest point in the received and should be of sufficient size to prevent choking. If it is possible to isolate the

safety valve from the receiver a fusing plug must be fitted to release pressure and discharge the received in the event of heating due to a fire in the vicinity. The fusible plug should have a melting temperature of 150°C and a connection must be made to discharge the contents in a safe manner.
The venting connection on the safety valve must be piped in and led to atmosphere outside the engine room space, therefore in the event of an engine room fire; the contents of the air receiver will not feed the fire.
All stop valves should be slow-opening valves to prevent sudden build-up of pressure when connecting any piped system.
The filling connection from the air compressors must be independent of all other. A manhole must be fitted for access to allow internal inspection and cleaning. This should be either fitted to the cylindrical shell with its minor axis arranged longitudinally or else situated within the dished end. A flat internal joint face is made for the manhole door gasket.

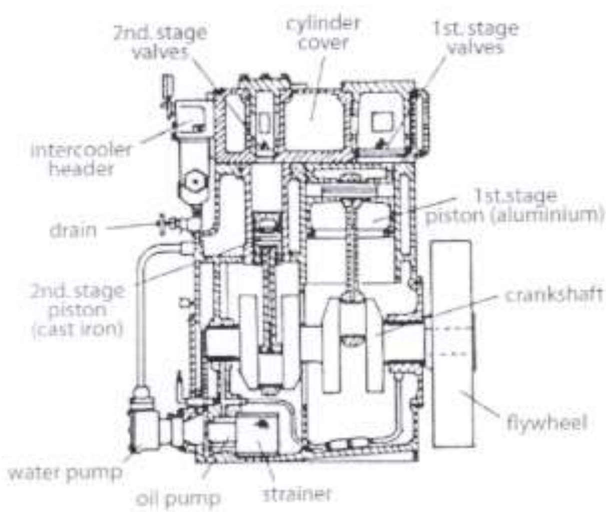


Care must be taken when filling the receiver that the air supplied is free of oil or moisture and is not of excessive temperature. Drains are fitted in the filling lines and these should be open when not under pressure; they are closed after the start of filling, opened periodically during filling, and opened again when filling is complete. Similarly drains are fitted and used in discharge lines. The drain on the receiver should be 'blown' periodically and particularly before using air from the receiver. Discharge from the drain should be observed to five an indication of conditions within the receiver and also the possible carryover from the compressor discharge. Discharge valves should be opened slowly to prevent shock waves in pipelines, and drains should be open while this takes place. When air is being used from the receiver the pressure should not be allowed to fall too low in case an emergency should arise. In most starting systems, unless manoeuvring the main engine, one receiver is kept closed at full pressure while the other is in use.
When opening up the receiver for maintenance, care must be taken to ensure that it is isolated by locked valves from any pressurised part of the system and that internal pressure is completely discharged before opening the manhole door. This door is opened inwards and, if undue force is required, it should be confirmed that no pressure remains in the receiver.
Before entering the receiver its interior must be well ventilated and at least two closed stop valves should be situated between the receiver and any pipeline under pressure.Positive isolation can be obtained by removing a length of pipe and fitting blanking flanges.

Internal cleaning must be thorough and car taken to avoid debris entering connections. It is usual to overhaul all fittings while cleaning takes place. Careful inspection must be made for possible internal corrosion.
Before applying protective compound all surfaces must be clean and dry and connections plugged. Many compounds give off noxious fumes and great care must be taken in confined spaces; protective clothing and goggles should be worn and a second person outside the manhole must keep watching in case the person inside is overcome. The compound must be allowed to dry thoroughly, plugs must be removed and all connections cleared before boxing up the receiver and recharging.

Starting Air Compressors

Starting air compressors are required to charge the starting air receivers and supply compressed air for a variety of uses. Safety regulations demand at least two compressors, each capable of supplying all demands. One must have an independent drive for emergency use. With the high pressures demanded and to obtain the best efficiency at full or part load, reciprocating compressors are invariably used. These are generally two-stage compressors, electrically driven.
Pistons for each stage may be arranged in line, either as trunk pistons or with crossheads. Alternatively, to reduce size and weight, a tandem arrangement with one piston mounted above the other and driven from a common crank may be used. An in-line two-stage trunk piston compressor as shown below. It can be seen that the second stage (h.p.) piston is smaller than that for the first stage (i.p.).



This is to accommodate the corresponding reduction in the volume of air with a common piston stroke. Compression and oil control rings are fitted to each piston; cylinders and covers and water-cooled.

Each stage has light, spring-loaded non-return suction and delivery valves of low-inertia stainless steel places. Limited life reduces hammering and will create high air velocity to maintain cleanliness.
It is important that the suction and delivery valves all overhauled correctly on a planned maintenance basis. One full set of spare overhauled valves must be held in stock at all times.
Sometimes forgotten, the landing between the valve and the compressors head must be ground in to ensure a good seal.

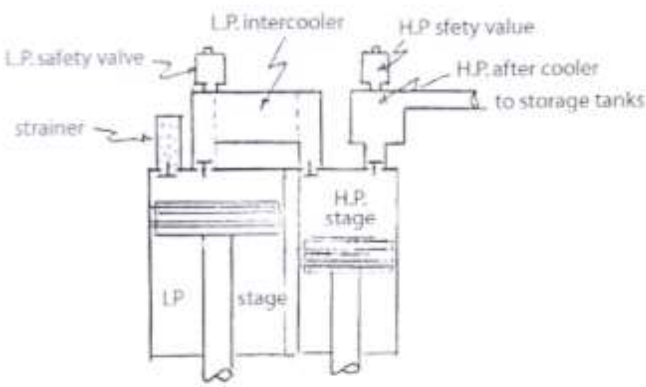
Air Compressors

Compressed air is used on board ship for a number of purposes and at varying pressures depending on that purpose.

1. High-pressure air – 25 to 40 bar – for the starting and reversing of diesel engines.
2. Medium pressure air – 7 bar – for general service air, deck air pneumatic systems, power positioners, servo mechanisms and air puff soot blowers.
3. Medium/low pressure air – 4 and 5 bar – ‘pneu-press’ and ‘grinell sprinkler’.
4. Low-pressure air – 2 bar – pneumatic control systems. For the above the following types of air compressors are used:
    a. High pressure by two or three stage-reciprocating units.
    b. Medium pressure by single or two stage-reciprocating units.
    c. Medium/low pressure by single or two stage-reciprocating units or by rotary vane units.
    d. Low pressure by single stage or rotary vane units. Multi stage compressors are used for three reasons:
        i. By cooling between stages the air is kept in a moderate temperature range,
        ii. By cooling between stages less work is required to compress a given quantity of air to a required pressure.
        iii. Lubrication difficulties will be minimised by keeping air temperatures as low as possible.

Temperatures in excess of 200°C tend to carbonise oil-leaving gum and carbon deposits on piston rings and delivery valves. This in turn leads to further problems and an impairment of the efficiency of the machine.
Rotary vane units are limited by gas slip past the seals and a differential of about 7 bars per stage is about the limit.
The capacity of an air compressor is measured by the number of cubic metres of free air discharged per minute.
The volumetric efficiency of an air compressor is measured by the number of cubic metres of free air discharged per minute compared with the displacement of the LP piston in cubic metres per minute. Modern air compressors have a volumetric efficiency of between 80 to 90%.

1.3.2 Operating limits of propulsion plants



Stage air compressors under normal running conditions operate with cool suction valves and hot delivery valves. Suction valves are cool because air from the atmosphere for from the intercoolers is being drawn in. Delivery valves are hot because part of the energy expended on the air during compression shows up as heat. Branch pipes to and from intercoolers should be as short as practical thus limiting the re-expansion of the compressed air. Also prevents expansion trouble and vibration.

Valve failure can be readily established. If a suction valve fails it will run warm due to the air leaking back through it during the compression stroke. In the LP stage this will also result in a lowering of the volumetric efficiency, all the stage pressures will be low and the compressor will run warmer. In the LP or HP stage a leaking suction valve will cause the relative and following stage pressures to be low and the LP pressure to be high.

If a delivery valve fails the valve will run cooler and the stage pressure will rise and the initial pressure will be higher due to the compressed air expanding back into the stage. This would also be an indication of increased clearance volume caused by wear down. The air remaining in the clearance volume would expand, less air would be taken from the preceding stage and that stage pressure would rise.

Valves springs and lifts are important. If spring tension is weak, valve will not close promptly and if too strong will cause valve to hammer. Increased valve life will lengthen the opening of the valve and also cause the valve to hammer giving rise to damage of seat and failure of valve plate due to fatigue. After grinding in valve plates and seats check valve plate list against manufacturers requirements. Dirty intake filters leads to loss of efficiency.

1.3.3 EFFICIENT OPERATION, SURVEILLANCE, PERFORMANCE ASSESSMENT AND MAINTAINING SAFETY OF PROPULSION PLANT AND AUXILIARY MACHINERY.

Cylinder lubrication requires high-grade oil to meet the exacting conditions. As crankcase conditions are less demanding we could use an oil of lower grade. The use of one oil is advantageous since the possibility of error in application is eliminated and storage is simplified. Purchase is also simplified. Therefore we will consider only the application of oil to the cylinders. Cylinder lubricating oil requires to have the following properties:

1. Ability to be distributed over the surfaces requiring lubrication. Viscosity correct at operating temperature.
2. Ability to resist severe oxidation although oils will always oxidise to a greater of lesser degree. High chemical stability.
3. Ability to withstand a degree of air contamination. Moisture in air leads to rusting while dust particles lead to a build up of carbon. An ability to 'cling' to the internal surfaces by careful blending of suitable additives. Again viscosity is important, as too high a viscosity oil will hold solid contaminants.
4. Ability to withstand pressure between cylinder walls and piston rings. High film strength to combat film rupture and consequent wear.
5. Ability to give some degree of sealing qualities to the piston rings, valves and rod packings where applicable.

Excessive lubrication must be avoided as this could lead to localised build-ups and crease the situation for explosive conditions. The flash point of the oil should be in the order of 200°C. Oil collectors are fitted directly to the compressor discharge after the delivery valves and are usually of the directional change type i.e. the flow of air is changed through 180° at least once. Suitable drainage is arranged.

Because of the moisture which air naturally carries when we compress it we reduce its volume, thus increasing the humidity. This humidity is usually 100% plus an amount of free moisture and this humidity and moisture is deposited in the coolers as water and is drained off periodically. Moisture separators can also be fitted and can be of the directional change, coagulant mesh or porous ceramic type to gather moisture.

Where air can be trapped between any two points a safety device must be fitted – fusible plug, bursting disc or relief valve. If CO_2 fire extinguishing is used discharge from safety device must be piped to the open deck.

Air-cooled machines run hotter than water-cooled and have a greater tendency toward carbonising of valves etc.

Water cooled machines have a higher crankcase condensation rate but have a low noise level due to jacketing.

Air compressor cylinder lubrication requires an oil, which will not be washed off the cylinder walls when condensation of moisture occurs during operation. This is achieved by using a compound oil. Compound oils are base oils or blends of base oils to which is added 5 to 25% of non-mineral oils. This compound oil would also have a rust inhibitor included. Fatty oils are commonly added to oils, which are required to lubricate in the presence of moisture. They tend to form an emulsion, which clings tenaciously to the surfaces being lubricated.

Water cooled heat exchangers are fitted to act as intercooler, which cools the air after first stage compression, and an after cooler to cool it again after the second (final) stage. Both

cooler discharge headers have pressure relief valves and drains. The maximum air temperature at compressor discharge must not exceed 93°C and a fusible plug or alarm may be fitted.
The compressor intake, which has an air filter, should be placed in a position free of any oil vapour. Compressors should be started withal drains open, the drains being operated intermittently during running and opened again on shutting down.
The crankcase must meet normal regulations for pressure relief and will hold the oil reservoir and self-contained oil pump.
Automatic controls for compressors and their drains may be fitted.
Another air-starting system, above, employs a series of cam-operated air-starting valves. An air manifold supplies starting air to all starting valves when the quick-opening control valve is opened. These starting valves are opened by the engine camshaft to admit air to each cylinder on its power stroke through a short passage an air-opened starting check valve in the cylinder head.
Manual starting is attractive because it is both inexpensive and simple. It does not require an external source of energy, which must be stored and replenished periodically, but unfortunately it can only be applied to relatively small engines. Even then, unless adequate inertia can be provided by employing a large flywheel, which may be unattractive from considerations of installation and cost, it is necessary to incorporate a decompressing device in the design of the engine, and this should preferable be automatic in operation.
This starting sequence is first to accelerate the crankshaft to the required cranking speed with the decompressing device in operation so that kinetic energy is stored in the flywheel and attached rotating and reciprocating masses of the engine, and then to release the decompressing device and use this kinetic energy, supplemented by continued cranking effort, to maintain the mean cranking speed at a satisfactorily high level.
The smallest engines require a cranking speed of about 7 rev/s in an ambient air temperature of 15°C and a higher speed at lower ambient temperatures, unless a starting aid is employed. An economic and effective means of cranking the engine at these speeds is by a pulley attached to the crankshaft. To crank the engine, a rope is wound several times around the pulley and the operator then applies a sustained pull, which accelerates the crankshaft to the required cranking speed. A considerable length of rope is necessary to sustain the torque, and in some applications this cannot be accommodated in the space available. It is then necessary to adopt the more usual form of hand cranking.
The cranking speed required varies inversely with the swept volume of the cylinder. The smallest engines may employ a cranking speed of about 7 rev/s, while engines have a cylinder swept volume of the order of 0.70 litres may require a cranking speed of approximately 2 rev/s. In all cases, the total inertia of the rotating and reciprocating masses of the engine is most important and in some engines, the inertia of the flywheel employed is dictated largely by starting considerations.
The cranking speeds required by the smaller engines are higher than can be achieved directly with a conventional crank handle, even if this has a small throw. It is therefore necessary to interpose gearing between the crank handle and the crankshaft. On four-stroke engines the 2:1 gear ratio between the crankshaft and the camshaft is utilized, so that the crankshaft rotates at twice the speed of the crank handle, which is attached to the camshaft. On smaller

engines, an even higher cranking speed may necessitate the use of speed increase ratios of 3:1 or 4:1.

Although not widely used at the present time, the inertia starting systems should be mentioned because it is a variant of the manual starting system. It consists of a unit incorporating a small flywheel, which is connected to a conventional crank handle through speed increase gearing having a ratio of 100:1. The crank handle is rotated manually and accelerated to a speed of approximately 2 rev/s so that the flywheel is rotating at a speed of some 200 rev/s. The kinetic energy in this flywheel is then transmitted through a clutch, to a pinion, which engages with the flywheel of the engine, so that it provides the torque required to start the engine.

Power for the gear-drive starters is obtained from an electric, air or hydraulic motor or a small petrol engine. A pinion on the power shaft engages a flywheel ring gear during the starting period through a Bendix drive, or other similar mechanism. The Bendix drive is mounted on the end of the power shaft. The small drive gear, or pinion, is normally disengaged from ring gear and when power is applied to the shaft, it moves along the shaft into engagement.

When starting with the drive illustrated, power is applied through the spring-loaded clutch to the screw shaft, the shaft rotates inside the pinion, and the screw threads cause the pinion, stationary because of its inertia, to move to the right, engaging the flywheel gear. As soon as the pinion contacts the collar at the right end, it rotates with the shaft and power is transmitted to the flywheel gear cranking the engine. When the engine starts, the high speed of the flywheel gear causes the pinion to move to the left on the crew shaft, disengaging the drive.

The starting system consists essentially of a direct current starter motor, a battery to provide the electrical energy and a means of charging the battery. This type of system is widely used on high-speed and medium-speed diesel engines having cylinder diameters of up to approximately 200mm.

The starter motor is mounted adjacent to the engine flywheel which has a gear ring attached to its periphery. The pinion of the starter motor engages with this by means of a Bendix-type drive and it is usually arranged so that it engages at a low rotational speed in order to minimize damage and wear of the gear teeth. In addition, provision is made to ensure that the pinion will remain in contact with the gear ring even if temporary torque reversals occur during the engine starting process. There is also provision to safeguard the starter motor from damage due to serious overspeeding, when the engine accelerates rapidly to its normal running speed.

In many applications, the 12-volt or 24-volt engine starting system is integrated with other electrical systems: a typical example is a lifeboat in which the battery provides energy for lighting, and the operation of ancillary control systems. A lead-acid battery is usually employed and while this is an economic and satisfactory source of electrical energy in temperate climatic conditions, special consideration is necessary if the engine is required to operate in very low ambient temperatures. This is particularly so because engine starting aids which require electrical energy may then increase the total demand on the battery.

A problem with the lead-acid battery in an arctic environment is that as the state of charge of the battery falls, the density of the electrolyte falls and its freezing point rises. In a low-temperature environment there is an increasing risk of the electrolyte freezing as the battery discharges. If this occurs, the battery output is reduced to zero and, of course, the freezing may damage the container and the plates.

Nickel-cadmium alkaline batteries are also used for engine starting but they are larger and significantly more costly than the equivalent lead-acid battery; consequently their use is generally confined to specialized applications. Their advantages are long life, very low self-discharging rate, robust construction, and an ability to stand for long periods at any stage of charge without deterioration. The nickel-cadmium alkaline battery is also temperature-sensitive and it has performance characteristics similar to those of the lead-acid battery; but it has the advantage that the density of the electrolyte does not vary with the state to charge.

The normal specific gravity is 1.190, which corresponds to a freezing point of about -25°C, but for very low temperature applications a stronger electrolyte can be used which has a freezing point of about –42°C.

It will be seen from the above, that if equipment is required to operate in a very low temperature environment, there is a good case for thermally insulating the battery and providing some form of heating, possibly from the battery itself.

A battery, which is in good condition and properly maintained will hold its charge for a considerable period but the energy taken from it to start the engine must be replaced to ensure future starts, and therefore a means of recharging the battery is provided. The most common means of recharging the battery is by the use of a direct current generator or an alternator with a rectifier, which is driven by vee belt from the diesel engine and supplies the battery through a voltage regulator and a cutout.

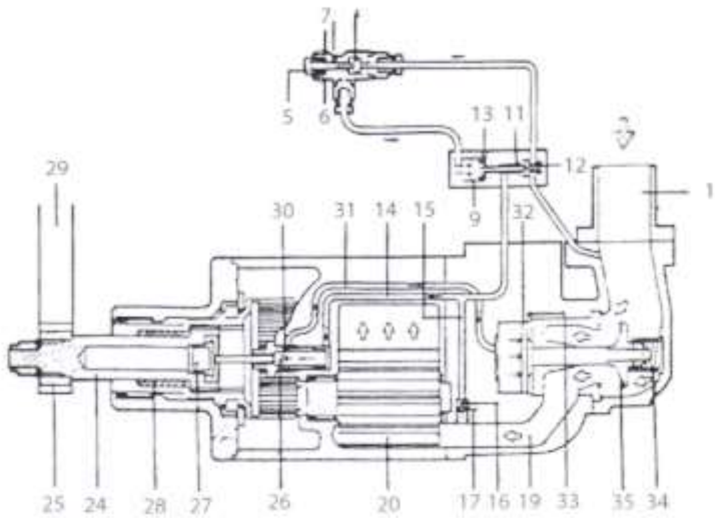
On some small high-speed engines, a simple alternator is built into the engine itself by attaching a moulded stator winding to the end wall of the crankcase so that it is in close proximity to two permanent magnets, which are attached to the flywheel.

If the diesel engine is the power source for a generating set, the battery can conveniently be charges through a transformer and rectifier, from the electrical energy produced; while in the case of stand-by or emergency, the battery can be charged by the primary power source which will probably be the main switch board supply.

In installations where high-pressure air is already available or can be obtained conveniently, air-starting motors are often used. This type of system is widely used to start high-speed and medium-speed diesel engines which require more power than can conveniently be provided by electric starting equipment.

They avoid the problem of battery over-charging as may occur when an engine runs for long periods between starts. Elimination of the electrical starting system may also be a desirable safety feature in hazardous atmospheres. If air supply is maintained, an air motor is not subject to as great a loss of starting torque at low temperatures as is and electrical starting system.

Like its electrical counterpart, the air-operated starter motor must incorporate a means of engaging the pinion with the stationary gear ring on the engine flywheel, at a low speed and torque, before the full cranking torque is applied. Similarly, provision must be made to safeguard the starter against damage due to overspeeding. The gear type starter has therefore been taken as an example and its method of operation is described in the following paragraphs.



Referring to the figure above the compressed air supply enters the starter motor at 1 and is conveyed through the drilling 2 and the pipe 3 to the valve 4 in the Start button 5. Depressing the Start button opens the valve and closes the vent to atmosphere 7. The compressed air then flows through the pipe 8 and depresses the piston 9, which is vented to atmosphere on its lower side by the drilling 10. In doing so, it opens the valve 11 and closes the vent to atmosphere 13; thereby permitting compressed air from the duct 1 to pass through the drilling and into the pipe 14, which communicated with the pipe 15. This compressed air passes through the orifice 16 and the non-return valve 17, to the duct 19. It provides a restricted flow of air to the rotary gear-type motor 20m, which rotates slowly, driving the pinion 25 through the aped reduction gearing 21 and 22 and the helical splines formed on the inside of the sleeve 23 and on the shaft 24.

At the same time air pressure in the pipe 14 acts on the piston 26 and exerts a thrust through the cap 27, which compresses the spring 28 and moves the slowly rotating pinion towards the gear ring on the engine flywheel. As the pinion 25 engages fully with the gear ring 29, the piston 26 opens the orifice 30 and permits compressed air to flow into pipe 31 and so apply pressure to the piston 32, which is vented to atmosphere on its opposite side, through the drilling 33. The area of the piston 32 is greater than that of the valve 35 and therefore, the piston opens the valve against the air pressure in the duct 1 and force of the spring 34, and so connects to main air supply to duct 19. Consequently, the rotary gear-type motor 20 accelerates rapidly under the full torque available and rotates the engine flywheel through the pinion 25 and the gear ring 29; so that the engine starts and accelerates to its normal running speed.

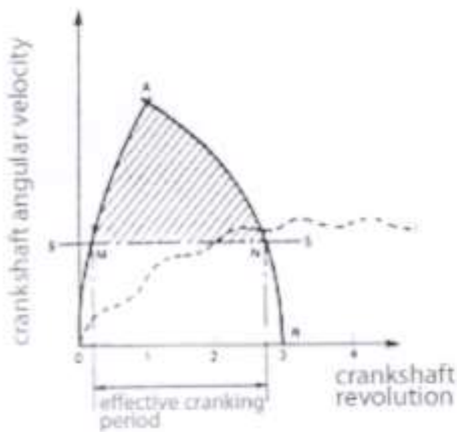
Releasing the start button closes the valve 4 and vents the pipe 8 to atmosphere through the orifice 7. The spring 12 then closes the valve 11 and in so doing, vents the pipe 14 to atmosphere through the drilling 13. The air pressure in the duct 19 then closes the non-return valve 17 and isolates the pipes 14 and 15, which have already been vented to atmosphere. The air pressure acting on the piston 33 will also be vented to atmosphere through pipes 31 and 14, so that the valve 35 will close under the action of the spring 34. The rotary motor 20, which is running at high speed, will then create a considerable depression in the duct 19 and this will reopen the non-return valve 17. The depression will cause a rapid deceleration of the motor and this, aided by the force from the spring 28, by the depression acting on the piston 26 and by the action of the helical splines, will withdraw the pinion 25 from engagement with the gear ring 29.

If the start button is not released when the engine starts, the pinion 25 will be driven by the gear ring 29, and, owing to this torque reversal, the pinion will move axially under the action of the helical splines in the sleeve 23 and on the shaft 24, and the force exerted by the spring 28, out of engagement with the gear ring on the flywheel. In doing so the piston 26 is moved against the air pressure in the pipe 14 so that it uncovers the orifices, 30 and 36, which vent the pipe 31 to atmosphere. This releases the air pressure on the piston32, so that the spring 34 closes the valve 35, which cuts off the main supply of compressed air to the rotary gear-type motor 20; although it will continue to rotate slowly as a result of restricted air supply through the orifice 16, until the Start button is released. When the starter motor is used on a remotely controlled or automatic starting installation, an overspeed device is employed which interrupts the air supply to the Start button if the starter motor overspeeds.

Hydraulic starting systems are unaffected by extremes in climactic conditions and they are independent of all ancillary services because the energy required can, if necessary, be produced manually. They are therefore well suited to the operating environment of engines employed for marine service, including the propulsion of workboats and lifeboats.

Two well-established designs are the Hydrotor Starter, and the Handraulic Starter. The Hydrotor Starter employs a swash-plate-type hydraulic motor, which rotates the flywheel of the diesel engine through gearing and Bendix-type drive, in the conventional manner; while the Handraulic Starter applies an impulse to the engine crankshaft for hydraulic rams, and this system is described below.

