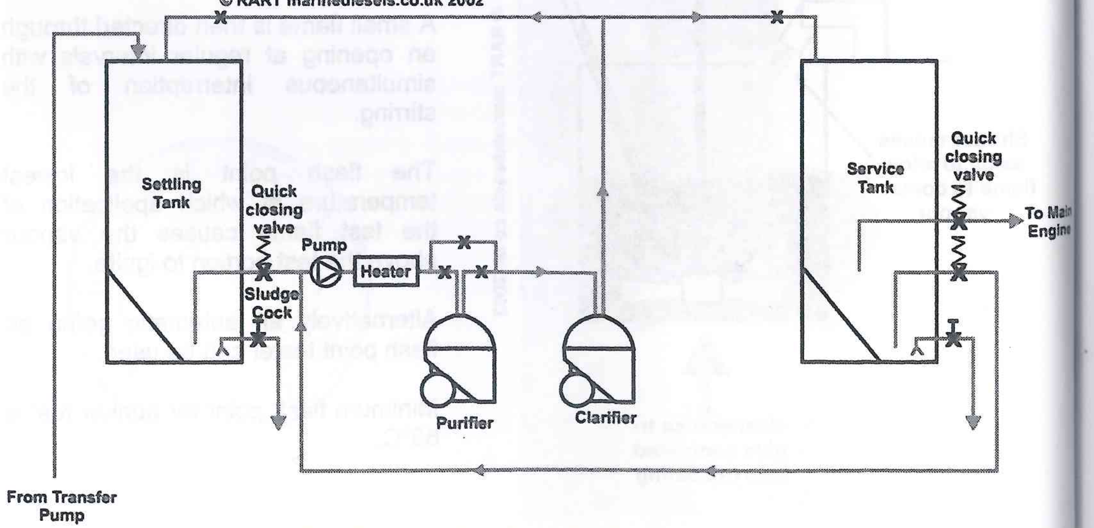
Chapter 4: Storage and Purification of Fuels

The fuel will be stored in the bunker tanks till required for use. It may have to be heated to keep it above its pour point and to make pumping easier. Classification societies stipulate:

Oil fuel in storage tanks should not to be heated to temperatures within 10°C below the flash point of the fuel oil, except that where oil fuel in service tanks, settling tanks and any other tanks in supply system is heated the following arrangements should be provided:

- The length of the vent pipes from such tanks and/or a cooling device is sufficient for cooling the vapours to below 60°C, or the outlet of the vent pipes is located3 m away from a source of ignition;
- The vent pipes are fitted with flame screens;
- There are no openings from the vapour space of the fuel tanks into machinery spaces (bolted manholes are acceptable) ;
- Enclosed spaces are not located directly over such fuel tanks, except for vented cofferdams;
- Electrical equipment is not fitted in the tanks unless it is certified to be intrinsically safe.

Particular care should be taken to ensure that any flame screens/ traps are in good condition on the various fuel oil tank vent pipes, and that no ignition sources are in the area immediately surrounding the venting system. This is because when tanks are being filled the tank headspace gas will be displaced through the vent pipes. When filling empty or nearly empty tanks the heating coils must be cooled and shut down. Fuel oil contacting hot exposed heating coils could rapidly lead to the generation of a flammable atmosphere. All residual fuel oil tank headspaces should be classified as 'hazardous' and all electrical equipment within these spaces must meet the appropriate safety standard.



Purifier/Clarifier Fuel Oil Treatment System

Fuel to be used is first transferred from storage tanks to a settling tank in which it is heated to allow some water and sludge to settle out by gravity and be drained off. The fuel is then passed through the purification system and discharged to a daily tank. There are usually two daily tanks, used alternately, one in use while the other is being recharged. Settling and service tanks are lagged to conserve heat.

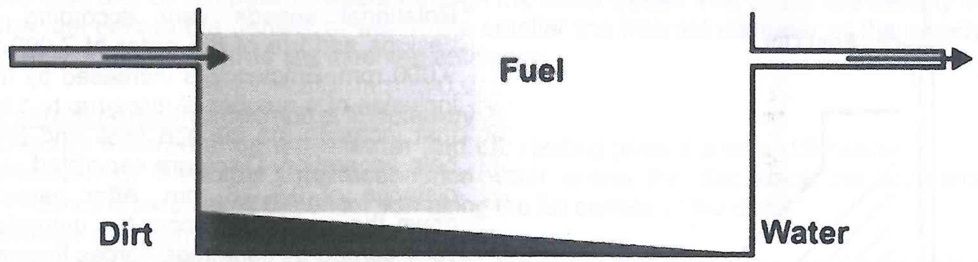
A recommended standard of treatment for residual fuel to be used in a large engine requires two centrifuges of adequate capacity operating in series. The first acts as a purifier to remove water, solubles, sludge etc while the second acts as a clarifier to remove solids. The purifier must be fitted with the correct disc or dam to match the oil density. The oil is heated before purification (max. temp. 98°C) and the rate of throughput is limited to assist efficient separation. Both centrifuges must be cleaned frequently. Such systems can operate effectively on oils of densities up to 0.99.

From the service tanks the treated oil is pumped through a pressurised fuel system to the engine. With the oil temperatures necessary for high viscosity fuel, and the possibility that a trace of water may still be present, it is necessary to maintain the engine pump suctions and circulating connections under pressure to inhibit boiling, gasification and cavitation.

SEPARATION, PURIFICATION and CLARIFICATION

Separation

Separation as a means of removing impurities from a fuel can be undertaken by means of gravity in a settling tank or by means of centrifuging the fuel. Both methods work on the same principles that by subjecting the fuel to a constant force, the denser components of the fuel i.e. water and dirt will be separated from the lighter components i.e. the fuel itself.

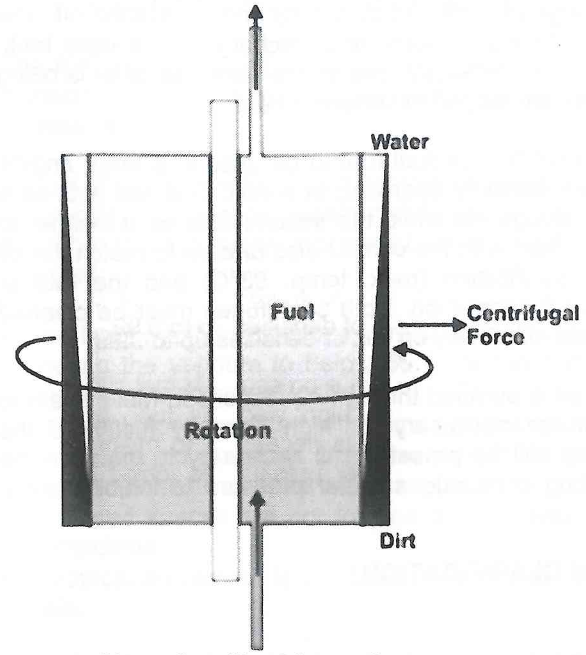


Simple Gravity Separation

Gravity acting on the fuel as it passes slowly through the tank will separate the denser components from the fuel where they will accumulate at the bottom of the tank. The contaminants can then be removed by sludging the tank.

Centrifuging

Centrifuging is the process by which the effects of gravity can be amplified by the use of centrifugal force to the extent that the separation process becomes rapid and continuous. Centrifuges work by rapidly spinning a bowl containing the liquid, thus producing the required centrifugal force to produce separation

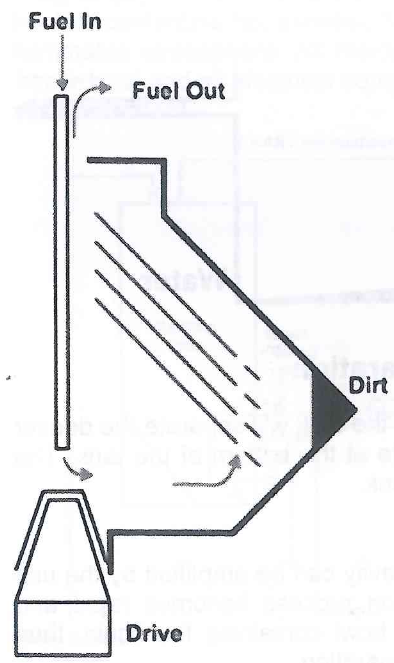


Simple Centrifugal Separation

The principle of operation of the centrifuge is simple. When a bowl containing impure fuel is rotated, centrifugal forces will throw any item with density greater than the fuel oil density (solids and free water) to the periphery of the bowl

Centrifugal separators used for the separation of two liquids of different densities (fuel and water) are known as purifiers and those used for separating solid impurities are known as clarifiers. Purifiers will also remove some solids and clarifiers will also remove small quantities of water.

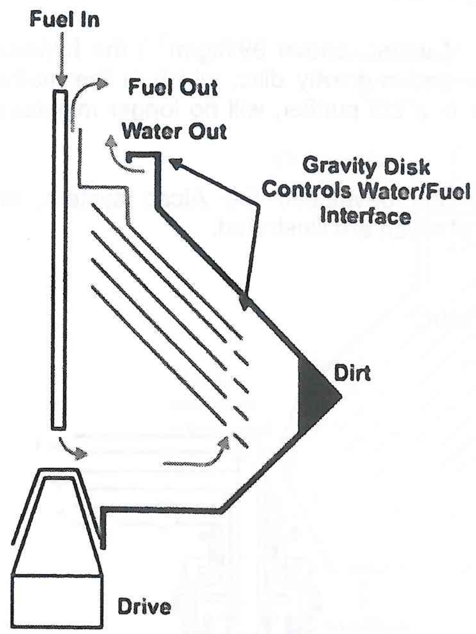
Clarifier



CLARIFIER

The addition of an inlet and an outlet connection forms a simple clarifier. Rotational speeds vary according to designs and are of the order of 7,000 to 9,000 rpm. Efficiency is increased by the inclusion of a number of discs (up to 150) that increase the surface area and thus help separation. Discs are separated at a distance of 0.5-0.6 mm. After passing down the central passage, the untreated oil is carried by centrifugal forces towards the periphery of the bowl and then passes up through the disc stack. Here is where the actual separation takes place, in the channel formed between two discs. Two forces act on each solid or liquid particle. The particle is pushed upwards with the oil stream towards the centre while the centrifugal force directs it to the periphery. The residual force on denser particles (impurities) will drive them towards the periphery, while the less dense particles (oil) will be directed towards the centre of the bowl and raised to the outlet connection.

Purifier



PURIFIER

When a centrifuge is set up as a purifier, a second outlet is used for discharging water as shown. In the fuel oil purifier, the untreated fuel contains a mixture of oil, solids and water, which the centrifuge separates into three layers. While in operation, a quantity of oil remains in the bowl to form a complete seal around the underside of the top disc and, because of the density difference, confines the oil within the outside diameter of the top disc. As marine fuel oil normally contains a small quantity of water, it is necessary to prime the bowl each time that it is run, otherwise all the oil will pass over the water outlet side to waste. The water outlet is at greater radius than that of the fuel. Within the water outlet there is a gravity disc, which controls the radial position of the fuel water interface

A set of gravity discs is supplied with each machine and the optimum size to be fitted depends on the density of the untreated oil. If the internal diameter of the gravity disc is too small the separating efficiency will be reduced as the interface will be formed within the disc pack. If the internal diameter is too large the interface will form at a diameter greater than the top disc and oil will pass to waste through the water outlet. The closer the density of the fuel gets to the density of water, the smaller the internal diameter of the gravity disc required to operate the machine efficiently.

Factors Affecting Separator Efficiency

Density difference between water and oil. Heating gives a greater differential.
Position of oil/water interface. Once water enters the disc stack the separator efficiency is reduced as oil cannot flow along the full surface of the disc.
Sludge discharge frequency.
Viscosity of oil. The lower the viscosity the lower the drag force on dirt particles. Viscosity is reduced by heating.

When the fuel centrifuge is operating, particulate matter will accumulate on the walls of the bowl. If the centrifuge is set as a clarifier, the particulate matter will be a combination of water and solid material. If it is set as a purifier, the free water is continuously discharged, therefore, the particulate matter will consist of solid material. In older machines it is necessary to stop the centrifuge to manually clean the bowl and disc stack, however, the majority of machines today can discharge the bowl contents while the centrifuge is running.

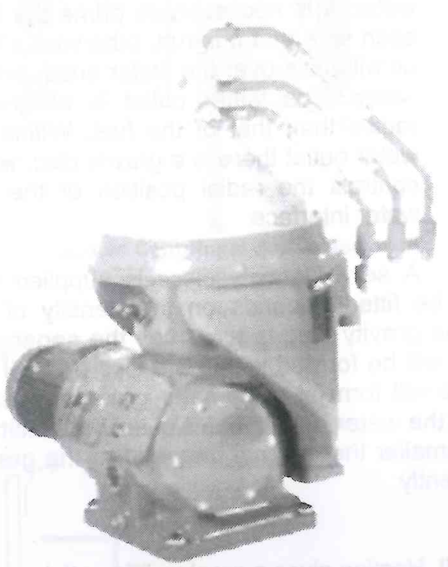
A centrifugal separator can be set to run as a purifier or clarifier. A clarifier does not require a water seal. The gravity disc gets replaced by a clarifier disc with a smaller inside diameter.

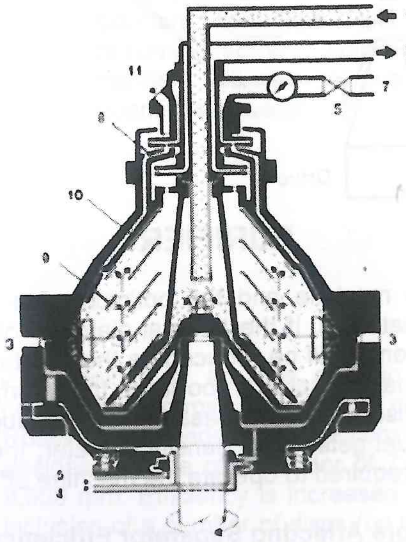
Separators for Dealing With High Density Fuels

As the density of the oil approaches that of water (above 991kg/m^3) the hydraulic equilibrium in the bowl becomes unstable, and a gravity disc, which is the method used to maintain the oil/water interface, as in a LO purifier, will no longer maintain a water seal.

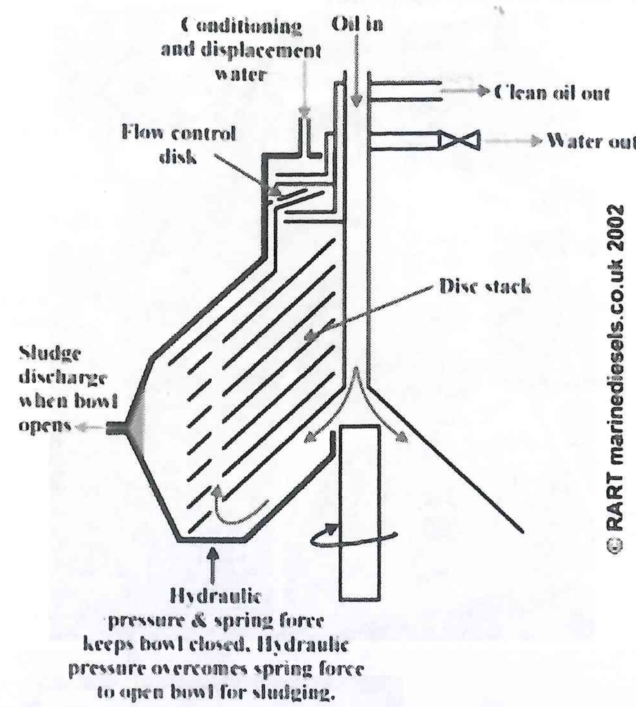
To overcome this problem, Alpha Laval has developed the Alcap system, and Westfalia the Unitrol system, the principles of which are illustrated.

The Alcap system using the FOPX separator.



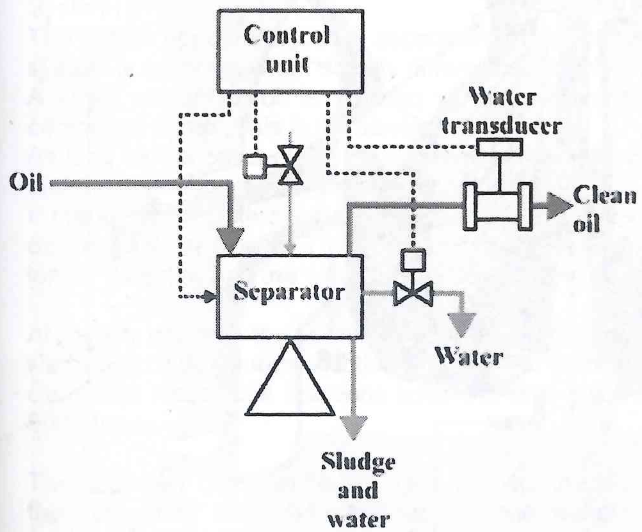


The FOPX separator comprises a frame containing in its lower part a horizontal drive shaft with friction clutch and brake, worm gear and vertical bowl spindle. The worm gear is placed in an oil bath. The bowl is fixed on the top of the spindle inside the space formed by the upper part of the frame and the frame hood which also carries the feed and discharge systems. Instead of a range of gravity discs, the FOPX separator bowl is supplied with one permanently fitted flow control disc. Paring disc pumps (centripetal pumps) are built-in to the separator bowl for discharge of clean oil and separated water under pressure.



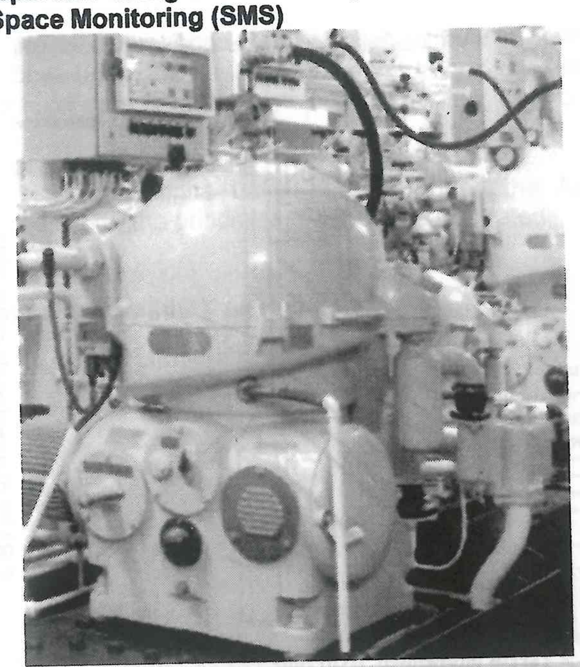
Oil is fed into the high speed rotating bowl which basically operates as a clarifier, but water and solids are separated and are thrown to the outside of the bowl by centrifugal force.

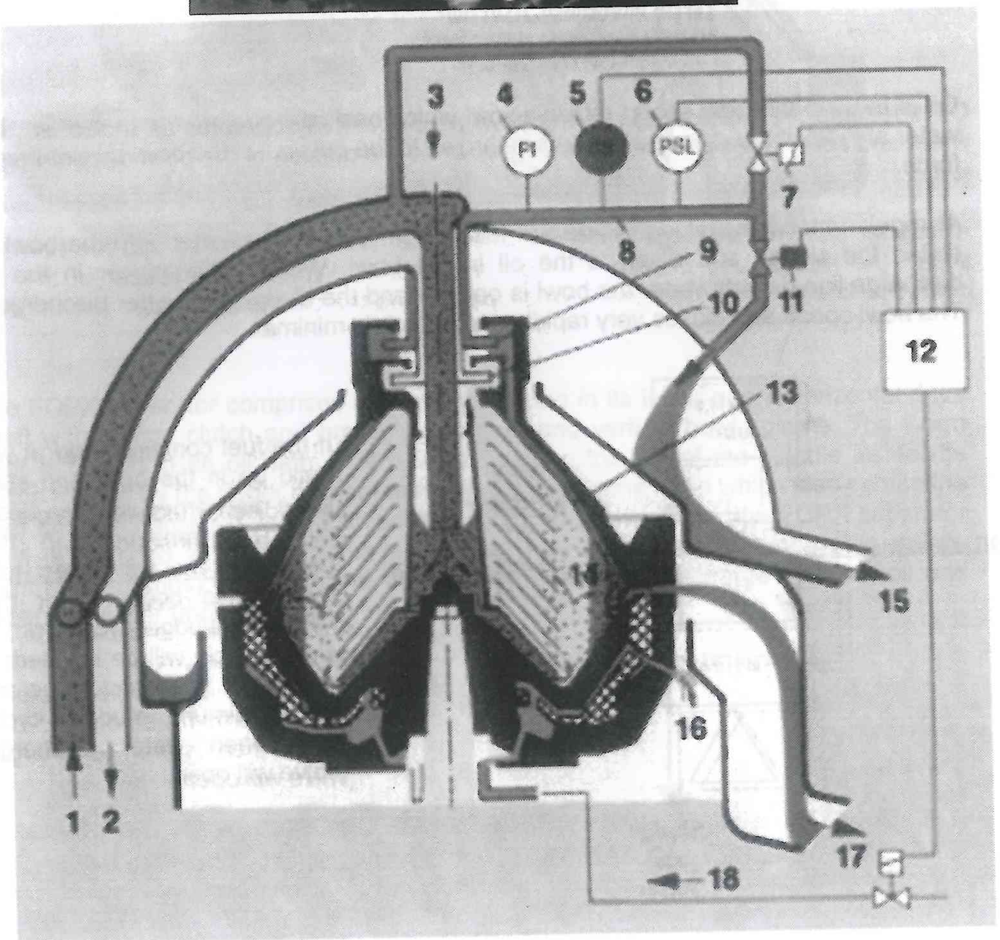
At regular intervals a sludge cycle will take place. Water is admitted into the bowl to soften the sludge and displace the oil in the bowl. When a transducer in the oil discharge line detects water the bowl is opened and the sludge and water discharged. The bowl opens and closes very rapidly and oil loss is minimal.