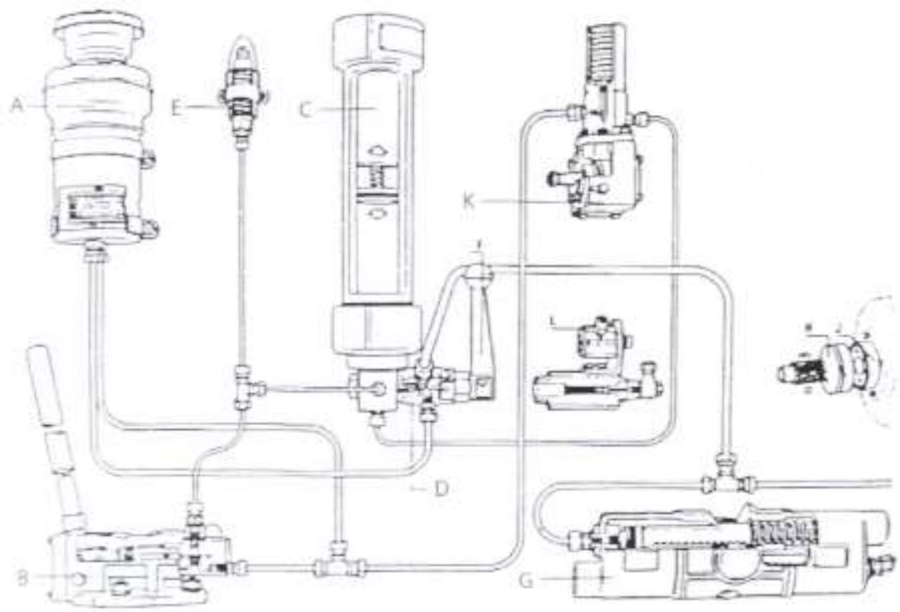
The power operated starting systems described so far, are designed to accelerate the reciprocating and rotating masses of the engine and any permanently attached driven machine; from rest to a specified cranking speed, which must be above the minimum starting speed of the engine; the horizontal line S-S below. At this cranking speed, the system will be in a state of equilibrium and the energy input to the starter will be equal to the total motoring resistance of the engine and permanently connected driven machine. This is represented by the curve O-E below. The starting system will maintain this cranking speed until the engine starts or the supply of energy is either cut off or becomes exhausted.



In contrast the Handraulic Starter applies a very high torque to the crankshaft for approximately one revolution, during which the reciprocating and rotating masses of the engine and any permanently attached driven machine are accelerated to a speed well above the minimum starting speed of the engine, curve O-M-A above. The torque ceases at point A, but the momentum in the system continues to rotate the crankshaft, along the curve A-N-R.

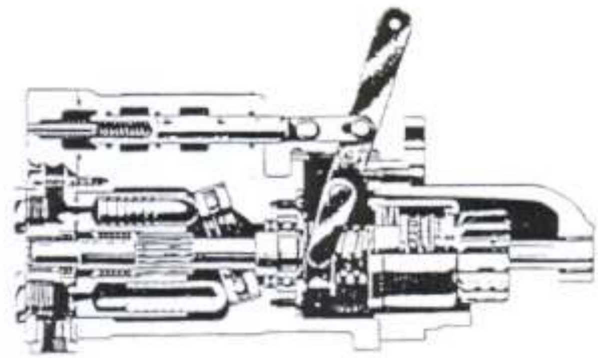
The effective cranking period is represented by M-N and the shaded area M-A-N above shows that, during the whole of the interval, the cranking speed is above the specified minimum starting speed of the engine.

The Handraulic starting system is shown schematically below. It is operated by energy stored in a piston-type hydraulic accumulator C, which contains nitrogen in the sealed volume above the piston and hydraulic fluid below it. When the hand pump B is operated, hydraulic fluid is transferred from a supply tank A to the lower portion of the accumulator C. This raises the piston and compresses the nitrogen. The pressure is limited to 340 bar by a relief valve and it is shown on the pressure indicator E. The system is controlled by a two-stage relay valve attached to the base of the accumulator. This can be operated by a lever, a pushbutton or a solenoid.

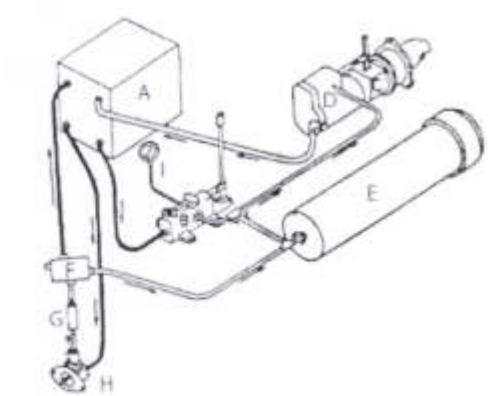


The two-stage relay valve D is connected to the starter unit G, which is shown partly sectioned above. This contains two horizontally opposed hydraulic rams, each attached to a toothed rack. These racks engage with a helically toothed pinion, having one part of a serrated, face-type coupling formed integrally with it: the mating part of this coupling is attached to the end of the engine crankshaft. Initial movement of the operating lever F on the relay valve D permits slow movement of the rams in the starter unit G. These apply a pure torque to the pinion H and, owing to the helical teeth, cause it to move axially and engage with the crankshaft. Further movement of the control lever F admits the full hydraulic pressure to the rams of the starter unit G, which applies an impulse to the crankshaft, causing it to accelerate very rapidly to an angular velocity which is significantly above the minimum cranking speed required, thereby achieving the advantage of high-speed cranking. Release of the operating level F on the relay valve D isolates the starter unit from the hydraulic accumulator and vents the hydraulic rams to the feed tank A, so that they return to their original positions.

This starting cycle can be repeated as often as required and the system can be arranged to provide several starts required and the system can be arranged to provide several starts without the need to recharge the hydraulic accumulator. This can be accomplished by means of the hand pump B or automatically, by employing the auto-charging pump K, which is usually driven from the engine.



The other starting motor is the hydraulic "swash-plate" type. A section of a hydraulic starter can be seen above. A rotor, which is splined to the shaft, carries several axial cylinders and pistons. High-pressure oil, 1000 to 3000 psi, is admitted to each cylinder when just past its outermost positions (to the left) through the cover plate at the left. Oil forces the pistons against the inclined "swash plate". Reaction of the pistons against this inclined plate causes rotation of the assembly of cylinders and pistons and the shaft, thus producing power. The oil discharge port is at the lower left. When the control lever is moved to the left, the pinion is meshed with the flywheel gear and then the oil valve (top left) is opened, starting the motor. A diagrammatic layout of this hydraulic starting system 138 shown below. High-pressure oil is carried in a piston-type accumulator E, the end at the right being pre-loaded with nitrogen. The accumulator is charged either by the engine-driven pump H or hand pump B. When only infrequent starts are required, the engine-driven pump is sometimes omitted, since less than a minute is required for hand-pump charging of the system. The operation of this system is practically unaffected by low temperatures.



As a generalisation, the smallest high-speed diesel engines will start without the assistance of a starting aid, in ambient air temperatures down to about 15°C, while commercial-vehicle-type engines will start in air temperatures down to about 0°C, but these temperatures will be influenced significantly by the general condition of the engine and the cranking speed attained. High-speed diesel engines having cylinders of larger swept volume will usually start without the assistance of a starting aid, at somewhat lower ambient air temperatures. In arctic area, diesel engines must be capable of starting and operating satisfactorily in ambient air temperatures below - 30°C. Appropriate starting aids have therefore been developed and these can be grouped broadly within the following categories.

It is a common practice with small hand-started diesel engines, to inject a measured quantity of lubricating oil or diesel fuel into the air manifold before commencing to crank the engine, so that it will be carried into the cylinder when the inlet valves open. This oil both improves the sealing of the piston rings and reduces the effective clearance volume in the cylinder; thereby temporarily increasing the compression ratio and these effects together, can lower the minimum starting air temperature by between 5°C and 10°.

By prolonged cranking combined with the injection of the full load fuel quantity per cycle, the minimum unaided cold starting temperature of an engine can be lowered by between 5°C and 10°C. This is not strictly a starting aid but it comes near to being one, because by over-fuelling to the extent of about 50 per cent, any direct-injection engines can be started in air temperatures down to -15°C.

The excess fuel can be provided by means of a manual override on the maximum fuel stop. This practice has the disadvantage that the fuel which collects in the cylinders during cranking and the products of incomplete combustion during the initial firing strokes produce exhaust smoke which, in some applications may not be acceptable on grounds of environmental pollution.

The glow plug is an electrically heated plug, which is somewhat similar to the familiar sparking plug used on petrol engines. It commonly has an energy consumption of 50-60 W and when supplied with current from the starter battery, the heating element attains a temperature of about 1000°C in a period of about 30 seconds. The glow plug is fitted in the combustion chamber where it provides a hot-spot, and consequently it can start combustion of the fuel only in its immediate vicinity or actually in contact with it. The glow plug is therefore most effective as a starting aid in engines, which induce rapid air movement in the combustion chamber, at the relatively low speeds of cranking. This is a characteristic of the indirect-injection or pre-chamber combustion system and of some direct-injection systems used on small engines. In these engines, the use of glow plugs can reduce by some 25°C, the minimum ambient air temperature in which the engine starts.

The usual starting procedure is first to energize the glow plugs, which are connected in parallel, for a period of about 30 seconds before beginning to crank the engine. Under the most arduous starting conditions, the energy available from the battery may be sufficient both to maintain the glow plugs at their full operating temperature and to provide sufficient current to enable the starter to crank the engine at the designed speed. An effective practice in such cases is first to apply all the electrical energy to the plug and then transfer the total battery capacity to the starter motor, so that the maximum available cranking speed is attained.

The interval of 30 seconds required for the flow plugs to attain their full temperature is unacceptable in some applications and therefore, rapid warm-up systems have been developed. These use conventional sheathed element glow plugs which are temporarily overloaded electrically, so that they warm up rapidly under the control of a thermostat which reduces the rate of energy input when the full temperature is attained. By this means, the warm-up period is reduced to between 5 and 10 seconds without damage to the glow plugs.

The Fast Start Aid System is a further development of this philosophy. It employs an advanced design of glow plug and an electronic controller, which virtually eliminates the warm-up period before cranking is commenced. In addition, the glow plug continues to be energised for a short period after combustion has commenced, in order to minimise the possibility of the engine stalling.

A manifold air heater raises the temperature of the combustion air during its passage through the inlet manifold of the engine by means of an electrically heated element or a combustion burner using a liquid or gaseous fuel. Thermally the heater is inherently very inefficient because a large proportion of the heat added to the combustion air is lost by radiation and convection from the surfaces of the inlet manifold and to the cold surfaces of the inlet ports, valves, pistons, combustion chambers and cylinder walls. Even so, providing the required amount of energy can be made available, the manifold air heater is an effective starting aid.

The electrically heated manifold air heater has the merit that it does not consume any of the oxygen contained in the engine combustion air but its field of application is restricted by the high-energy requirement. The electrical energy required is of the order of 400 W/1 of engine cylinder swept volume and this demand occurs concurrently with a high demand from the starter. It is therefore essential that batteries of a very generous capacity should be provided to ensure that the cranking speed of the engine is not prejudiced by the additional electrical load. A situation could arise in which the beneficial effect of heating the combustion air is more than offset by a reduction in cranking speed, which is a very significant factor in regard to the cold starting ability of a diesel engine.

The combustion-type manifold air heater is a small burner, which is fitted in the intake manifold of the engine to burn a limited quantity of liquid of gaseous fuel in order to raise the temperature of the engine combustion air as it passes through the inlet manifold. The oxygen for the combustion of the fuel used in the burner is taken from the engine air supply and therefore the amount of fuel burnt must be kept at a minimum to avoid significantly depleting the oxygen available for combustion in the engine cylinders. The fuel quantity must also be limited to avoid the risk of the engine overspeeding due to the carry-over of unburnt fuel into the engine itself.

The starting aids described so far are all means of increasing the temperature of the air in the cylinder of a diesel engine at the end of the compression stroke, so that it will be satisfactorily above the self-ignition temperature of the diesel fuel employed, at the lowest ambient air temperature at which the engine will be required to operate. The alternative approach is to employ a fuel for cold-starting the diesel engine, which has a self-ignition temperature below the temperature of the air cylinder at the end of the compression stroke, when starting a completely ‘cold’ engine at the minimum ambient air temperature at which it will be required to start.

The starting fuels employed are usually ether-based but because ether itself produces an undesirably high rate of pressure rise during combustion in the engine cylinder and has virtually no inherent lubricating properties, appropriate additives are included in the formulation of the fuel to protect the engine against the effects of these undesirable characteristics.

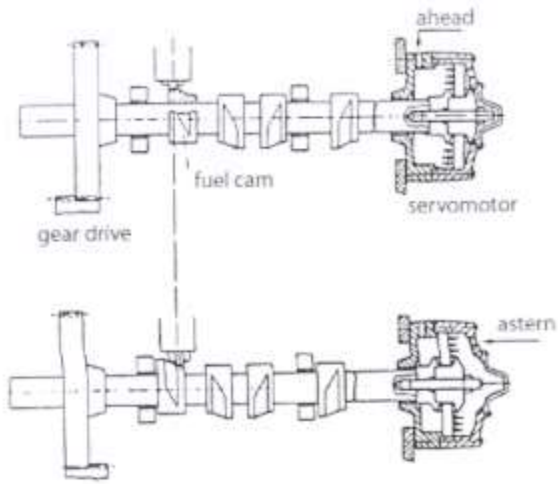
This form of starting aid is now widely used and in its simplest form is an aerosol container marketed under such trade names as Aerostart, Gasomastic and Quickstart. Some fluid from the aerosol is sprayed into the air filter or air intake while the engine is being cranked. This is effective as a means of obtaining a cold start under occasionally extreme conditions, but for general use, a more precise control of the process is highly desirable

The starting aids which have been described in this section greatly extend the field of application of the diesel engine by promoting combustion in a complete ‘cold’ engine exposed to a low-temperature environment, but the most effective starting aid for these adverse conditions is the provision of an artificial environment for the engine and its equipment, which will be independent of climatic conditions. In addition to providing temperature conditions, which are favourable to the initiation of combustion, this enables the lubricating oil viscosity, engine coolant temperature and starter battery temperature to be maintained at ‘temperate’ levels. This solution is not always possible owing to constraints imposed by the particular duty.

In order to manoeuvre a ship, the propeller thrust must be reversible, by means of reversing the propeller drive or by altering propeller pitch. Controllable pitch propellers, or diesel-electric drive, allow the use of unidirectional (non-reversible) engines. In systems of limited power using medium or high speed engines through gearboxes, arrangements of clutches and reverse gears may be used. In many ship, however, it is necessary for the main engine to be reversible and able to operate efficiently in both ahead and astern directions.

To run in the astern direction, all the operations in the engine cycle may need retiming. The starting air must first rotate the engine in the reverse direction and this will require retiming the distributor to supply compressed air to the appropriate cylinders in the correct order. The retiming may be carried out by altering the position of the distributor cam with respect to its drive from the main camshaft.

The number of the readjustments to be made and the methods used depend upon the engine cycle and type. Four-stroke engines will require a change in timing of fuel pumps, a different change for the air inlet valves, and yet another for the exhaust valves. To obtain all these changes on the same camshaft, a separate set of astern cams is fitted. Each astern cam is fitted to the camshaft adjacent to its corresponding ahead cam (below). The reversing procedure is then carried out by moving the whole camshaft axially, which moves the ahead cams clear of their followers, which now engage the astern cams. Ramps (sloping sides) fitted between corresponding ahead and astern cams cause the follower’s roller to slide smoothly from one to the other. The axial movement is carried out by a hydraulic cylinder fitted to the camshaft; locking devices and safety cut-outs ensure that the camshaft has carried out its full axial movement and is in the correct position before the engine can be restarted. To maintain alignment of the camshaft drive, a spline coupling may be necessary.

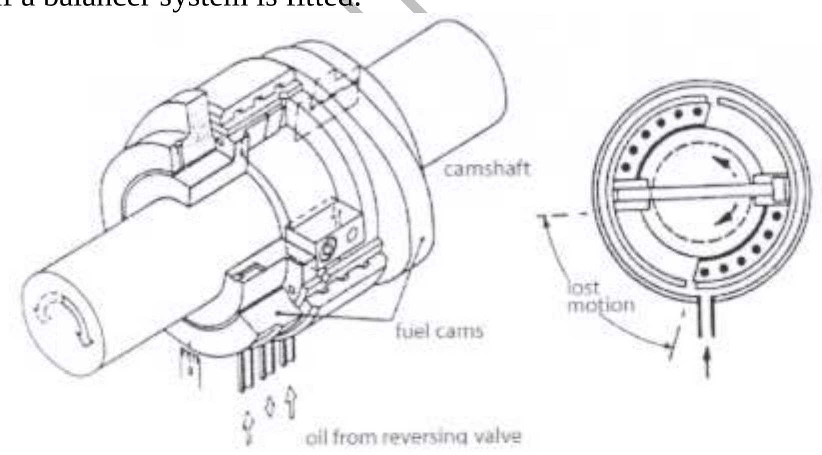


Turbo chargers are of course unaffected by reversal of the engine, but engine driven pumps must be reversible.

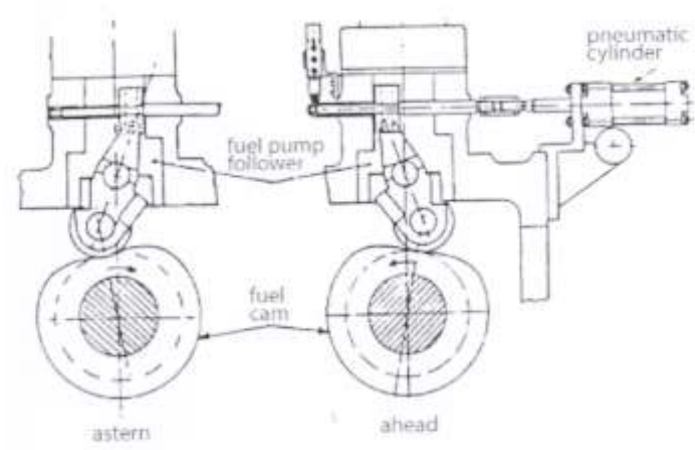
Large two-stroke engines have scavenge ports which control scavenge timing. This must therefore be symmetrical and will thus be unchanged when reversed. Engines operating with constant pressure turbocharge have almost symmetrical exhaust valve timing. Consequently no change in timing is necessary for exhaust cams.

Fuel pump timing must be readjusted since it will be the opposite flank of the cam, which will now raise the pump plunger to deliver fuel. There are alternative methods employed to change the fuel pump timing without altering the main camshaft. Two such systems are illustrated and described.

In both cases the main camshaft drive timing is not altered and therefore any other drives taken from this remain synchronised with the engine while running astern. This is important if a balancer system is fitted.



Sulzer RTA engines have oil pressure operated hydraulic ‘lost motion’ servomotors on the camshaft, which rotate the fuel pump cams to their astern positions. Fuel pumps and their cams are grouped in pairs along the camshaft and servomotor is fitted for each pair of adjacent cams. Oil pressure located and secures each servomotor in its correct position while the engine is running. A similar servomotor is used to re-time the starting air distributor and its drive from the camshaft. 'Lost motion' is the term used to indicate that the timing has been retarded, or moved back, through a given angle with respect to the 'new' direction of rotation.



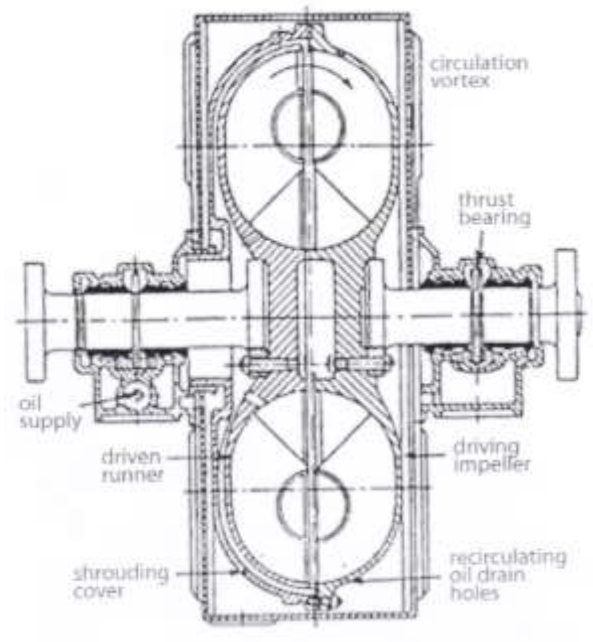
MAN – B & W MC engines have their fuel pump cams fixed directly to the camshaft but the follower rollers can be displaced to alter the pump timing as shown below. The link, which displaces each follower, is actuated by the pneumatic cylinder and piston, powered by compressed air from the starting system. The link is self-locking in either position and a sensor is fitted to each pump to cut off fuel delivery if the link is not locked in its correct position.

Earlier models of two-stroke engines use elaborate systems of servomotors to rotate their whole camshaft to reverse the timing.

Where the shaft speed of a medium-speed diesel is not suitable for its application, e.g. where a low speed drive for a propeller is required, a gearbox must be provided. Between the engine and the gearbox it is usual to fit some form of flexible coupling to dampen out vibrations. There is also often a need for a clutch to disconnect the engine from the gearbox.

Elastic or flexible couplings allow slight misalignment and damp out or remove torque variations from the engine. The coupling may, in addition function as a clutch or disconnecting device. Couplings may be mechanical, electrical, hydraulic or pneumatic in operation. It is usual to combine the function of the clutch with a coupling and this is not readily possible with the mechanical coupling.

A clutch is a device to connect or separate a driving unit from the unit it drives. With two engines connected to a gearbox, a clutch enables one or both engines to be run, and facilitates reversing of the engine.



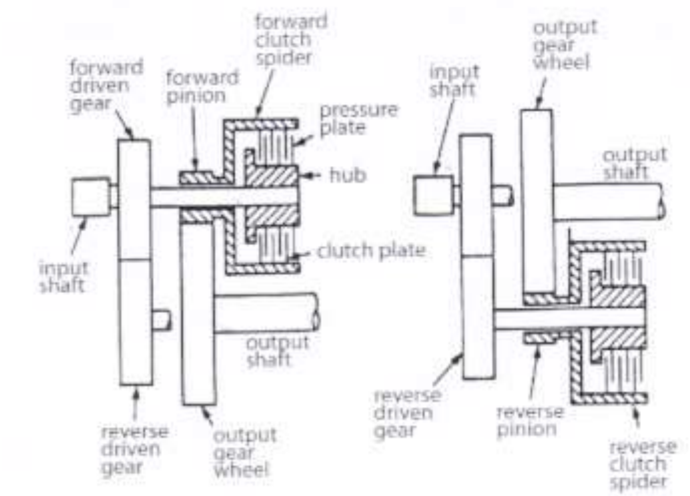
The hydraulic or fluid coupling uses oil to connect the driving section or impeller with the driven section or runner (above). No wear will thus take place between these two, and the clutch operates smoothly. The runner and impeller have pockets that face each other which are filled with oil, which transmits the drive to the runner. Thrust bearings must be provided on either side of the coupling because of axial thrust developed by this coupling.

A plate-type clutch consists of pressure plates and clutch plates arranged in a clutch spider (over). A forward and an aft clutch assembly are provided, and an externally mounted selector valve assembly is the control device, which hydraulically engages the desired clutch. The forward clutch assembly is made up of the input shaft and the forward clutch spider. The input shaft includes the forward driven gear and, at its extreme end, a hub with the steel pressure plates of the forward clutch assembly spline-connected, i.e. free to slide. Thus when the input shaft turns, the forward driven gear and the forward clutch pressure plates will rotate. The forward clutch plates are positioned between the pressure plates and are spline-connected to the forward clutch spider or housing.

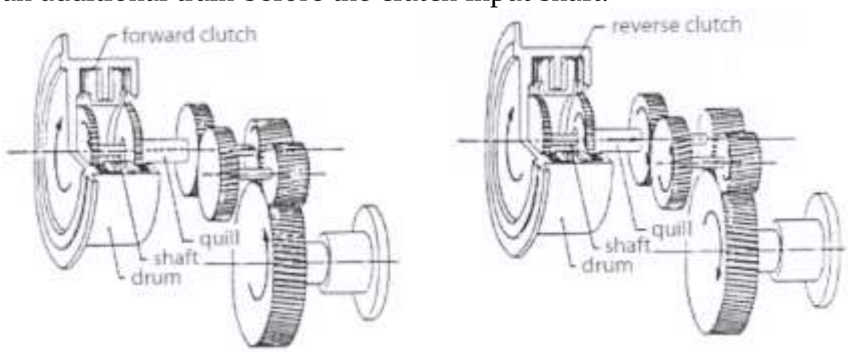
This forward clutch spider forms part of the forward pinion assembly, which surrounds but does not touch the input shaft. The construction of the reverse clutch spider is similar.

Both the forward and reverse pinions are in constant mesh with the output gear wheel, which rotates the output shaft. In the neutral position the engine is rotating the input shaft and both driven gear wheels, but not the output shaft. When the clutch selector valve is moved to the ahead position, a piston assembly moves the clutch plates and pressure plates into contact. A friction grip is created between the smooth pressure plate and the clutch plate linings and the forward pinion rotates. The forward pinion drives the output shaft and forward propulsion will occur. The procedure when the selector valve is moved to the astern position is similar but now the reverse pinion drives the output shaft in the opposite direction.

The gearing arrangement used to reduce the medium-speed engine drive down to suitable propeller revolutions is always single reduction and usually single helical. Reduction ratios range from about 2:1 to 4:1 on modern installations.
Typically on a reverse/reduction gearbox the input shaft(s) drive(s) the outer member of the clutch (below). Since it is normally essential that the gearbox has oil pressure as soon as the input starts to turn, the oil pump is driven from the input side of the clutch.