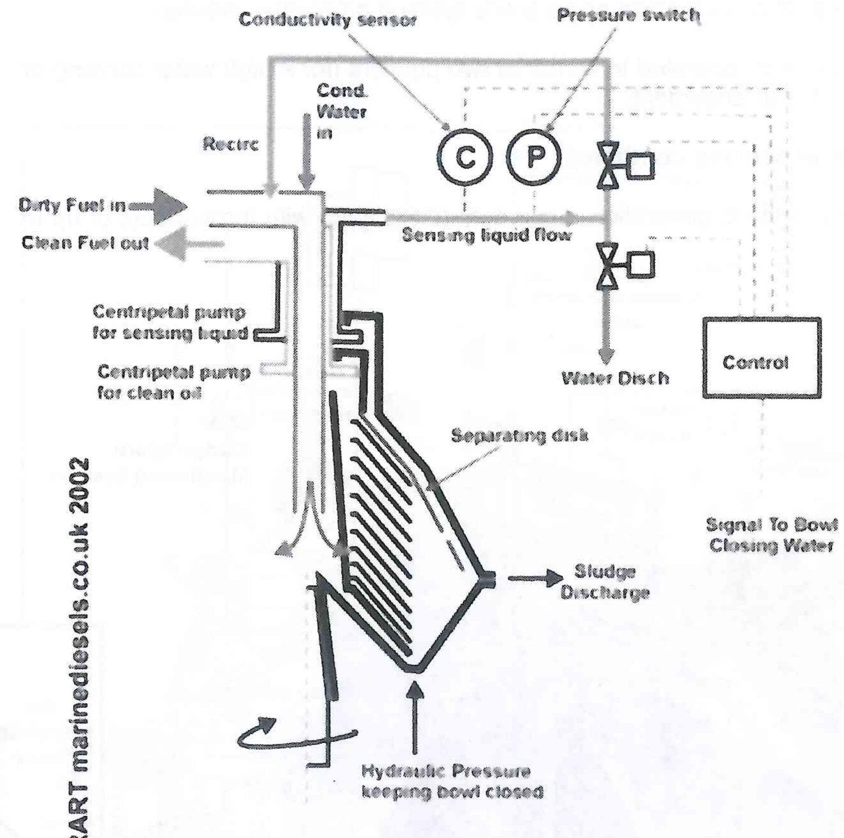


If the fuel contains water it will build up in the bowl and start to be discharged with the clean oil. The transducer in the discharge line will detect this and if this occurs after the minimum sludge cycle time, a sludge cycle will be initiated; if the water is detected before the minimum sludge cycle time, then water discharge valve will open.

The OSB type separator using the Unitrol system for either Water Monitoring WMS or Sludge Space Monitoring (SMS)







PRINCIPAL OF THE WESTFALIA UNITROL SYSTEM

The separator can either be set up to monitor water content in the oil discharge (Water Monitoring System) or a sludge build up in the separator (Sludge Space Monitoring System).

The sketch opposite shows a separator set up for the Water Monitoring System. This system is essential when density differences between the oil and water are very small.

A small amount of oil is diverted via the separating disk and pumped out using a centripetal pump (This is the sensing liquid).

As long as the conductivity sensor registers oil, the oil flows back to the purifier inlet., and the separator is operating as a clarifier.

If the sensor registers water (95% by vol), then the recirc valve closes and the water discharge valve opens. The separator is now acting as a purifier until the water is no longer detected and the valves change back over.

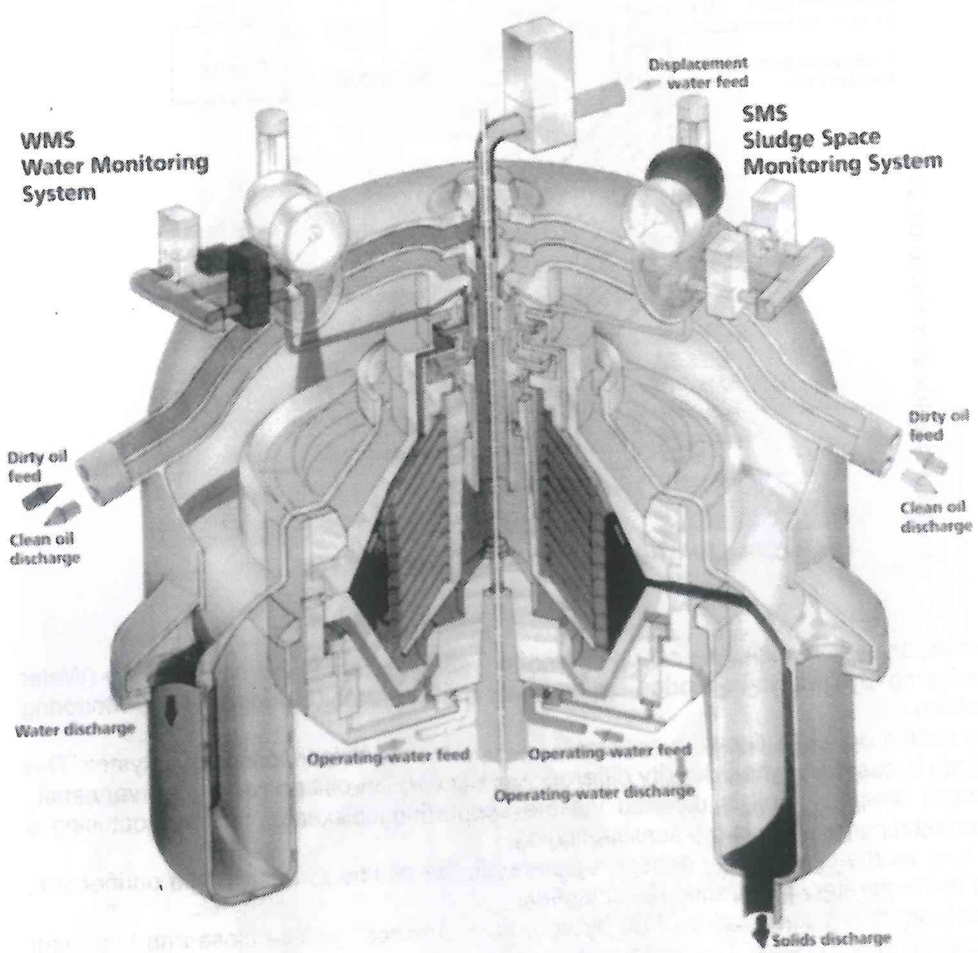
At regular intervals the separator will go through a discharge cycle. Oil is displaced by water before the sludge ejection which takes place over a very short time. Westphalia claim that these total ejections keep the disk stack clean and increase TBOs to 6 - 8000 hours.

The separator can also be set up to monitor the sludge space for solids. In this case the separating disk is exchanged for one without any holes. The control unit is adjusted to monitor the pressure in the sensing liquid flow. If the sensing liquid flow is interrupted due to an accumulation of solids at the periphery of the bowl, the pressure switch registers a drop in pressure and a solids ejection program is initiated.

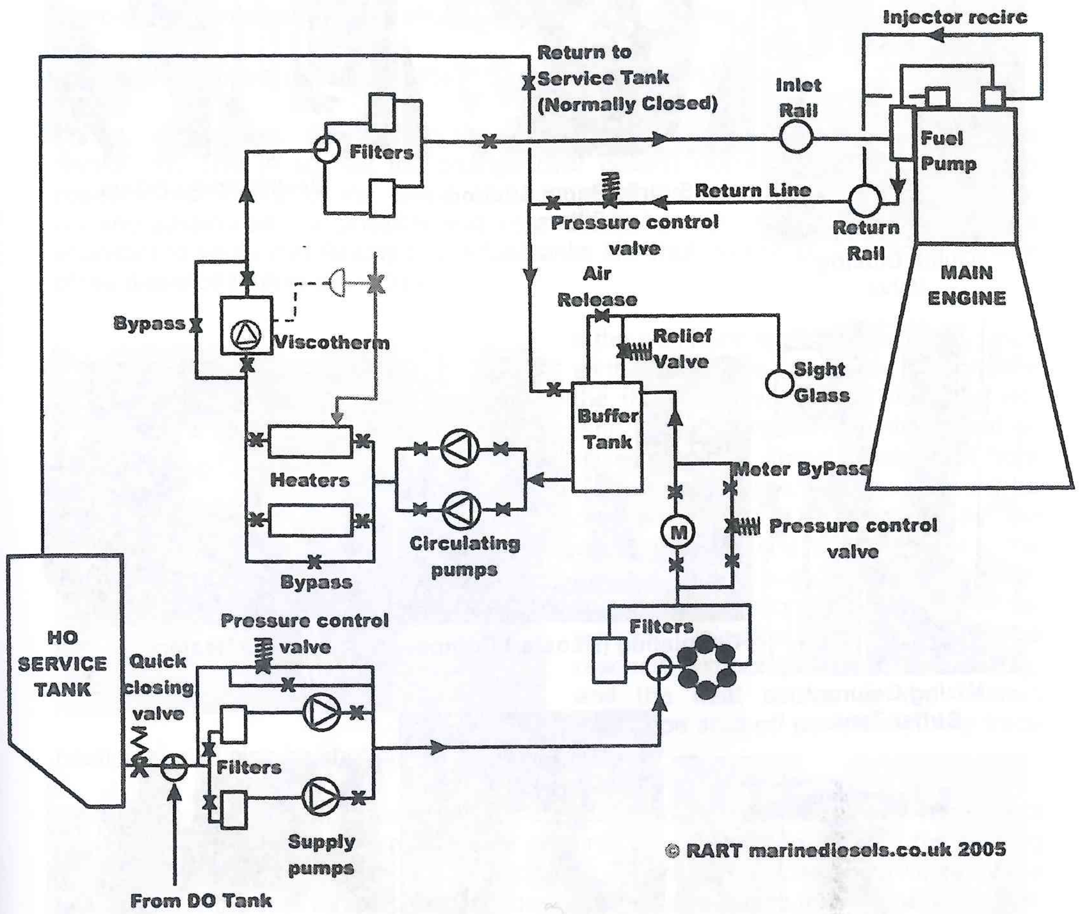
Two separators can be operated in series as two purifiers (for a high water content) or as a purifier/clarifier arrangement.

Sludge and water sensing combined

This is achieved in the C generation separators (OSC type) with throughputs of up to 43100 l/h.

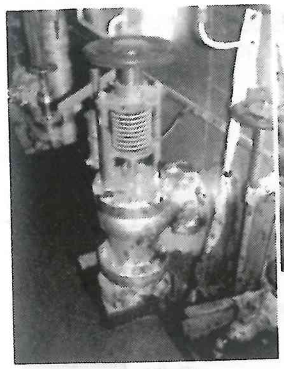


Chapter 5: The Fuel Oil System



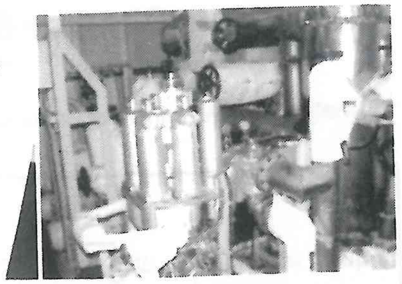
The sketch above illustrates a fuel oil supply and return system incorporating a heater and viscotherm. Both the heater and the viscotherm would be fitted with a by pass, and the heater steam supply could be controlled by hand if required. There will be more than one heater to allow for redundancy, and there are two supply pumps and two circulating (booster) pumps.

Fuel leaves the settling tank via a quick closing valve and passes through the change over valve and suction filter before being pumped through backflushing filters (25 micron) and the meter into the buffer tank (or mixing column), where it mixes with fuel from the return line before being pumped through the heater by the circulating (booster) pumps. After the heater the fuel viscosity is monitored by the viscosity controller. An amplified output signal from the viscosity controller operates the heater control valve. The fuel then enters the engine fuel rail via a set of final fine filters. The fuel is continuously recirculated back down a return line to the buffer tank (mixing column), from where it enters the system once again; this ensures that the fuel in the fuel rail is kept at the correct temperature to maintain the desired viscosity. The system will be lagged to prevent unnecessary heat loss, and will be fitted with trace heating.

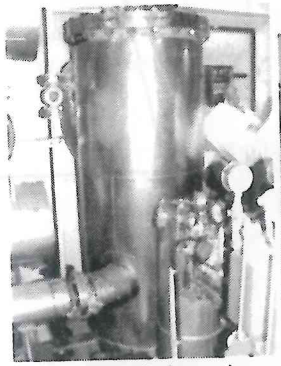


Quick Closing Valve

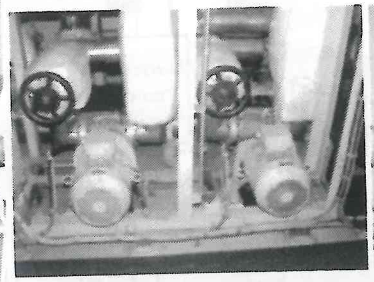
Supply Pump Suction Filters



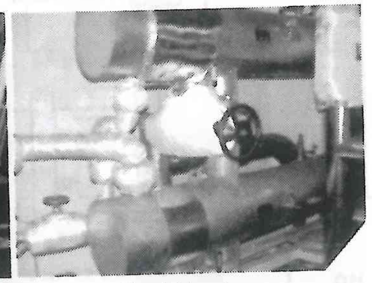
Backflushing Filters



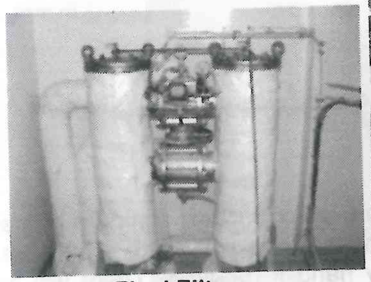
Mixing Column/ Buffer Tank



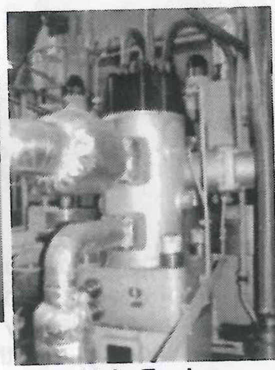
Circulating (Booster) Pumps



Fuel Heaters



Final Filters



Main Engine Fuel Pump

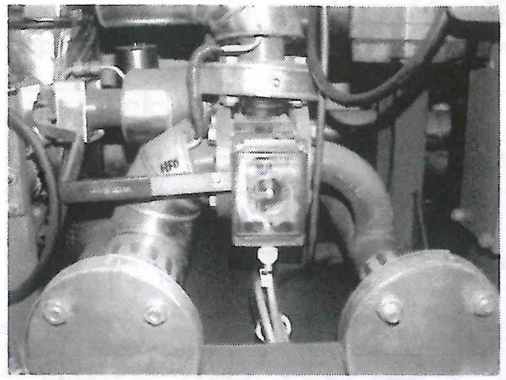
Pressure Control valve

Changing from HFO to MDO and Vice Versa

The timing of the change over will depend on the size of the system, but is normally programmed so that complete change over is achieved before the vessel begins manoeuvring on standby. This should take about 30 minutes.

Desludge the diesel oil tank to ensure there is no water in the tank.

Before change over, the load on the engine is reduced to manoeuvring full ahead revolutions. This is so that the change over doesn't occur too quickly, leading to possible overheating of the diesel oil because of the residual heat in the heaters, causing gassing up and possible seizure of the fuel pumps. Before change over, it is important to verify that returns to the fuel tanks are shut, as this could lead to transfer of the diesel oil tank to the HO tank.



If the vicotherm is working correctly, then all that should be necessary is to change the three way valve over from the HO tank to the DO tank. As the diesel oil mixes with the heavy residual oil from the mixing column, the viscosity will be reduced; this will be detected by the viscotherm, and the energy source to the heaters shut in accordingly. While there is still a proportion of heavy oil in the system, injection viscosity will be reached without the need for heating, and the heat source to the heaters should be shut off completely. Any trace heating should also be shut off.

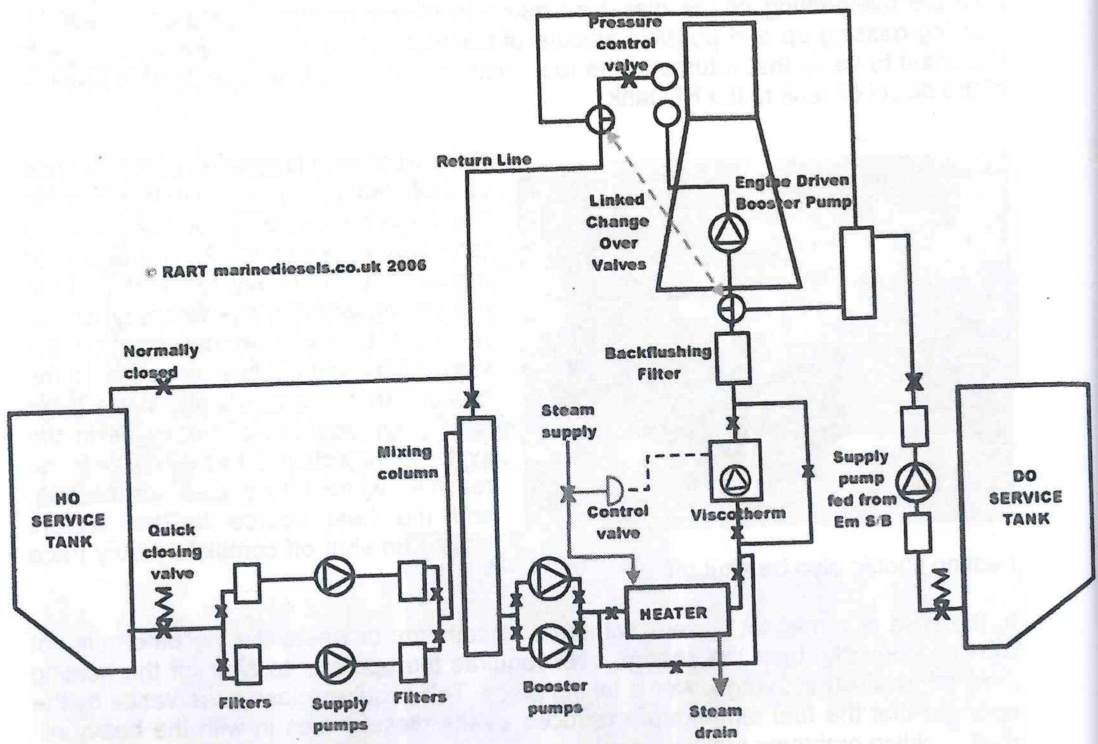
In the case of a manual system, without a viscotherm, or where the viscotherm is not working correctly, then the change over requires the operator to shut off the heating medium, whilst the change over is taking place. This requires close observance by the operator that the fuel temperature reduces as the diesel mixes in with the heavy oil, thus avoiding problems outlined above.

When changing from diesel oil to heavy, open the steam isolating and heater drain valves (if steam heaters). In case of thermal oil, ensure that inlet and outlet valves are open, and in the case of electric heaters ensure that breakers are closed. Ensure the viscotherm is switched on and running. Open trace heating. Desludge the HO service tank. Ensure return is open to the mixing column/buffer tank. Change the three way valve over. As the Heavy Fuel mixes with the Diesel oil in the mixing column/buffer tank, so the viscosity will rise. The Viscotherm should detect this and open the heating supply to the heaters, heating the fuel to correct viscosity for injection (14 – 17 Cst.)

Auxiliary Engine (Generator) Fuel Oil System

If the auxiliary engines run only on distillate fuel, then the fuel system is simple with no viscotherm , heaters or buffer tank.

However when the engines run on residual fuel, then the system is similar to a main engine fuel system, but with provision to change individual machines over to run on distillate fuel.



Black Out Pump

Some ships incorporate a blackout booster pump for the auxiliary engines. This is a pump driven by compressed air, which in normal operation is isolated by a solenoid valve. In the case of a black out, the solenoid will be de-energised, allowing compressed air from the air bottles to drive the pump. The dedicated auxiliary engine will then attempt to start, and connect to the bus bars. Should it fail, then the emergency generator will start as normal.

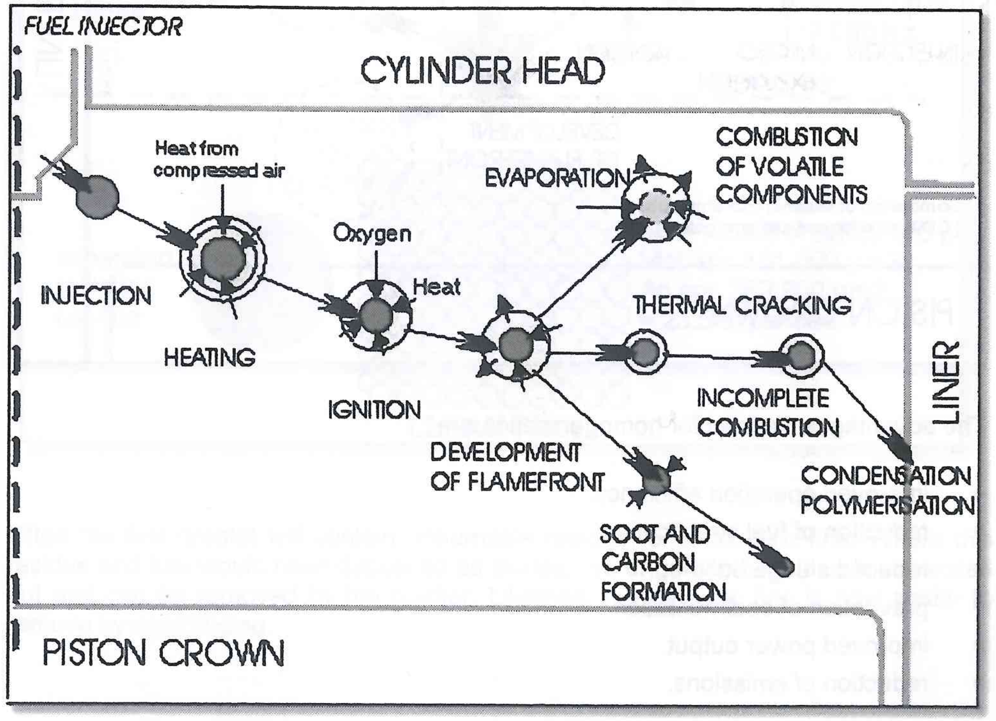
Chapter 6: Homogenisers

What is Homogenisation?

Homogenise: a : to reduce to small particles of uniform size and distribute evenly usually in a liquid b : to reduce the particles of so that they are uniformly small and evenly distributed.