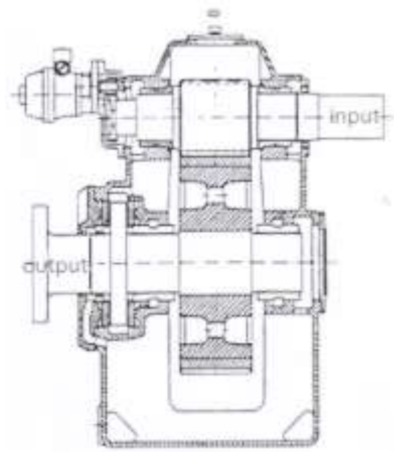


The input side of the clutch may incorporate a gear rim meshing with that of another clutch on an intermediate shaft, in order to provide a reverse rotation. Which is ‘Ahead’ and which ‘Astern’ will depend on the constraints of the engine and the installation, but usually the mode involving the fewer gears is preferred as the ‘Ahead’ configuration. Some designs have the ahead and astern clutches before the gear rims, so that with the clutches disengaged, running the engine during maintenance does not turn any of the gearing. In either case engaging the ahead clutch turns the layshaft, which carries the final pinion meshing with the bullwheel or final output wheel, while engaging the astern clutch does the same via intermediate shaft. With a stepped input and output configuration the input and output normally turn in opposite directions when running ‘Ahead’. (If for any reason the engine or propeller cannot be adapted to do this, most (but not all) gearbox designs would permit operation via the normally ‘Astern’ train to be used for the ‘Ahead’ duty.)
If the co-axial configuration, or extra reduction, is required, this is achieved by incorporating an additional train before the clutch input shaft.



If reversing is possible by reversing the engine, or by the use of a controllable pitch propeller, the gearbox can be simplified to a single train (above), though it may retain a clutch if this is not fitted externally.

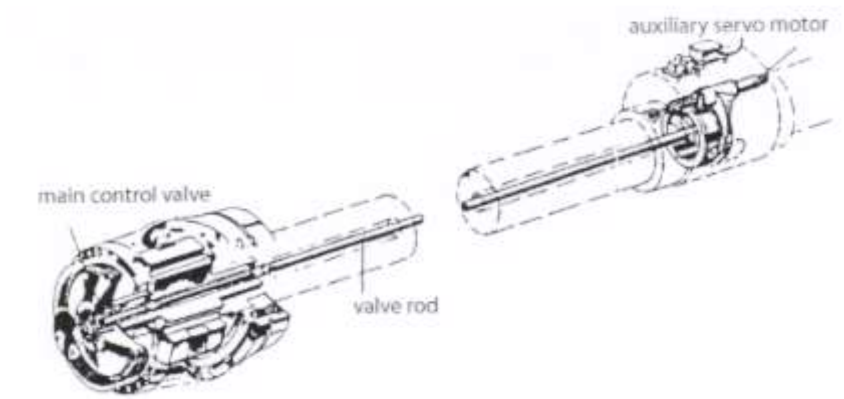
Internal clutches are invariable oil operated, usually of the multi-plate design. Plates are of dissimilar materials, for instance, sintered bronze and steel. To permit prompt disengagement one set of the plates (the steel) will be produced in a concave form, so that releasing the engaging pressure enables them to push away from the flat bronze plates. The facility is usually provided to lock the clutches in the engaged position in the event of a hydraulic failure.



The gears themselves are usually cut to a shallow helix, which ensures a quieter, continuous drive. The teeth are cut to as large a modulus as can be accommodated and, increasingly in modern gearboxes, all are hardened. The helix angle is chosen to span the tooth pitch, so the angle only generates a modest end thrust, usually arranged to oppose the propeller thrust.

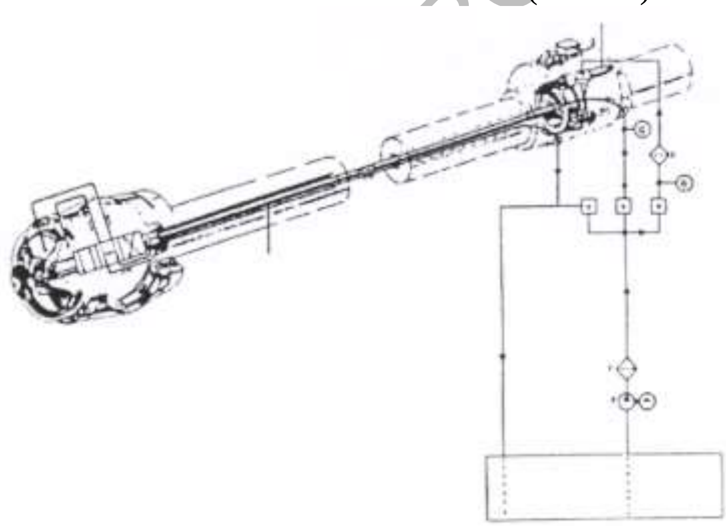
Pinions are usually integral with their shafts, but wheels are keyed or, increasingly, fitted by the keyless oil injection method, on an appropriately tapered seat.

Bearings in early gearboxes were usually plain, and the trust bearing of classical Michell pattern. However, the attraction of roller bearings, namely lower friction, greater precision, higher load capacity and the ability to forgo pressure lubrication for a period, combined with their development and wealth of experience, have led to their growing acceptance in modern designs. The gearbox oil circuit passes from the pump to the filter and cooler before the relief valve which provides the clutch operating pressure. The spill is used for lubrication.

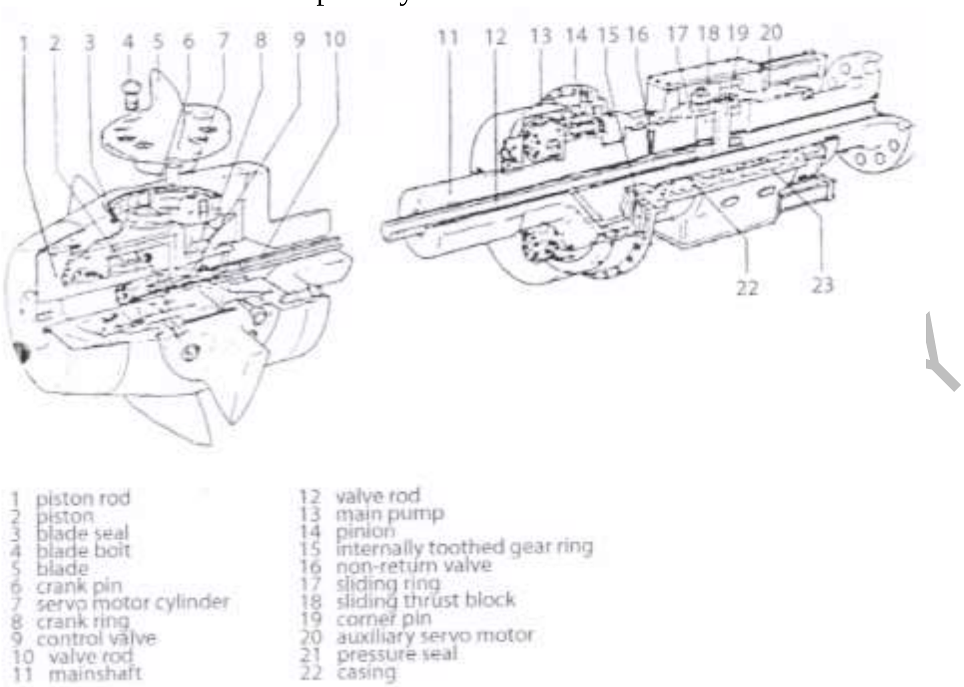


This type of propeller is usually associated with medium speed diesel engines and reduces speed through a uni-directional gear box to the output shafting, rotating and constant speed. There are other arrangements, which use reversing gearboxes, and can reverse the output shafting.

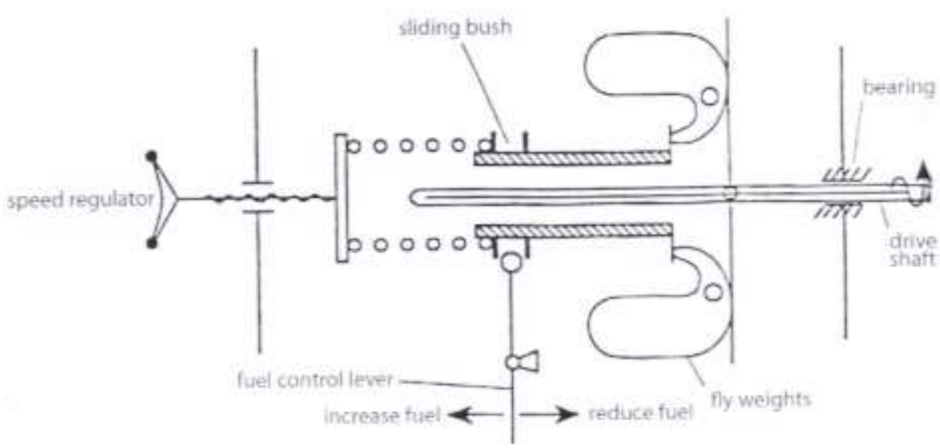
The propeller is attached to the rail shaft by means of a flange. The boss is hollowed out to accommodate the operating mechanism. The operating mechanism is a crosshead which can be operated hydraulically or mechanically, pushing the crosshead forward or aft. Set into the crosshead is a sliding shoe with a hole into which fits the crankpin. The crankpin ring is bolted into the propeller blade. The crankpin being offset thus, when the cross is moved, the blade is rotated. Each blade is set into the boss and is connected to the crosshead as described above. For the system to operate, the tail shaft has to be hollow to allow room for the valve rod and pressure oil for the hub. The pressure oil flows through the hollow shaft outside the valve rod back to the oil distribution box (OD box).



The hydraulic system provides pressure oil for the auxiliary servomotor and for the main pitch setting servomotor. With the control on zero pitch the valve is in the neutral position. The hydraulic oil is supplied up the centre of the valve rod and returns to the supply tank around the outside of the control valve rod. In the neutral position, the high-pressure hydraulic oil exerts equal pressure on both sides of the main piston. When the auxiliary servomotor control rod is moved in the appropriate direction, thereby pressuring the opposite side of the main piston and putting astern pitch on the blade. The working principle is illustrated above. A complete system is shown.



Considered by many merely as a means of speed regulation, the governor is, in fact, a very refined component, which in its most developed form is able to load limit, load share, load sense, regulate rates of acceleration. Not all these features, however, are available or even required in any one unit. A governor is usually made to suit the service demands on the engine to which it is to be fitted. It may provide single speed running conditions irrespective of load changes (isochronous), or be able to respond to increases in load so that acceleration is regulated to a level compatible with the effective and safe running of the engine.



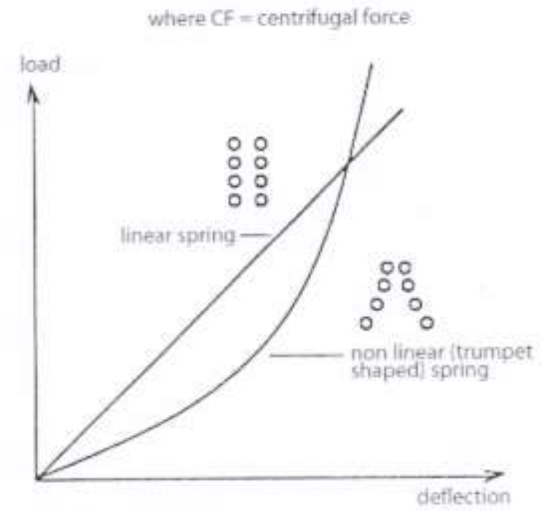
The early forms of 'inertia' type governors were, in essence, overspeed trips, and were not able to increase fuel to suit increases in load. Although these governors are now largely obsolete, the principle behind them is still used in 'overspeed trips'. These trips shut down an engine in the event of an excessive and rapid increase in speed such as may occur if the propeller shaft were to fracture or when the vessel is in heavy weather with the propeller coming out of the water. These units commonly have a 'fly' or 'bob' weight restrained by a spring. When the engine exceeds a predetermined speed, the weight moves out to strike some form of fuel cut off. The important thing about this action is that as soon as the weight begins to move, its centre of gravity moves radially outward from the centre of the shaft, increasing the centrifugal force so that the weight moves outward with increasing force. This process is therefore very positive in action and no hunting or hesitation occurs. Once the pre-set speed is reached, the overspeed cut out operates, very rapidly.

Centrifugal governors, unlike the above units, are able to both increase and decrease the fuel setting as loads either rise or fall. However, it is not possible to make a centrifugal governor truly isochronous (constant speed). When an increase in load is experienced by an engine it will tend to slow down.

This causes the flyweights of the CF governor to move inwards (with respect to the centre of their drive shaft) under spring force. This, in turn, causes the fuel racks to be pulled out to increase fuel, but if the racks are in a new position then the slide of the governor will also be in a new fly position, and so the balance between the flyweights and spring will be achieved at some new running speed. This change in final, steady running speed is known as the 'permanent variation', whereas the fall or rise in speed which occurs as loads change is called 'temporary variation'. The temporary variation fluctuates above and below the desired speed value as the governor attempts to settle down to a steady running speed again. The period of hunting that occurs across the desired value is a function of the size of weights; the smaller the weights, and therefore the more sensitive, the longer the period of fluctuations in speed. Large weights settle to a final steady speed more quickly than small weights, but the magnitude of their temporary variation is greater. Thus it can been seen that such governors are not suitable for regulating engines which drive alternators, where frequency stability is important, but are a adequate for dc generation and the control of any other prime mover where strict adherence to a set running speed is not important. One of the major drawbacks of these governors are their limited 'governor effort', i.e. the power it develops to operate the fuel racks of the engine. Although large powers can be developed, fairly large flyweights are required; the governor then becomes less sensitive and large changes in running speeds will occur before a steady condition is reached. Although the governor effort can be increased by gearing up the rotational speed of the flyweights, usually to a maximum and optimum of 1500 rev/min, there is still a limit to the power output.

Where routine maintenance is concerned, the governor should be checked regularly for adequate lubrication. The operating range is usually quite small, giving a tendency for them to wear over limited areas. Then a sudden and larger change in speed than normal may carry the governor onto a ridge of debris or gummy oil deposit so that it may stick at that point. To restrict this problem as far as possible, the governor pivots, slide, etc should be cleaned and well lubricated whenever possible. It should be borne in mind that the governor structure is such that, were the spring to fracture in any way, the flyweights would be able to move outward and shut the engine down. The connections from the governor to the fuel racks should be designed in such a way that the governor can both increase and decrease the fuel within the bounds of some hand setting; i.e. the governor can adjust the fuel settings but cannot release more fuel to the engine than is dictated by some predetermined value set by the engine operator.

To overcome the above limitations of the centrifugal governor, ‘servo governors’ have been developed. These use the power of hydraulics to move the heavier fuel rack systems associated with the larger engines into the desired position. This ‘powered’ operation is rapidly and accurately achieved, and the hydraulic flow can be either electrically or mechanically controlled. The speed sensing can be done by a tachometer arrangement that can be set to the desired speed, and on sensing any variation a solenoid operated flow valve allows pressurised hydraulic flow into a servo system of pistons/plungers which resets the rack positions. Although this system is quite effective, more mechanically controlled governors are fitted to larger engines. These use the principle of the centrifugal governor, i.e. flyweights acting against spring pressure, but instead of the slide working directly onto the fuel racks it simply regulates the flow of hydraulic fluid to the servo pistons controlling the rack positions. This system therefore has the proven reliability and sensitivity of the small centrifugal governor and yet develops quite a large governor effort through the hydraulic fluid.



The spring is usually of the ‘trumpet shape’ meaning that the weaker coils are compressed out as the spring is loaded so that the spring can follow the curve of the ‘square law’, rather than the linear reaction associated with the parallel spring. The square law relates to the increment of centrifugal force developed as speed increases, (CF =mv/r). Instead of the spring strength and CF force only matching at one point over the operating range, the trumpet shaped spring allows a more balanced relationship to occur over the whole of the speed range. By a simple lever arrangement the spring tension can be varied with load changes. Then the change in load, causing a change in fuel setting, does not set up a protracted period of temporary variations in speed.

As the engine speed approaches the desire value, the spring tension is automatically adjusted so that its original demand for change is moderated. The amount by which this reaction works can be regulated by the governor.

The fall in speed which occurs as the load on the engine is increased is called 'droop'. With the original CF governor this was inevitable, but with some clever linkages inside the modern hydraulic governor this fall off in speed or 'droop' can be avoided. The governor; is said to be 'isochronous' if there is not change between no load and full load speed. Where there is a small reduction in speed as load increases the governor is said to have 'fine droop' and 'coarse droop' occurs when the final running speed drops well below the desired value as loads are imposed onto the engine. There are usually quoted as a percentage of the no load running speed, so

$$\text{Droop} = \frac{100 \times (\text{no load speed} - \text{full load speed})}{\text{full load speed}}$$

The zero droop options means that the governor changed the fuel setting continuously and substantially, whereas coarse droop allows a smaller and less protracted adjustment of the rack setting. The modern governor is a refined precision instrument and should not be tampered with unnecessarily. Even the oil within it has 'drag' characteristics that are allowed for in the design, so that deterioration of the oil will adversely affect its operation. (Use of the wrong type of oil will dramatically affect the behaviour of these units.) The figure below shows the relationships between zero droop, fine droop and course droop.

It may be desirable to have zero droop for an alternator (to maintain frequency), but such a refined governor may not be essential on a main propulsion unit. Problems could also arise when engines are run in parallel so that two governors set to too fine droop so that the desired speed can be maintained, and the other to a coarse droop, so that it is able to take care of the load variations that occur during operation. In fact, load sharing is a difficult concept and should only be undertaken with advice from the manufacturers of the governors concerned, since specific models of governor may be available to suit the particular problem in hand.

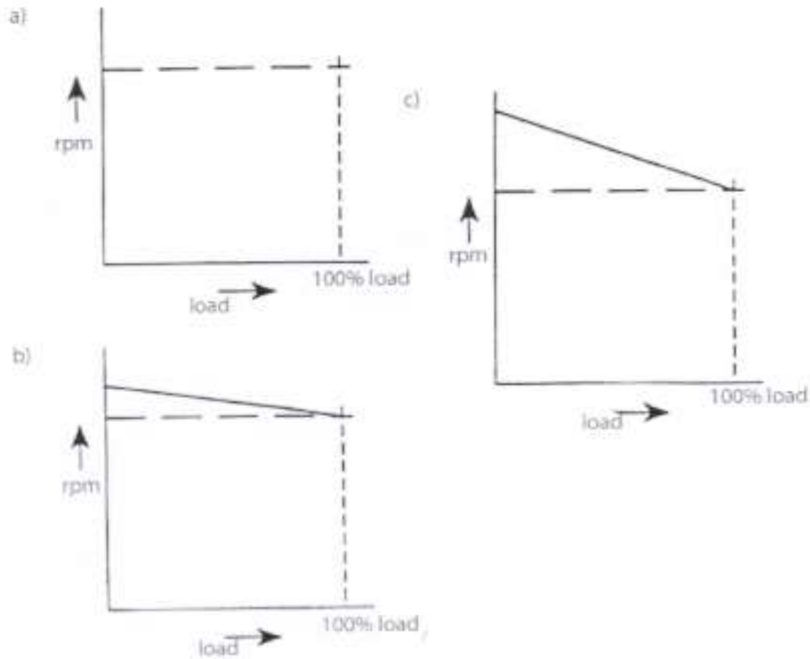
Load sharing should not be confused with 'load' limiting'. Many governors reacting to changes in speed, and in particular to a fall in speed, will attempt to increase the flow of fuel to recover the loss of speed. However, the fall in speed may be due to the engine reaching its power capability and any further release of fuel may only lead to damage to the engine and a loss of efficiency. To protect against this, most governors have inbuilt, load limiting devices, which are set (possibly during engine trials) to an upper limit of engine operating temperatures, exhaust jacket, etc., so that the engine, on reaching this predetermined loading, is not fed with any more fuel. Some governors have an external adjuster that allows fine trimming of the load limiter, which is simply a 'stop' up which even decreasing speed cannot cause the release of further fuel. The result is that the maximum thermally acceptable load on the engine is not exceeded.

Another refinement for governors regulating alternators is a load 'sensing' process, achieved electrically from the main switchboard (above). Sensors, reacting to changes in both load and frequency, send an integrated signal back to the governor which pre-empts the changes in speed of the prime mover to such an extent that the governor is adjusted to accept the change in conditions before the mechanical effects of slowing down/speeding up occur through the system. The net result is a much steadier running speed and a more stable frequency; important for many of the instruments on the vessel, in particular the gyroscope (compass). The signal is applied through a small servo motor on top of the governor. The motor regulates the load on spring, thereby regulating the flow of hydraulic fluid to the servo piston controlling the position of the fuel racks.

The alternative to this would be to allow the speed changes incurred by load changes to work their way back down the system, through the rotor of the alternator, crankshaft and governor drive. The governor would then begin to react to correct for the change in speed, but the change in speed would have also affected the fuel rack setting, in turn causing a change in the amount of exhaust gas generated, affecting the speed of the turbocharger, which changes the throughput of air, which affects the combustion process and running temperatures of the engine. Whereas small changes in load may be absorbed without too much difficulty, a process like this would suffer greatly were there to be a large change such as stopping and starting of a mooring winch or air compressor. It is important that the load sensing equipment operates fully and effectively. The same servo motor is used to regulate the speed of an incoming switchboard frequency. Once coupled, the engine is locked to the frequency by the synchronising torque of the system and the governor becomes a regulator adjusting the fuel flow to match the load fluctuations.

With controllable pitch propellers, speed sensing equipment may be used to increase the propeller pitch as the speed rises, so that propeller absorbs more torque and increases the load on the prime mover. As the load torque then exceeds supply torque the speed will fall until the set value is reached again.

Governing prime movers, particularly diesel engines, requires careful consideration. The cyclic variations of a diesel cycle can be passed into the governor drive if it is too 'stiff'. That is, the cyclic vibrations will be imposed on the internal gearing etc. inside the governor housing. To prevent this, some form of damper should be used on the drive into the governor. The mounting point for the governor should be rigid; a vibrating mounting would soon downgrade even the best of governors. Chain or belt drives should be avoided as far as possible, as slapping of the belt or chain produces speed variations causing malfunction of the governor. Similarly the drive from the end of the cam shaft is subjected to torsional vibrations, and governors should not be located at that point. They should be located as close as is practicable to the fuel pumps, thereby limiting the mass/inertia of operating linkage. In all cases, the governor should be matched to the engine requirements in terms of droop, load limiting, response time etc. On large engines there is an inertial resistance to acceleration within the masses of reciprocating and rotating elements of the engine, so that during acceleration fuel could be released to the cylinders at a faster rate than efficient combustion can burn it. In an attempt to compensate for this, and to maintain acceptable combustion during acceleration, a tapping from the scavenge space may be taken and the pressure used to regulate the rate of fuel release to the engine. This process is incorporated into the governor operating system so that the governor releases a quantity of fuel commensurate with the increase in air pressure in the scavenge space (see below). (during deceleration the problem is not so great, as excess air can be tolerated far more easily than can the incomplete combustion associated with insufficient air).



Other controllers are integrated into the governor. These include droop control, load limiting and speed setting. From the complexity and inter-reaction between these it should be understood that these units, once calibrated and set, should not be casually adjusted. Even the viscosity of the oil is important. An oil that is too thick would slow down the reaction of the governor and would completely alter the flow through the needle valve(s). Whenever a problem is experienced with these refined and reliable governors it is advisable to call in an expert.

The two factors essential for the production of generated voltage in an ac generator are rotational speed and magnetic flux. Field windings on the rotor create strong magnetic field 'poles' when direct current is passed through them.

The rotor is driven at constant speed by the prime mover (diesel, turbine or main shaft). This produces voltage at the generator stator terminals of the correct frequency (60 HZ or 50HZ).

The dc current (called the excitation) in the rotor is adjusted until the generator produces the correct voltage (typically 440V).

Both the frequency and voltage are affected by changes of electrical load on the generator.

To keep the frequency constant when the load changes a speed governor is fitted to the prime mover.

To keep the voltage constant when the load changes an automatic voltage regulator (AVR) is fitted to the generator.

The governor and AVR also play an important part in the successful parallel operation of AC generators

When the generator is on no-load the governor set-to is manually adjusted until the frequency is correct. The AVR trimmer (if fitted) is adjusted until system voltage is correct. The prime mover does not require much fuel to run the generator on no-load so that governor has only opened the fuel throttle valve a small amount. If a KW load such as heating is switched on to the generator, then energy is drawn from the generator and converted into heat. This energy must be provided by increasing the rate of fuel supply to the prime mover. This happens automatically in the following way:

1. When kW load is applied the load draws current from the stator windings.
2. This current flowing in the stator windings produces a rotating magnetic field. This field rotates at the same speed as the rotor.
3. The stator field lies across the rotor field and exerts a magnetic ‘pull’ or ‘torque’ on the rotor which tries to pull the rotor backwards as shown below.
4. The magnetic torque exerted on the rotor causes the rotor to slow down. This reduction of sped is detected by the governor.
5. The governor opens up the throttle valve to increase the fuel supply.
6. The throttle valve is opened until the frequency is back to normal (in fact slightly less).

Now the prime mover is developing enough power to drive the alternator at the correct speed and meet the KW load demand.

The governor responds to changes of kW load to keep the system frequency constant.

Governor characteristics

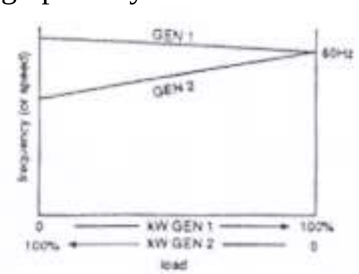
When kW load is applied the governor tries to keep the frequency constant. The graph of frequency against kW for the governor shows how closely it maintains constant frequency.

For perfect accuracy the characteristics should be horizontal. This means the system frequency is exactly constant at every kW load. This is called isochronous. In practice most marine governors exhibit a ‘droop’ of up to 5%. This is so that the generator can be run in parallel with other generators.

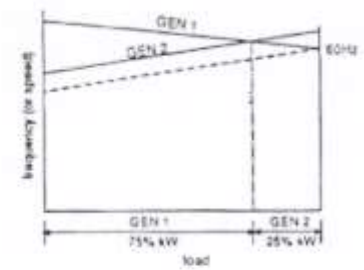
Some modern electronic governors may provide a selector switch where non isochronous operation is selected when the generator is running in parallel.

After the incoming generator has been synchronised it is now ready to take up load. It will be recalled that the generator will have to provide two types of ac power, kW and kVAr load sharing.

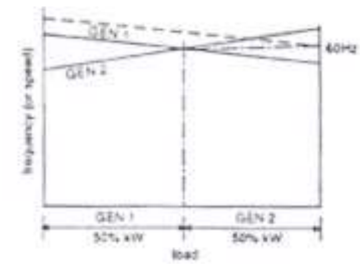
After synchronising, GEN1 is still supplying all the load kW while GEN2 supplies zero kW. The governors of both machines are producing 60 Hz. This situation can be depicted graphically below.



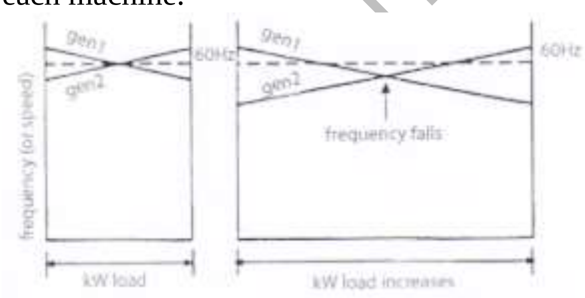
The kW of GEN2 are measured right to left. It can be seen above that both machines are producing 60Hx, GEN1 is supplying 100% of the load kW and GEN2 is supplying 0 kW.



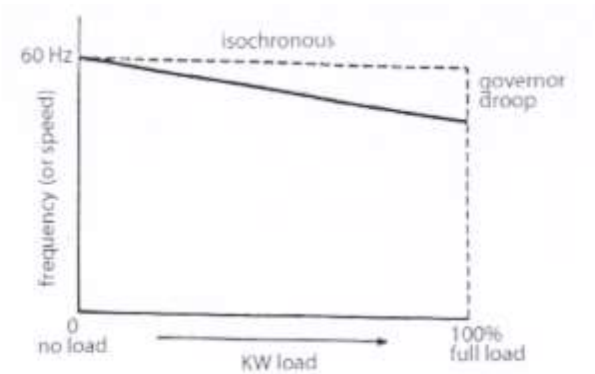
GEN2 can be made to supply Kw by adjusting its speed trimmer to increase the set point of the governor as shown above. This has the effect of 'lifting' the whole characteristic which results in GEN2 taking load and GEN1 losing load. A problem is that the system frequency increases.



Now the speed trimmer of GEN1 is adjusted to reduce the set point of the governor see above. This lowers the characteristics of GEN1 allowing GEN2 to take up more of the load and brings the frequency back to 60Hz. This load balancing is monitored on the kW meters of each machine.

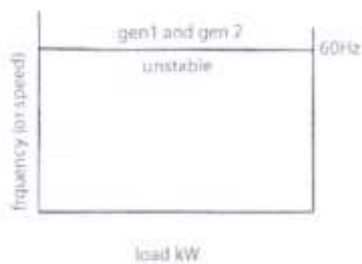


If two generators are to share load their governor characteristics must have a definite 'crossing point' that is why governor 'droop' is necessary.

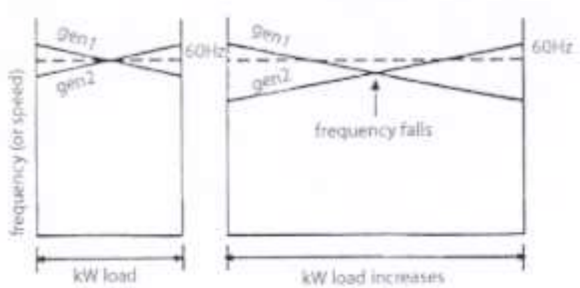


If the characteristics are flat (isochronous) as shown above then system accuracy is good because frequency stays constant as kW load changes, but machines cannot be run in parallel. With flat characteristics the load swings repeatedly from one machine to the other because the characteristics have no definite crossing point.

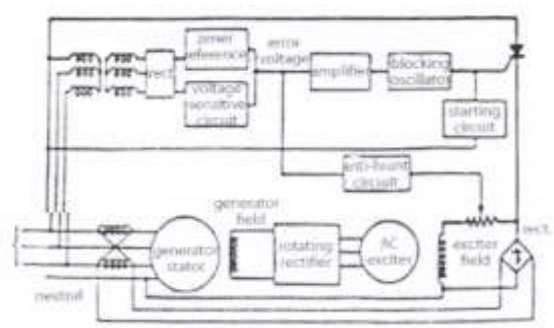
The amount of governor droop is a compromise between accuracy and stability. If the governor droop is large then the system is stable but the frequency will change slightly as kW load changes as shown below.



This is achieved automatically by the AVR units which adjust the excitation after synchronising so that each machine shares kVAr and generates the correct voltage.

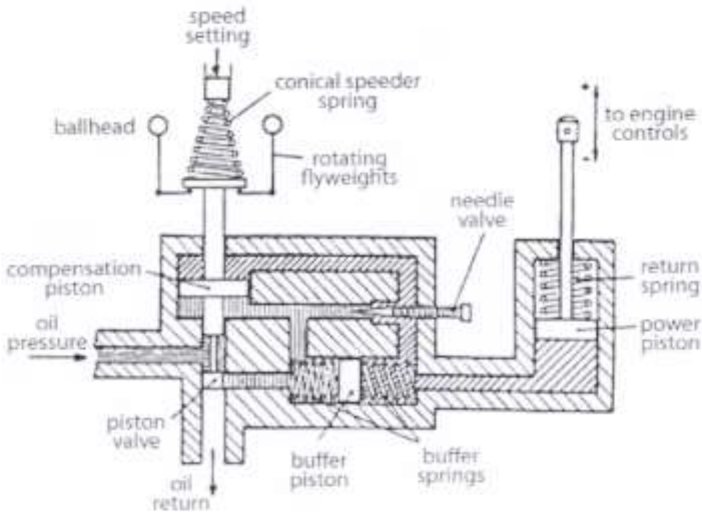


As with a governor, the AVR requires a 'droop' for stable parallel operation. As kVAr load changes the AVR responds to keep the system voltage constant.



A simplified diagram of a typical 'direct feed' thyristor AVR is shown above. The generator voltage is stepped down by a transformer and rectifier and then applied to the reference circuit. Any differences between the generator voltage and the desired voltage produces an error voltage. The error voltage is amplified and fed to a blocking oscillator which controls the fitting angle of the thyristor. The magnitude of the excitation current depends on the time during each cycle for which the thyristor is conducting. If the generator voltage falls the conduction time is increased by the increased error voltage. This results in increased excitation current and rotor flux which brings the generator back to the desired value. Short circuit excitation current transformers (CTs) are used to prevent complete collapse of the generator excitation under short-circuit conditions. These CTs provide all the excitation under short circuit conditions and enable a sufficiently large generator current to be maintained to ensure circuit-breaker tripping.
For parallel operation the AVR must have 'droop' and a quadrature current compensation (QCC) circuit consisting of a CT and resistor is used. The CT detects lagging load current and caused the AVR to reduce the output voltage.

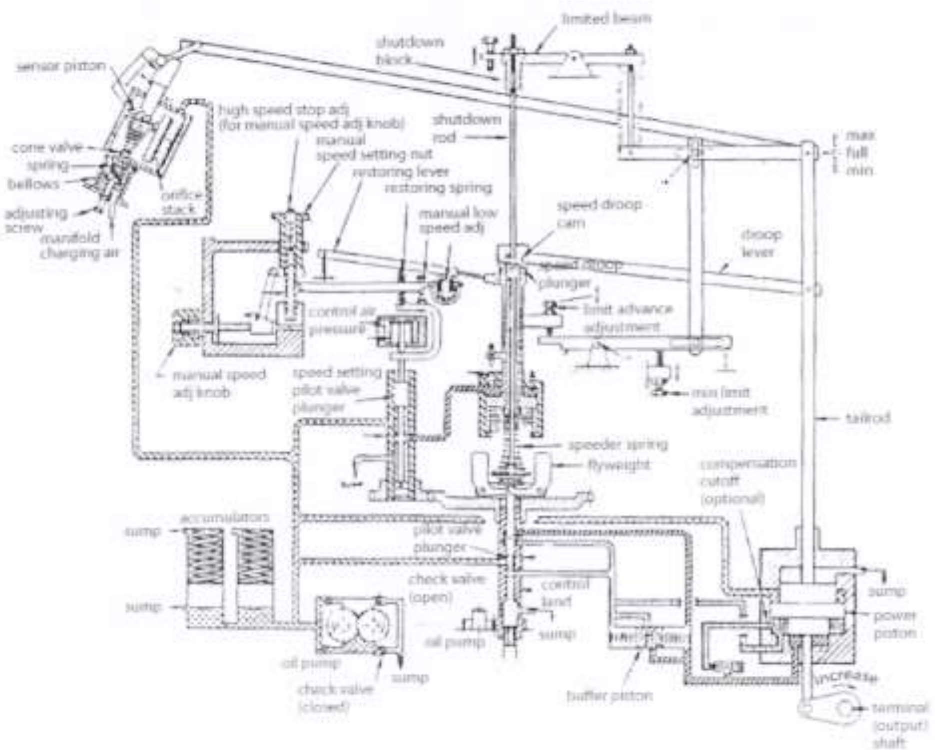
A governor automatically controls engine speed by regulating the fuel supply. Modern practice requires a governor to be sensitive to small changes in speed. If it maintains the engine at a set speed, irrespective of change in load and power, it is said to be isochronous. When fitted to main engines, there must be the facility to adjust the set speed on the governor, which is then said to be a variable speed type.



Earlier large, slow running, direct drive main engines were inherently stable under normal condition. Hand controls were adjusted to give a set speed regulated by the propeller load. Only an overspeed cut-out was considered necessary to prevent racing and damage in an emergency such as a shaft fracture, loss of propeller or the propeller leaving the water in heavy weather.

Modern practice requires an engine to be fitted with a governor giving close speed control for fuel economy, in particular for engines driving electric alternators. The type and size of governor must be designed to match closely the characteristics of the engine.

Many diesel engines are fitted with mechanical-hydraulic type governors. These use a hydraulic servo-piston which creates sufficient power to operate the engine fuel pump controls without any loss in sensitivity of the mechanical speed-sensing ballhead. Hydraulic oil pressure is take either from the engines lubrication system or from a separate gear pump operated by the governor drive. This is usually preferred as it allows the use of selected oil maintained in a clean condition. It will require oil pressure boosters, charged form the starting air system, to ensure sufficient power to manipulate the engine fuel pump controls when starting from rest.



The figure above shows the working parts of a mechanical-hydraulic, isochronous type governor; with variable speed control. The ballhead consists of two identical, eccentrically pivoted, flyweights mounted on opposite sides of a rotating sleeve. Speed of rotation is proportional to engine speed and may be by direct drive from the camshaft or through a step-up gear to increase governor speed and sensitivity. Dampers are fitted in the drive to damp and reduce any speed and sensitivity. Dampers are fitted in the drive to damp and reduce any torsional vibrations. A crank on each flyweight bears on a sliding compression plate, which is held in equilibrium between forces from the flyweight and a compressive force from compression of the governor speeder spring. A conical or trumpet shaped spring is used as this gives a more effective relationship between spring compression force and the centrifugal force on the flyweights. If the engine speed slows, the centrifugal force on the flyweights decreased allowing the moving sleeve to be lowered by the spring. If the engines speed increases the centrifugal force increases and flyweights raise the sleeve.

The sleeve is connected to a hydraulic piston valve by a rod and there is also a compensation piston (pilot valve receiving piston) attached to this rod which is subjected to a force if oil pressures on each side of it are unbalanced. This force will then add to, or subtract from, the speeder spring compression force at the ballhead, the effect being to cause a slight, temporary change in engine speed (temporary speed droop).

As the engine speed slows, forces on the ballhead move the piston valve down, uncovering the port and allowing oil under pressure to pass into the servo system. The pressure acts on the buffer piston, forcing it to the right, compressing the right-hand buffer spring, displacing oil on that side and raising the power piston, which in turn increases the engine fuel pump settings. Due to compression forces on the buffer springs, the oil pressure on the right of the

buffer piston will be slightly less than that on its left. These pressures are communicated to opposite sides of the compensation piston giving it an upward force which adds to the compression on the speeder spring. This assists in returning the piston valve to its shut position even though engine speed has not yet returned to its set value.
The pressure difference across the compensation piston is only temporary because the needle valve allows oil to pass slowly and balance both sides. The buffer piston springs also return to its mid-position.
The ballhead has now returned to its original setting (at the set speed), while the controls are at a higher setting commensurate with the demand for greater power.
Conversely, if the engine speed increased the ballhead raises the piston valve, releasing oil from the servo system. The buffer piston moves to the left: the power piston moves down reducing fuel settings to slow the engine. There is now a downward force on the compensation piston and this together with the speeder spring compression forces the piston valve down to close the oil passage.
These changes are also temporary until pressure equalises through the needle valve. The flow rate past the needle valve is adjusted to match the engine's response characteristics (the time it takes to respond to a change in the fuel setting.)
Additional attachments to the governor system allow control of a permanent speed droop, which is necessary if two or more engines are to operate in tandem through a common geared drive. In this case their speeds are locked together, but their respective power settings must be governed.
Alternator drive engines will require synchronisers to control frequency. Maintenance of governors must ensure that working parts are in a free and unworn condition. Oil passages must be clean. The oil supply must be maintained and replenished when necessary. A heat exchange may be fitted to the oil circuit to regulate a constant oil temperature.
Speed Droop is the change in operating speed to cause the fuel controls to move from full to zero, or vice versa.
Temporary Speed Droop means that the governor will, after a short delay, return to its original setting giving constant engine speed.
Permanent Speed Droop means that the governor will take a different position and normally a different speed as load changes.

It is possible that an engine governor may fail, or not act quickly enough in an emergency situation to prevent damage to the engine. Thus it is usual to have an addition simple overspeed cutout fitted. This should act independently of main speed governor, and in the event of overspeeding it will immediately cut power off the engine, either by raising fuel pump plunger followers clear of their cams or by opening pump suction valves, either of which will shut off fuel and power. Cutouts are fitted at each pump and they can also be used, if required, to shut power off one unit of the engine without affecting the remainder of the safety system.
Power to operation the emergency system may be electrical, pneumatic or hydraulic. The system may be utilised for other emergencies such as failure of vital engine operating systems. It can be coupled to remote emergency stop buttons.; Any override of the overspeed trip can only be carried out manually at the engine.

Simple electronic control systems can be designed to carry out the functions of a mechanical-hydraulic governor including facilities to control load-sharing, synchronising power sensing etc. They may readily be incorporate as part of an overall control system to include starting and stopping routines, and can be programmed to avoid running at critical speeds, to prevent overspeed and for other safety measures. The figure below shows a simple block diagram of the processes.
A speed sensor such as a magnetic pickup transmits a signal representing the actual engine speed and this signal is compared with one for the desired (set speed) value. The error (difference) in these is amplified and passed to a controller and actuator which generates sufficient mechanical force and power to operate the engine pump controls.

Crankcase explosions can cause serious damage to engine room equipment, but more important is the hazard to the engine room personnel. It is necessary therefore for the engineer to completely understand the process leading to the propagation of conditions favourable to an explosion. The engineer can then maintain his engine so that those conditions should not occur.
It must be understood that an explosion can take place in any enclosed space such as a chain case, gear case, crankcase of a diesel engine or air compressor where oil is present. The magnitude of the explosion is governed mainly by the available volume of explosive vapour, and it is this, that makes large, slow speed main engine explosions potentially devastating.
The cause of the crankcase explosion may be a 'hot spot' or overheated part within or adjacent to the crankcase of an operating engine. Under normal running conditions the air in a crankcase will contain oil droplets formed by lubricating oil splashing from the bearings onto moving surfaces. This mixture will not readily burn or explode. Crankcase lubricating oil should normally have a high closed flashpoint (above 200°C) and this must be maintained in order to reduce the risk of explosions. The most common cause of lowering the flashpoint is contamination with fuel oil.
It has been provide that engine size does not affect the incidence of explosion (which are likely in lifeboat engines as they are in large main propulsion engines), and that any moving part within the enclosed space can be responsible for the explosion, e.g. piston rods, piston skirts, chains, gears, bearings and so on.
Local hot spots may arise due to overheating of bearings, piston rod gland, timing chain, hot combustion gas or sparks from piston blowpast in engines where no diaphragm is fitted; or from fires in spaces adjacent to the crankcase, such as scavenge trunks etc. There is an interspace between the scavenge space and the crankcase thus preventing direct contact.
Such sources can be eliminated by proper maintenance, correct lubrication and oil condition, cleanliness and by avoiding the engine. The general use of white metal bearing materials which have moderate softening and melting temperatures also helps to avoid a rapid rise in temperature.
The sequence of events leading to explosive conditions is as follows. The natural atmosphere in a crankcase consists of large globules of oil (100-300mm in diameter) dispersed through the air. These globules are, relatively, so large that they will not ignite explosively, though they may burn under the correct conditions. A 'hot spot' (minimum temperature approx 360°C) can vaporise these globules. The vapour, rising to cooler parts of the crankcase, is

then condensed into an oil mist. This oil mist consists of small globules of oil of approx 2-10 mm in diameter. When ignited, an accumulation of this oil mist can cause a heavy explosion. The initial vapour created by the hot spot may cause an explosion, though in most cases there would not be sufficient to cause a heavy explosion.

The oil may be ignited by coming in contact with a hot spot or spark at a temperature of 270°C. It may also be ignited if heated about 370°C (self-ignition temperature).

The amount of oil mist generated before ignition regulates the severity of the explosion. A small amount will create a fire; a large amount an explosion. The sooner the generation of oil mist is discovered, the smaller is the chance of an explosion, provided that the correct procedures are then followed.

The ratio of oil mist to air also governs the severity of the explosion. A weak mixture (2% or 3% by volume) will give a mild explosion causing little, if any, damage. A mixture in the middle of the range (5 to 7%, oil fuel vapour in air) will, if ignited, cause a heavy explosion, probably blowing off crankcase doors, causing external damage and engine room fires. A rich mixture (9-10% of fuel vapour to air by volume) may cause a mild explosion. It should be appreciated that, following the explosion, a partial vacuum is created in the crankcase, and the engine room atmosphere flows back into it.

In the case of the rich mixture, the explosion will be followed by a period when air flowing back into the crankcase dilutes the rich mixture into the middle of the explosive range. A secondary explosion at this condition could be devastating. In the past cases the vacuum has been responsible for drawing off the crankcase doors of adjacent engines, laying their atmospheres open for combustion. It is to avoid this 'chain reaction' that crankcase explosion doors are designed to close as rapidly as possible after relieving and explosion, the closing being a way of preventing air ingress to the crankcase. For similar reasons, there should be no cross connecting pipes between the crankcase of engines. Oil return pipes to a common sump should be taken to below the surface of the oil so that an explosion in one engine cannot find its ways into the second engines.

Extraction fans exhausting to atmosphere up the funnel are sometimes fitted to keep the engine clean. The fans cause a small pressure depression in the crankcase that prevents oil leakage, as air is drawn in through any small aperture that would otherwise weep oil. The fans must be shut off if conditions that could lead to a crankcase explosion are suspected. If left running, they could dilute a rich mixture to the middle of the explosive range.

Should the conditions of a hot spot arise within the crankcase, a watchkeeper may detect them by irregular running, engine noise, increase in temperatures and by the appearance of the dense white oil mist.

Detection by instruments may be by temperature sensitive probes within the crankcase near the bearing oil returns, or more commonly by the use of a crankcase mist detector. This operates visual and audible alarms in the event of a white mist being formed at well below the concentrations required for explosive conditions.

Crankcase explosion relief valves must be fitted to all but the smallest crankcase. They open automatically at moderate pressures allowing the pressure of the primary or minor explosion to be dissipated and preventing possible rupture of the casing. The valves instantly close when the pressure drops and thus prevent the ingress of air, eliminating the possibility of a major explosion. Valves are fitted with wire gauze to prevent the emission of flames and may have external deflectors to aim hot gases in directions where they will do least damage.

An alert watchkeeper can detect rising oil temperatures quickly and respond to the dangers before conditions get too severe. Stopping the engine is by far the best thing to do but this can only be done with agreement from the bridge. Only when there are no hazards in a navigational sense should the engineer slow the engine down and stop it. Permission from the bridge watchkeeper should always be sought before slowing or stopping the engine; which may cause a collision/grounding that would otherwise have been easily avoidable. After checking with the bridge, slow, or preferably stop, the engine, and, if possible, increase the flow of lubricating oil. It may be advisable to operate the engine turning gear, with indicator cocks open to prevent seizure of overheated parts. Personnel should avoid the vicinity of relief valves.

Never open the crankcase until adequate time for cooling has elapsed. 'Adequate' times is not easy to define but in most cases at least 30 min should elapse, preferably much more. In the crankcase, the hot spot will still have enough heat left in it for it to be located. Carbon dioxide flooding would inert the crankcase, approx 30% by volume being sufficient, but not many engines are fitted with such facilities.

Permanent inerting is not practicable, as not only could the gas leak into the engine room atmosphere, but routine maintenance, would be inhibited. Inevitably, cost would also preclude the use of permanent crankcase flooding.

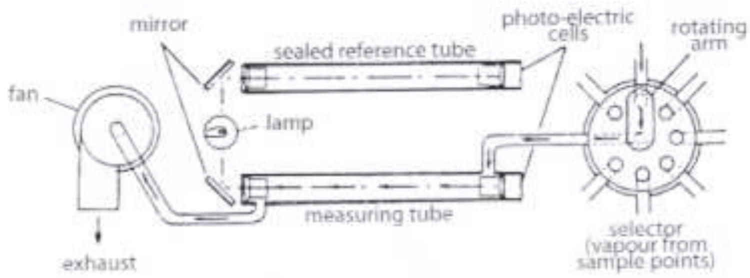
Subdivision of crankcase will inhibit the build up of high velocities and pressure of flame propagation through the crankcase from a primary explosion.

Crankcase doors should be or robust construction to prevent rupture. Any internal crankcase lighting must be flameproof. Vent pipes fitted to crankcases should not be too large; they must be led to a safe place, remote from the engine, and fitted with gauze. Connections from the engine must extend below the oil level in the sump.

In the cases where gas flooding systems have been fitted to crankcases after cooling the crankcase must be well ventilated before personnel may enter for inspection.

Above all, good and regular attention to the maintenance of the engine, avoidance of overloading and the provision of adequate lubricating oil should mean that explosions never occur, but to protect against the unpredictable, mist detectors and crankcase explosion doors should always be checked and maintained in satisfactory condition and be part of the planned maintenance system.

The figure below is a diagrammatic view of a Graviner oil mist detector which may be fitted to monitor samples of the air and vapour mixture taken continuously from the crankcase of a diesel engine. Such a device will detect the presence of oil mist at concentrations well below the level at which explosions may occur giving a warning in time to allow avoiding action to slow the engine and prevent either serious damage or an explosion.



The detector consists basically of two parallel tubes of equal size, each having a photo-electric cell at one end which generates an electric current directly proportional to the intensity of the light falling on its surface. Lenses are fitted to seal the ends of each tube but allow light to pass. Two identical beams of light from a common lamp are reflected by mirrors to pass along the tubes onto the cells which are then in electrical balance.

One tube is sealed to contain clean air and is termed the *reference tube*. The other, the *measuring tube*, has connections through which samples of the crankcase vapour are drawn by an electric extractor fan. If a concentration of oil mist is present in the sample, light will be obscured before reaching the cell of the measuring tube; electrical balance between the two cells will be disturbed and an alarm will be operated.

Sampling points should be fitted to each cylinder crankcase and their connections are brought to a rotating selector valve which is driven from the fan motor. This repeatedly connects each sampling point to the measuring tube in sequence. Sampling connections should not exceed 12.5 metres in length and must slope to ensure positive drainage of oil; they must avoid any loops which could fill with oil.

In the event of oil mist being detected the rotator stops to indicate which sampling point is concerned. The instrument must be reset before the alarm ceases and sampling will recommence.

The extractor fan is very small and after testing the samples are exhausted to atmosphere.