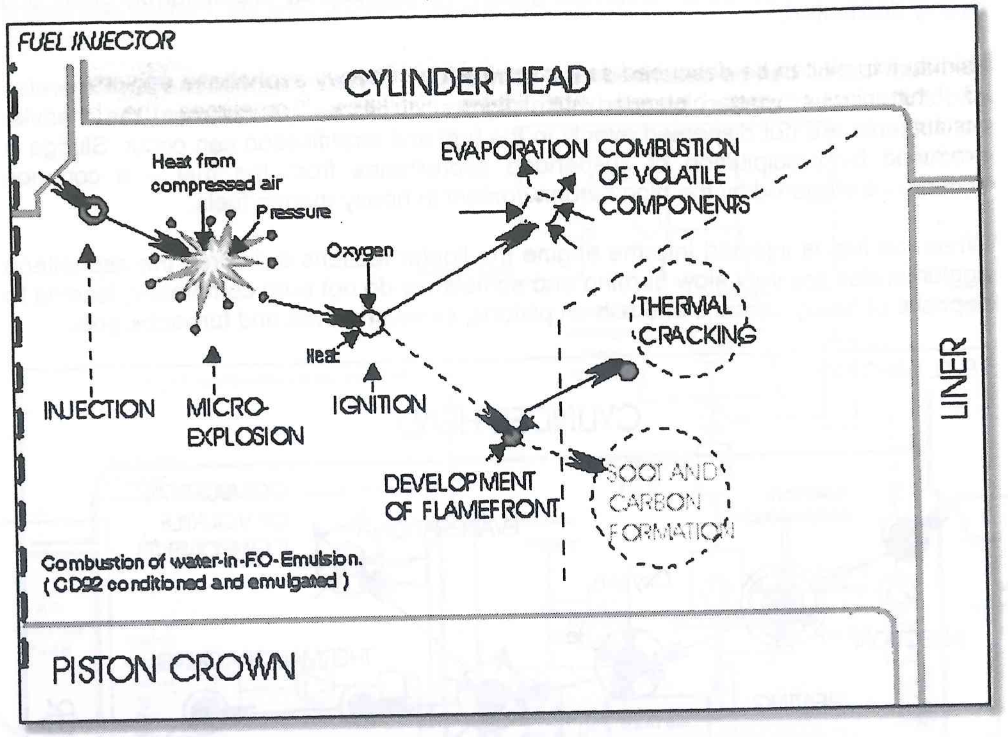
Residual fuel oil can be described as a combination of heavy asphaltene agglomerates and bituminous matter blended with lighter distillates. Sometimes the heavier constituents are not dispersed evenly in the fuel and stratification can occur. Sludge is produced by precipitation of suspended asphaltenes from the fuel – a common occurrence triggered by the high carbon content in heavy marine fuels.

When the fuel is injected into the engine the lighter factions burn first; the asphaltene agglomerates are very slow burning and sometimes do not burn completely, leading to deposits of heavy carbons and ash on pistons, exhaust valves and turbochargers.



If these heavy, relatively large particles of fuel can be broken down into smaller droplets, then the surface area is increased and the droplets will heat up more quickly and burn more efficiently with fewer harmful carbon deposits and lower equipment maintenance costs. With smaller particles passing through the purifier, sludge output is also greatly reduced.

A homogeniser is a piece if mechanical equipment which reduces the fuel oil particle size and evenly distributes them. If the fuel system is fitted with appropriate water dosing equipment it will also form a useable emulsion with water content up to 50%, leading to a 10%-NO_x -reduction per 10% water. This system has been researched and developed by MAN B&W.



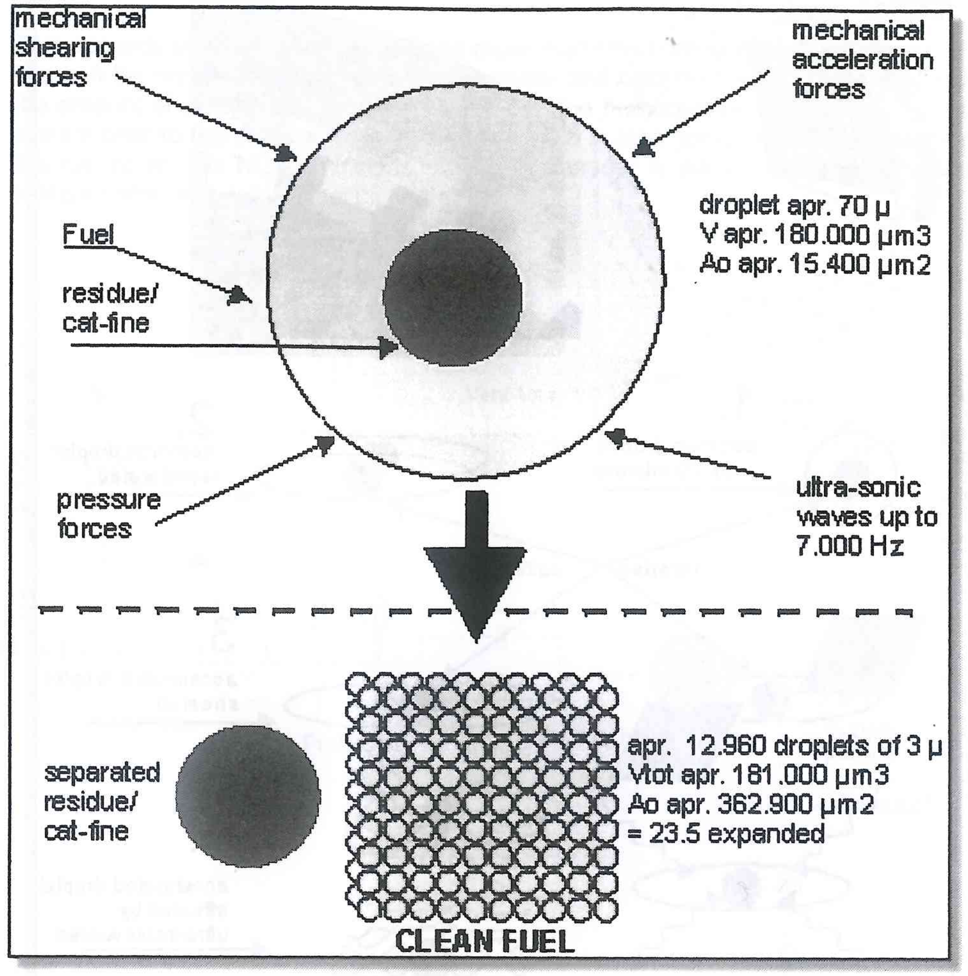
The advantages claimed for homogenisation are:

- improved operation efficiency.
- reduction of fuel stratification.
- reduced sludge build-up.
- prevention of sedimentation.
- improved power output.
- reduction of emissions.

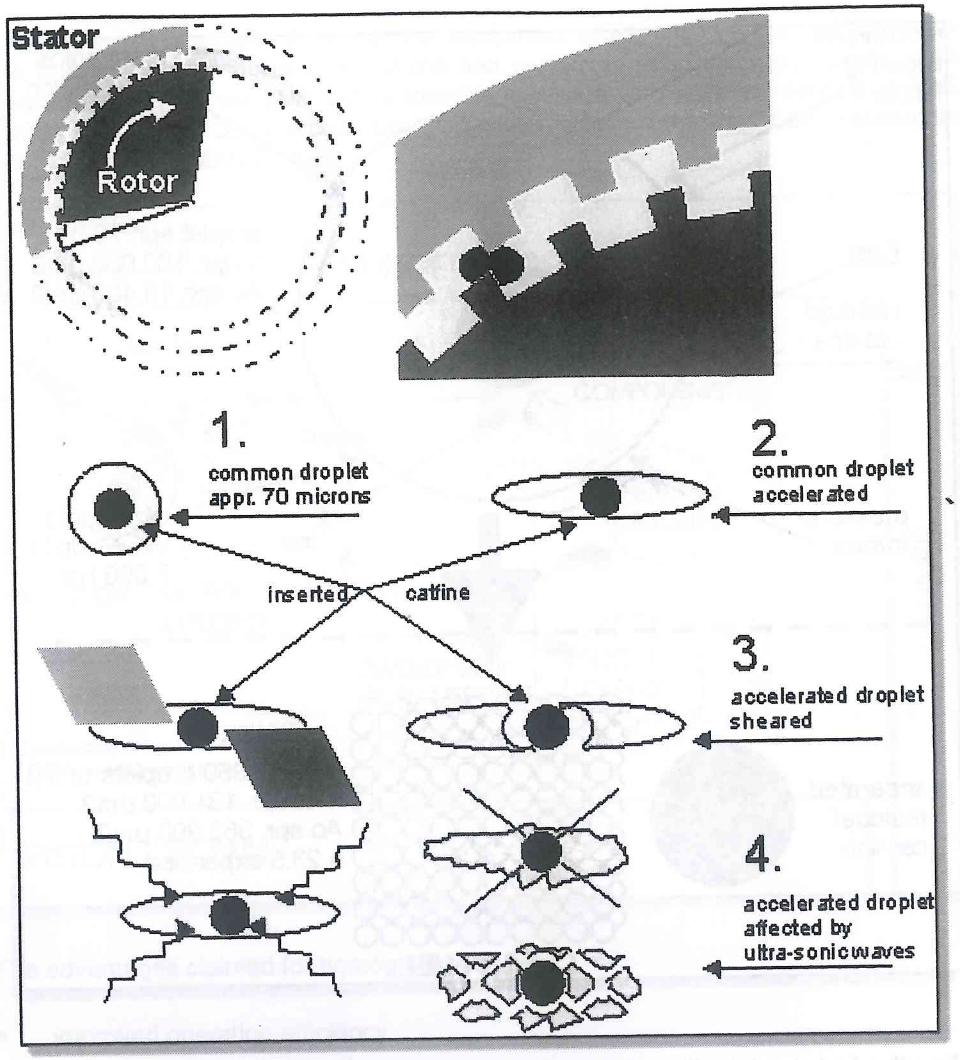
How does it work?

there are different types of homogenisers, but basically the principle is to take a droplet of fuel and to chop it up using mechanical shearing and acceleration forces and ultrasonic waves to produce many thousands of much smaller droplets with a much greater surface area.

For example a droplet 100µm (microns) in diameter has a surface area of 31416µm^2 If it is broken up into droplets of 5µm diameter, the total surface area increases by 20 fold; If broken up into droplets of 2µm diameter then the surface area increases 50 fold.



Often the fuel droplet will contain unburnable residue, or a catalytic fine. Where this residue and fuel would have deposited as sludge, the unburnable residue is separated out and can be removed by the purifier. Likewise, the catalytic fine is now easier to remove by centrifuging.

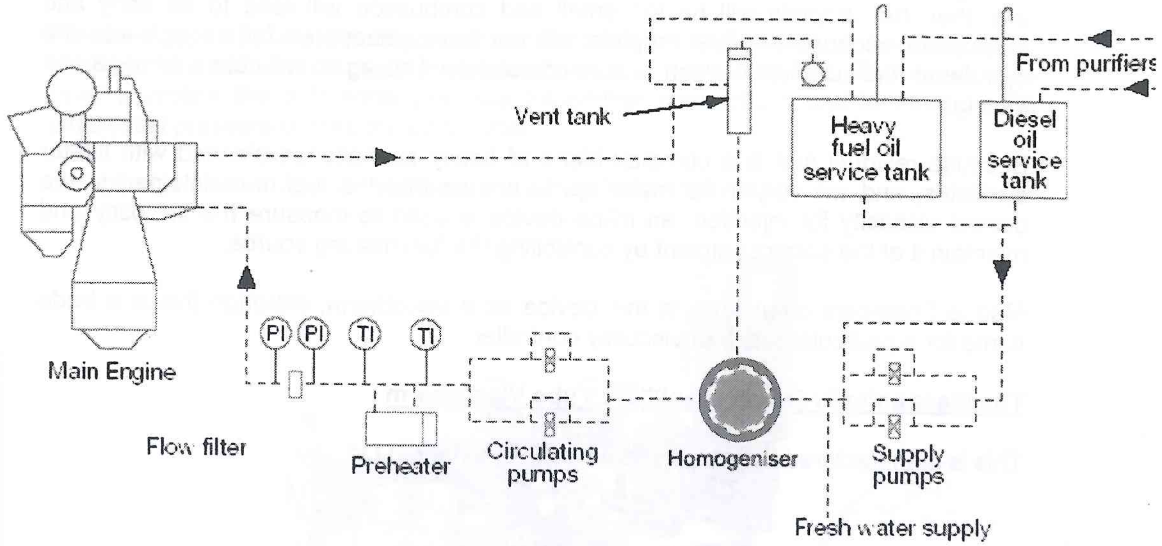


The homogenizer attacks sludge and combustion problems directly by mechanically reducing the size of asphaltene particles.

Pumped through the machine's concentric gears with cone-shaped grinding surfaces, heavy fuel oil is exposed to frictional forces that shear asphaltenes to well under the maximum size that manufacturers recommend for efficient operation.

Positioning of Homogeniser.

This depends on the set up. Sometimes more than one homogeniser is employed. The fuel can be circulated through the homogeniser and back to the settling tank. To limit the amount of sludge loss through the purifier, the homogeniser can be placed in the system prior to the separator. For a system which is also going to introduce water into the fuel to reduce NOx emissions, The homogeniser is placed in the fuel pressure system before the engine fuel oil heaters.



Chapter 7: Viscosity Control

INTRODUCTION

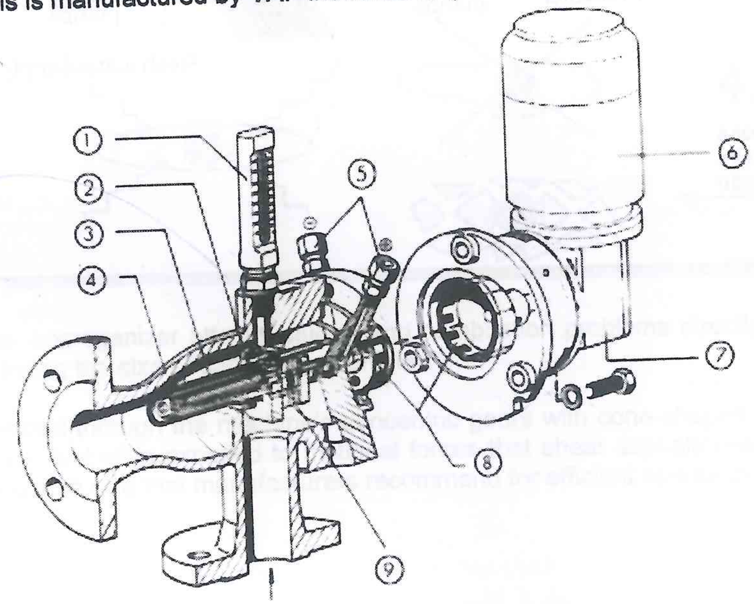
For efficient and complete combustion, residual fuel must be heated before it is burnt. For correct atomisation in the cylinder, the fuel must be at the correct viscosity. If the viscosity is too high, the fuel droplets will tend to be too large and will take too long to absorb the heat energy from the compressed air before they start to burn. This will lead to late and incomplete combustion, lack of power, afterburning and damage or fouling to liner, piston crown, exhaust valve and turbocharger. If the viscosity is too low, then the droplets will be too small and combustion will tend to be early and incomplete because the fuel droplets will not have penetrated far enough into the cylinder to find sufficient oxygen to burn completely. This again will cause damage and fouling.

Because residual fuel is a complex blend of heavy asphaltenes blended with lighter distillates, and will vary in its make up, to ensure that the fuel is maintained at the correct viscosity for injection, an inline device is used to measure the viscosity and maintain it at the correct setpoint by controlling the fuel heating source.

Marine Engineers often refer to this device as a viscotherm, although this is a trade name for a particular make of viscosity controller.

The Mechanically Driven Capilliary Tube Viscotherm

This is manufactured by VAF Instruments (Netherlands) Ltd.



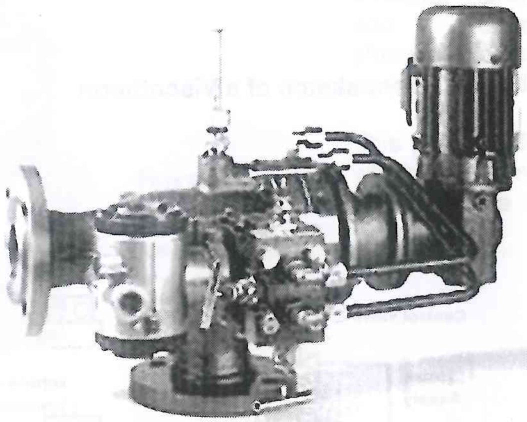
1. Thermometer
2. damping capilliary
3. measuring capilliary
4. housing
5. d.p. transmitter connections
6. motor
7. reduction gear
8. magnetic coupling
9. gear pump

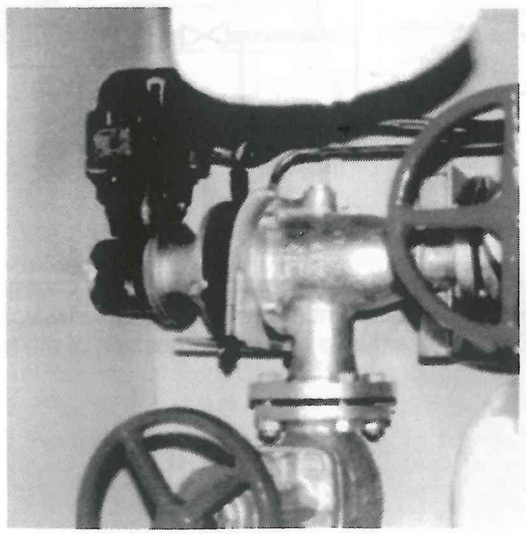
The sensor consists of a housing (4) in which the measuring element, a capillary tube assembly (2,3) is mounted together with a gear pump (9). An electric motor (6) with reduction gear (7) drives the pump such that a continuous and constant flow through the capillary tubes is achieved. The laminar flow through the measuring capillary creates a pressure differential which is proportional to the dynamic viscosity of the fuel oil. A magnetic coupling (8) prevents both leakage and overload of the electric motor in the event of an obstructed pump.

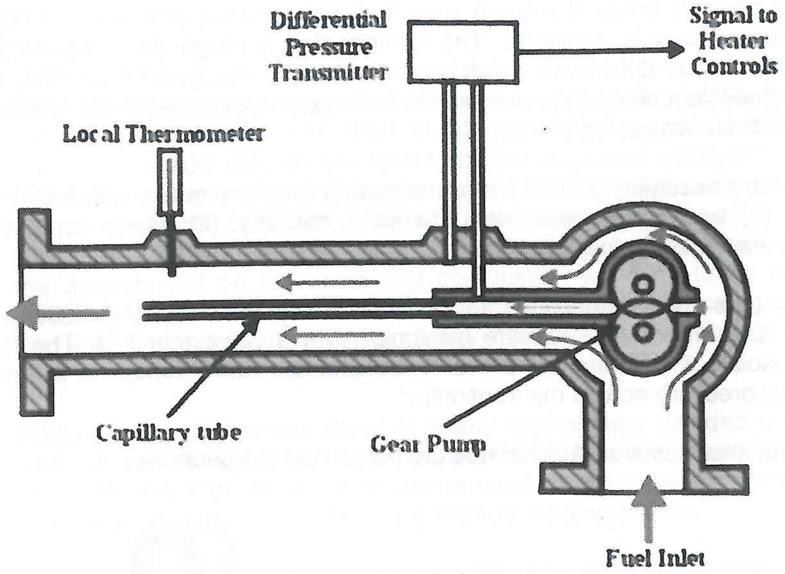
The capillary assembly consists of a measuring capillary in a resilient stainless steel housing (3) and a stainless steel damping capillary (2) which compensates for pressure waves in the fuel lines.

Pressure taps (5) are provided to connect the inlet and outlet of the measuring capillary to a differential pressure transmitter via a valve manifold. The manifold is used to isolate the differential pressure transmitter connections and to equalize the differential pressure across the transmitter.

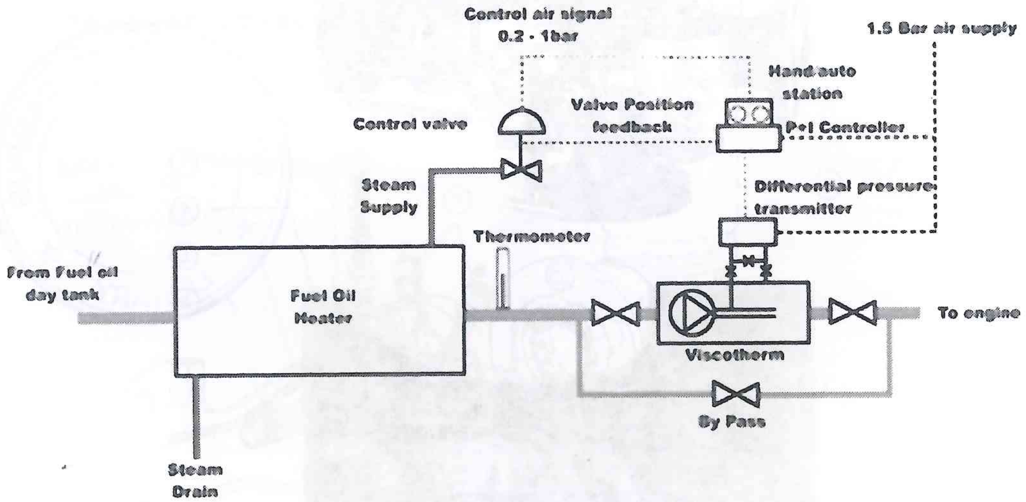
An optional thermometer (1) indicates the actual fuel temperature.







Exam sketch of a Viscotherm



The drawing above shows a pneumatic control system for controlling fuel oil viscosity. Modern systems convert the differential pressure to an low voltage electrical signal between 4 - 20 mA DC and use this to control the position of the heater valve.

Electronic Viscosity Measurement.

Systems are manufactured by VAF (Viscosense), Alpha Laval (Viscochief) and Solartron Mobrey (Viscomaster). Basically the systems all use the principle that the damping of a vibration signal is proportional to the square root of the viscosity. Not affected by vibrations or pressure and flow fluctuations. No moving parts to wear out.

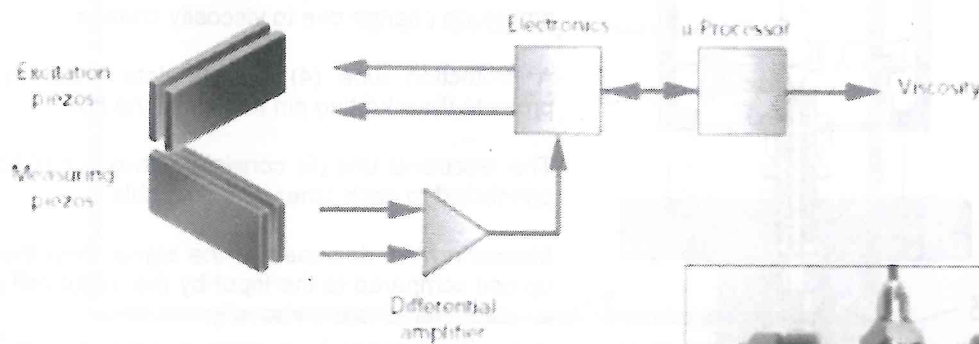
The Viscosense

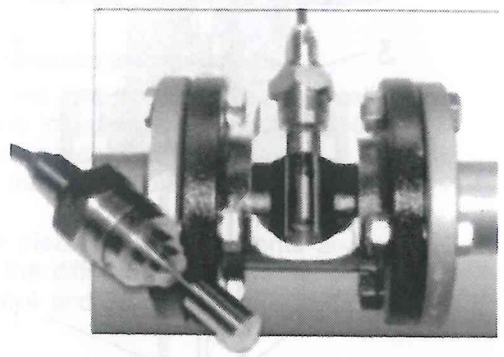
The sensor comprises of a stainless steel pendulum attached to a base plate via a torsion tube.