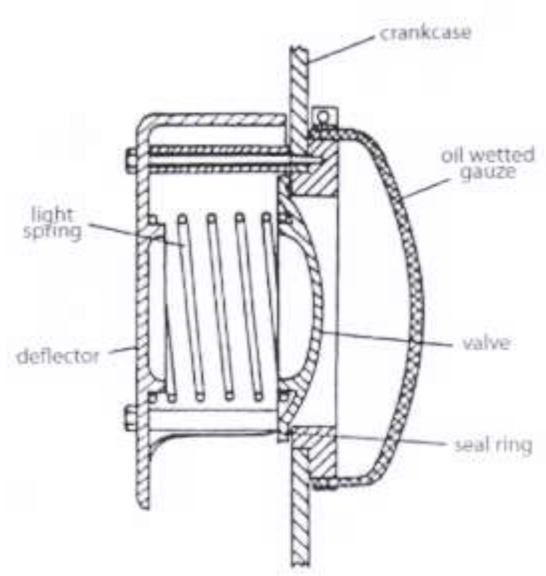
The detector should be tested daily and the sensitivity checked. Lenses and mirrors should be cleaned periodically.

In this model the total mist concentration is measured with respect to clean air. An alternative model draws samples through both reference and measuring tubes.

A mixture from all cylinder crankcases is passed through the reference tube while comparison is made with samples for each cylinder crankcase and also from the atmosphere. In this manner a general sample of all cylinders is compared with normal atmosphere and each individual samples is also compared against the average.

The alarm activation by each individual sample point in the crankcase should be tested on a regular basis with a test spray.

The figure below shows a crankcase explosion relief valve which may be fitted to a diesel engine crankcase. It consists of a light spring-loaded non-return disc valve of simple construction. The valve disc is of aluminium alloy which reduces its mass and the inertia to be overcome when opening or closing valves rapidly. The large diameter spring will give sensitivity and allow the valve to float. The absence of a valve spindle eliminates the risk of the valve jamming.



The valve landing must make a gas and oil tight seal when closed and a non-stick oil and heat resisting rubber ring is fitted to the disc face.

An external aluminium valve cover secures the valve spring and acts as a deflector to direct any gas emitted over an arc of 120° aimed where it can do least damage. Inside the crankcase is a dome-shaped flame trap made of several layers of woven, mild steel wire gauze. This projects into the crankcase where it will become wetted with oil mist or splash from adjacent bearings. When wet with oil the gauze dissipates heat at a greater rate and becomes more effective as a flame trap. Free area of the gauze must at least be equal to the area of the open valve.

The valve assembly is secured to an aperture cut in the crankcase by a number of cover studs and distance spacers; these act as guides for the valve disc. The valve spring is designed to allow the valve to open under an internal pressure of approximately $5kN/m^2$ and will close automatically when pressure has been relieved.

Regulations demand that for engines of over 300mm bore, one crankcase relief valve of approved design is fitted to each crankcase and chain case. The combined area of the relief valves should be not less than 115 cm^2 per cubic metre of crankcase volume. The free area of each valve is to be not less than 45 cm^2. For smaller engines a reduction in the size and number of valves is allowed. These regulations also apply to the crankcase of large air compressors, etc.

Crankcase doors should be robust to prevent damage or rupture before relief valve operate to relieve pressure.

Valves will require little maintenance but should be tested periodically by hand; the spring should be inspected and the gauze cleaned.

The class surveyor will survey the relief valves at intervals.

For a scavenge fire to occur there must be the three sides of the fire triangle; fuel and source of ignition. The removal of any one of these would not only extinguish a fire, but to prevent air flow through the scavenge spaces is impossible as scavenging implies air flow. However, fuel should never be present in the scavenge spaces so a clean scavenge space can never ignite. Ignition itself could occur were there to be blow past the piston or were the piston to begin to seize in the liner. It may even be possible for the piston rod gland to overheat to the point where it could cause ignition.

The easiest way to avoid scavenge fires is to ensure that the scavenge spaces are maintained clean and free from oily deposits.The cleaning of the scavenge space should be part of the hours ran planned maintenance system, cleaned every 1000 hours ran. The ease of this depends, to some extent, upon the engine design, with respect to its breathing, and in particular depends on the pressure of exhaust gases still in the cylinder at the opening of the scavenge ports. However, the engineer can limit fouling of the scavenge spaces by ensuring that combustion is being carried out as cleanly and crisply as possible; there is good fuel timing, atomisation, penetration. Air fuel ratio and so on. Similarly, the lubrication of the ring pack needs to be controlled to prevent a build up of lubricating oil in the scavenge spaces. There is a possibility that oil may pass over with the scavenge air from the turbo-charger, particularly if the air filters are fouling up. Dust brought in with the air may also be a source of fuel within the scavenge spaces. The liner/ring interface should be well maintained. Use good quality piston rings and renew them and the cylinder liner in good time.

A scavenge fire may be caused by the ignition of unburned oil and carbon which has been blown from the engine cylinder into the scavenge spaces. This may include unburned fuel or cylinder lubricating oil and may be due to incorrect combustion caused by a defective injector, faulty fuel pump timing, incorrect fuel condition, lack of scavenge air, partially choke exhaust, low compression, afterburning, by operating the engine at overload conditions, or due to defective piston rings, badly worn cylinder liner, or by wrongly timed or excessive cylinder lubrication.

The oil will build up in scavenge spaces where it will become carbonised by further heating and will then reach a condition in which it can burn in the presence of air. It may be ignited by hot gases and burning particles from blowpast of piston rings.

A scavenge fire will manifest itself as a drop in power and irregular running of the engine. There will also be a rise in the exhaust and jacket temperatures local to the fire area, high local temperature in scavenge trunk surging of turbocharger, sparks and smoke emitted form scavenge drains and a smell of smoke/hot paint will be apparent. Automatic alarm systems are available, many of which are wires, the resistance of which alter with changes in temperature, the corresponding change in current flow activating an alarm. Scavenge fires are capable of generating conditions favourable to a crankcase explosion because they put heat into the top plate of the crankcase. That is one reason why the fire should be extinguished as soon as is reasonably possible.

When a fire occurs, the watchkeeper should, apart from raising the alarm, reduce speed (checking with the bridge first), shut the fuel off, inform the Chief Engineer, and slightly increase the cylinder lubrication oil to the affected unit to prevent, if possible, seizure and wear. A minor fire may shortly burn out and conditions will gradually return to normal. The affected units should be run on reduced power until inspection of the scavenge trunking and overhaul of the cylinder and piston can be carried out at the earliest safe opportunity.

Should a fire persist, if there is a risk of fire extending or if the scavenge trunk is adjacent to the crankcase with risk of a hot spot developing, the engine must be stopped, normal cooling maintained and it may be advisable to engage turning gear to prevent seizure. Without turning it is possible that the localised overheating of a piston or piston rod may lead to distortion and subsequent problems.The cylinder lubricators should be exercised and the turning gear should be operated, the ammeter for the turning gear should be observed during the running period, any excessive load, stop the turning gear and investigate. The tie bolts are generally shielded by the tubes form the extreme temperatures. Otherwise they may 'stretch' and relax their grip on the structure. In any case it is prudent t check the tension of these bolts after a large scavenge fire.

Fire extinguishing medium should be applied through fittings in the scavenge trunk: these may inject carbon dioxide, dry powder or smothering steam. The injection of carbon dioxide will rapidly extinguish the fire, but time must be allowed to pass before opening the doors, for a hot spot could cause reignition. Carbon dioxide could cause thermal cracking of the hot components within the engine. The use of dry powder would add to the cleaning up required once the emergency is over. Steam is ideal in this situation, provided the line is adequately drained first and the valve have not sized with corrosion. However, good it is as a fire fighting agent, steam is not recommended because of the problems associated with corrosion, water slugs preceding the steam and the need to generate it in the first place.

Measures must be taken to avoid the spread of the fire and if necessary cooling may be applied to the outer surfaces. On no account must the scavenge trunk be opened up while it is still hot. The early ingress of air may allow an explosion to occur. Air flow through the engine will occur naturally, even when it is stopped. This is due to the convection currents generated by the heat it the uptakes. Wrapping canvas around the turbocharger filters can limits this.

After extinguishing the fire and cooling down, the scavenge trunking and scavenge ports should be cleaned and the trunking together with cylinder liner and water seals, piston, piston rings, piston skirts, piston rod and gland must be inspected. Fire extinguishers should be recharged at the first opportunity and the faults diagnosed as having caused the fire must be rectified.

To prevent scavenge fires good maintenance and correct adjustment must be carried out. Scavenge trunking must be periodically inspected and cleaned and any build-up of contamination noted and remedied. Scavenge drains should be blown twice daily, morning and evening, and any passage of oil form them noted.

During a scavenge fire, sparks and burning soot emit from the funnel, in the case of vessels which carry inflammable cargoes, the wind direction should be noted and the vessels course altered to prevent burning embers landing in the cargo area.

On a vessel, which was very prone, to scavenge fires with a specific scavenge fire alarm connected to the Chief Engineer's cabin, the following procedure was adopted with success.

Indications: High scavenge temperatures, strong smell of sooty type smoke, scavenge fire alarm sounding, irregular running of the engine and thick smoke, sparks and burning embers emitting from the funnel.

Action: Inform the bridge, put the engine at Slow Ahead, (Buckets containing water must be hung under the scavenge drains at all times.). To find the area of the fire crack open and close the scavenge drains one at a time, the drain emitting sparks will be the area on fire, To prevent seizure do not stop the engine, increase the cylinder lubrication on the units affected, and apply the extinguishing agent to area on fire (In this case dry powder.).

Check round for hot spots on the scavenge belt, check the affected scavenge drain.
When no sparks emit from any scavenge drain and the funnel, also the scavenge area has cooled down. Stop the engine, engage the turning gear, turn the engine and exercise the cylinder lubricators, observing the turning gear ammeter. Open up the scavenge belt and muck out.

Safety devices fitted to scavenge systems may include an electrical temperature sensing device fitted within the trunking which will automatically sound an alarm in the event of an excessive rise in local temperature (above 200°C).
Pressure relief valves consisting of self-closing spring-loaded valves are fitted and should be examined and tested periodically. Other safety devices could include the scavenge drains and the fitting of a fixed fire extinguishing system. With such a system maintenance will include inspection and cleaning of injection spreaders, weighting of gas containers and rotation of dry powder freeflowing.
The alarm systems should be tested daily.
When any fire occurs in the engine spaces, the fire alarm should be sounded and assistance or advice summoned. Cleanliness in these spaces will help to prevent fires spreading.

Possible causes of an explosion in high-pressure starting air pipelines are the continuous leaking of a defective cylinder non-return valve while the engine is operating, or such a valve sticking in the open position during manoeuvring.
Under normal operation, some lubricating oil mist may be discharged from the air compressor to the air start system. This oil may be from excess compressor cylinder lubrication, from faulty oil scraper rings, or may even be suspended oil vapour contaminating the engine room atmosphere and drawn in at the compressor suction. Oil discharge is kept to a minimum by draining the after cooler, air receiver and starting system. If small quantities of lubrication oil do get passed into the starting air system, they will deposit as a thin moist film over internal pipe surfaces but are not readily combustible.
If a cylinder non-return valve should leak while the engine is in operation, some hot gas, possibly with unburned fuel and cylinder lubricating oil, may be blown through the valve to the adjacent air manifold. With further heating from the leaky valve, this together with the already deposited oil film will carbonise and form incandescent carbon. If starting air is applied to the system while still hot, the high pressure air coming into contact with burning carbon may cause an explosion. Such an explosion the deposited oil film and igniting it in the presence of air. Very high velocities and shockwaves are generated which may rupture pipes and fittings.
Alternatively, if excessive oil has entered the air start system, a mixture of air and oil droplets may be discharged through the open cylinder non-return valve during starting. This spray

may ignite due to high temperatures in the cylinder, causing a flame to pass back through the still open valve to the air manifold.

To prevent an explosion, air start valves must be correctly maintained and lubricated to ensure correct timing and free movement with positive closing. Oil in the system must be kept to a minimum, pipe lines must be drained and cleaned internally when necessary and oil discharge from air compressor must be kept to a minimum, by good maintenance.

To minimise the effects of such explosions, the air start manifold to each cylinder valve must be fitted with a flame trap and ample relieve valves; bursting caps or discs must be fitted to relieve excess pressure. An isolating non-return valve is fitted at the outlet from the main control valve.

A leaking air start valve can be detected while the engine is operating by local overheating of the pipe adjacent to the valve. If this should occur, the engine should be stopped at the first opportunity and the valve replaced. As a temporary measure, a blank flange may be fitted to the air manifold connection to isolate this valve, but since it will no longer operate it is possible for the engine to stop in a position from which it will not readily restart. Warning of this situation must be transmitted to the bridge. When the air start system is not is use it must be shut down and all drains should be opened. Drains are closed after air pressure has been put on the system. Air start valves should be lubricated, where such fittings are present, before the start of a voyage or during a long voyage without use. Cylinder non-return valves may be tested for tightness while in port by shutting isolating valves on the control air connections and applying air to the start manifold. Escape of air through open indicator cocks will disclose a leaking valve.

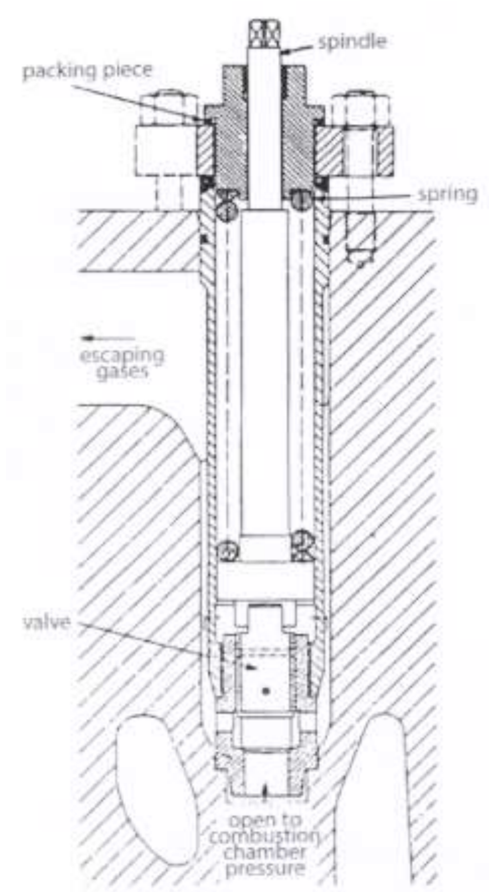
In the event of overheating of the discharge from the air compressor to the filling line, an explosion would be possible between the compressor and the air reservoir.

Overheating may be caused by failure of compressor intercooler and circulating water. In this case the high temperature within the high-pressure stage will make operation of the compressor and its cylinder lubrication difficult.

Excess discharge temperature is detected either by an alarm system or a fusible plug which will melt at 121°C to give warning.

In some engines it is possible to gag an air start valve. It must be stressed that gagging does not stop the valve leaking and should not be adopted.

The figure below shows a half-section of a cylinder safety valve fitted to the covers of a large two-stroke engine to release excess gas pressure from the cylinder. The valve is of stainless steel with a mitre seat and is loaded by compressing a helical spring. The lower end of the spindle is radiused to allow the valve to align with its seat: valve lift is limited by a shoulder at the top of the spindle. The spring keep or cap nut is locked in position to regulate the correct spring compression and the valve is set to lift at not more than 20% above the designed engine pressure.



Maintenance consists of cleaning and inspection at the same intervals as cylinder overhaul. The valve and seat should be examined and reground if necessary, the spring checked for its free length against an unused spare with no warping. After assembly the valve should be set and pressure tested.

Lifting of a safety valve relieves the dangerous pressure in the cylinder and also warns of incorrect conditions. The reasons for this must be ascertained and corrective action taken. The high temperature gas and flame expelled may damage the safety valve seat.

Valves may lift manoeuvring or slow running for a number of reasons. Ignition may be violent if engine speed is too slow, if a fuel injector has leaked during priming, or a fuel pump setting is too high or incorrectly timed. Should starting air be used as a brake when stopping an engine for reversal or during a ‘crash stop’, high compression pressures at about top dead centre may cause safety valves to lift momentarily.

Valves lifting during running may indicate an overload or timing faults including the camshaft drive.

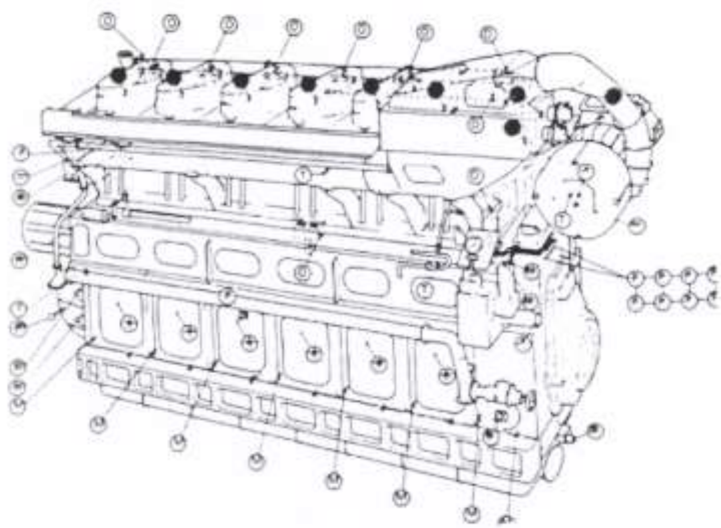
Safety valve area is only designed to relieve excess gas pressure and may be insufficient to prevent damage in the event of cooling water or oil leaking into the cylinder. Before starting an engine for the first time it should always be turned slowly with indicator cocks open to expel any leakage.

When testing the engine after maintenance, personnel must stand well clear of the cylinder safety valves, personnel have been seriously burnt by flame from a lifting safety valve.

While the practices evolved over the three generations for direct drive engines and for two generations for medium-speed engines betray substantial differences in important detail, there are basic principles common to both. The operators of either require to achieve:

1. Reliability: there should not be unplanned stops.
2. Long periods between overhauls.
3. Optimum performance to meet the designed duty.
4. Minimum annual cost in fuel, attention and parts.

To achieve these objectives it is obvious, though it should not be taken for granted, that the ship's engineering officers and engine room staff must not only be competent but well versed in the characteristics of the engine in question.



Every manufacturer will provide facilities and recommendations for taking such observations of the engine's behaviour as he considered helpful in maintaining its full efficiency. See, for instance, the figure above which shows typically for a medium-speed engine the measuring points for data logging, automation and protection. He will also provide for guidance a schedule of maintenance attention recommending intervals at which all necessary servicing work is undertaken. This will be based on his general experience with similar designs of engine, perhaps on long experience of large numbers of engines of the same type, but it will inevitably be pessimistic, so that operators can form a judgement in safety about the ideal intervals for their own machinery. This will be influenced by the owner's own views, by the operating conditions in which the engine must work, and by the vessel's trading pattern: no owner wishes to take his vessel off hire when it is most busy.
As the trend against 24-hour manning continues, more reliance is inevitably placed on condition monitoring plus alarms to replace the eyes and ears of the watch keeping engineers,

and on data logging to achieve the continuous monitoring of the engine's behaviour. The crucial alarms which are invariably provided are for low lubricating oil pressure, low cooling water level, high cooling water temperature, but many others can be added if required. Some, particularly those listed above, are backed up by a shut down capability, although such protection must involve a trade off between damaging the machinery and hazarding the vessel.

It must be said, however, that notwithstanding the inevitability – not to mention the ingenuity, and in several cases the noteworthy dependability of data logging condition monitoring installations – the absence of skilled ears and eyes in the engine room is on occasion sorely missed. Fortunately most engine builders have accepted the challenge of unmanned operation, and have assiduously studied the evidence of operators' experience (and of failures) to learn the lessons necessary to improve reliability and time between overhaul (TBO).

Particularly with the significant inroads into marine service made by medium-and high-speed engines, engines have been introduced which in other environments are normally unmanned and all but devoid of instrumentation. They depend in such cases almost totally on the 'hours elapsed' recommendations of the manufacturer for carrying out servicing, plus one or two crucial alarms. The kind of engine used as auxiliary power in coasters, for instance, may have not even any provision for such things as cylinder readings.

Every reputable maker endeavours to put his designs on the market in a state which represents the optimum compromise between all his design objectives and the constraints of material and component capability. In older times one might draw conclusions from, say, the exhaust temperature achieved in Engine A versus other. Such comparisons today may have to be tempered to recognise that one maker may have adopted a different scavenge ratio, or a different valve material, or even just a different arrangement of instrumentation. That is not to discourage the right to an explanation, but the ultimate criterion is still the reliability, and the annual cost as demonstrated by experience.

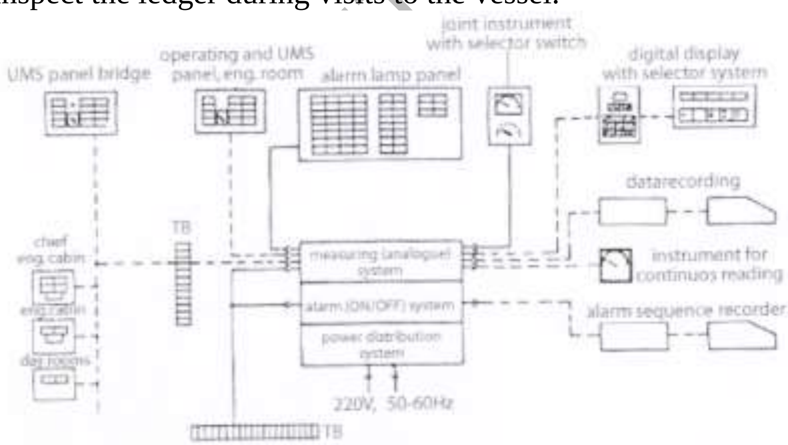
To replace the human operator, who would normally carry out the role of monitoring any operation, automatic monitoring systems must be introduced. Monitoring systems vary in both size and complexity, ranging from a simple make-break switch operated by pressure to activate an alarm, to a sophisticated sequential scanning system.

The sophisticated system may have some of the following features.

1. Sequential monitoring of sensors and comparison of readings with a stored data bank of alarm limit settings. Some modern systems can have over 6,000 monitoring points around the ship.
2. Data acquisition and storage on computer tapes or disks for later reference. Some ships now will automatically transmit this data by satellite to the company headquarters for statistical analysis.
3. Data logging of monitored processes, with trend analysis computer VDU displays.
4. Assessment of machinery operating conditions, and automatic adjustment to provide the optimum operating conditions for the prevailing conditions. This particular facility may be used to adjust the speed of a ship in passage to give the greatest fuel economy possible.

5. Machinery condition monitoring. The machinery may be fitted with sensors to monitor the combustion process and general health of the engine to aid efficient running and predictive maintenance schedules.

Within the rules and regulations are features which must be included into the design of control equipment, in particular the alarm system. Alarm systems are associated with control and safety systems and are normally an integral part of the monitoring system. The design must allow the alarm system to function independently of any control or safety systems, where practical, so that the alarm system will still function if there is a fault in these other systems.
Any alarm system must have an automatic change over to a stand-by power supply in the event of a main power supply failure. It must be self-monitoring for faults within the alarm system itself, such as a broken wire or sensor failure. Any internal system fault should cause the alarm system to give an alarm.
The alarm system fitted must advise duty personnel quickly of any fault condition. The presence of any unrectified faults should be indicated at all times.
If a vessel is being operated in the UMS mode, then audible and visual indication of machinery alarms must be relayed to the engineers' accommodation so that the engineering staff are aware that a fault has occurred. If any machinery alarm has not been acknowledged in the control room within a predetermined time the engineers' general alarm should sound automatically.
A ledger must be maintained and kept up to date concerning the testing and maintenance of all alarms; also, it should be part of the planned maintenance system. The class surveyor will inspect the ledger during visits to the vessel.



Any indication of a machinery fault should also be relayed to the bridge, so that they are aware of the fault, know that it is being attended to, and when it is cleared.
Visual alarms are colour coded to give an indication of priority level. They can be steady state lamps or flashing lamps, depending on their application. An audible alarm 'silence button' should not extinguish any visual alarm.

Audible alarms for different systems should have different tones or sounds. The telegraph alarm should be different from the general engine room alarm, which in turn should be different from the fire alarm bell, so that ship's staff responding to the alarm can both quickly react to the alarm and have some knowledge of the alarm type. A typical method of logic of operation for a machinery alarm system, using a visual lamp and audible siren, would be as shown.

There are many other different features which may be fitted to alarm systems and these include:

a) automatic reset – where the alarm will automatically reset after normal conditions have been restored (but this would not be acceptable to classification societies unless the alarm has already been accepted or acknowledged);

b) manual reset – where the alarm must be manually reset after normal conditions are restored;

c) lock in on fleeting alarms – where the alarm conditions is still displayed even though the fault condition has quickly appeared and then disappeared;

d) time delay to prevent raising of spurious alarm signals;

e) event recorder – which prints out a record of the alarm details and the sequence and time of alarms;

f) 'first up' or first out' – enabling identification of the first alarm that operated within a group or 'flood' of alarms.

The industry is currently facing a problem with 'flood' alarms or alarm overloads. With a fully automated main propulsion plant, if there is a failure of some nature which causes a shutdown of the plant, such as a total electrical 'blackout', then the alarm system may have to cope with hundreds of alarm signals in a very short space; of time. If the recording devices are not of suitable speed and quality then it becomes difficult to actually identify the correct order of events and the initial cause of the failure.

Safety is of paramount importance in any control system. A safety system is a system which reduces dangers and risks of injury to personnel and damage to machinery. Any safety system should operate automatically to prevent endangering both personnel and machinery.

There are numerous examples which could be used to illustrate safety systems, below are some of the more commonly fitted.

These systems are provided with a stand-by device which will automatically start in the event of the running device failing through a fault condition. The start-up of the stand-by device must restore the normal operating conditions and give an alarm on failure of the running pump.

Electrical generators can be arranged with automatic start-up, which can be initiated by a failure of the running generator, or by the electrical load on the switchboard exceeding the maximum safe load for one generator. In the latter case the switchboard must also be fitted with automatic synchronising equipment to allow the two generators to run in parallel and load share.

With this safety system the machinery output power is temporarily reduced to meet the prevailing conditions. There are several situations which may trigger this device, the most common being excessive high temperatures, low pressures or high loads on the machinery.
This device is fitted to a main propulsion diesel engine cooling water temperature monitoring system. If the engine become overloaded and the jacket cooling water outlet temperature exceeds a 'high' set point, an alarm will be raised. If that alarm is not responded to and the temperature continues to rise to a 'high-high' set point, then the engine will automatically go into a load reduction, e.g. the engine revolutions will be reduced from 120 revs/min to 45 revs/min in the case of a slow speed diesel engine.
This type of safety system with its alarm is known as a first stage protection device.
Typical systems with power reduction protection on a main propulsion diesel engine are:
a) high scavenge air temperature;
b) high oil mist level in crankcase;
c) low piston cooling pressure or flow;
d) high piston cooling outlet temperature;
e) low cylinder cooling pressure or flow;
f) high cylinder cooling temperature;
g) high exhaust gas temperature on a cylinder, or high exhaust gas temperature deviation from average exhaust temperature.
It is very important that the correct operation of all Main Engine slow – down and shut – down devices are tested, on at the least a monthly basis, also be included in the "Critical Equipment" list. Thus preventing spurious shut – downs in enclosed waters.
A recent grounding occurred due to a defective oil mist detector.

With the shut down safety system the machinery is protected from critical conditions by shutting off the fuel supply or power supply thereby stopping the machinery. In some cases a shut down will follow a reduction of power if the prevailing conditions continue to develop into a critical situation or if no remedial action is taken after a certain time period.
Consider the scenario of the diesel engine with a high-high jacket water temperature. If, after the reduction in power decreases the speed of the engine to 45 rev/min, the temperatures stay high-high, then after 3 minutes an engine shut down will be triggered, stopping the engine.
The electrical power supply to electric motor driven circulating pumps may be isolated if, for example, a shaft bearing fails, which may increase the electric load on the motor. An overload trip will isolate the power.
This type of safety system with its associated alarm is known as a second stage protection device, and it must be independent for the first stage device.

An alarm system must be fitted to provide warning when the contents of the machinery space bilge wells has reached a predetermined level. This level must be low enough for the contents of the bilges not to overflow onto the tank tops.
Bilge water moving over the tank tops is particularly dangerous for several reasons.

1. It can be a fire hazard, especially if there is oil in the bilge water. A local fire could rapidly spread through the machinery space.
2. There is danger of free surface effect on the stability of the vessel.
3. There is a possibility water damage to electrical cables and motors, from splashing.

Accumulation in the bilge wells must be detectable at all angles of heel and trim of the vessel. Ships of 2000 tonnes gross or more must be fitted with two independent detection systems so that each branch bilge is provided with a level detector.

Some ships are fitted with automatic pumping for bilges. Before the bilge level reaches the alarm level a float controlled will activate the bilge pump, open the required valves and activate the bilge pump. the system must be designed to avoid causing pollution or masking an actual leak situation.

The fire detector indicator and alarm system must be situated in such a position that fire in the machinery spaces will not make it inoperative. Commonly it is sited on the bridge or in a special fire control centre. The system panel normally gives local audio-visual alarm and indicates the source of the fire alarm. If the local warning alarm is not acknowledged within a certain time it will initiate the main audible fire alarm, which must be capable of being hears on the bridge, in the fire control station, and in the accommodation and the machinery spaces.

Particularly fire detector loops or individual detectors are capable or being temporarily isolated, and the status of loops must be indicated on the panel. If a detector is advertently left off, the alarm system must reactivate the detector automatically after a certain time period, usually 30 minutes.

The alarm system must be self monitoring and any power or system failure, such as short circuits or broken wires, should raise an alarm with a different tone to that of the main fire alarm.

Any control system should be designed to 'fail safe'. This means that if the control system has a failure, then the controlled equipment must fail to a condition so as not to cause an unsafe situation to arise, such as mechanical or thermal overloads of machinery.

Depending on the particular use of the equipment the failure mode can be different, for example a pneumatically operated valve can be arranged to:

a) 'open on air failure' (OAF);
b) 'close on air failure' (CAF); or to
c) 'fail fixed', i.e. the valve remains in the position it was in at the time of the air failure.

According to the Rules of Lloyd's Register, failure of the actuator power should not permit a valve to move to an unsafe condition.

A good example of fail safe operation is with a controllable pitch propeller system. The response firstly depends on the type of hub fitted, which can be either a spring loaded type or an all hydraulic type. With the spring loaded type the hub is fitted with a spring so that in the event of a hydraulic failure the propeller blades will fail to the ahead position. The vessel will be able to maintain its navigation speed, but reduced to about 75% of maximum, as the water pressure acting on the propeller blades can overcome the spring pressure above this power level.

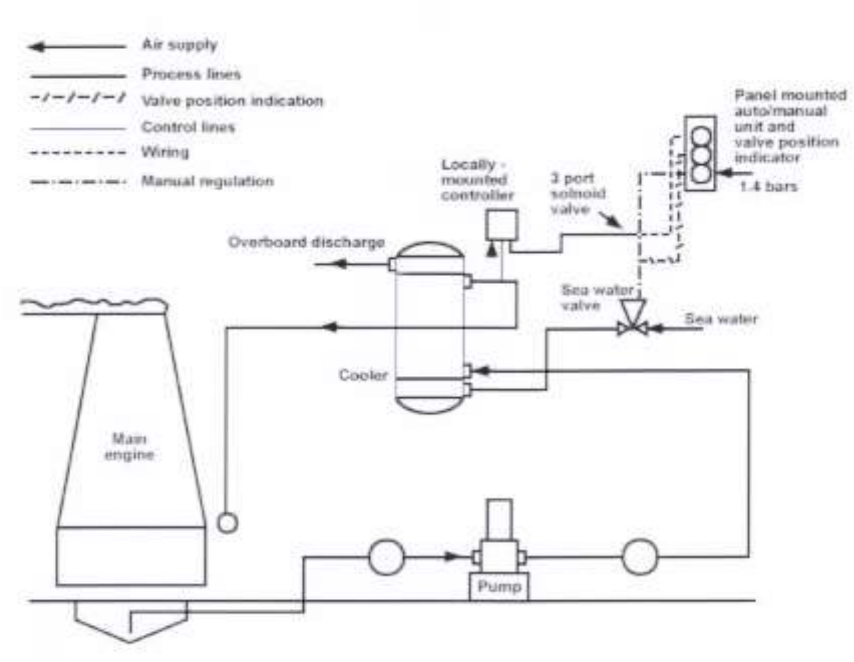
With the all hydraulic hub type the response is dependent on the speed of the vessel through the water. Generally speaking, the blades will move to the zero pitch position to get under way again the blades will have to be jacked, using a manually operated hydraulic pump, and locked in the ahead position. If the main engine is reversible the vessel can operate as if with a conventional fixed pitch propeller.
For any fail safe device it is important to establish what is should do in a failure mode and then test the device to ensure it operates correctly.

1.3.4 FUNTIONS AND MECHANISM OF AUTOMATIC CONTROL FOR MAIN ENGINE.

Diesel Engine Control Systems

In general it is fair to say that the control systems found on diesel engine applications are far more simple than those on steam turbine vessels and in the main provide temperature control of oil and water.
Described below are a few typical applications.

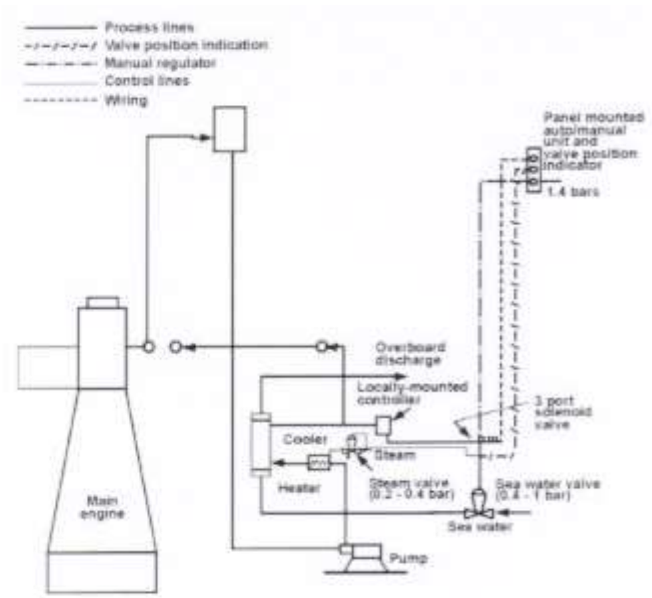
Lubricating Oil Cooling System



The figure above shows a plant mounted controller which accepts the measured variable signal directly, providing an output via a solenoid valve to the control valve regulating sea water flow through the cooler. The electrically operated solenoid valve is used as part of the auto/manual switching facility and when operated will seal the output from the controller and pass the signal from the manual loading station, which would probably be mounted remotely in a control room.

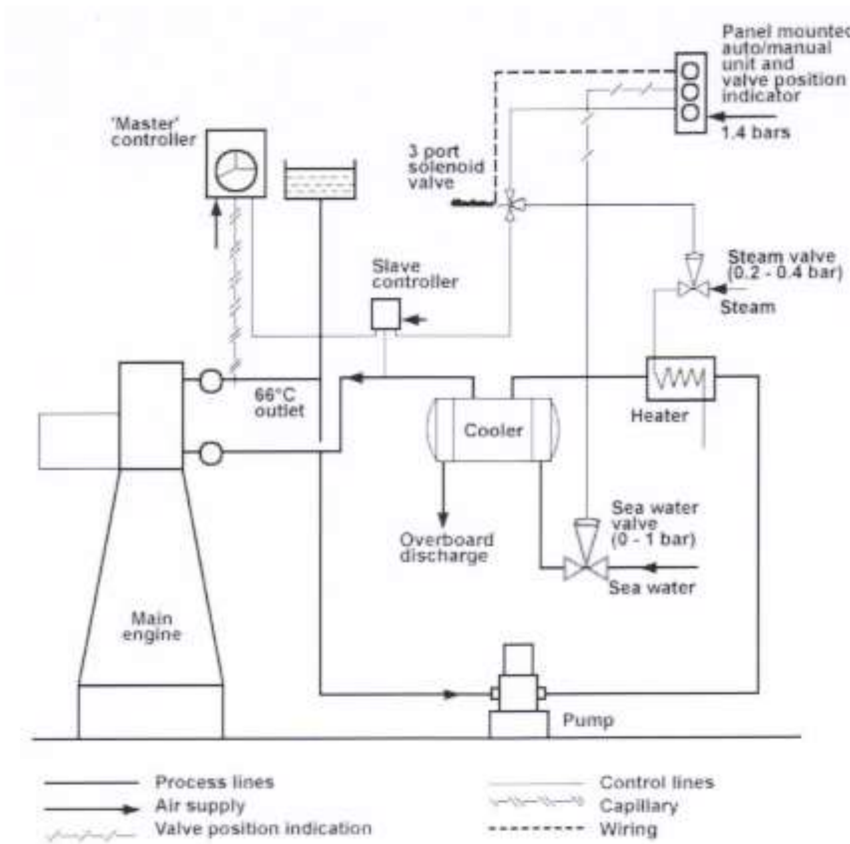
12.74 Fuel Valve Water Cooling System with Auxiliary Heating

This system shown below demonstrates the use of split range valve actuation, where under normal operational conditions, cooling is required, but during start-up heating is necessary to bring the engine up to temperature.



Jacket Water Cooling System

Jacket Water Cooling System



With this type of system, a single controller is usually quite satisfactorily under steady state conditions, but is unable to maintain the temperature within acceptable limits when the ship is manoeuvring. This is mainly due to the thermal inertia of the main engine and associated cooling circuit and, therefore, to meet the requirement, a mast and slave system is used as shown below. The output of the main engine outlet temperature controller continuously resets the desired value of a cooler outlet temperature slave controller.

Alarm Indication Systems

The alarm systems in marine engine room can vary extensively from simple individual alarm lights actuated by the closure of electrical contacts, to sophisticated data logging and alarm annunciation systems incorporating such facilities as alarm pot scanning, memory banks and automated shut-down operations. This latter type of equipment could well be included in computer systems with which many new vessels are now being equipped.
It is impossible to deal with the complete subject within this section and therefore only two typical alarm systems will be described.
An alarm system basically consists of one or more actuating devices, or transducers, providing a signal related to the process variable state, with a monitoring device such that, if

the variable being measured exceeds pre-set limits, an alarm is given which can be both visual (a flashing light) and/or audible (klaxon or bell).

Simple System

There are many vessels fitted with simple alarm systems comprising a series of pressure or temperature operated electrical switches. When the operating temperature or pressure of a machinery parameter rises above or falls below a pre-set limit, the switch closes a circuit to an alarm light and sound an audible alarm if necessary. A more advanced version incorporates a flashing unit with “test” and “accept” push button facilities, so that when an alarm condition exists, a light flashes and a klaxon sounds. The watch-keeper can then press the “accept” button which will cancel the audible alarm and cause the flashing light to remain constantly alight. He will then immediately investigate and take the necessary corrective action to eliminate the alarm condition, such that the alarm light will be extinguished when the process condition, such that the alarm light will be extinguished when the process variable is returned to within the pre-set limits. In this type of system, test buttons are provided to enable the lamps to be periodically checked. Variations of the alarm indication are many, ranging from a simple alarm light with red coloured lens, which is extinguished when in the safe condition, to a double light system with red and green lights on the alarm annunciator fascia. This may incorporate between 20 and 30 alarms per fascia panel, and several fascia panels may be used in any one installation. A third type of alarm fascia panel may be used having small opalescent screens engraved or marked with the process variable service; the screens are only illuminated in the alarm condition.
Simple, pneumatically operated alarm systems can also be provided for areas which require flameproof equipment and in this application, the indication will be by coloured flag and air operated whistle.

Scanning Type System

Alarm annunciators with scanning type systems provide more comprehensive facilities than the simple system previously described and are obviously more costly.
The basic details and functions of Richwest RR 1100 Series equipment which is a typical scanning alarm system with various facilities available, are illustrated below.
In the normal mode of operation, which is alarm scan, each measured point is automatically selected in sequence and presented to the measuring system. If an alarm is recognised while a measurement is taking place, a visual and audible warning is given.
With this system, two scanning speeds are available and in the case of a slow scan which has a scanning speed of 1 point every 3 seconds, both the point identification and the measured value of the at point are displayed on a panel during the scan that a handwritten log can be taken of the points being scanned, if required. In the fast scan mode, the measured value indication is that of the associated point number indicated, which can be selected manually for any of the measured points. For example, if an operator suspects a particular measured point, he can manually switch to that position whilst watching the measured value display, the value of which is being updated each time the scanner “looks” at that point.

Measurements and alarm comparisons are made on all other points as they are scanned and if any other point goes into an alarm condition, this is displayed on the alarm annunciator separately. The fast scan speed on this system is 1 point/sec.

If it is required that a specific point be measured without waiting for the scanner to arrive at that point, the point is selected on the manual selection matrix and the "read" button is depressed. The equipment will immediately make repeated measurements on that point until the "read" button is released, when it will revert to the alarm scan mode and commenced measuring each point sequentially again.

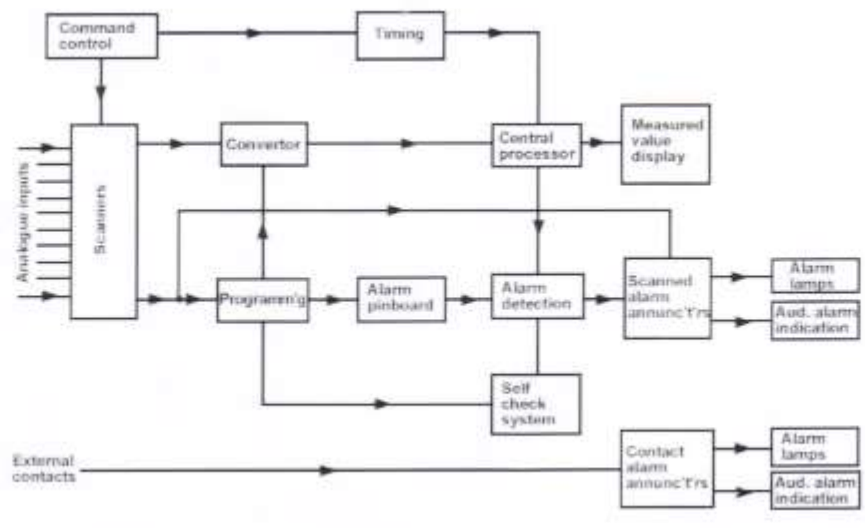
This type of equipment can have information presented to it from various types of transducers, such as platinum resistance thermometers, thermocouples, potentiometric pressure transducers and contact for continuously monitored alarms.

For temperature measurement, the resistance thermometer is the basic measuring system and the output of other transducers are scale accordingly. The resistance thermometers are supplied from a current source, which is controlled by the voltage developed across the transducer in such a way as to provide a linear output voltage directly proportional to temperature.

Where thermocouples are used, they are connected to a data transmitting circuit which produces a current proportional to the thermocouple temperature; this measurement, the transducers consist of either a barometric capsule or Bourdon tube, the free to travel along a resistance element. Thus, if a voltage is applied across the resistance element, a second voltage will be developed between one side of the element and the wiper and the magnitude of this voltage is proportional to the applied pressure.

The output voltage from the appropriate transducer is selected by the scanner and presented to the measuring system.

With contact alarms, the external contacts are connected to the individual alarm annunciators in cases where certain parameters must be continuously monitored for an alarm condition. As these points are not being scanned, no information is available for indication on the measured value display unit. Where contact alarms are being used to monitor liquid levels in tanks, an adjustable delay circuit is placed between the contact and the alarm annunciators so that spurious alarms will not be generated due to the ships motion.



Referring to the figure above the basic circuit blocks are clearly shown each having the following function.

Scanners

The scanners, which in this type of equipment are multi-bank uni-selectors with gold plated contacts on the signal banks, perform 3 basic functions for any particulate point selected. These are as follows:
a) routing the transducer signal into the analogue to frequency (A/F) converter;
b) selecting the programme for the point; the programme provides instructions
for, the type of measurement, i.e. temperature or pressure, etc and switching the alarm annunciator and alarm pinboard value to that point;
c) setting up the point identity display in the slow scan mode or enabling the measured value to the updated when the point coincides with that selected on the manual selection matrix, when in fast scan.

Converter

The A/F converter consists of the control circuitry, which selects the mode of operation (resistance thermometer or voltage input) and sensitivity, a precision crystal controlled voltage to frequency converter, and output and an isolate stage.
A comparison technique is used when making a measurement and the operation of the converter is described below for the case of a resistance thermometer.
Initially, a compensated current supply is fed into a reference resistor contained within the A/F converter and the voltage developed applied to the converter input. The resulting output frequency is fed into the counting chain of the central processor for a defined period, with the total number of pulses being stored (reference count). The compensating current is then fed into the input. Again, the output frequency is fed into the counting chain of the central

processor (forward count), but in such a manner that the reference count is subtracted from the forward count. Complete dc and low frequency isolation between the converter and the central processor is obtained by feeding the output pulses via a transformer. Thus, any electrical noise generated which is external to the equipment cannot be introduced into the central processor or other logic circuits where it might cause spurious operation.

Central Processor

The central processor comprises a number of sub-system as follows:
a) the totaliser;
b) the decoder and measured value store;
c) the alarm comparator.
The totaliser is a four decade reversible counter preceded by reversible binary and associated gates having the following method of operation.
The pulses generated by the A/F converter during the forward and reverse count periods are fed into a reversible counter where they are totalised so that the number of pulses stored at the end of measurement is the difference between the total number of pulses generated in each case. The double count technique ensures maximum accuracy and freedom from drift. The gating times and the operating frequency of the converter are chosen so that the number of pulses stored in the totaliser, when decoded, give the measured value of the unknown parameter in engineering units. The circuitry is reset to a reference condition determined by the programme before the start of a new measurement. The position of the decimal point is also determined by the programme.
The output from the totaliser is in binary coded decimal (BCD) form and feed into the decoder and the alarm comparator.

Display Register, Decoder and Lamp Drivers

The BCD information in the totaliser has to be decoded prior to display, in which case the output from the totaliser is transferred to a store and thence to the decoder and lamp drivers, which initiate the appropriate lamp in each decade of the measured value display. IN the "slow scan" and "read" modes, the stored information is changed each time a new measurement is made, but in the "fast scan" mode only, the information generated on manually selected points is permitted to enter the store.

Timing Circuit

The timing circuits consist of the timing generator and the control logic, with the timing generator being made up of crystal oscillator and frequency divider boards which generate the precision timing signals required by the control logic. The control logic governs the sequence of events during the measurement and display cycles, and is responsible for stepping the scanners during the alarm scan mode.
Programme Distribution Board

The scanner selects the group programme required for each specific point via this board and in addition, the particular alarm board setting and alarm annunciator are selected. On this board the group instruction is broken down into the individual instructions for the totaliser and converter (i.e. "decimal point", 10^{-1}, etc).

Command Control

The "read" and "alarm scan" modes and the "measured value updating" mode are selected in the command control module.

Alarm System

The high and low alarm levels are "set in" on the alarm pinboard in decimal form, being converted internally into a pre-determined code for use in the measuring circuits. The alarm setting for any particular point is selected and compared with the measured value in the totaliser through the alarm comparison circuits as the measurement progresses. Further logic in the alarm detector establishes whether a normal condition exists if the measured value exceeds the low alarm setting, or a high alarm condition exists if the measured value exceeds the high alarm setting.

If an alarm condition is recognised, an alarm signal is routed to all annunciators and a red background illuminated on the point identity display. If no alarm is detected, a "clear" signal is generated.

Each alarm point has its own annunciator and the alarm annunciator will only accept an "alarm" for "clear" signal from the alarm detector when it is selected by the programme from the scanners. Thus, although the alarm detector sends out a signal to all annunciators, only that annunciator associated with the alarm level being compared can change its state. If it is necessary to check for both high and low conditions on a signal point, two alarm levels are set up on the pinboard. Initially, the low level setting is compared with the measured value and if the low levels is exceeded, the comparison switched to the high level setting. In this way, both the high and low limits may be checked during one measuring cycle.

Groups of annunciators may be switched out by means of inhibit switches on the alarm display panels, a facility which may be required when machinery is shut down.

As in the simple type of alarm system, the alarm lamp operating cycle operates as follows:

State Lamp

No alarm Extinguished

Alarm Flashing light

Alarm accepted Steady light

Accepted alarm reverting to normal Lamp extinguished

Contact Alarm

A number of contact alarms can be displayed on the equipment, in which case the contacts are brought in through a junction box to alarm annunciators in a visual display. Tank level alarm signals pass through delay circuits, which permit the alarm contact information to be passed to the annunciators only after a discreet period in order to avoid the possibility of displaying spurious alarms when tank levels are disturbed by ship movement. This delay is normally adjustable.

Self-Checking System

It is usual to incorporate a self-checking systems in this type of equipment, in which case the alarm detection system is checked once every complete scan. Alarm settings are incorporated on the test point so that, for example, the system would detect a low alarm on the pressure signal test point and a high alarm on the temperature signal test point. Another example is to have a temperature signal test point of 50°C which has high and low settings of 45°C to 55°C and the system requires a clear signal on this point as follows. As the scanner steps through the test points, failure to detect the sequence low alarm, high alarm, clear, will cause the self-check system to give out its own alarm. This also acts as a check on the accuracy of the measuring system, since if the 50°C test point reads outside the limits of 45° to 55°C, an alarm will also be given. Failure of the scanner to continue scanning when the monitor is in the alarm scan mode is indicated by an alarm annunciation. All the dc power supplies are monitored and failure of any one will initiate an alarm.
If there is a failure in the system, an audible will be given and the system failure annunciator will come up flashing. If the mute switch is put down, the audible alarm will cease, the flashing system failure annunciator will come up steadily and the mute annunciator will also come on flashing. When the fault in the system clears, the system failure annunciator will go out but the mute annunciator will remain on until the mute switch is returned to the “off” position.
The self-check system also has test facilities to check itself and it is advisable that the system be tested once a week.

Operation

The operation of instrumentation and control equipment on marine applications is similar, no matter which type or make of equipment is used. However, variations in the switching procedures from manual to auto control do exist between different makes of equipment and therefore marine engineers when first meeting equipment of which they have no previous experience, should carefully read the manufacturers operating instructions to ensure that, for example, when switching from manual to auto control or vice versa they do not create severe instability in the plant conditions through lack of the correct operating procedure.
The general procedure when starting up a plant which has automatic control facilities, from cold is to manually regulate the control valves from the auto manual controls stations, which on modern ships are located on a panel in the centralised control room. When the plant has been started up and is operating at low load and under stable condition on manual control, the system can then be switched to the automatic mode.