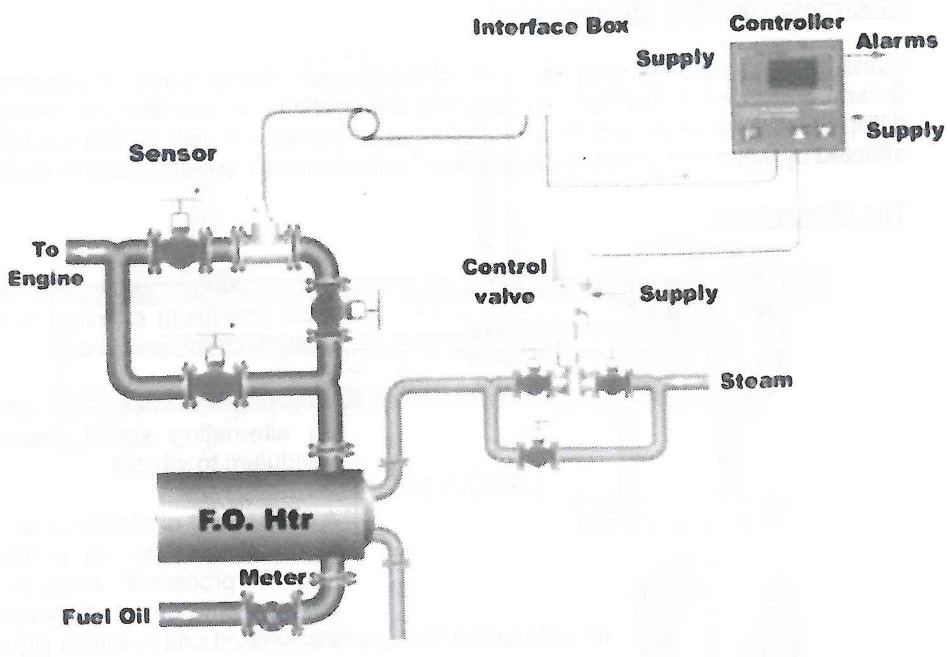
Two piezo elements are driven by an alternating signal causing the pendulum to vibrate.

A second set of elements sense the torsional vibration via a feedback, and a processor measures the phase difference between the transmitted and received signals.

This phase difference is processed which results in a value proportional to the square root of the fuel oil's viscosity.



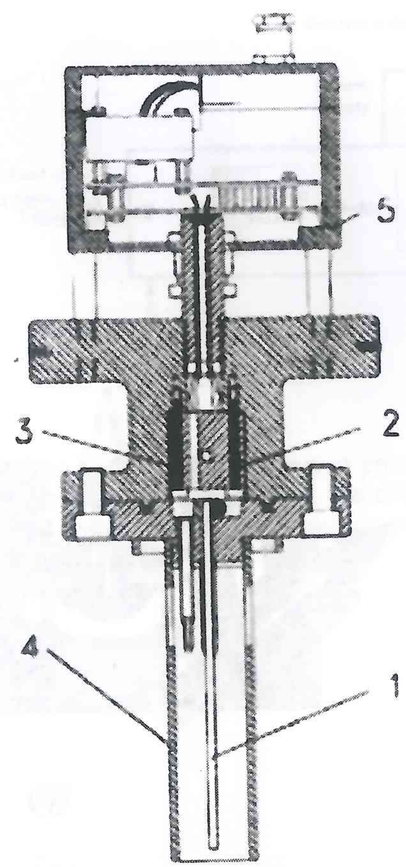




Viscosense Installation

The Viscochief

Fuel oil viscosity is measured by the damping effect of the oil on an oscillating rod.



Working Principle

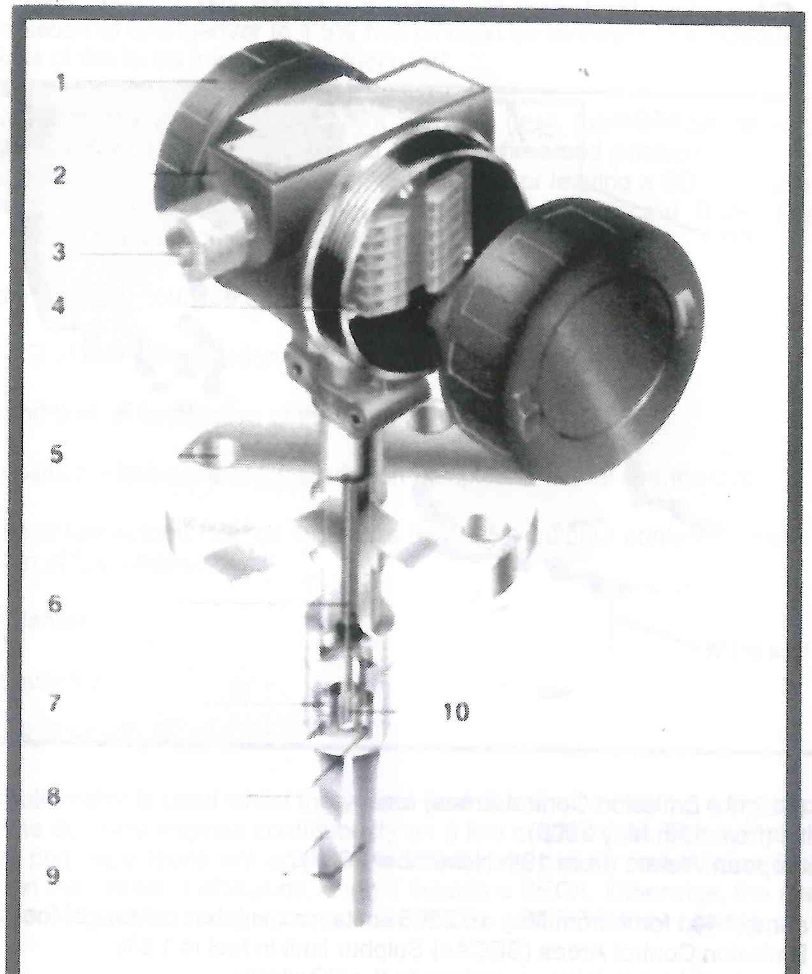
A pin (1) is always kept at its resonance frequency by a motor coil (2). A pick up coil (3) measures the amplitude change due to viscosity change.

A protection tube (4) with 3 slots encloses and protects the vibrating pin and limits the flow.

The electronic unit (5) consists of two circuit boards connected to each other by a flat cable.

Measuring the decrease of the signal from the pick up coil compared to the input by the motor coil gives a value related to the viscosity.

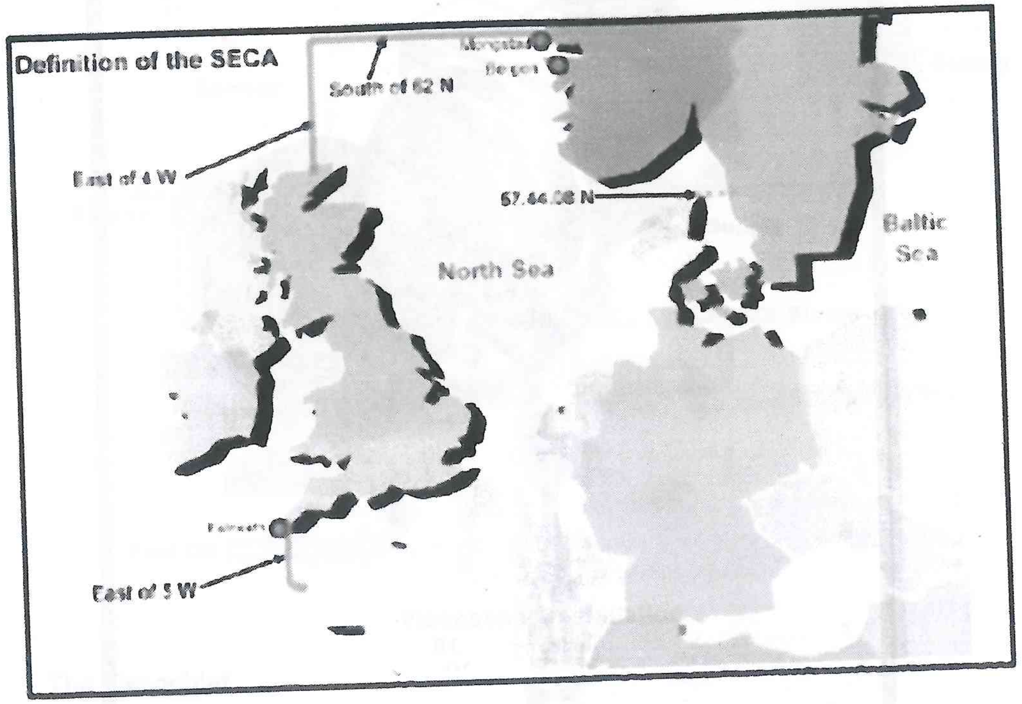
The Viscomaster



Solartron vibrating element viscometer
1 Access to maintaining amplifier
2 Amplifier housing
3 Cable gland
4 External connections
5 Mounting flange
6 Drive, pick-up and PRT wiring to amplifier
7 Piezo-resistive element clamp screw
8 Drive and pick-up Piezo-resistive elements
9 Vibrating tines
10 Platinum resistance thermometer

The Viscomaster uses a vibrating tuning fork where the tines are electronically maintained in resonance. Unlike similar sensors, the instrument also displaces the fluid, and this allows it to measure density and viscosity concurrently.
Resonant frequency is determined by the density of the fluid, and the damping of the vibration is proportional to its viscosity.
The damped vibration is measured by the pick up piezo resistive elements and a signal sent back to the processor which measures the difference between the drive and pick up and produces an output signal between 4 and 20 mA which is used to control the F.O. heater steam inlet valve.

Chapter 8: Low Sulphur Fuels and SECAs



SECAs (Sulphur Emission Control Areas) are
The Baltic (from 19th May 2006).
North European Waters (from 19th November 2007).

Marpol annex VI In force from May 19 2005 limits max sulphur content of fuel to 4.5%
In SOx Emission Control Areas (SECAs) Sulphur limit in fuel is 1.5%
or scrubbing to reduce sulphur emissions to 6 g SOx/kWh.

When ships are using separate fuel oils, the changeover to the lower sulphur content fuel must be carried out in sufficient time to ensure that the ship's fuel oil system is totally flushed of all fuels containing more than 1.5% m/m sulphur prior to entering the SOx Emission Control Area (SECA).

Modern vessels are built with separate low sulphur fuel oil settling and service tanks. 48 hours before the vessel enters the area ensure that the low sulphur settling tank is full and start circulating the fuel through the purifier to the low sulphur service tank. Classification societies recommend that there are separate purification systems for each grade of fuel, and that older ships are retrofitted to provide separate settling and service tanks for low sulphur fuels to prevent the risk of sludges forming in the tanks because of instability of the low sulphur fuels when mixed with standard fuels.

Two hours before entering the SECA the change over valve on the service tanks should be operated so that the low sulphur fuel has time to circulate through the system and replace the high sulphur fuel in the buffer tank or mixing column. Although the viscotherm should adjust the temperature to take account of any change in viscosity, this should be monitored. Additionally, the time, ship's positions at the start

and completion of changeover to 1.5% fuel oil must be recorded in a logbook, together with details of the tanks involved and fuel used.

The volume of the low sulphur content fuel oils (less than or equal to 1.5% m/m sulphur content) in each tank as well as the date, time and position of the ship when any fuel changeover operation is completed entering or leaving a SOx emission control area, must be recorded in Section I of the ships Oil Record Book (Part 1) or appropriate log book which has been agreed with by the MCA.

A suitable log entry could be as follows::

ENTRY TO SECA – Completion of the fuel change-over operation

1. Date and time of completion of the fuel change-over

2. Ship position – latitude and longitude, on completion of fuel change-over

3. Volume of low sulphur fuel oil (not more than 1.5% sulphur content) in each tank on completion of fuel change-over

(i) Tank identity

(ii) Tank quantity

(iii) Signature of responsible officer.

If a shaft alternator is used whilst the vessel is at sea, then it may be a better option to operate the auxiliary engines continuously on a low sulphur fuel. This will also ensure that local port regulations are adhered to which may call for low sulphur fuels to be used whilst the vessel is alongside, even if outside a SECA. Otherwise, the alternators must be running whilst changing over from HFO to LSHFO if they operate on residual fuel.

For ships with standard fuel oil system configurations (one service and settling tank), the change over would involve filling of the settling tank with low sulphur fuel oil, adequate fuel treatment of same and subsequent filling of service tank. The size of the service tank and fuel consumption of the engine will determine the time scale involved, but the procedure would entail running down the settling tank or using transfer pumps to empty the settling tank back to appropriate double bottom tank whilst running down the service tank. The settling tank would be filled with low sulphur fuel which would be circulated through the purifier before commencing transfer to the service tank. The time scale must take into account dilution of the low sulphur fuel by the high sulphur fuel, depending on the levels in the service and settling tanks and the operator must be aware of possible problems due to instability. Because this is not a viable proposition, ships using residual fuel oil which intend to enter a SECA, but which do not have the capability for two segregated fuel oil grades, will therefore need to operate continuously on the lower sulphur fuel oil with a detrimental effect on fuel costs.

Chapter 9: Chief Engineer Exam Questions

December 2007 Question 2

Write a procedure for changing the entire main and auxiliary engine fuel oil supply and treatment system from Heavy Fuel Oil (HFO) to Low Sulphur Heavy Fuel Oil (LSHFO) in preparation for the vessel entering a Sulphur Emission Control Area (SECA), indicating the approximate times of EACH action prior to entering the SECA. (16)

July 2007 Question 3

With reference to Heavy Fuel Oil (HFO)

a. State, with reasons, the effect on the engine of burning fuel which is off specification with relation to each of the following:

(i) density; (2)
(ii) viscosity; (2)
(iii) sulphur; (2)
(iv) aluminium/silicon content. (2)

b. explain what system adjustments are required to enable the fuel to be burned, for EACH of the off specification parameters mentioned in Q3(a). (8)

October 2006 Question 1

Analysis of fuel available at a bunkering port on a vessels new trade route shows that it is outside of the specifications of the fuel normally used in the main engine.
Comment on EACH item and explain the modifications which may be required to the fuel conditioning process and to the engine operating systems to enable the fuel to be used efficiently. (16)

	Fuel used at present	Fuel available on new route	Recommended quality at engine
Density at 15°C (kg/cm^3)	970	1008	
Kinematic viscosity at 50° (cst)	380	500	
Kinematic viscosity (cst)			14 - 17
CCAI	840	880	
Carbon Residue (%)	12	20	max 15
Sulphur (%)	3	4.5	max 3.5
Ash (%)	0.05	0.15	max 0.05
Vanadium (ppm)	120	180	max 150
Sodium (ppm)	20	60	max 30
Aluminium + Silicon (ppm)	50	80	max 15
Water (%)	0.5	1	max 0.2
Pour point (°C)	30	35	
Flash point (°C)	90	98	

July 2006 Question 2

Explain the problems associated with the storage, treatment and combustion of heavy fuel for use in the main engine. (16)

April 2006 Question 8

With reference to a vessel on a five year time charter

a. after four weeks the Chief Engineer Officer (CEO) has received complaints that the vessel is not maintaining charter speed. explain how the CEO would investigate and attempt to remedy the situation; (8)
b. the charterer has requested the use of a lower quality fuel as his costs for bunkers are excessive. Outline the advice the CEO would offer to the owners on this request. (8)

April 2006 Question 2

a. Describe an automatic self sludging centrifuge suitable for dealing with fuel of density up to 1010kg/m³ at 15°C. (7)
b. Explain how the centrifuge described in Q.2(a) is able to remove water from a fuel which has a density that is higher than that of water and state the factors that may assist the operation. (3)
c. As Chief Engineer, write out the start up procedure for the centrifuge described in Q.2(a) for the benefit of ships staff. (3)
d. State how the problem of catalytic fines in fuel oil may be dealt with. (3)

December 2005 Question 4, October 2003 Question 1, March 2003 Question 1, March 2002 Question 3, March 2001 Question 3.

With reference to operating medium speed diesel engines on residual fuel:

a. state, with reasons, FOUR of the main problems; (4)
b. describe how the problems stated in Q4(a) may be minimised in order to ensure that an engine may be operated correctly; (4)
c. outline the procedure that should be adopted to ensure that bunkers of the correct specification are ordered and accepted on board. (8)

October 2005 Question 2

a. Describe, with the aid of a sketch, how a viscotherm operates and how it automatically monitors and regulates the fuel viscosity. (10)
b. State, with reasons, the standing orders to be observed during the change over period, for an engine which is manoeuvred on distillate but operated at sea on residual fuel. (6)

December 2004 Question 1

a. Explain how the quantity and specification of bunker fuel to be ordered may be assessed. (6)
b. State, with reasons, SIX properties which would be quoted in an HFO specification. (6)
c. State, with reasons, FOUR topics which must be explained during a prebunkering meeting. (4)

October 2004 Question 2

a. As a newly appointed Chief Engineer Officer, describe how correct bunkering procedures are ensured. (6)
b. Explain the difference between unsuitable fuel and poor quality fuel. (6)
c. State how it is ensured that fuel received is suitable and of adequate quality. (4)

July 2003 Question 2

With reference to the storage, treatment and combustion of heavy fuel in the main engine, explain the problems associated with EACH of the following:

a. compatibility; (2)
b. flash point; (2)
c. viscosity; (2)
d. catalytic fines; (2)
e. sulphur content; (2)
f. wax content; (2)
g. water content; (2)
h. vanadium content; (2)

October 2002 Question 7

While operating in heavy weather the main engine loses power and misfires. Investigation shows considerable quantities of water in the fuel.

a. As Chief Engineer Officer explain the immediate action which should be taken to ensure safe operation of the engine. (5)
b. State, with reasons, the possible places where water could enter the fuel system. (5)
c. As Chief Engineer Officer write the standing instructions that would be issued with respect to the operation of the fuel system in order to prevent major problems due to water in the fuel. (6)

July 2002 Question 8

Due to excessive bunker costs the Chief Engineer Officer of a ship on a five year time charter has been requested by the owner/charterers to use a lower grade of fuel. The fuel cost is 70% of that currently in use but contains catalytic fines, 3% water, a 10°C pour point and negligible sulphur content. As Chief Engineer Officer write a letter, to the owners offering advice on this request. (16)

July 2002 Question 2

a. Describe with the aid of a sketch, the main engine ancillary equipment for automatic monitoring and regulation of fuel viscosity. (7)
b. Explain the operation of equipment described in Q.2(a) (4)
c. Discuss the single fuel concept. (5)

December 2001 Question 2

The Chief Engineer of a ship, currently on time charter which is due to end at dropping outward pilot (DOP) from the current port, is required by his company to submit a fuel quantity and condition report prior to the attendance of independent charterer's surveyor because of disagreements

As Chief Engineer explain in detail how the report should verify the exact weight of fuel remaining on board (ROB) and its quality, allowing for possible discrepancies due to malpractice. (16)

Chapter 10: Second Engineer Exam Questions

October 2007 Question 9

a. Explain the steps to be taken to ensure that a vessel, which normally operates on HFO, is operating completely on low sulphur fuel prior to entering a Sulphur Emission Control Area (SECA). (10)
b. Explain the possible consequences of operating an engine on fuel with a very low sulphur content (below 1% sulphur) if the cylinder oil used has a base number suited to HFO with a sulphur content of 3%. (6)

March 2007 Question 3

a. Sketch a fuel system from the fuel service tanks to the main engine showing all safety features, important valves and the direction of flow when the engine is using HFO. (8)
b. Describe how the main engine supplied by the fuel system sketched in Q3(a) is changed over from HFO operation to MDO operation whilst the engine is running, explaining the precautions which must be taken to ensure the engine operates correctly and cross-contamination of fuel in the service tanks is avoided. (8)

April 2006 Question 5

a. Sketch a generator engine fuel system, showing the facilities for heavy fuel oil heating and changing over from heavy fuel oil to diesel oil operation. (6)
b. For the system sketched in Q4(a), explain the procedure for changing a single generator engine from heavy fuel oil operation to diesel oil operation, stating the precautions which must be observed. (6)
c. Explain the purpose of a *blackout pump*, stating how it operates. (4)

December 2005 Question 2

With reference to residual fuels used on board ship:

a. explain the correct procedure for obtaining a representative fuel sample while bunkering; (4)
b. describe FOUR fuel testing procedures; (8)
c. explain the importance of the test for flash point. (4)

October 2005 Question 3

a. Sketch a main engine fuel system including the fuel oil service tanks. (5)
b. Describe how the engine fuel system is changed from diesel oil operation to heavy fuel operation. (5)
c. State, with reasons, the precautions which must be observed when changing the engine fuel system from diesel oil operation to heavy fuel operation. (6)

July 2005 Question 2

With reference to fuel handling equipment:
a. explain why the settling tank is considered necessary; (2)
b. describe the operation of a purifier; (6)
c. explain how a clarifier may be adapted for use as a purifier; (3)
d. state the features of a centrifuge system for residual fuels of a density similar to that of water; (3)
e. state why a homogeniser may be fitted. (2)

April 2005 Question 7, October 2003 Question 8

a. Sketch a main engine fuel oil system from the service tank to the fuel injector system, labelling all essential valves and devices. (10)
b. Describe the procedure for changing engine operation from HFO to MDO whilst the engine is still running, explaining the precautions which must be taken. (6)

December 2004 Question 2

With reference to fuel, explain how on-board tests for EACH of the following are carried out:
a. viscosity; (4)
b. flash point; (4)
c. water content: (4)
d. compatibility (4)

December 2003 Question 3

With reference to bunkers and bunkering:
a. explain the planning procedures required before the vessel arrives at the bunkering port; (6)
b. explain how to organise the engine room staff in order to ensure that the bunkering procedure was carried out effectively. (6)
c. describe the immediate action to be taken in the event of serious leakage at the bunker hose connection flange. (4)

October 2003 Question 5

Define EACH of the following terms, explaining its relevance to fuel combustion in diesel engines:
a. Calculated Carbon Aromacity Index; (see note) (4)
b. after burning; (4)
c. ignition delay; (4)
d. turbulence. (4)

July 2003 Question 6

a. Sketch a main propulsion engine fuel system incorporating both diesel and heavy fuel oil systems from the service tanks to the fuel injectors.. (10)
b. Explain the purpose of the main components in the fuel system sketched in Q6(a). (6)

March 2003 Question 2

With reference to fuel storage
a. explain the meaning of the term *flash point* ; (2)
b. state the reasons for the minimum flash point stipulation for fuel in storage, stating the permitted figure; (3)
c. (i) describe, with the aid of a sketch, an approved closing device for double bottom fuel tank sounding pipes which are situated in the machinery space; (7)
(ii) explain why this type of device is necessary. (4)

December 2002 Question 5

With reference to the residual fuel loaded at a port which a ship has recently left:
a. describe the effect off specification fuel would have on an engine, if analysis showed EACH of the following was outwith the acceptable limits:
(i) water content; (2)
(ii) sulphur content; (2)
(iii) CCAI (calculated carbon aromacity index); (2)
(iv) aluminium content. (2)
b. state the engine or other adjustments which may be made in order to reduce the effect of EACH of the off specification properties in Q.5(a)

October 2002 Question 2

Describe, with the aid of a sketch, a viscotherm, explaining how it operates. (16)

July 2002 Question 8

With reference to a main engine fuel system:
a. explain why the viscosity must be maintained at a particular value at the injectors; (2)
b. state, with reasons, why temperature is not an effective means of monitoring viscosity with modern residual fuels; (2)
c. describe, with the aid of a line diagram, a fuel oil heating system incorporating a device for monitoring and regulating the viscosity of the fuel delivered to the fuel injection pumps. (12)

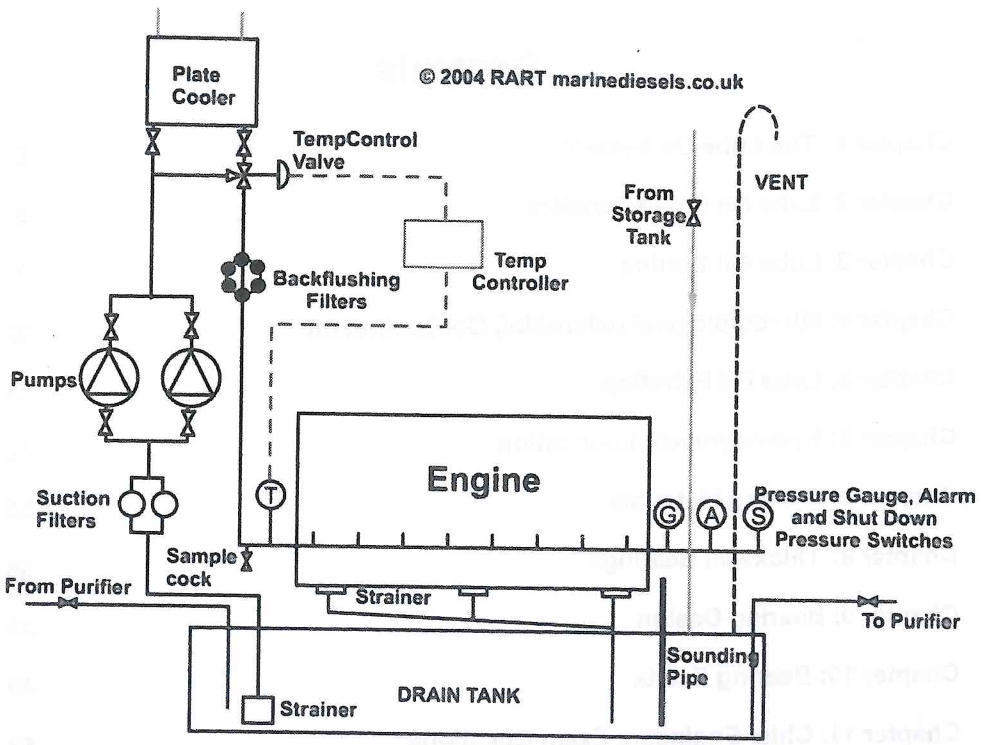
July 2002 Question 4

With reference to bunkers and bunkering:
a. as Second Engineer Officer outline the planning and precautionary measures to be taken to ensure that the fuel oil which had been ordered could be loaded, stored and treated correctly (8)
b. outline the duties of the personnel involved in the bunkering procedure. (8)

Lubricating Oil and Bearings

Contents

Chapter 1: The Lube Oil System



Drain Tank: Usually part of the ships double bottom, surrounded by cofferdams. Fitted with sounding pipe, vent and low level alarm (not shown). Large enough to hold complete charge of oil for engine.

Strainer and Suction Filters: Protect LO pumps from foreign bodies being drawn in which would damage pump rotors.

Pumps: Two electric pumps or one electric/one engine driven. Positive displacement screw type. fitted with pressure regulating valves: To pressurise and circulate oil around the system.

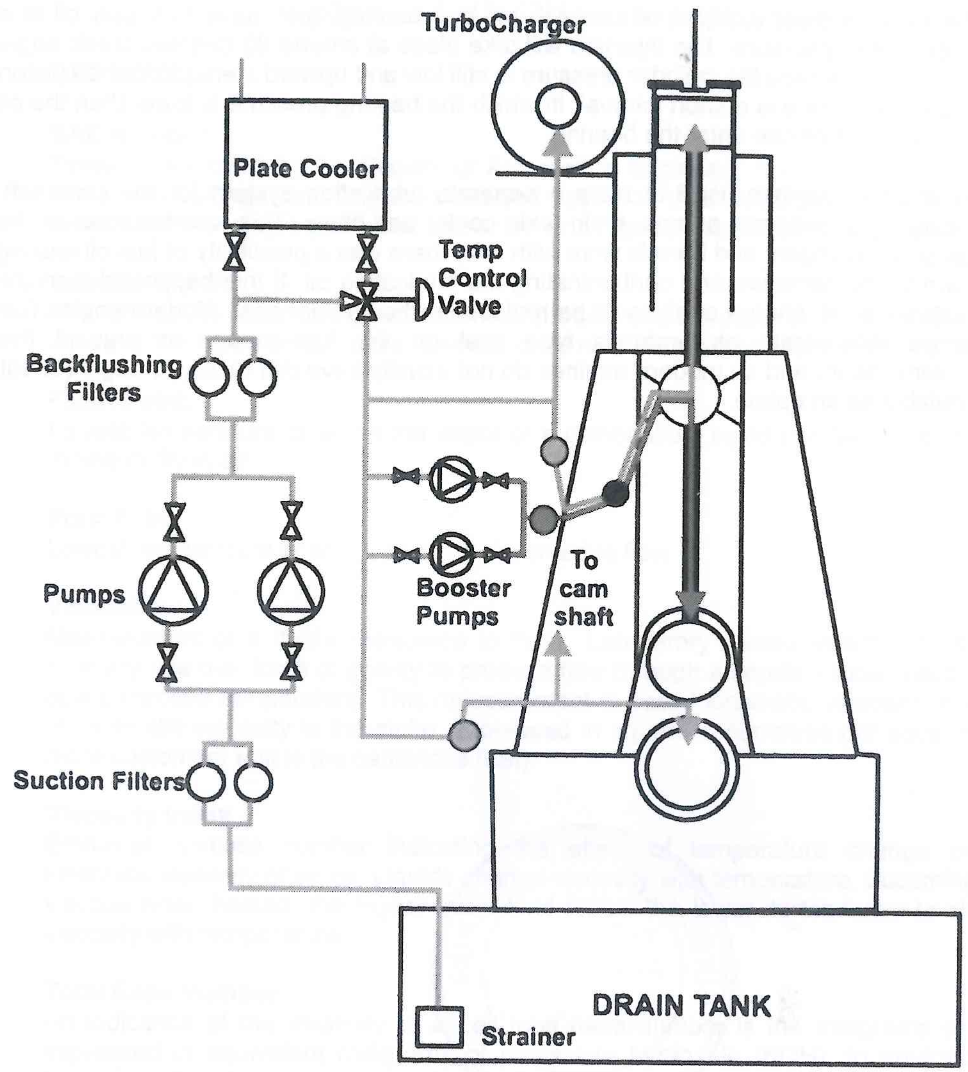
Backflushing Filters: To filter fine impurities in the oil. Filter size dependant on engine size but approx 50 micron for a large two stroke, 20 micron on medium speed engine.
Cooler. Two normally fitted. Usually of plate type, FW cooled: To remove heat energy from oil.

Temp Control Valve: To regulate flow through cooler to maintain oil at the correct temperature (and therefore viscosity) at inlet to engine.

Sample Cock: For drawing off sample for analysis.

Temperature sensing device: To monitor inlet temperature.

Pressure sensing devices: To monitor LO pressure and to protect the engine in case of loss of LO pressure (alarm and shutdown).



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The diagram shows a lubrication system for a Sulzer RTA 2 stroke engine. Sulzer boosts the pressure of the lub oil supply to the crosshead to 12 bar. using a separate set of pumps; this oil at higher pressure is also used to lubricate the bottom ends and to operate the camshaft fuel oil pump cam servomotors.

The crosshead bearing is acknowledged as a difficult bearing to lubricate effectively because it swings about the crosshead pin changing direction twice per revolution. This means that true hydrodynamic lubrication cannot be built up. Instead, as the swing starts, boundary lubrication between pin and bearing occurs. As the rubbing speed increases so hydrodynamic lubrication starts, but as the bearing swings past the midway point it starts to slow down and boundary lubrication starts again. Separation of the two metal layers by a oil film has always been a problem for designers.

More oil has to be supplied than just to lubricate. The oil must be supplied in sufficient quantity to cool the bearing. The Sulzer crosshead has a plain lower bearing without channels. In order to inject oil between pin and bearing, they have to supply oil at a much higher pressure. The injection will take place at around 20 degrees crank angle before TDC, where the cylinder pressure is still low and upward inertia forces on piston is still high. There is a short interval, in which the bearing pressure is lower than the oil pressure and oil can enter the bearing.

Older B&W engines used to have a separate lubrication system for the camshaft, consisting of separate pumps, drain tank, cooler and filters. This was because as the fuel pump plungers and barrels wore with use, there was a possibility of fuel oil leaking down to the camcase and contaminating the lubricating oil. If this happened then the relatively small charge of oil could be replaced without major cost. Modern engine fuel pumps incorporate an umbrella type seal on the fuel pumps to prevent this contamination, and so modern engines do not usually have this facility, though it is still available as an option.

Chapter 2: Lub Oil Characteristics

DEFINITIONS

SAE Number
System developed by the Society of Automotive Engineers (SAE) to classify engine oils by viscosity grades. Oils are classified based on their measured viscosity at high temperature for single grade oils and at low and high temperatures for multi-grade oils.

Specific Gravity
The ratio of the mass of a given volume of product and the mass of an equal volume of water, at the same temperature. The standard reference temperature is 15.6°C (60°F).

Flash Point.
Lowest temperature at which the vapor of a combustible liquid can be made to ignite momentarily in air.

Pour Point
Lowest temperature at which an oil is observed to flow.

Viscosity
Measurement of a fluid's resistance to flow. Laboratory measurements of viscosity normally use the force of gravity to produce flow through a capillary tube (viscometer) at a controlled temperature. This measurement is called kinematic viscosity. The unit of kinematic viscosity is the stoke, expressed in square centimetres per second. The more customary unit is the centistoke (cSt).

Viscosity Index
Empirical, unitless number indicating the effect of temperature change on the kinematic viscosity of an oil. Liquids change viscosity with temperature, becoming less viscous when heated; the higher the V.I. of an oil, the lower its tendency to change viscosity with temperature.

Total Base Number
An indication of the alkalinity of an oil total base number is the milligrams of acid, expressed in equivalent milligrams of potassium hydroxide (KOH), to neutralize all basic constituents.

Sulphated Ash
The ash produced from burning new engine oils is principally related to the quantity or ash-producing additive contained therein. If the oil is burnt, some additives will leave ash, which may thereby be used to indicate the amount of additives in the oil.

The two oils used in the lubrication of a two stroke crosshead engine are very different from each other. The crankcase oil is used to lubricate and cool the main, bottom end and crosshead bearings, the crosshead slippers, camshaft, bearings and followers, and the chain or gear drive. On modern engines the oil is also used to cool the pistons. The cylinder oil is used to lubricate the piston rings as they reciprocate in the liner and to neutralise the acids formed by the combustion of the sulphur in the fuel.

The typical characteristics of a crankcase oil for a 2 stroke crosshead engine are as follows:

SAE No	30
Specific Gravity (15°C)	0.894
Flash Point min °C	229
Pour Point max °C	-15
Viscosity: cSt at 40°C cSt at 100°C	108 11.8
Viscosity Index	98
Total Base Number	5.3
Sulphated Ash, % wt.	0.73

Additives

The oil will contain detergent additives which are alkaline in nature. these interact with varnish and sludge, neutralising them and keeping the particles suspended. Because they are alkaline, they give the oil its alkalinity, combating the strong acids; sulphuric acid formed by combustion of the fuel or hydrochloric acid arising from seawater, which may find their way into the crankcase. If the TBN of the oil drops to below 30% of its original specification, then there is a danger of sludge formation.

If the alkalinity of the oil is depleted then the strong acids present will be indicated by the Strong Acid Number (SAN) of the oil which should never be present (i.e. Max allowable SAN = 0)

Dispersants keep soot and combustion products in suspension in the body of the oil charge and therefore prevent deposition as sludge or lacquer.

Also present will be antioxidants; Antioxidants delay or inhibit the processes of decomposition that occur naturally in lubricants as they 'age' or oxidise in the presence of air. Oxidisation can be caused by high temperatures, excessive air entrained in the oil and catalysts such as wear particles (especially particles of copper and ferrous materials). These oxidation processes give rise to formation of gums, lacquers and sludge resulting in an increase in acidity and viscosity. Excessive oxidation is a common reason for condemning a lubricant, usually because acidity and/or viscosity have exceeded the permissible limits. Depletion of the antioxidants in an oil will show up as an increase in the Total Acid Number (TAN) of the oil (Max allowable 2) and by an increase in the insolubles present in the oil. The oil will also begin to smell acrid or pungent. Paint will peel within the crankcase, machined surfaces become lacquered, excessive carbon deposits will form in piston cooling spaces, and sludge collected in the purifier will increase.

Cylinder Oil

This is a high BN, high viscosity oil that is injected into the cylinder liners through one or sometimes two rings of injectors. The oil serves three roles; lubricating the liner, neutralizing acids from combustion and removing debris from the rings and liner surface to drain via the scavenge space. The oil is used once only and not recovered. The typical characteristics of a cylinder oil for a 2 stroke crosshead engine are as follows:

SAE No	50
Specific Gravity (15°C)	0.942
Flash Point °C	241
Pour Point ° C	-9
Viscosity: cSt at 40°C cSt at 100°C	247 21
Viscosity Index	100
Total Base Number (mg. KOH/g)	70

Cylinder oil must be thermally stable. It must be able to retain an oil film at the high surface temperatures found in the cylinder. The oil must possess anti wear characteristics and detergents to ensure minimum deposits on the piston and in the ring grooves. Deposits in the ring grooves may cause the piston rings to jam in the grooves and possibly break.

The oil has a high TBN of 70 to neutralise the acids formed by the combustion of the sulphur in the fuel. These alkaline additives make up about 30% of the oil.

The viscosity of the oil is relatively high (21 cSt at 100°C) This is so that it can lubricate effectively at the higher liner temperatures (190°C) The downside is that it is more difficult to spread the oil over the liner surface at the lower temperatures.
Cylinder oil is a "use once consumable" It is injected into the cylinder at a feed rate to give optimum protection against acid corrosion and microsiezure (scuffing). The feed rate can be about 1.3g/kWh on a modern highly rated engine.

FOR DETAILS OF CYLINDER OIL LUBRICATION SYSTEMS SEE STUDY GUIDE BOOK 1 (CYLINDER LINERS)

TRUNK PISTON ENGINE CRANKCASE OIL

The make up of a crankcase oil for a 4 stroke engine differs from that of a crosshead engine. This is because the oil not only lubricates and cools the bearings, it must also lubricate the cylinder liners and combat the acids formed by the products of combustion. It must have good dispersion properties to keep the products of combustion in suspension in the oil, detergents to keep the ring grooves and piston cooling spaces clean and prevent sludge build up, antioxidants to prevent the oil oxidizing and becoming acidic, and must have the viscosity to maintain a lubricating film on the upper surfaces of the cylinder liner.

The deciding factor for the choice of medium speed lubricant is the type of fuel the engine will be burning. For engines burning a distillate fuel or a light fuel blend with a low sulphur content (<1%) then an oil with a Base Number (BN) of 15 may be sufficient. The lubricating oil for an engine burning a residual fuel with a sulphur content of 3% may have a BN of 50.

As the engine is operated the alkalinity of the oil will decrease as the acidic products of combustion are neutralised by the oil. Normally the oil in a trunk piston engine will be replenished as oil is burnt in the cylinders. However in the continuing battle to reduce pollutants, engine builders have reduced LO consumptions to the point where the base number may fall below an acceptable level. In this case, the oil must be "freshened" by replacing 10% of the charge. Normally it is not acceptable to allow the BN of an oil to fall below 50% of its original value. A rough guide for the minimum BN value for a crankcase oil is 6 × % sulphur content of fuel + 10; i.e. for a 3% sulphur, (6 × 3) + 10 = 28

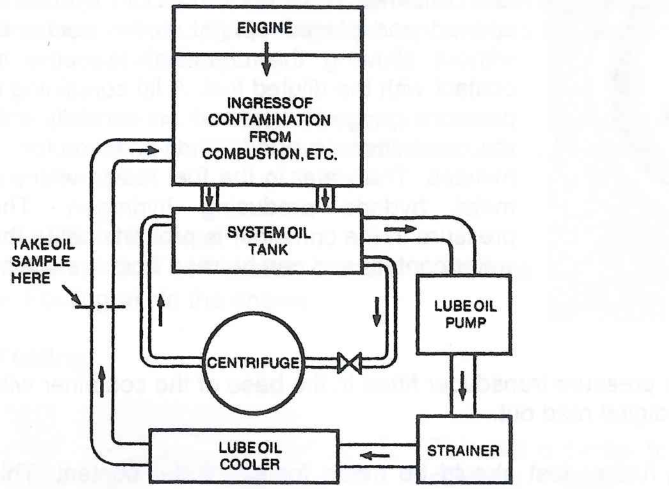
Property	For Engine Burning Distillate Fuel	For Engine Burning Heavy Fuel
SAE No	30	40
SG at 15°C	0.896	0.926
Flash Point °C	266	250
Pour Point °C	-9	-12
Viscosity cSt at 40°C	108	142
Viscosity cSt at 100°C	12	14.5
Viscosity Index	100	99
TBN	16	50
Sulphated Ash %wt.	2.1	6.5

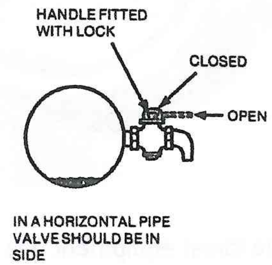
The table above shows the properties of two oils at either end of the scale. The Sulphated ash content gives a guide to the amount of additives in the oil. The viscosity of the oil is higher for the engine burning the residual fuel because the temperature will be higher in the cylinder (residual fuel burns at a higher temperature) and the oil must be able to maintain an oil film of the correct thickness.

Chapter 3: Lub Oil Testing

Sampling

Optimum point for LO Sampling





Areas where lubricant flow is restricted or where contaminants and wear products tend to settle or collect should be avoided as sampling points. Lubricating oil should be sampled while the machinery is running, if it is safe to do so, or within 30 minutes after shutdown. This ensures that wear products and lubricating oil contaminants are thoroughly mixed with the lubricant and that the heavier wear particles have not settled out.

Oil samples should not be taken before or after the centrifugal separator (purifier) unless testing for the effectiveness of water removal.

The ideal sample point is on the inlet rail to the engine. If the run of pipe from the rail to the sample point is of any length, then remember to allow enough oil to flow before taking the sample which should be representative of what is going into the engine.

Samples can be sent ashore for full analysis (including spectrographic analysis for metal particles) and these analysis can be used as part of a trend analysis maintenance programme.

Tests on board can be carried out for water, viscosity, TBN (Total Base Number, a measure of the alkalinity), Total Acid Number, Insolubles, flashpoint and microbial contamination.

Water

The water test for fuel oil is similar to that for fuel oil. A sample of the lubricating oil (5ml) is diluted with kerosene (20ml) and placed in the test container. A sachet of calcium hydride is opened and placed upright in the container without allowing the chemical to come in contact with the diluted fuel. A lid containing a pressure gauge is screwed on carefully and the container inverted and shaken for 2 minutes. The water in the fuel reacts with the metal hydride producing hydrogen. The pressure in the container is proportional to the water content and can be read from the scale.

The latest equipment has a pressure transducer fitted in the base of the container with an on board computer and digital read out.

If water is present then a further test should be made for salt water content. This involves separating the water from the oil and testing for the presence of sodium chloride using a go/no go indicator.

Test For Salt Water

- Add 5 ml of oil to a test tube containing 2 ml of test reagent.
- Place test tube upright in hot water for 1 hour to encourage separation.
- Puncture test pad several times with pin.
- Draw clear sample from test tube using pipette.
- Squeeze pipette and allow 2 drops to fall back into test tube.
- Let third drop fall on test pad
- After 5 minutes examine pad. If yellow patch appears, water is salt.

If no test equipment is available, to test for water apply one droplet of the used oil to a hot plate. If the oil contains water, the latter will evaporate rapidly and, in overcoming the capillary force of the oil, it will escape with an audible noise (crackle test).

Latest water test kit: Container with pressure transducer and digital read out, kerosene reagent and calcium hydride sachets

Total Base Number

The TBN of oil is the measure of the alkaline reserve, or the ability of the oil to neutralise acids from combustion. Severe depletion of the TBN results in acid corrosion and fouling within the engine.

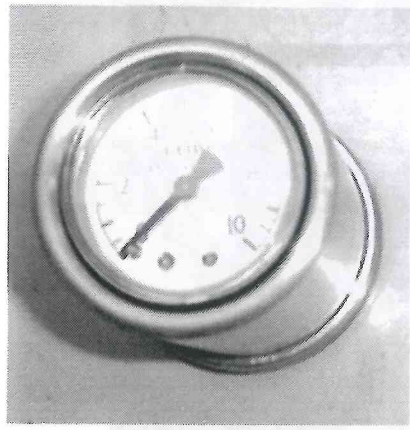
Maintaining a correct alkaline reserve is critical in preventing unnecessary corrosion of the upper piston, piston rings and top end bearing. Additionally, low TBN is indicative of reduced oil detergency.

This test is extremely important for medium speed engines burning high sulphur residual fuel. The TBN of the used oil should not be allowed to fall below 50% of that of the new oil.

Low TBN will cause:

- Corrosion of combustion space and bearings.
- Fouling within the engine.

Testing



This test is similar to the test for water except a different reagent (Alcohol Ethoxylate and Stoddard Sovent) is used. The older test kit incorporated a separate test container with the pressure gauge graduated as relative TBN between 0 and 10 (see photo).