There are certain basic rules for operating process control equipment which must always be followed. It is essential when switching a control station from auto to manual that the manufacturers procedure is followed closely to obtain a "bumpless" transfer. The procedure is basically as explained below.
If the operator wishes to make the process variable move up scale, or down scale, when the station is on manual, he must first ascertain whether the control valve, if pneumatically operated, operates on an "air to open" or "air to close" action. He must determine what affect opening the valve has on the process, i.e. on level, does it allow more fluid into the tank or does it drain it? On temperature, does it heat or cool the process? On pressure, does it pressurise or vent, etc? Once the operator has established these facts and is maintaining the process at the desired value, he may wish to transfer the process to automatic control. He first moves the auto/manual selector into the sealed position and adjusts the controller output by means of the desired value adjustment until the output indicates the same value as the present output of the manual regulator. The selector may now be moved into the automatic mode and a "bumpless" transfer will have been effected.
To transfer from auto to manual control, it is necessary to ascertain the value of the controller output signal and once this value is know the auto/manual selector can be moved to the sealed position. It is then necessary to adjust the manual operating regulator until the output pressure of that equals the controller output. When this position is reached the auto/manual selector can be moved into the manual position and again a "bumpless" transfer will be effected.
When shutting a plant down, depending upon the application, it is possible to gradually lower the desired value until the plant shuts down automatically control becomes unstable. Therefore, under these circumstances the system must be switched to manual control to completely shut down.

Installation

Even today there are many examples where one finds that the installation of instrumentation on marine applications has not been given the thought and attention it justifies, with equipment often having been fitted wherever there is a convenient space. When this occurs, apart from the maximum exposures to extreme environmental conditions, poor access for maintenance purposes causes many operational problems. Space in ships machinery rooms is often very limited and, if possible, control cabinets should be designed with front access for maintenance purposes. This will allow the cabinet to be mounted adjacent to a bulkhead or item of main plant. If rear access to the control panel is absolutely necessary then adequate space must be allowed for an engineer to work on the equipment and, if required, the withdrawal and replacement of same.
However, transmitters and other similar equipment mounted locally to the machinery are those items mainly installed incorrectly. Manufacturers installation instructions, which are usually packed with the instruments, should be closely adhered to.
It is still not uncommon to find examples such as, steam pressure sensing lines, which should be unlagged to allow condensation to form, lagged adjacent to the main steam piping causing a very high temperature at the sensing element, and therefore, a drastically reduced life span of the component. Distant reading temperature indicators of the capillary type should not

have the capillary tubing run adjacent to any hot spots, since this will obviously affect the accuracy of the instrument.

Flow is always the most difficult parameter to monitor accurately in marine applications, particularly where the differential pressure type instrument is employed, because of the necessary length of straight piping, up stream and down stream of the primary element. One must ensure that the sensing lines to the differential pressure transmitter are maintained at common reference levels, otherwise difficulties will be experienced when they are subjected to the ships movement and extreme care must be taken with the installation.

When selecting the actual tapping points for pressure measurement, particularly on steam systems, adequate attention must be given to ensure the location is not in a noisy section of the line. This occurs adjacent to bends, tee pieces or valve where turbulence is caused by change in the direction of flow. However, it is also as important to ensure that the tapping point is situated in such a position as to keep the plant time lag to a minimum. One appreciates that it is often extremely difficult to comply with both of the above requirements on marine plants and it may be necessary to select a noisy location to keep the plant lag to a minimum with partial signal snubbing, to reduce any tendency to instability in the control loop which may result. Where strain gauge type transducers are specified, then, generally speaking, the bonded type are more suitable as they are more able to withstand the normal range of vibration experienced.

Control valves will usually function satisfactorily in any position, but most manufacturers recommend that they should be mounted in the vertical position to keep spindle and glad wear to a minimum. With diaphragm operated control valves, it can be an advantage to mount the valve upside down, on the assumption that the radiated heat is significant compared to the conducted heat. An elementary aspect which is often overlooked, is that there is a right and wrong way to mount control valves in a process line. All manufacturers indicate quite clearly which way round their valves should be mounted in the process line, but it is surprising how often these instructions are ignored.

Signal lines from transmitters to control units can often be the cause of unstable systems, if not carefully routed.

With electronic control systems – apart from the commonsense procedure of not running the cable through extremely high temperature areas and thereby causing breakdowns in the insulation – it is also imperative that the routing is not adjacent to power lines where "pick-up" can occur from the high power source. From the installer's point of view, it is often convenient to run signal lines on the same cable tray as power lines, but this must be avoided at all costs, if satisfactory operation if the control equipment is to be achieved.

Installation of pneumatic lines should also be carefully observed and it is advisable that, in machinery spaces, i.e. outside control rooms, only copper piping be used and the running of plastic piping should never be considered. All copper piping should be adequately supported on cable tray and run in a similar fashion to electrical cabling, since without adequate support (apart from the possibility of a direct fracture), work hardening of the copper will occur and cause problems for the future.

There have been many examples over the last few years, where the technicians responsible for the installation of pneumatic elements have followed the manufacturers component installation instructions rigidly, but have routed the air supply line adjacent to extremely high temperature areas. This has caused the temperature of the air supply to the instrument to rise to a level exceeding the maximum permitted for the neoprene diaphragm within the instrument. Therefore, although the instrument is sited in a relatively cool position, its internal temperature will rise above the tolerable limit due to the extremely high temperature of the air supply.

It is very easy to be wise after the event but all engineers concerned with the design of marine instrumentation systems, must when laying out the plant installation systems, must when laying out the plant installation, carefully consider problems which may be encountered during the maintenance procedure. As mentioned earlier, this requirement is never more apparent than on control panels where adequate attention is usually given to the frontal aspect and the presentation of indication and controls, etc from the operations point of view; but when the rear doors are opened for maintenance purposes, access to the forward mounted components is often impossible without removing a considerable amount of other equipment. Another aspect which is not always borne in mind concerns the mounting of direct reading gauges in control panels. From the operators point of view, it is convenient to site these gauges at the top and the switches, push buttons, levels and all other types of hand operated controls should obviously be mounted between waist and chest height. However, since these controls are usually of electrical actuation within the control panel, there is a potential fault risk, or possibly even fire risk, should there be a leak from the direct reading gauge connections on to the electrical circuits below. It is suggested, therefore, that if direct reading gauges are to be employed in control panel, they should be sited to one side of all the electrical equipment and preferably within a separate section. This point indicates the advantages or receiver type gauges compared with the direct reading type, when mounted in control panels.

It is considered by many almost inevitable that instrumentation and control systems will receive some damage during installation on board ships. Such damage is caused by the movement of large pieces of machinery and pipework, etc in confined spaces, and this applies particularly to locally mounted components such as transmitters and control valves. However, it is in the interests of all concerned that not only the maximum protection should be given to these components, but all the shipbuilding staff involved should be encouraged to take the maximum care and to understand the need to meet the required installation standards.

Commissioning

Commissioning of instrumentation and control equipment must follow several clearly identifiable testing trails with procedures as follows.

Initial Functional Check

Subsequent to the installation completion, all instrumentation components should be checked for mechanical damage and a simple functional or calibration check is carried out to ascertain that the accuracy of the individual instruments is still within the design limits.

System Cold Run Trials

Whilst sections of the main machinery are undergoing initial run up tests, the instrumentation systems should undergo functional checks to ensure that when a measured variable moves in a certain direction, the control valve responds in the correct direction also. These are vital trials since negligence at this stage could cause serious damage to a costly piece of main plant.

Final Sea Trials

During the final sea trails, complete system performance checks and recordings during all stages of machinery states and through the complete power range from low speed manoeuvring to full power sea trials must be carried out to ensure that the instrumentation and control equipment works at optimum performance under all conditions.

General

The unit calibration accuracy obtained by manufacturers during testing in their works is usually of the order of +/-½ percent full scale deflection or better and this level of calibration testing cannot normally be obtained on board ship during the commissioning stages, but substantial deviations from the nominal calibrated range can usually be determined with the various types of commercial testing equipment available for onsite checks.
Careful consideration must be given to the timing of commissioning instrumentation in marine applications, since although the work must be carried out thoroughly and often involved considerable time, it is pointless for the checks to be made at too early a stage in the shipbuilding programme. In such circumstances work on the machinery can still be progressing and damage to the instrumentation may well occur, resulting in the initial checks having to be repeated.
It is absolutely vital that a fully detailed commissioning programme be prepared and is discussed with both representatives of the shipbuilders and the eventual ship owner prior to the trials being carried out. This is to ensure that the instrumentation and control equipment has been installed correctly and is functioning at its optimum performance.

Maintenance Procedure

Other than when a failure has occurred in an instrumentation system, when obviously repairs are necessary, determining the period between routine maintenance functions is obviously a matter of experience. Manufacturer's instructions for individual components should be referred to for advice in this direction.
Apart from control valves, where regular overhauls are obviously necessary at intervals depending upon the application, instrumentation has, in general, few moving parts and should not be dismantled just for the sake of it. However, there are several vital requirements for instrumentation systems. For example, with pneumatic components it is absolutely essential that the equipment is supplied with clear dry air. Thus, routine maintenance, in the form of

daily checks and blow-down of the air filter regulators, is necessary in conjunction with inspection and cleaning of the pneumatic pilot valve and local instrument filters at intervals depending upon the application. Also, where instruments, particularly transmitters, are located in an adverse environment, i.e. subject to high temperature or vibration or high humidity, then deterioration of the components parts will obviously be rapid and the inspection/maintenance period must be reduced.

The majority of the above conditions apply to both pneumatic and electrical/electronic instrumentation, but with the latter type of equipment and particularly with solid state modular construction, the maintenance procedure is usually in the form of repair by replacement. In such installations, complete printed circuit card modules or integrated circuit components are normally stocked as spare parts to be replaced as necessary when the location of a failure is detected.

Recognition of poor performance by an instrumentation system, unless there has been a complete failure, is very much a matter of experience and some form of regular checks on performance by pen recordings taken of the process variables will quickly illustrate trends towards poor performance.

Unfortunately, with modern integrated plant, design troubles which manifest themselves in one section of the instrumentation equipment may be caused by a failure in a separate item of equipment entirely. Also, since the instrumentation in an automatic control loop only forms half of the closed loop, the other half being the plant and associated equipment, fault fining procedures must involve a thorough inspection of each item of plant as well as the instrumentation. There are several golden rules to be adhered to and these are as follows:

a) Second-hand reports never provide one with the “feel” of the problem and before any of the equipment is disturbed always try to witness the symptoms for oneself;

b) never make adjustments blindly hoping that the fault will miraculously disappear since this will never be the case, and in fact usually makes the situation far rose by disguising the original symptom;

c) take logical steps to isolate the control loop into sections, for example with an automatic control system having a remote manual facility, switch to remote manual and determine if the plant can be controlled in this mode. This immediately isolates half of the system from which further deductions can be made;

d) ensure you have an adequate supply of spare or replacement parts and at all costs avoid cannibalisation of other instruments since this usually results in damage to those components and further problems.

On Board Testing

Regular on board testing and maintenance of the control installation and correct calibration of instruments is vital if the benefits that automation can bring are fully realised and the survey requirements are to be met without undue difficulty.

Test and maintenance periods and the way in which these activities are carried out should be determined with regard to the system and component reliability and their performance criteria or criticality of function. There are a number of important considerations to be taken into account when formulating test procedures and a correct balance has to be achieved:

1. Shortening the intervals between testing and maintenance should increase the success of detecting faults, but it also increases the degree of human interference and disturbance to the system. Consequently, an increase in testing can mean that the system is more sensitive to human error and faulty test procedures.
2. Test procedures should be completely thorough and constitute a check of all functional aspects of the system. Partial testing may fail to reveal faults which are already in existence, but it is not always expedient or practical to carry out a complete test due to operational restrictions.
3. Test procedures should be fully described and leave no doubt as to the methods to be used and the results to be expected. This however, can produce an approach which is inflexible and difficult to modify.

It would be impractical to test all control, alarms and safety systems at one time and accordingly a schedule of testing is required bearing in mind the three foregoing points. The test schedule should be arranged so that over a given period of time all these functions are tested at least once, but, depending on their criticality, certain functions may be tested more frequently. Having regard to the workload involved, a typical schedule could be based on a twelve to sixteen week period.

Where it is only possible to partially test a particular function provision should be made in the schedule to carry out a realistic test, including a test of the sensor. The test schedule should identify each alarm and safety systems channel and the associated set point, and make provision for appropriate remarks where adjustments etc are required as a result of the test.

Where it can be demonstrated to attending surveyors from any of the classification societies or national administrations that regular testing is undertaken and is well documented it given them confidence that the control installation is being maintained in good condition, but not least, it gives the ship's engineers confidence that they can operate unattended safety and reliably.

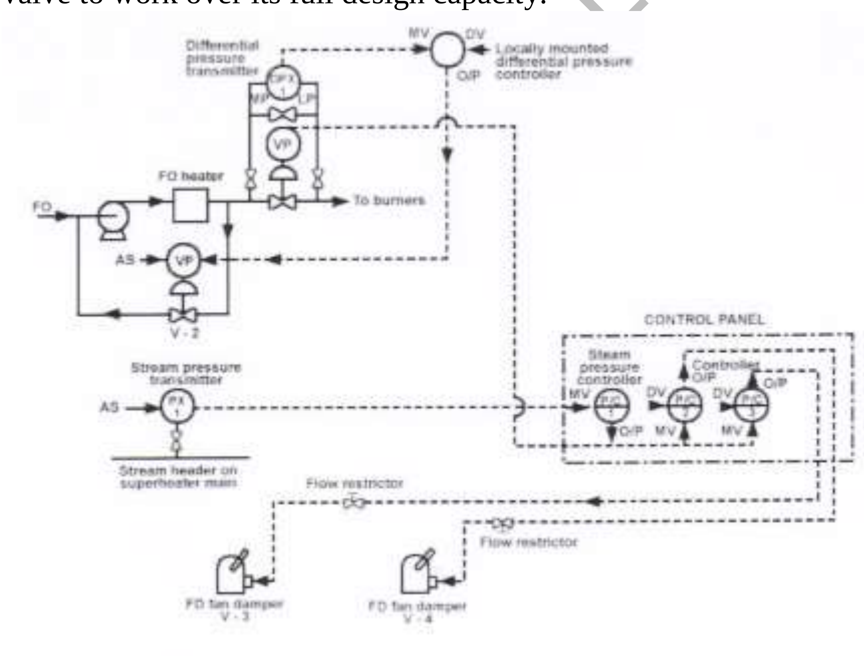
The testing and maintenance of alarm equipment must be carried out in a planned rotational basis and be part of the planned maintenance system. The events must be logged in a ledger, which is open to inspection, by the class surveyor and ship inspectors.

1.3.5 FUNTIONS AND MECHANISM OF AUTOMATIC CONTROL FOR AUXILIARY MACHINERY

Boiler Combustion Control

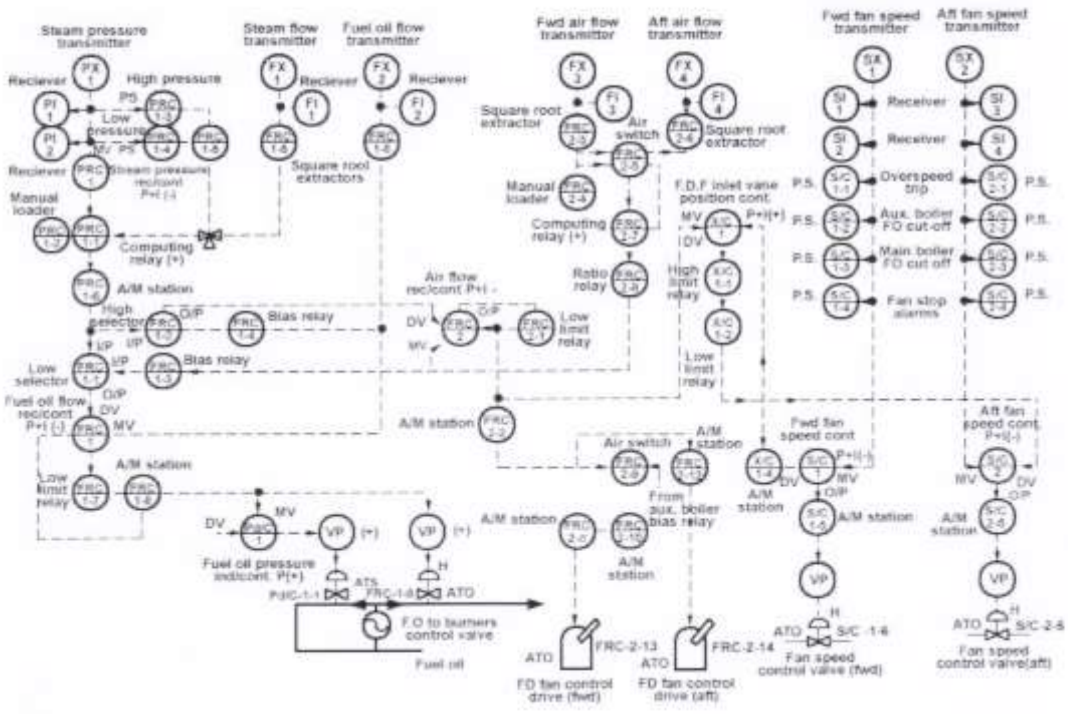
The simple combustion control system shown below is typical of those used for the control of auxiliary boilers in motor ships and will provide adequate control for the reasonably steady loads this type of plant is subject to. The pressure transmitter measures the steam drum pressure and converts it to a proportional 0.2 to 1 bar pneumatic signal which is fed to the master controller as the measured variable. This signal is again compared with the internally set desired value and any deviation causes the controller to change its output. The output from the controller is taken directly to the fuel oil supply valve and also to the measured value connection of the two force draught controllers. The force draught controllers are proportional only and the output from each operates the two force draught fan dampers respectively. In the true sense, the force draught controllers are calibrating relays only, which modify the master controller output signal so that acceptable combustion is obtained at the steady power loads at which each system is designed to operate. Since the boiler load does not vary considerably, it is unnecessary actually to measure the force draught air flow and the engineer would merely vary the proportional band of the controllers to obtain the desired combustion with load fluctuations.

For this system to operate successfully, it is essential that the fuel flow through the supply valve is directly proportional to the supply valve opening; therefore, it is necessary to maintain a fixed differential pressure across the supply valve. This is accomplished by measuring the differential pressure across the valve with a DP transmitter and taking the pneumatic output of this unit to a locally mounted two term controller as it measured variable signal. Any variation of this signal compared with the fuel oil controller desired value will cause a change in controller output, therefore modifying the flow of oil through the spill oil control valve until the desired differential across the control valve feeding oil to the burners is re-established. In control engineering terminology, we are increasing the turn down ratio of the supply valve, since by maintaining this fixed differential, we are allowing the supply valve to work over its full design capacity.



Typical Combustion Control System For A VLCC

When controlling high capacity boilers of the type fitted to VLCC's it is advantageous to measure the steam flow in conjunction with the boiler drum of superheater outlet pressure for accurate control. Since it is extremely difficult to accurately programme the fuel air requirements, and since flow measurement by differential pressure methods tends to be inaccurate, particularly at low flow rates, the steam pressure signal is necessary to operate the system satisfactorily at low loads, and provides a trimming signal at high loads.



Referring to the figure above, the steam pressure transmitter PX-1 transmits a signal as the measured variable of a two term steam pressure controller PRC-1 whose desired value is manually adjusted to the required steam pressure. The output from this controller is fed to a computing relay PRC-1-1 where it trims the steam flow signal received from the square root extractor FRC-1-5 in the output line from the steam flow transmitter FX-1. The latter instrument is also used as part of the boiler water level control system. The output from the computing relay is the master desired value signal for both the fuel oil and air flow control loops.

With this system, a rapid change in load is first seen by the steam flow transmitter which, via the computing relay, alters the master signal to give a quick change in fuel and air to cater for the rapid load change. After the load has settled down, the steam pressure controllers, also via the computing relay, trims the master signal to maintain the correct steam pressure. As the steam flow orifice plate is inaccurate at low flows, the steam pressure controller output, via the computing relay, is used to trim the master signal.

The master signal from the computing relay PRC-1-1, via a low pressure selector FRC-1-1, passes to the fuel oil controller FRC-1 as it desired value where it is compared with the measured variable signal from the fuel oil transmitter FX-2 via a further square root extraction relay FRC-1-6. This controller output, via an auto/manual station FRC-1-8, is fed as a control signal to the burner fuel oil control valve FRC-1-9. This signal is also fed to the fuel oil pressure controller PdIC-1 as its measured variable, the output from which controls the spill valve PdIC-1-1 which maintains a constant differential pressure across the burner fuel oil valve FRC-1-19 to maximise its effective range.

The master signal previously referred to is also fed to the forced draught fan control loops passing through a high selector relay FRC-1-2 to the air flow controller FRC-2 as its desired value. The measured variable for this controller is the output from the operative air flow transmitter, say FX-3 via the appropriate square root extractor and the selector switch FRC-2-5. The controller output passes through a low limit relay FRC-2-1 and an auto/manual station FRC-2-2 to operate the force draught fan vanes. The controller output is also used as the measured variable for the force draught vane position controller XIC-1, the desired value of which is manually adjusted to approximately 60 percent open.

The output from the vane position controller passes to the fan speed controller SIC-1 as its desired value, the measured variable being the output from the fan speed transmitter SX-1.

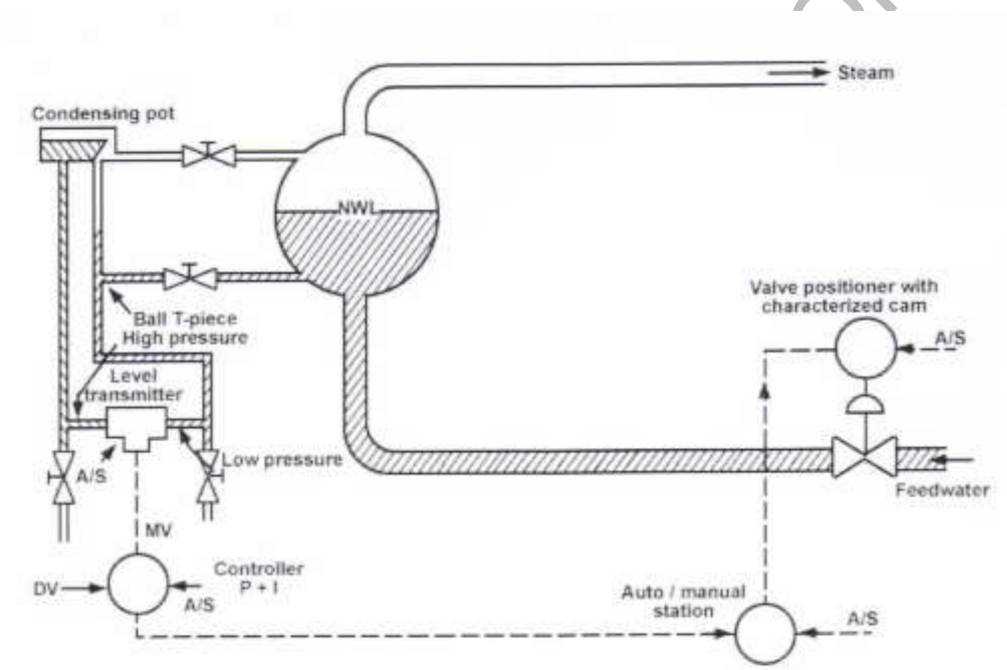
The output from the fan speed controller SIC –1 positions the fan speed control valve until the measured variable from the fan speed transmitter coincides with the desired value, which, as explained previously, is the output from the vane position controller XIC-1.

The system is necessarily complex is this type of vessel where the forced draught fans, being turbine driven, have considerable inertia; therefore, to achieve a rapid change in air flow, damper vanes are fitted to the fan intake. To compensate for a series of load changes, the vanes have to be returned to their nominal position (60 percent open) after the previous change and this is achieved as follows. A rapid load change causes the master signal to quickly change, immediately altering the vane position to cater for the new demand. The output from the air flow controller is also fed to the vane position controller, which adjusts the fan speed via the fan speed control valve. The fan speed and vanes are now incorrectly balanced, causing the air flow being supplied to be incorrect and, therefore, the air flow controller will change its output to alter the forced draught fan vanes to compensate. The fan speed will continue changing until the output from the air flow controller equals the desired value for the fan vane position controller and when they are equal the vanes will have returned to their original position of 60 percent open, and the fan will be at a new speed. In practice on, say, an increasing load, the vanes will immediately open up to cater for the new load. As the fan speed starts to increase the vanes close in simultaneously to their nominal 60 percent open, ready for the next load change.

To prevent the boiler producing black smoke whilst load changes are taking place, it is necessary to ensure that the air is always in excess of the fuel oil and this is achieved with the high selector FRC-1-2 and low selector FRC-1-1 relays. On a decreasing load change, the high selector relay prevents the desired value of the air flow controller being decreased until the fuel oil flow has decreased, thus ensuring that there is always an excess of air.

On an increasing load change the low selector relay prevents the desired value of the fuel oil controller being increased until the air flow has increased.

Boiler Water Level Control

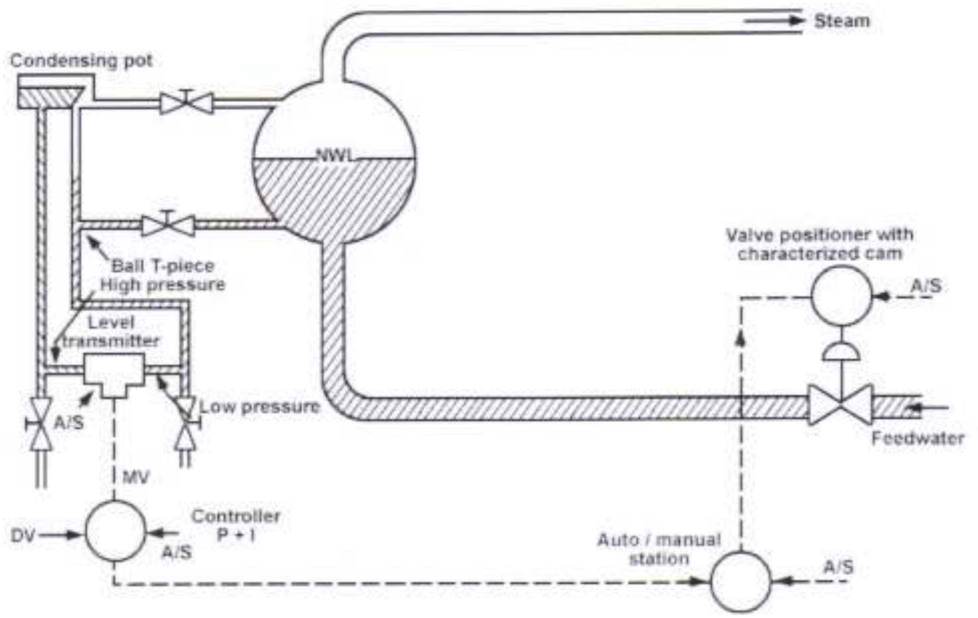


The shrink and swell characteristic of feed water in a boiler drum are well known to the marine engineer, together with the fact that the level or water as indicated by the gauge glass is not a true identification of water level or quantity of water whilst steam is being generated. With an increased steam demand, pressure in the boiler will tend to fall, causing the release of large quantities of steam bubbles at the heating surfaces. These bubbles force their way through the water in the generator tubes to the steam space in the drum and in so doing, raise the water level in the boiler drum above that previously indicated by the gauge glass.
Instantaneously therefore, the water level appears to rise in the boiler drum, although the actual input of feed water is less than the output of steam from the boiler. Any control system based solely upon the measurement of level will, therefore, function incorrectly under these

conditions since a rise in the level will cause the controller to respond in such a way as to reduce the input of feed water to the boiler.

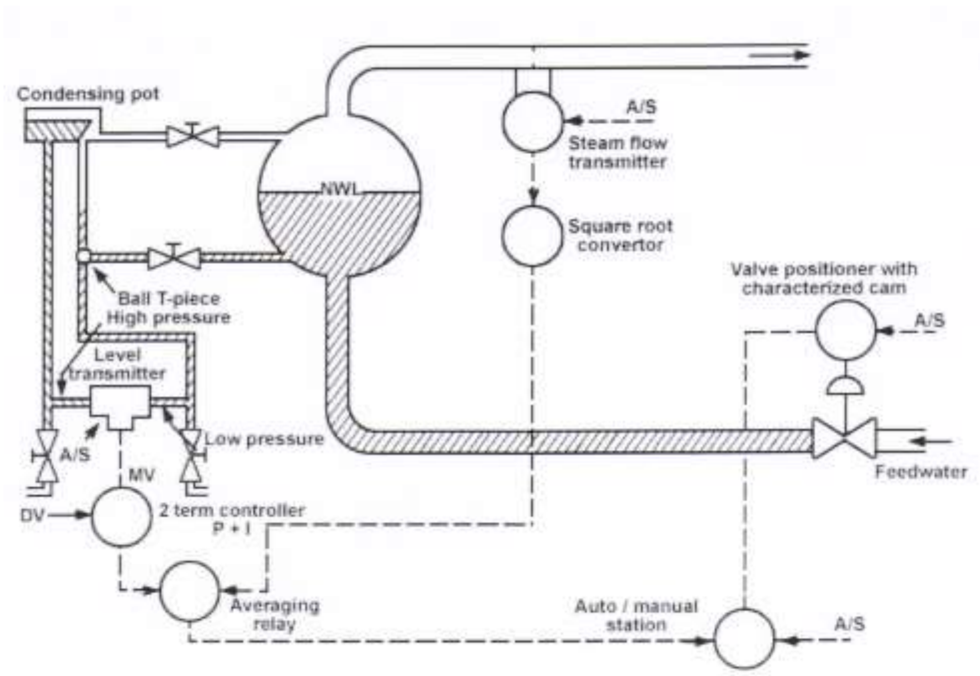
Single Element Feed water Control

A single element feed water control system (below) will respond to a change in the level of water in the boiler drum as mentioned above and the suitability is therefore limited to boilers where the steam release water storage ratio is low, i.e. where the amount of water contained in the boiler relative to the steam output is reasonably high and also where load variations are of limited magnitude.



The level of water in the boiler drum is referred to a constant head with the resulting differential being applied to a differential transmitter, which converts the measurement to a proportional pneumatic signal. This signal is passed to a controller as the measured variable signal where it is compared with a desired value and any deviation between the two causes the controller output to change and pass the changed signal, via an auto/manual station, to the feed water control valve.

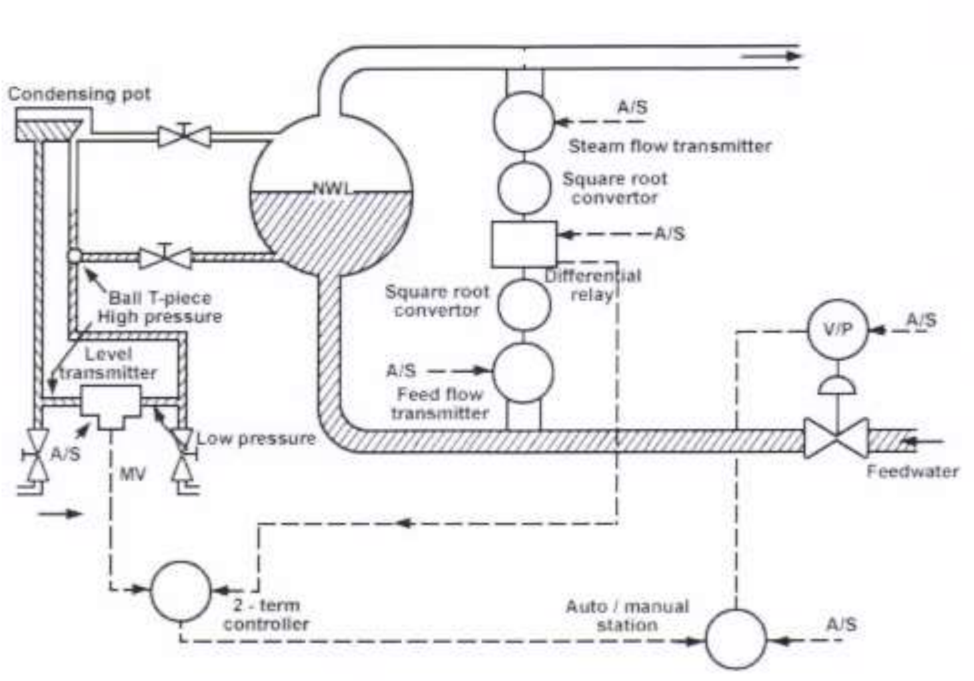
Two Element Feed Control System



The primary control element in this system is initiated from the steam flow and from this measurement a control signal can be generated to position the feed water regulating valve so that the inflow of feed water will equal the outflow of steam. This system in itself will be insufficient to satisfactorily maintain the level in the boiler drum at a desired value since during the period of time that elapses between the change in the steam flow and the repositioning of the feed water valve to bring the inflow of feed water into alignment with the outflow steam, the level in the boiler drum could change to any position. It is therefore necessary to introduce another element, i.e. water level control, so that the level in the boiler drum can be maintained at its proper value.
The steam flow is measured by an orifice plate in the main steam line, between the drum and the primary superheater, using a differential pressure transmitter to convert the steam flow into a proportional pneumatic signal. This signal is introduced to the control system via the averaging relay which also accepts the signal from the water level controller. Therefore, with a change in steam flow there is an immediate corrective action on the feed regulating valve via the averaging relay, with the level controller being used as a trimming device to ensure the boiler water level returns to the correct position during stable conditions.

Three Element Feed Water Control

In the three element system, the basic control is carried out by a comparison of steam flow and water flow (below). In a closed feed system the water flow will equal the steam flow when the system is in equilibrium and any change in this condition will result in a control signal being applied to the feed water control valve. The signal from the water level will also effect the re-adjustment of the feed water valve to trim the level back to the desired value when the stability is achieved.



In addition to moving the feed water valve in the correct direction on a change in steam demand, the water flow signal adjusts the control system to ensure that the position of the valve is such that the water input equals the steam output from the boiler. Therefore, any variations in feed water pressure ahead of the feed water valve causing a change in water flow will immediately be detected by the flow meter and the valve will be repositioned to maintain the correct water flow before this effects the level in the boiler drum.

1.4 MANAGE FUEL, LUBRICATION AND BALLAST OPERATIONS

1.4.1 OPERATION AND MAINTENANCE OF MACHINERY, INCLUDING PUMPS AND PUMPING SYSTEM.

PUMP THEORY AND CHARACTERISTICS

There are a number of different pump types. Each type has its own special quality and therefore certain advantages and disadvantages. The selection of pumps is determined by a thorough study of the capacity needs and under which operational conditions the pump will operate. The following factors are important when you evaluate these conditions:

- Estimated back pressure
- Capacity requirement
- Capacity range
- Requirement for installation and arrangement
- Expenses for purchase, installation and maintenance
- Availability of parts and service
- Suction terms
- Characteristics for the liquid to be pumped

Selection of the right pump for a determined purpose qualifies a close co-operation between the customer and the producer of the pump. The customer has a special responsibility to clarify all conditions concerning the pump installation, so the producer can choose the best pump from his product range with the best match.

When you choose a pump you must find out how much the pump needs to deliver under a specific condition. Definition of capacity range is important. Demand for capacity or capacity range and expected discharge pressure must be specified. The capacity requirement is determined by the intended use of the pump. The discharge pressure is determined by various conditions where the pump's delivery pipeline design, the capacity of the pump and the liquid's characteristics, is the essential.

Alternative installation locations of the pump are limited due to special demands from Class and Shipping Authorities and also from lack of space.

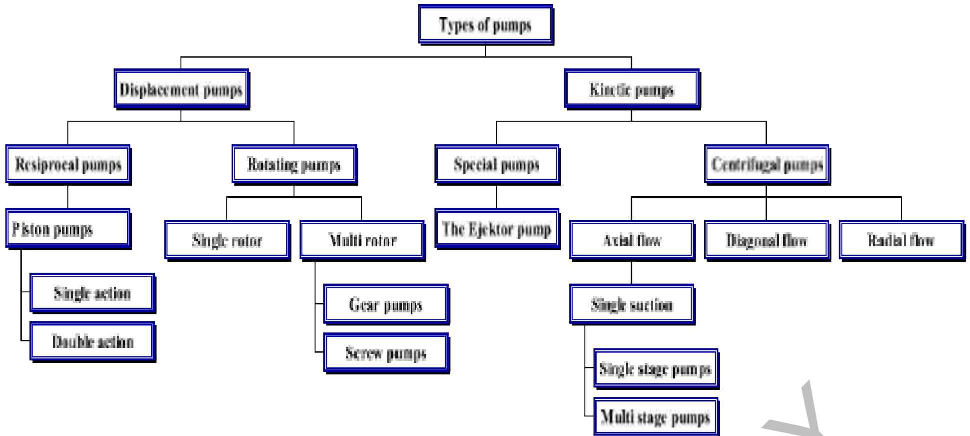
Purchase and installation cost is important. Future maintenance expenses, availability of parts and service now and over the next years, are also important and must be included in the evaluation of alternative pump supplies.

The liquid's properties and which other arrangements you have to consider, often limits the options. Density, viscosity and boiling point are important properties to consider. The liquid temperature and corrosive properties are important factors when pump material is selected.

The pump's suction condition is determined from where the pump is located in relation to the liquid to be pumped. A given suction pipe creates a certain resistance that will have influence on the pump capacity. The main principle is to minimise resistance on the suction side by decreasing the suction pipe length, have the largest diameter possible and few as possible restrictions in form of bends, valves and so on.

The different types of pumps are divided into two main groups, displacement and kinetic pumps. The displacement pumps displace the liquid by reducing the volume inside the pump. An example is a piston pump where the piston is moving up and down inside a cylinder or when the screws revolve inside a screw pump. Kinetic pumps (kinetic energy is equal to "movement" energy) increase the liquid's velocity through the pump.

The diagram below gives a brief view of the different available groups and types of pumps. The diagram would be more comprehensive if the pumps were divided in all details according to number of rotors, design of pump inlet/outlet and flow directions.



A kinetic pump like the centrifugal pump increases the liquid's velocity in the pump by means of a rotating impeller. A displacement pump, like the piston pump, mechanically displaces the liquid in the pump, either by help of a piston or screws. Resistance on delivery side gives a liquid pressure rise (pump delivery pressure). One should be aware of this difference for these two pump types.
The pressure rise on a kinetic pump is restricted by the increase in velocity over the pump, which is controlled by the pump design. All kinetic pumps therefor have a designed or built-in limitation for maximum discharge pressure. The displacement pumps limitation depends only on available power and the constructional strength. In contrast to a kinetic pump, such a pump will operate against resistance with all its available power. A closed-delivery valve after a displacement pump is damaging. The same closed valve for a kinetic pump will not bring any immediate danger.
Piston pumps and screw pumps have good suction capacity and are used where these characteristics are required. The weakness of these pumps is the complex construction and the relatively low capacity.
Centrifugal pumps are simply constructed with few parts and no valves. There are no immediate problems if the outlet of the pump is closed. These qualities result in relative low purchase and servicing costs. Operation at high speed makes the pump small in proportion compared to the capacity and flexibility in relation to the pump's location.
The most negative side of using a centrifugal pump is the **lack of self-priming capacity**. This weakness is improved by constructional efforts and positioning, which consolidate the free flow of liquid. Location of a pump, for instance below the liquid level, can reduce the flow resistance. High viscosity liquids are therefore particularly difficult to pump due to this condition.
A centrifugal pump's efficiency is high only within a small range. This is the reason it is especially important to have a clear understanding of what capacity range the pump will operate under, in connection with the selection of a centrifugal pump.

The differential pressure over each impeller is relatively low. Using so-called multistage pumps where several impellers are mounted in serial, increase the pump's capacity to deliver against higher backpressure.

A centrifugal pump will, without a non-return valve on delivery side, give complete back flow at the time the pump stops. For all operators of centrifugal pumps, this relationship is important to know.

Centrifugal pump

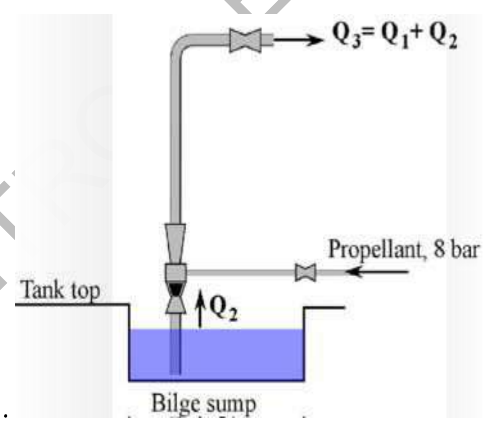
The ejector

The ejector design is simple and is used for stripping. This ejector has no revolving or reciprocating parts and is thereby especially easy to maintain.

The propellant (driving water), a liquid or gas, is forced through a nozzle into a mixer tube. The velocity of the propellant will naturally increase as it passes through the nozzle. Due to the propellant's velocity and direction, plus the friction force between the propellant and the liquid, the surrounding liquid will be sucked into the ejector's mixer tube. The mixer tube is connected to an expanding tube, the diffusor. Here some of the kinetic energy supplied to the liquid in the mixer tube is transformed into potential energy. The capacity depends on the friction force between the two mediums, suction head, delivery head and the propellant's velocity. The ejector has the advantage that it does not lose the suction capacity even if it sucks air or vapour.

The ejector's efficiency is between 30% and 40%. Even if the propellant's efficiency is up to approximately 70%, the total efficiency for the whole ejector system is far less than compared to a pump system, such as a centrifugal pump. Another drawback with ejectors is that the propellant is mixed with the pumping liquid. This implies that if the ejector is to be used in cargo transfer operation, the cargo itself must be used as propellant liquid.The ejector is frequently used as a bilge pump in hold spaces. A common arrangement for a hold space is as follows:

The ejector is usually submerged in a bilge sump and the propellant is normally supplied from a seawater pump. Onboard gas carriers where the hull is the secondary barrier, the ejector may also be used to pump cargo from hold space. In that case, the liquefied cargo itself must be used as a propellant

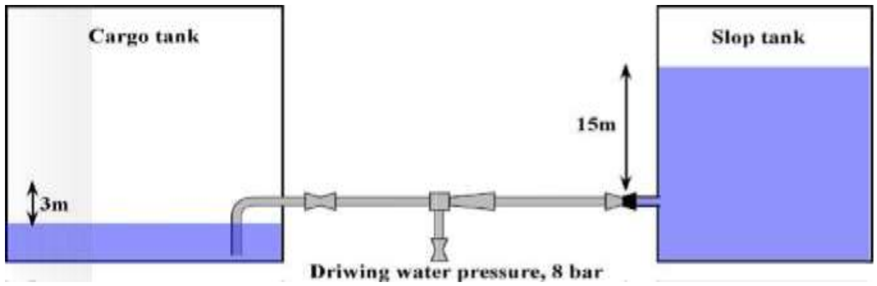


Tips

- Be aware that the ejector has a limitation on the propellant's pressure. Higher pressure than recommended by the supplier may result in reduced suction capacity.

- Start the ejector by opening all valves on delivery side first, and then adjust the correct propellant pressure. The ejector's suction valves should be opened last, which will prevent the propellant's flow back into the tank that is to be stripped.

- Stop the ejector by using the opposite procedure.



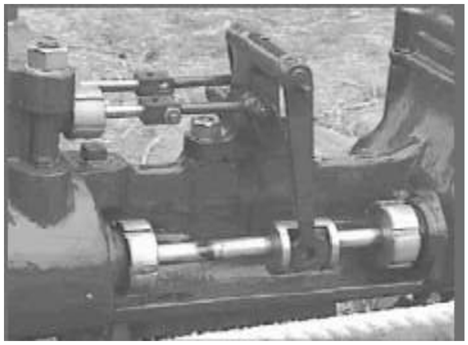
As the drawing shows the ejector is positioned 3 meters above the liquid level. The liquid level in the slop tank is 15 meters above the ejector and the propellant's pressure is 8 bars. The ejector's capacity can be found by use of the performance curve for the specific ejector. In the performance curve the ejector capacity is set as a function of the propellant pressure. Observe that this curve has curves for different suction lifts. The different performance curves are marked with different suction lifts. The ejector's suction lift in this example is 3 meters; this specific curve shall be used.
You can find the capacity of the ejector by drawing a vertical line from 8 bars on the scale for a delivery head of 15 meters and up to the performance curve with a suction lift of 3 meters. From this point of intersection, draw a horizontal line to the left and over to the ejector's capacity side. The found capacity in this case is 600 m^3/h.

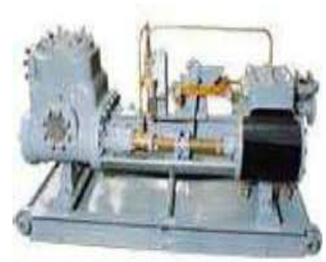
Displacement pumps

Pumps are very old machines. The first types of pumps (screw pump and piston pump) are more than two thousand years old.
A pump's purpose is for the transport of liquid, usually from a low level to a higher level. Its purpose can also be to press a liquid into a tank, which contains higher pressure than the surroundings. The pump increases the liquid's energy. The increased energy is potential energy; the liquid is transported from a low level to a higher level. This is the kinetic energy, the liquid's flow has increased as pressure energy, if the liquid is pumped into a tank with a higher pressure than its surroundings. As an example, the feed water pump to a boiler is working using these principles.
In addition to the mentioned increase of energy, the pump also has to maintain the energy which is lost due to streaming in the system.
As mentioned, kinetic pumps constantly have liquid streaming through the pump with pressure increasing simultaneously. In displacement pumps, a certain volume of liquid is branched off and moved from the pump's delivery side. Then a pressure increase occurs. Screw pumps and piston pumps will be viewed further in this chapter. A wide range of displacement pumps is available, such as the lamella pump, ring pump, propeller pump, etc.

Piston pump

The piston pump is used for relatively small amounts of liquid with large delivery heads. When the piston is pulled upwards, a vacuum occurs inside the pump housing. The suction valve will then open and liquid streams into the pump. When the piston is pressed downward the pressure will increase, the suction valve will close, the delivery valve is set open and the liquid sent out of the pump. The liquid does not stream in a smooth flow as in a centrifugal pump, but accelerates and slows alternately. This is of inconvenience with long pipelines. The valve is a weak point. They are sensitive to liquid pollution and they also increase the resistance against streaming.





Usually, the piston pump is double acting. Because of the pump's movements, the pump must have a relatively slow piston speed. The piston pump may sustain almost unlimited pressure. However, the limitation is the automotive power and the material strength. The piston pump does not have to be filled with liquid before starting. **Make sure that all the valves on the delivery side are open before starting.** The efficiency of piston pumps is higher than, for instance, centrifugal pumps. The piston pump is a well-known pump on board an oil tanker. This is the pump, which is used to pump cargo deposits ashore at the end of the discharging operation. These oil deposits from cargo tanks, lines and cargo pumps are pumped ashore through a small diameter line.

Screw pump

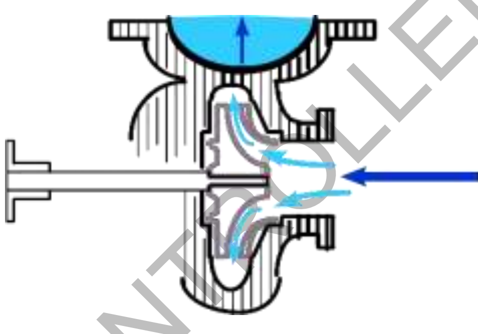
The screw pump consists of two screws or more, where one of them is activated. The screws are placed inside a pump house. A common and well-known screw pump is the Swedish manufactured so-called IMO pump. This pump consists of one active screw placed in the middle and two symmetrical side screws. The screws tighten to each other and to the housing, but have no metallic contact. When the screw rotates, the threads are filled with liquid. The liquid is displaced by axial through the pump. In this pump, the side screw rotates in the opposite direction of the middle screw. These screws are working like an endless piston which constantly moves forward. The liquid is not exposed to rotation. The pump is self-priming, running almost soundless and with little exposure for wear and tear when pumping clean liquids. The screw pumps are used a lot as a lubricating pump, but are also used as a stripping pump on oil tankers.

Screw pumps

Centrifugal pump

The centrifugal pump's mode of operation

A centrifugal pump consists of a rotating impeller inside a pump casing. The liquid inside the impeller is affected by the "blades", and will be lead through the "blades" due to the centrifugal force. Energy in forms of kinetic energy (velocity energy) is added to the liquid. New liquid is constantly lead into the impeller and put into rotation. A flow through the pump is established.



Use of eductors

Eductors may be used for ballast stripping purposes. To strip efficiently, an eductor used for tank cleaning operations should have a capacity of about twice the rate of liquid being introduced to the tanks.

- Eductors are always to be operated at or near their design driving pressure as, in general, lower driving pressures will considerably reduce eductor efficiency. Higher back pressures in the system than the eductor was designed for can also reduce suction capacity.
- The eductor drive liquid must always be flowing before the suction valve is opened to prevent back flow of the driving liquid to the tank suction.
- When shutting down an eductor the suction valve is to remain open until the eductor is stopped to prevent the eductor drawing a vacuum on the suction line.
- If, during use, the eductor driving pressure falls below the required operating pressure, the eductor suction valve is to be closed to prevent backflow of the driving liquid.

The tank suction must not be used to prevent backflow as the suction pipework is not designed for such high operating pressures.

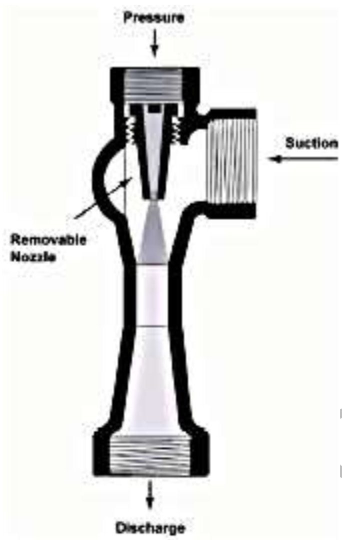


Fig:Water jet eductors

Pressure Surges

The incorrect operation of pumps and valves can produce pressure surges in a pipeline system. These surges may be sufficiently severe to damage the pipeline, hoses or metal arms. One of the most vulnerable parts of the system is the ship-to-shore connection. Pressure surges are produced upstream of a closing valve and may become excessive if the valve is closed too quickly.