The latest equipment uses the same container as used for the water test. The on board computer is set to measure TBN and has the ability to store data.

The test is first carried out on a sample of the new oil. This test only needs to be carried out once, and the result either recorded (for older equipment) or stored in the test kit on board computer.

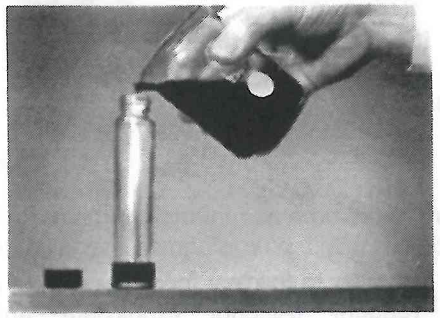
- Place reagent in the container to the marked line.
- Add 2ml sample of oil.
- Replace lid and shake for 2 minutes.
- Read pressure on lid of container.

The test is now repeated with a sample of used. The modern equipment will now calculate the TBN of the used oil.

With the older equipment, the pressure generated by the used oil sample is compared with the pressure generated by the new oil sample with known TBN and the TBN value obtained from a graph.

If depletion has reached 50% of new oil value then refresh the oil by renewing 10% of the charge.

Alternative Method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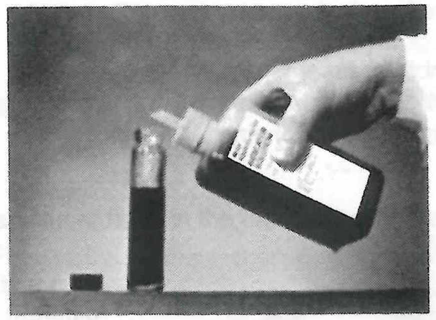
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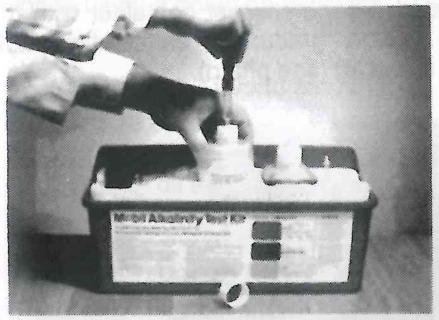
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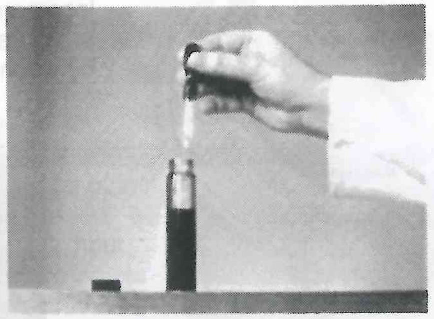
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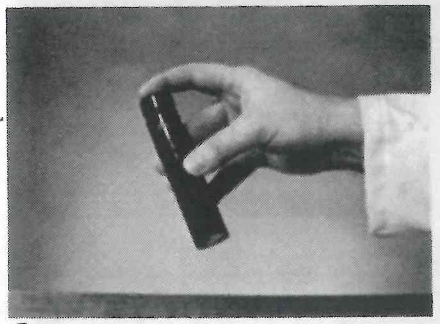
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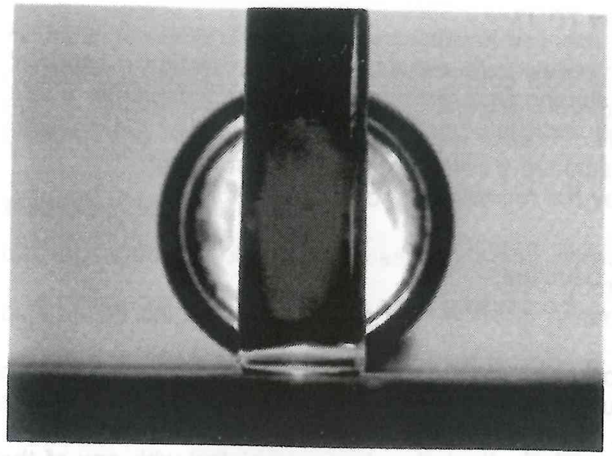
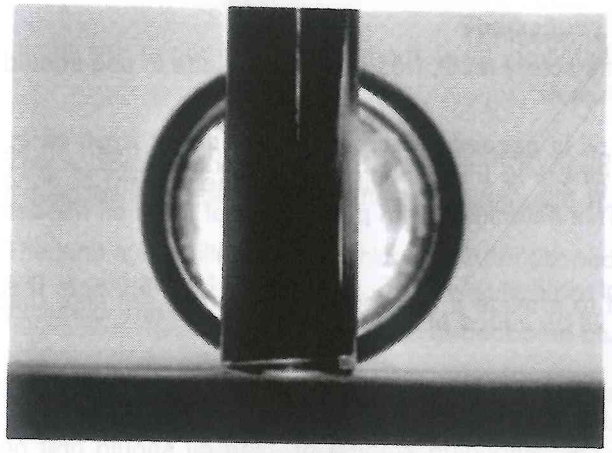
6

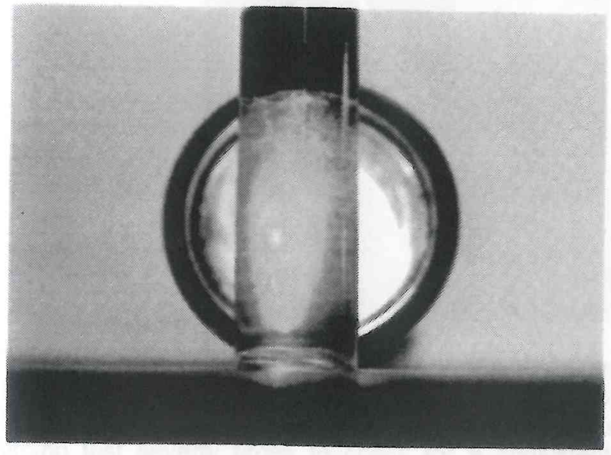
1. Pour sample to mark A in sample tube.
2. Add indicator solution to level B.
3. Use pipette to draw accurately measured quantity of reagent.
4. Add reagent to sample.
5. Shake vigorously.
6. Shine a strong light behind sample tube.



If the colour is PURPLE, the TBN level is GOOD, indicating the following levels:
Mobilgard 300 test: more than 2.5 TBN
Mobilgard 12 Series test: more than 5 TBN
Mobilgard 24 Series test: more than 10 TBN



If the colour is GREEN, the TBN level is BORDERLINE



If the colour is YELLOW or GOLD, the TBN level is LOW, indicating the following levels.
Mobilgard 300 test less than 2.5 TBN
Mobilgard 12 Series test. less than 5 TBN
Mobilgard 24 Series test. less than 10 TBN

What are the likely causes of low TBN?

A test that results in a green or yellow colour indicates TBN depletion-a condition which must be remedied immediately. Before taking action to re-establish a safe TBN level, the cause of the TBN decrease must also be investigated and rectified as soon as possible in order to achieve a continuous satisfactory level.
TBN depletion may be caused by the following conditions:

a) Faulty exhaust and intake valve operation resulting in poor combustion and consequent increased acid production.
b) Impaired fuel injector performance causing poor combustion and increased acid production.
c) Insufficient cylinder lubrication caused by a too low feedrate or by too severe scraper ring action. This results in improper piston ring functioning and permits blow-by of acidic combustion products
d) (Fuel with a high sulphur content, particularly when associated with any of the conditions (a), (b) or (c)

What corrective actions can be suggested?

To re-establish the TBN to a satisfactory level, fresh oil of the grade in use should be added to the system.

To determine how much fresh oil is needed, it is recommended that fresh oil be added to the sample in stages of 2% at a time until a borderline (green) or good (purple) condition is obtained. This establishes the percentage of fresh oil needed to reach a minimum TBN level.

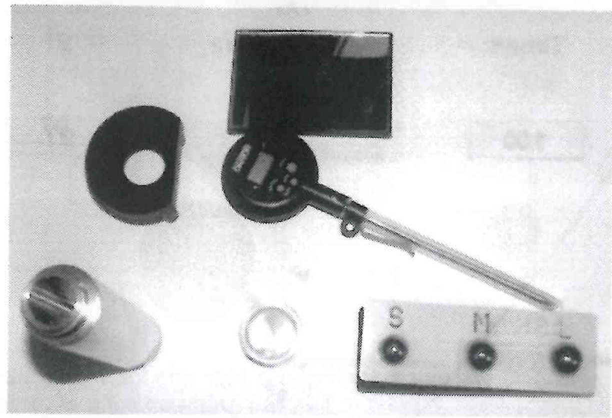
A further 10% should be added to provide a safe operating margin, but note that not more than 10% new oil should be added at one time.

If a borderline (green) result is noted from a first test, 10% fresh oil should be added, preferably in two stages. If the tank capacity is too small to accept the required amount of fresh oil, a corresponding amount of used oil should first be discarded.

Viscosity

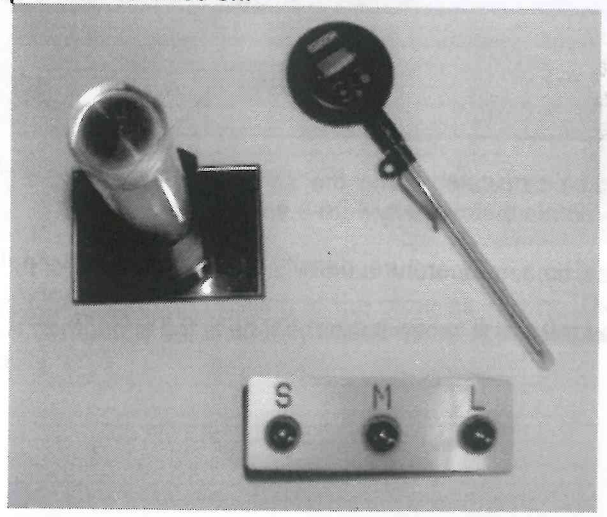
Although the laboratory test for viscosity of oil involves timing a quantity of oil passing through an orifice, the on board testing of viscosity usually involves rolling a ball down a tilted or inverted tube, which contains a sample of the oil. The time the ball takes to roll down the tube is measured and the result read directly from the instrument or from a conversion chart.

Method 1

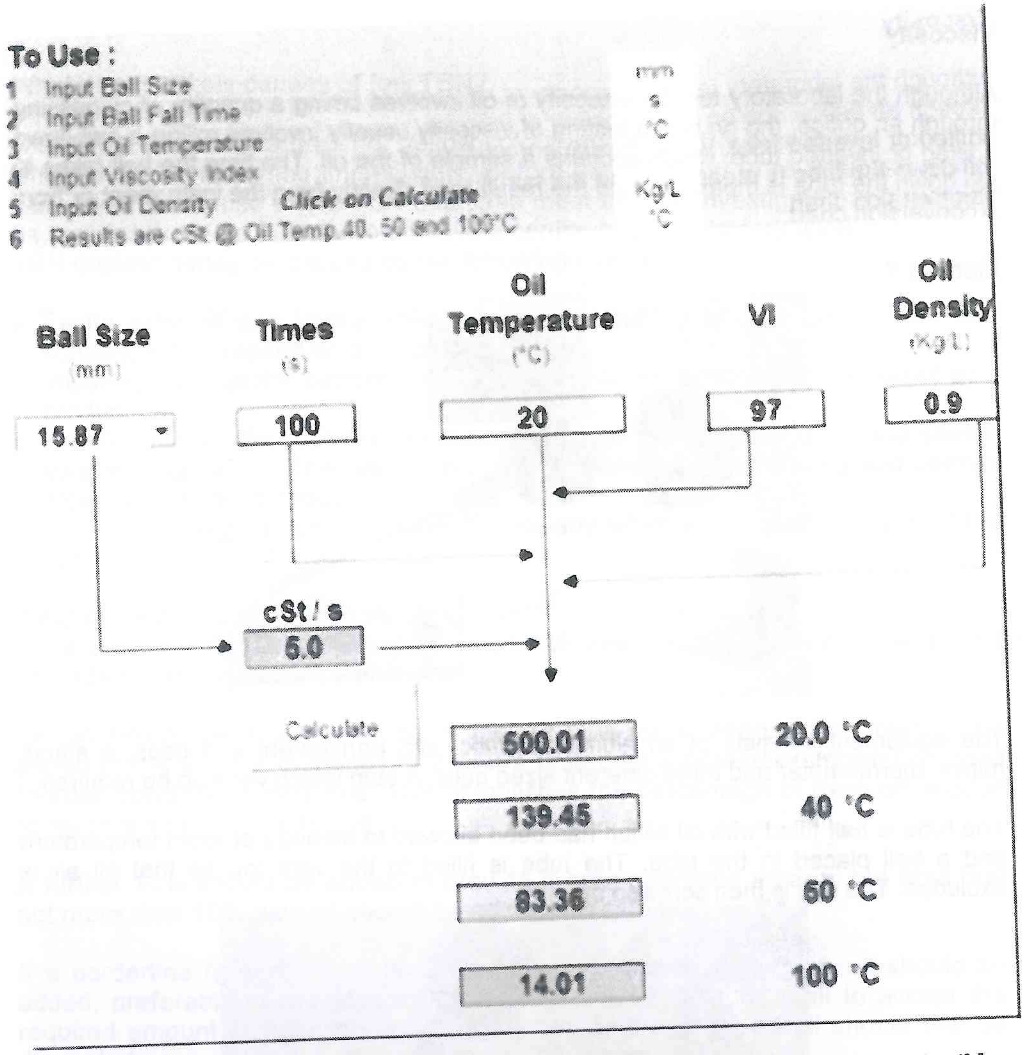


The equipment consists of an aluminium tube with transparent end caps, a stand, mirror, thermometer and three different sized balls. A stop watch will also be required.

The tube is half filled with oil which has been allowed to stabilize at room temperature and a ball placed in the tube. The tube is filled to the very top so that all air is excluded. The cap is then screwed on.



The tube is then inverted and placed on the stand over the mirror at the same time as the stopwatch is started. When the ball reaches the bottom of the tube, as observed in the mirror, the stopwatch is stopped, and the time noted. Invert the tube and repeat the timing test several times to check for a consistent reading. Unscrew the top and measure the temperature of the oil



The viscosity can be calculated using the spreadsheet supplied with the kit. (More basic versions will obtain the viscosity from a supplied graph).

Input the ball size, time, temperature, density and viscosity index of the oil.

If the time taken for the ball to move down the tube is too short, then use a larger ball.

Method 2

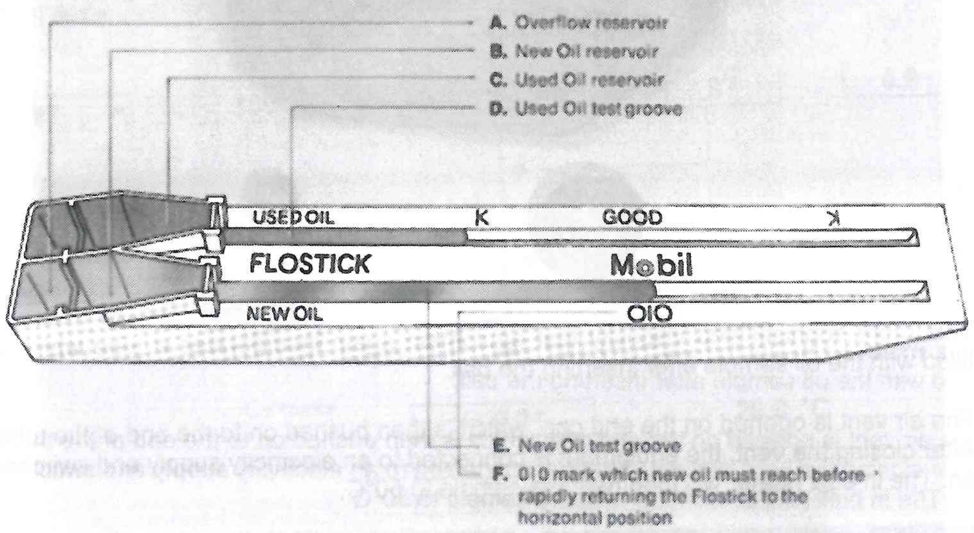
This more sophisticated viscosity test equipment again incorporates a tube which is filled with the oil sample after inserting the ball.

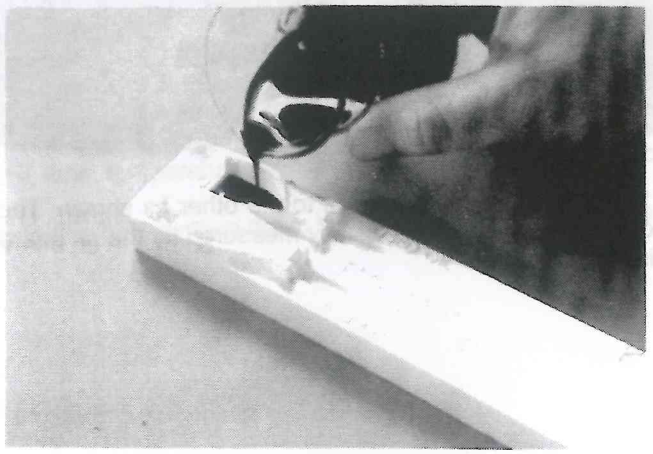
The air vent is opened on the end cap, which is then pushed on to the end of the tube. After closing the vent, the equipment is connected to an electricity supply and switched on. The in built heater will then heat the sample to 50°C.

The device is then tilted from one position to the other as shown. The time taken for the ball to roll down the tube is automatically measured by the on board processor and converted to viscosity.

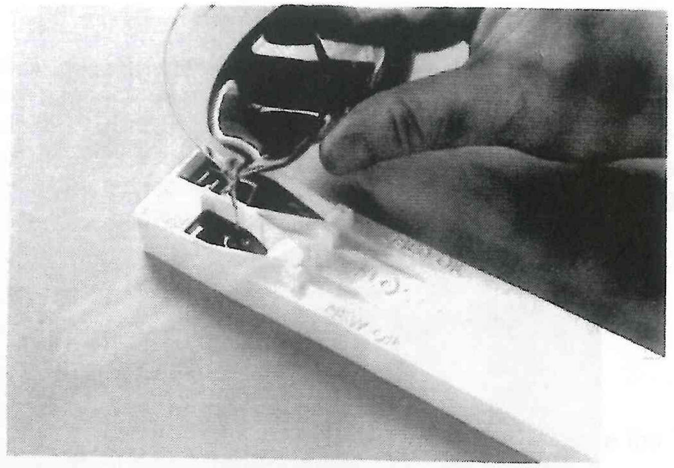
Viscosity Comparison (Flostick)

This is the most popular method of testing on board ship, but it must be realized that it will not give a viscosity reading. It is purely a test to see whether the viscosity remains inside limits.

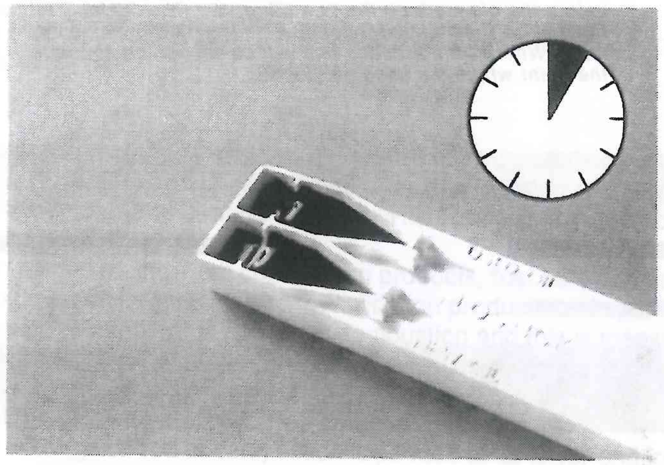




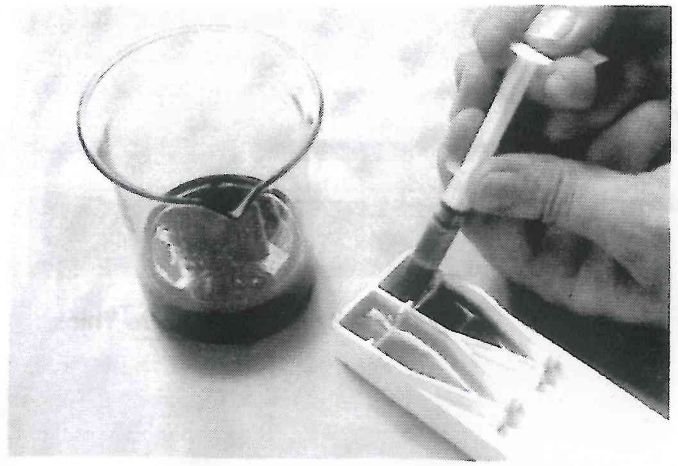
1. When all items have equalised at approximately room temperature fill the used oil reservoir until it overflows into the overflow reservoir.



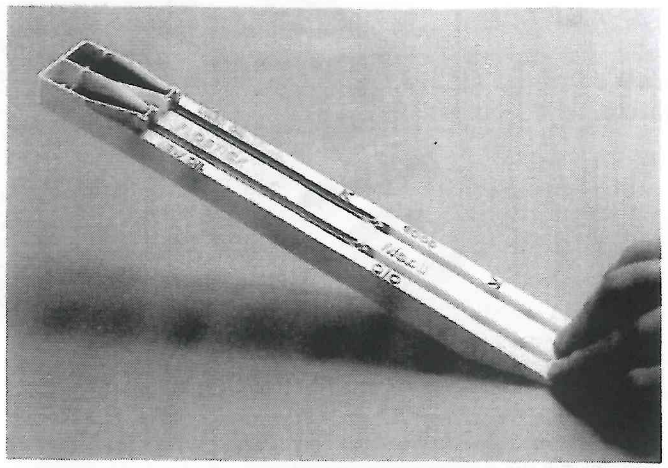
2. Fill the new oil reservoir with new oil of the same grade until it overflows into the new oil reservoir.



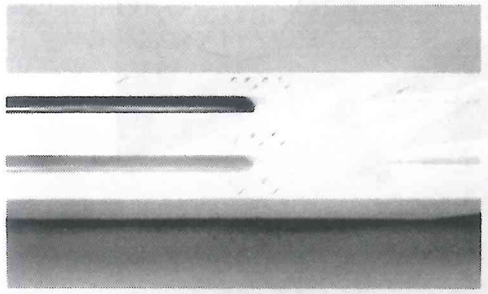
3. Leave the Flostick in the horizontal position for about five minutes to equalise the oil levels and temperatures in both reservoirs.



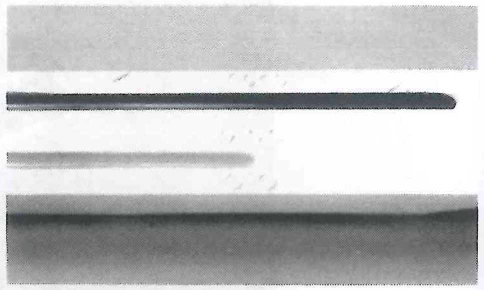
4. Remove the surplus oil in both overflow reservoirs using the syringes to be found clipped to the underside of the Flostick.



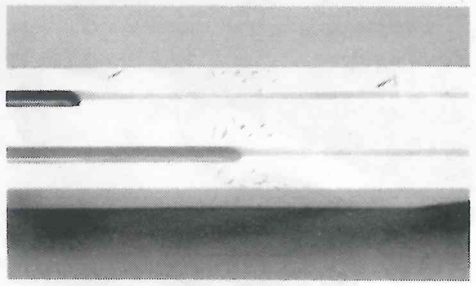
5. Tilt the Flostick by applying pressure with fingers until it rests on the oblique base at the opposite end to the reservoirs. Hold in the raised position until the new oil has reached a position just before the o/o mark on the new oil groove. Then quickly return the Flostick to the horizontal position so the new oil stops at the o/o mark. With a little practice this will be easy to do accurately. Note the point where the used oil stopped.



Oil Viscosity OK



Oil Viscosity too Low - Too Thin



Oil Viscosity too High - Too Thick

TAN total Acid number

A rise in TAN is indicative of oil oxidation due to time and/or operating temperature. High operating temperatures severely stress the oil. This results in oxidation and nitration, changes in viscosity, the build up of acidic waste products and deposits on metal surfaces. TAN is generally an issue in gearbox lubricants , gas engine , gas turbine and hydraulic lubricants . It is not generally associated with engine crankcase lubricants unless they are severely contaminated.

Testing

- Add 1ml of oil to 20ml of test reagent.
- If reagent turns from green to red the oil has a TAN value
- Titrate with titration reagent until sample turns green
- Multiply number of drops of titration reagent used by 0.1 to give the TAN of the oil (TAN is expressed as mgKOH/g).

Fuel Oil Contamination

If Fuel contamination of oil sample is suspected then this can be confirmed by measuring the flashpoint.

Insolubles

Insolubles are a build up of combustion related debris and oxidation products. High insolubles will cause lacquer formation on hot surfaces, sticking of piston rings and wear of the cylinder liner and bearing surfaces. The detergent property of the oil will decrease, speeding further deterioration.

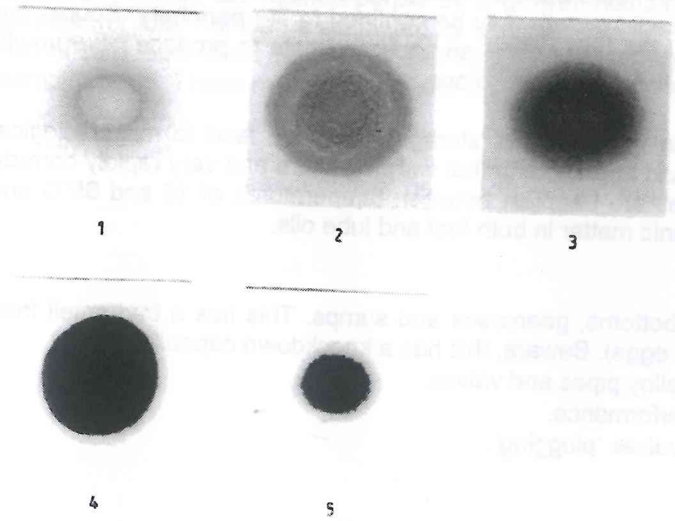
Contamination comes mainly from combustion products, fuel ash, carbon and partially oxidised fuel plus a small contribution of oil oxidation products and spent lubricant additive. The major contributor is soot from combustion and this is measured in the insolubles test.

Spot Test for insolubles in the oil

Dip a cleaned stick (glass rod or wire) which is pointed at its lower end into the lube oil at service temperature.

Let the oil adhering to this stick drip onto filter paper and let dry for several hours at room temperature.

Compare the filter paper with the samples shown



1 -3 Slightly contaminated

4 Analysis urgently required

5 Renew oil

Chapter 4: Microbiological (microbial) contamination

Hundreds of different species of micro-organisms are capable of proliferating in water associated with petroleum products and rapidly spread into the oil phase. They feed on hydrocarbons and oil additives. Most are aerobic (oxygen requiring); some are anaerobic (adversely affected by oxygen) and some are facultative (thrive with or without oxygen). Some basic knowledge of micro-organisms is desirable for an understanding of the phenomena which they produce and to plan logical anti-microbial strategies. In the microbial problems which occur in the production, distribution and use of petroleum products we are involved with three classes of micro-organisms; these classes are very briefly summarized as follows:

Bacteria.
These are spherical, ovoid or more often short rods about a micron (1/1000 mm) wide and a few microns long. They reproduce simply, by doubling in length and dividing into two and under ideal growth conditions they may do this every twenty minutes. Fortunately ideal conditions rarely exist and the time scale for the development of an operational problem is usually several weeks. The progeny may remain loosely attached to each other in clumps or they separate and disperse. There are thousands of different species; although in general they prefer neutral or slightly alkaline conditions, some species are not only acid tolerant but they can produce strong mineral acids. Some species produce spores which are very resistant to heat and disinfectants. Some produce copious, visible, sticky polymers which can seriously foul distillate fuels.

Yeasts.
These are typically ovoid, about 5-8 microns long. Reproduction is commonly by the formation of buds which form on the parent cell, increase in size and eventually separate. Under some conditions yeasts elongate substantially into filaments before they produce buds and may superficially resemble moulds. The reproduction doubling cycle takes several hours to complete even under ideal conditions; yeasts prefer slight acidity.

Moulds.
These are filamentous micro-organisms, the filament width being a few microns. The filaments branch and intertwine; a coherent mat of growth is thus produced. Increase in size is by increase in filament length and by the production of branches; the fastest doubling time is measured in hours but there are problems of slow nutrient diffusion to the centre of the mat and rapid growth may be confined to the periphery. Spores are produced which are inactive but they disperse and germinate to produce new growth mats. Most moulds prefer slightly acid conditions.

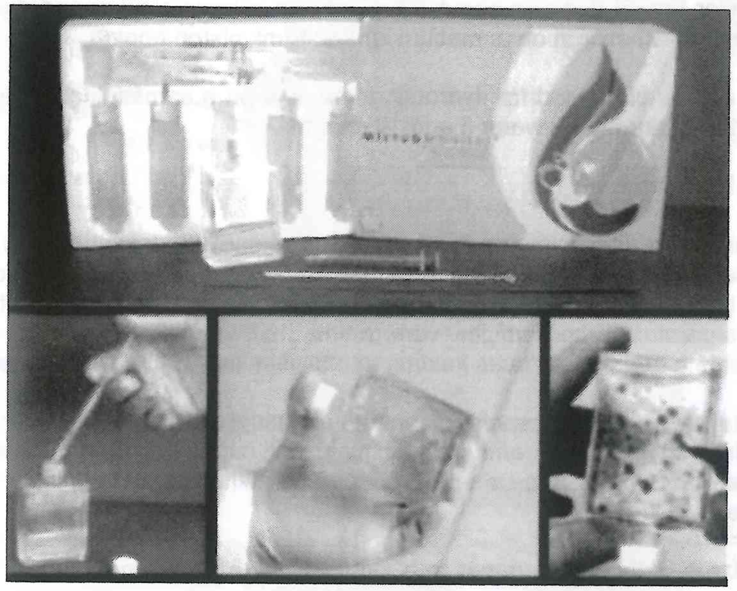
Water contamination within lubricating oil storage tanks can lead to microbiological growth, forming yeast, mould and bacteria that will clog filters and very rapidly corrode fuel systems. The microbes are happiest between temperatures of 15 and 65°C and feed on additives and organic matter in both fuel and lube oils.
Symptoms include:

- Slimy deposits in tank bottoms, gearcases and sumps. This has a bad smell from hydrogen sulphide (bad eggs). Beware, this has a knockdown capability.
- Staining in copper and alloy pipes and valves.
- Poor heat exchanger performance.
- Control and regulating valves 'plugging'.

- Purifier and separator problems. Both in discharge and in purifier internals as erosion and attack of aluminium bronze components.
- Blocking up of filters with sludge

High temperatures can kill the bacteria, and high temperature purification (above 90°C) is often recommended. However care must be taken not to oxidize the oil at these high temperatures. Biocides can be used to kill the bacteria, but the dead growths must still be removed. Often the only answer is to dump the oil, clean, treat and flush the system and replace the oil (expensive). Prevention is better than cure; keep water content to a minimum and purify at as high a temperature within recommendations.

Testing



The test consists of a screw capped rectangular glass bottle, partly filled with a thixotropic microbiological culture gel. A measured volume of sample is added to the gel using one of the sterile syringes provided. The bottle is shaken which liquefies the gel and disperses the sample. The bottle is kept warm (or incubated) for one or more days; all oil spoilage microbes in the sample can grow in the gel to produce visible "colonies". These are stained purple by a growth indicator in the gel and are easily counted, or their number is estimated by comparison to a chart. The figure obtained is numerically equivalent to the original number of microbial particles present in the sample tested. These microbial particles are referred to as colony forming units (cfu).

Chapter 5: Lube Oil Filtration and Purification

Purification of the lubricating oil for a diesel engine is done in several stages. The coarsest filter is no more than a strainer, placed on the end of the suction pick up pipe in the drain tank.

The pumps will be fitted with suction filters, generally a fine mesh filter, which can be cleaned in kerosene. These filters are to protect the pump and generally filter down to about 100 micron.
The oil will go through a set of final filters on the discharge side of the pump before entering the engine. These can be replaceable cartridge type filters on smaller engines, but are generally of the backflushing type on larger marine diesel engines. These wil filter the oil down to about 50 micron on a large slow speed diesel engine and between 20 - 30 micron on a medium speed trunk piston engine.

Where the engine oil is used for hydraulic purposes on a camshaftless engine the oil must be further filtered to between 5 and 10 micron.

BackFlushing Filters

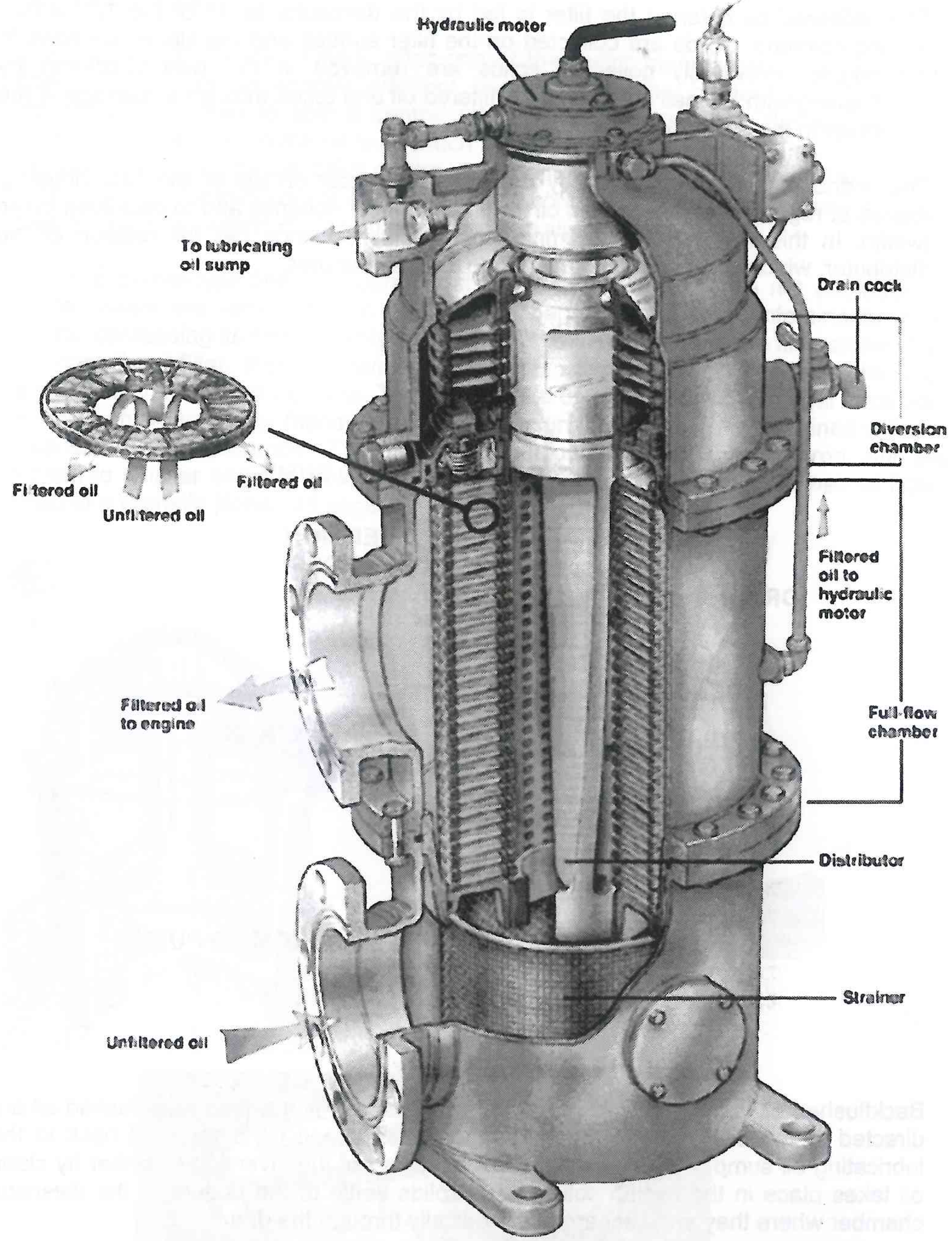
The function of the filter, placed as close to the engine as possible to stop harmful solid particles from entering the engine. These particles can then be removed from the system via the filter drain to the LO drain tank which can then be circulated through the centrifugal separator. If the particles were to find their way into the engine they would cause damage to bearing surfaces leading to possible loss of the hydrodynamic film.

The advantage over a replaceable or manual cleaning cartridge type filter is that the pressure drop is monitored and backflushing will occur when the pressure drop reaches a set amount or after a set period of time. This avoids adhesion of retained solids to the filter surface.

The filter size is reduced compared to a cartridge type filters and TBO is reduced to 12000 hours.

For environmental reasons there is little waste product to dispose of. Some backflushing filters incorporate an oil driven centrifugal filter for the backflushed oil before returning it to the engine sump.

There are two main types of backflushing filters; those which use candle type filter elements (B&K) and those which use disks (Alpha Laval).. Here the Alpha Laval type is described, although the principle is similar.

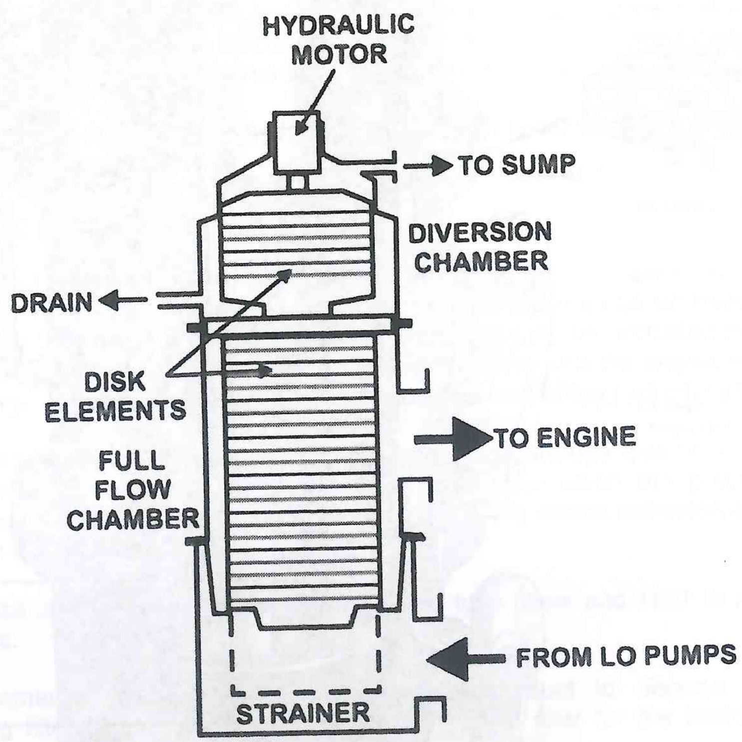


There are two types of filter elements, full-flow and diversion elements, which are assembled into two disc stacks. The filter elements comprise a filter frame and filter screen. The elements are divided into sections by ribs.

The discs, with sleeve, guide rods, springs and flanges, are mounted over the distributor to form the filtering unit. The sections, divided by the ribs, form twelve independent filtering columns in the full-flow and in the diversion chambers.

The unfiltered oil entering the filter is fed by the distributor to 11 of the 12 full-flow filtering columns. Solids are collected on the filter surface and the filtered oil flows to the engine. Previously collected solids are removed in the twelfth column by backflushing with a small amount of the filtered oil and taken through a passage in the distributor to the diversion chamber.

The distributor, which is driven by the hydraulic motor on top of the filter housing, rotates at regular intervals to feed oil for filtration in 11 columns and to backflush in the twelfth. In this way, all the columns are backflushed once per full rotation of the distributor, which corresponds to every one to three minutes.



BACKFLUSHING FILTER

Backflushed oil is filtered in 11 of the 12 columns. Solids from the backflushed oil are directed to the diversion chamber. Cleaned backflushed oil is then led back to the lubricating oil sump. At the same time backflushing of the diversion chamber by clean oil takes place in the twelfth column and solids settle to the bottom of the diversion chamber where they are discharged periodically through the drain.

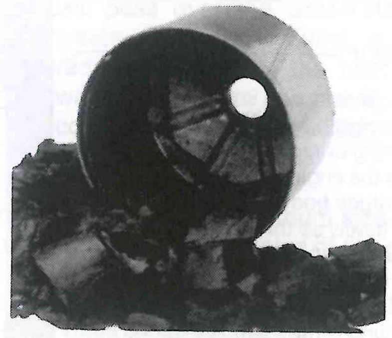
A pressure drop indicator connected between the inlet and outlet of the full flow chamber provides a reading and signals an alarm condition if for any reason the pressure reaches the alarm level. This indicates that there is a problem in the lubricating oil system.

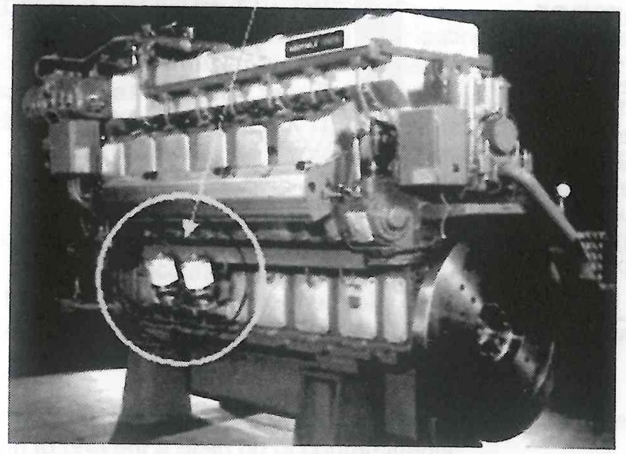
The driving force for the automatic backflushing is the pressure difference between the clean oil outlet and the backflushed oil outlet of the filter.

Centrifugal Filters

Often known as "Glacier Filters" after one of the major manufacturers, a centrifugal filter operates on an entirely different principle than the barrier-type filters. The incoming oil is used to spin a central rotor. In normal operation, this subjects the contaminant particles in the oil to as much as 4500 g of force, causing them to migrate outward and form a dense 'cake' on the inner wall of the filter's outer shell. This cake is made up of a combination of engine clogging soot (approximately 70 percent), wear metals and other ingested contaminants such as silicon dust.

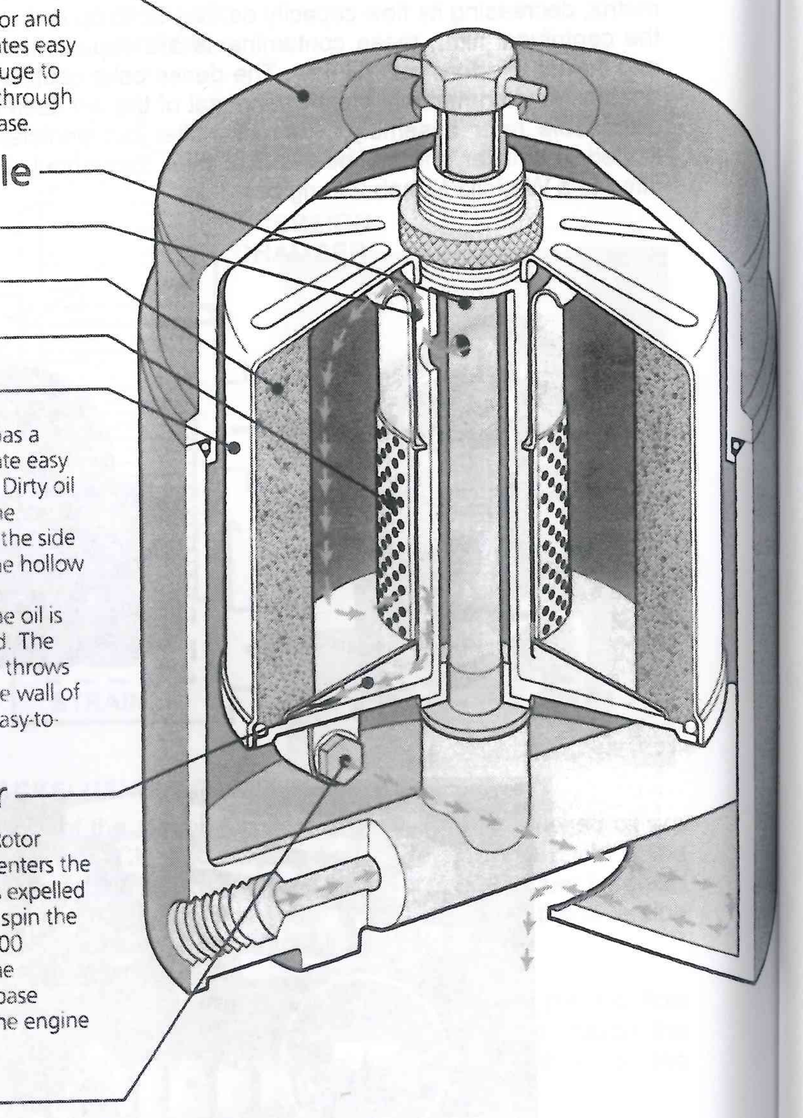
Unlike a barrier-type filter, the centrifugal filter's effectiveness does not decrease as contaminants are removed from the oil. The barrier filter traps contaminants in its matrix, decreasing its flow capacity as they build up in the pores of the filter element. In the centrifugal filter, these contaminants are deposited on the wall of the outer shell and do not interfere with oil flow. The dense cake caused by the centrifugal force also enables environmentally friendly disposal of the dirt itself or the dirt contained within a disposable rotor assembly. They can filter out particles below 10 micron, but are limited to smaller engines because of their throughput. Illustrated are a pair of filters fitted to a Wartsila Nohab 25 engine





HOW THE CENTRIFUGE OIL CLEANER WORKS

The centrifugal oil cleaning system consists of three major sections — The Body — The Rotor and The Drive Chamber.



Body

The body contains the Rotor and Drive Chamber and facilitates easy fixing of the whole centrifuge to the engine, with oil drain through the bottom to the crank case.

Hollow Spindle

Baffle

Dirt Mass

Screen

Rotor

The dirt removing Rotor has a removable bowl to facilitate easy cleaning or replacement. Dirty oil from the engine enters the centrifuge body through the side and travels up through the hollow spindle where it is evenly distributed by a baffle. The oil is accelerated to high speed. The resulting centifugal force throws the dirt particles on to the wall of the Rotor in a compact easy-to-remove mass.

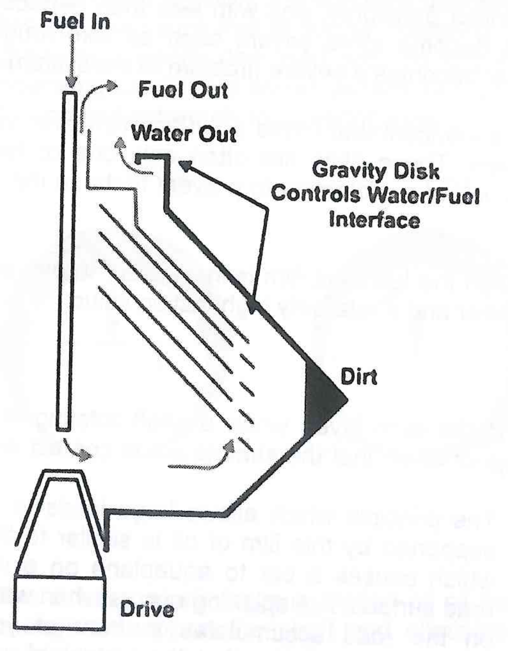
Drive Chamber

The clean oil leaves the Rotor through the screen and enters the Drive Chamber. The oil is expelled through twin jets which spin the rotor at speeds up to 8000 Rev/min finally leaving the centrifuge through the base where it is returned to the engine crank case/sump.

Jet

Centrifugal Separators (Purifiers)

Centrifuging is the process by which the effects of gravity can be amplified by the use of centrifugal force to the extent that the separation process becomes rapid and continuous. Centrifuges work by rapidly spinning a bowl containing the liquid, thus producing the required centrifugal force to produce separation.



PURIFIER

When a centrifuge is set up as a purifier, a second outlet is used for discharging water as shown. In the lube oil purifier, the oil may contain solids (metal wear particles and products of combustion) and water, which the centrifuge separates into three layers. While in operation, a quantity of oil remains in the bowl to form a complete seal around the underside of the top disc and, because of the density difference, confines the oil within the outside diameter of the top disc. Before introducing the oil into the separator bowl, it is necessary to prime the bowl with water, otherwise all the oil will pass over the water outlet side to waste. The water outlet is at greater radius than that of the fuel. Within the water outlet there is a gravity disc, which controls the radial position of the fuel water interface

A set of gravity discs is supplied with each machine and the optimum size to be fitted depends on the density of the lubricating oil. If the internal diameter of the gravity disc is too small the separating efficiency will be reduced as the interface will be formed within the disc pack. If the internal diameter is too large the interface will form at a diameter greater than the top disc and oil will pass to waste through the water outlet. The closer the density of the oil gets to the density of water, the smaller the internal diameter of the gravity disc required to operate the machine efficiently.

Factors Affecting Separator Efficiency

Density difference between water and oil. Heating gives a greater differential.
Position of oil/water interface. Once water enters the disc stack the separator efficiency is reduced as oil cannot flow along the full surface of the disc.
Sludge discharge frequency.
Viscosity of oil. The lower the viscosity the lower the drag force on dirt particles. Viscosity is reduced by heating.

When the purifier is operating, the free water is continuously discharged and particulate matter will accumulate on the walls of the bowl. In some machines it is necessary to stop the centrifuge to manually clean the bowl and disc stack, however, the majority of machines today can discharge the bowl contents while the centrifuge is running.

The purifier is normally run continuously on the main engine sump, to ensure water is removed and to prevent a build up of contaminants.

Chapter 6: Hydrodynamic Lubrication

Boundary Lubrication

Boundary lubrication in marine diesel engine bearings occurs during start up and stopping, relatively slow speeds, high contact pressures, and with less than perfectly smooth surfaces. As running conditions become more severe such as with rough surfaces, and high contact pressures, wear becomes a severe problem to the system.

With mineral oil, it is possible to create a lubricant that forms a surface film over the surfaces, strongly adhering to the surface. These films are often only one or two molecules thick but they can provide enough of a protection to prevent metal to metal contact.

Boundary lubricating conditions occur when the lubricant film is insufficient to prevent surface contact. This results in bearing wear and a relatively high friction value.

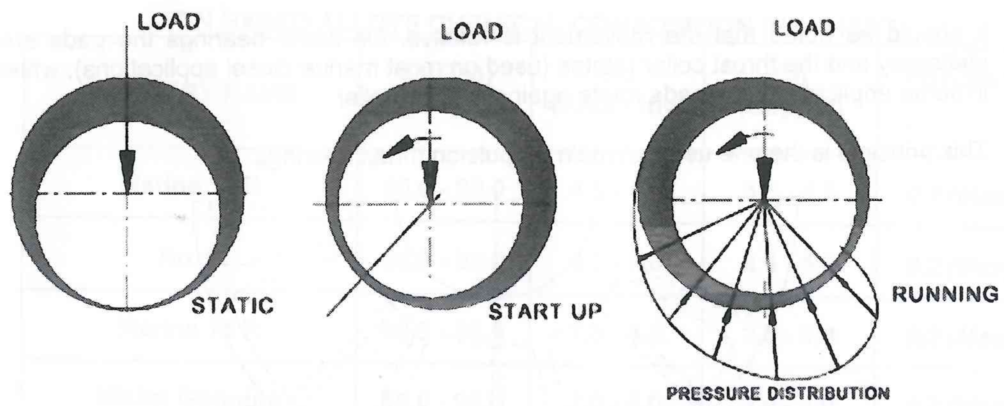
Hydrodynamic Lubrication

Fluid film or hydrodynamic lubrication is the term given when a shaft rotating in a bearing is supported by a layer or wedge of oil so that the shaft is not in contact with the bearing material.

The principle which allows large loads to be supported by this film of oil is similar to that which causes a car to aquaplane on a wet road surface. Aquaplaning occurs when water on the road accumulates in front of your vehicle's tyres faster that the weight of your vehicle and the pumping action of the tyre tread can push it out of the way. The water pressure can cause your car to rise up and slide on top of a thin layer of water between your tyres and the road. Just like a car has to be travelling at a certain speed before aquaplaning will occur (this varies according to tyre condition and road surface but is generally about 55mph), a shaft must be rotating at a certain speed before hydrodynamic lubrication takes place.

Hydrodynamic lubrication was first researched by Osborne Reynolds (1842-1912).When a lubricant was applied to a shaft and bearing, Reynolds found that the rotating shaft pulled a converging wedge of lubricant between the shaft and the bearing. He also noted that as the shaft gained velocity, the liquid flowed between the two surfaces at a greater rate. This, because the lubricant is viscous, produces a liquid pressure in the lubricant wedge that is sufficient to keep the two surfaces separated. Under ideal conditions, Reynolds showed that this liquid pressure was great enough to keep the two bodies from having any contact and that the only friction is the system was the viscous resistance of the lubricant.

The operation of hydrodynamic lubrication in journal bearings is illustrated below. Before the rotation commences the shaft rests on the bearing surface. When the rotation commences the shaft moves up the bore until an equilibrium condition is reached when the shaft is supported on a wedge of lubricant. The moving surfaces are then held apart by the pressure generated within the fluid film. Journal bearings are designed such that at normal operating conditions the continuously generated fluid pressure supports the load with no contact between the bearing surfaces. This operating condition is known as thick film lubrication and results in a very low operating friction and extremely low bearing load.



The rotating shaft drags a wedge of oil beneath it that develops a pressure great enough to support the shaft and eliminate contact friction between the shaft and bearing

Viscosity of the lubricant is an important feature. The higher the viscosity, the higher the friction between oil and shaft, but the thicker the hydrodynamic film. However friction generates heat, which will reduce the viscosity, the thickness of the film and may result in metal to metal contact. Using an oil with a low initial viscosity will also result in a reduced oil film thickness.

Care has to be taken that the distance between the two surfaces is greater than the largest surface defect. The distance between the two surfaces decreases with higher loads on the bearing, less viscous fluids, and lower speeds.

Hydrodynamic lubrication is an excellent method of lubrication since it is possible to achieve coefficients of friction as low as 0.001 (μ=0.001), and there is no wear between the moving parts. However because the lubricant is heated by the frictional force and since viscosity is temperature dependent, additives to decrease the viscosity's temperature dependence are used. The oil of course is cooled before it is pumped back through the engine.

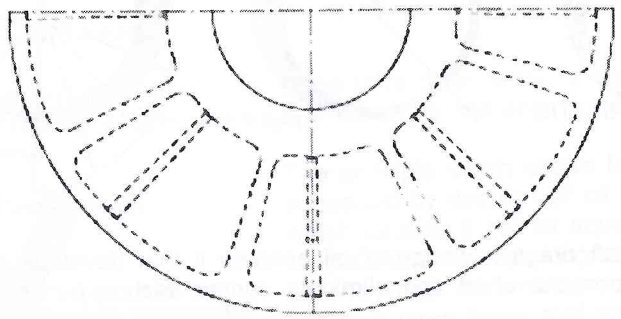
Thrust Bearings

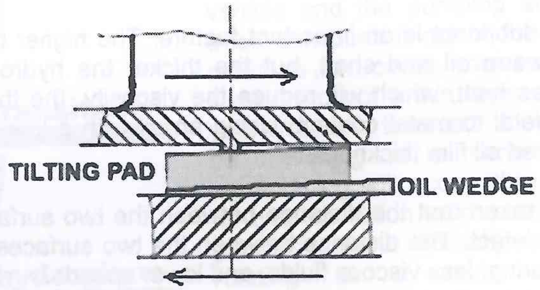
In a thrust bearing, the surfaces have to be such that a converging wedge of fluid can develop between the surfaces, allowing the hydrodynamic pressure of the lubricant to support the load of the moving surface.

This is obtained in a number of ways, a common design is the tilted pad bearing, where a tilted pad skims over a sheet of fluid. This was developed by Australian engineer George Michell in 1905. Albert Kingsbury, an American, simultaneously and independently invented a bearing operating on the same principle.

It should be noted that the movement is relative. On some bearings the pads are stationary and the thrust collar rotates (used on most marine diesel applications), whist in some applications the pads rotate against a fixed collar

This principle is the one used on main propulsion thrust bearings





Chapter 7: Bearing Materials

Babbitt Metal

Babbitt metal, is an antifriction metal alloy first produced by Isaac Babbitt in 1839. In present-day usage the term is applied to a whole class of silver-white bearing metals, or "white metals." These alloys usually consist of relatively hard crystals embedded in a softer matrix, a structure important for machine bearings. They are composed primarily of tin, copper, and antimony, with traces of other metals added in some cases and lead substituted for tin in others.

TIN BASED ALLOYS CHEMICAL COMPOSITION (%) CHART

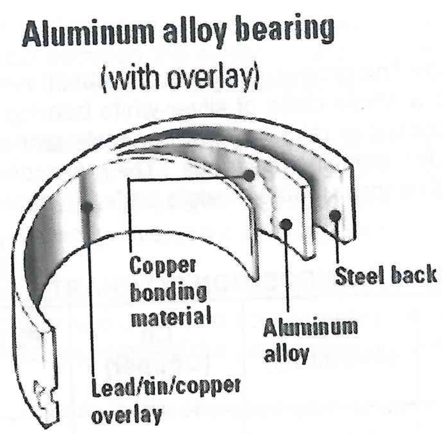
INDUSTRY NAME	Sn (Tin)	Sb (Antimony)	Cu (Copper)	Pb (Lead)
Marine 11 D	90.0 - 92.0	4.5 - 5.5	3.5 - 4.5	*0.2 (Max)*
No. 1	90.0 - 92.0	4.0 - 5.0	4.0 - 5.0	*0.2 (Max)*
Marine 11 R	89.0 - 89.5	7.5 - 8.5	2.5 - 3.0	*0.2 (Max)*
Nickel Genuine	88.0 - 90.0	7.0 - 8.0	3.0 - 4.0	*0.2 (Max)*
Marine 11	88.0 - 90.0	5.5 - 6.0	5.0 - 5.5	*0.2 (Max)*
Maximum Allowable Impurities:	Fe=0.08, As=0.10, Bi=0.08, Zn=0.005, Al=0.005, Cd=0.05			

Bearings used in large marine diesel engines are tin based babbitt metals. Lead content is a minimum. Tin based white metals have 4 times the load bearing characteristics and two and a half times the maximum surface speed of lead based white metals.

Tin-based white metal is an alloy with minimum 88% tin (Sn), the rest of the alloy composition is antimony (Sb), copper (Cu), cadmium (Cd) and small amounts of other elements that are added to improve the fineness of the grain structure and homogeneity during the solidification process. This is important for the load carrying and sliding properties of the alloy. Lead (Pb) content in this alloy composition is an impurity, as the fatigue strength deteriorates with increasing lead content, which should not exceed 0.2 % of the cast alloy composition. Tin based white metal is used in the main bearings, crankpin bearings, crosshead bearings, guide shoes, camshaft bearings and thrust bearings because of its excellent load carrying and sliding properties.

Babbitt metal is soft and easily damaged, and seems at first sight an unlikely candidate for a bearing surface, but this appearance is deceptive. The structure of the alloy is made up of small hard crystals dispersed in a matrix of softer alloy. As the bearing wears the harder crystal is exposed, with the matrix eroding somewhat to provide a path for the lubricant between the high spots that provide the actual bearing surface.

Tin - Aluminium



Tin aluminium bearings were developed to provide bearings that carry high loads. As a bearing material, unalloyed aluminium has a tendency to seize to a steel mating surface. It was found that 20% of tin added to the aluminium improved seizure resistance and that cold working and annealing helped to prevent brittleness. Special features are their good resistance to corrosion, high thermal conductivity and high fatigue strength, but they have the disadvantages of only moderate embedding properties, poor compatibility and high coefficients of thermal expansion. If used as solid unbacked bearings, this type of alloy is usually too weak to maintain an interference fit and too hard to run satisfactorily against an unhardened shaft. Considerable improvement in antiscoring characteristics and embedability is obtained by using a thin-lead babbitt or electrodeposited lead-tin overlay.

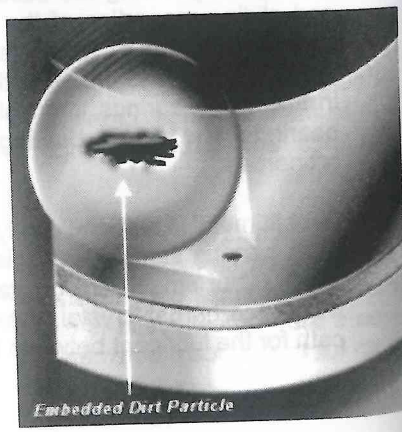
Alloys containing 20 to 40% tin, remainder aluminium, show excellent resistance to corrosion by products of oil breakdown and good embedability. The sliding properties of this composition are very similar to those of tin based white metal but the loading capacity of this material is higher than tin based white metals for the same working temperature; this is due to the ideal combination of tin and aluminium, where tin gives the good embedability and sliding properties, while the aluminium mesh functions as an effective load absorber. The higher-tin alloys (40%) have adequate strength and better surface properties, which make them useful for main and crosshead bearings in high-power marine diesel engines.

Lead Bronzes

Lead bronzes basically are copper-tin-lead-alloys. They are used in very highly loaded bearings because of their high fatigue strength; their drawback is poor tribological behaviour. That is why they require an electroplated overlay in most applications. Standard composition for conrod and main bearings is 78 % Cu, 20 % Pb, 2 % Sn. The alloy is used with electroplated overlay or cast babbit running layer. These bearings can be found in medium speed engines such as the MAN B&W L48/60 engine

Overlay

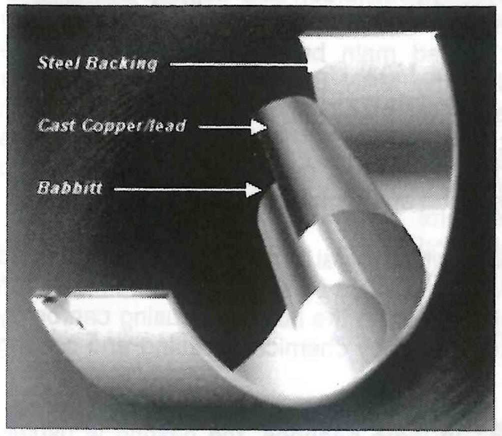
An overlay is a thin galvanic coating of mainly lead (Pb) and tin (Sn), which is applied directly on to the white metal or, via an intermediate layer, on to the tin aluminium sliding surface of the bearing. The overlayer is a soft and ductile coating, its main objective is to ensure good embedability and conformity between the bearing sliding surface and the pin surface geometry.



Flash layer

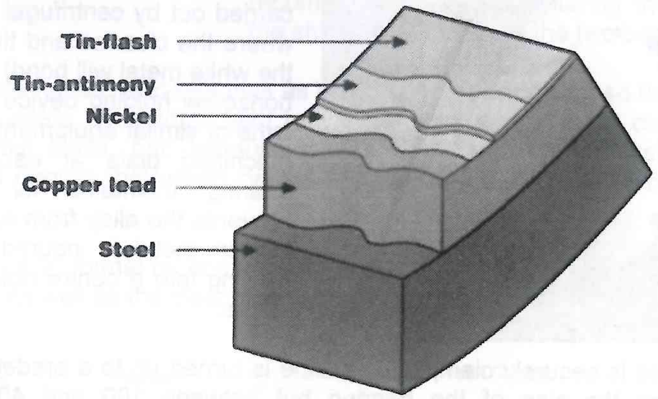
A flash layer is a 100% tin (Sn) layer which is applied galvanically; the thickness of this layer is from 2 µm to 5 µm. The coating of tin flash is applied all over and functions primarily to prevent corrosion (oxidation) of the bearing. The tin flash also functions as an effective dry lubricant when new bearings are installed and the engine is barred over.

Tri-Metal and Multi Layer Bearings



Tri-Metal and Multi layer thinwall bearings are used in modern diesel engines.

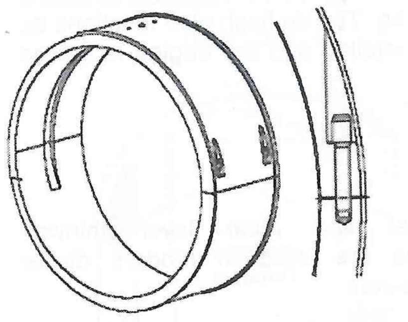
Babbitt metal lacks fatigue strength. It breaks down under load. The durability of babbitt greatly increases as the material decreases in thickness. The common solution is to apply a thin layer of babbitt over a supporting layer of copper/lead which acts as a cushioning layer and allows for slight misalignment.



A modern trimetal bearing infact has five layers: The nickel barrier plating prevents or limits diffusion of metallic components from the babbitt anti-friction layer into the copper/lead. supporting layer and vice versa.

The tin flash coating is, as previously mentioned to protect and provide a dry lubricant.

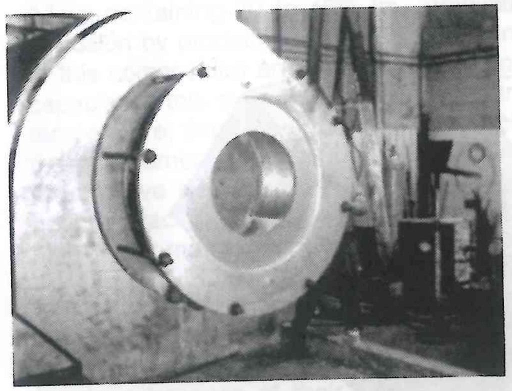
Chapter 8: Thickwall Bearings



MAN B&W Thick Wall Main Bearing With Guide Pins

Older engines like the Sulzer RND and the older B&W K series engines had bearings which were made by casting the white (Babbitt) metal either directly into the bearing housing (in the case of bottom ends or crossheads), or into steel backing shells to give the required stiffness and thus prevent distortion and support the cast on white metal. It should be noted that until recently thick walled main bearings of this type were used in the MAN B&W MC engine, and thus there are still many engines in service fitted with thick wall bearings. Refurbishment of these bearings is carried out by melting out the old white metal and recasting.

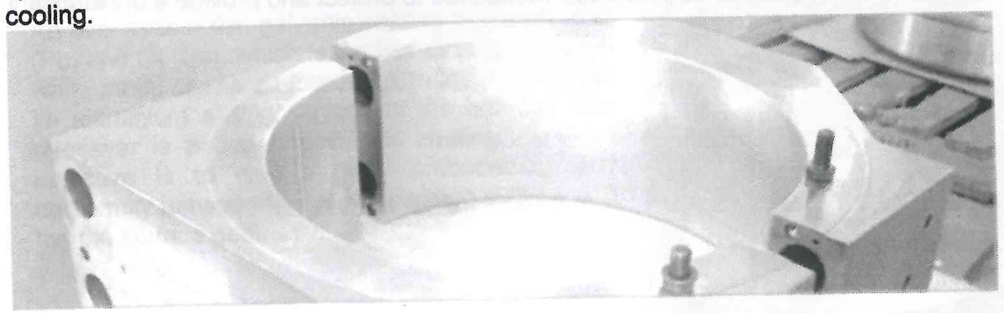
Static casting can be used where the molten white metal is poured into a preheated mould made from the bearing housing halves, separated by shims and a dummy shaft and sealed with fireclay. Bonding of the white metal to the bearing housing can be by mechanical methods such as a dovetail keyway or by chemical cleaning and coating the bonding surface with a thin layer of tin.

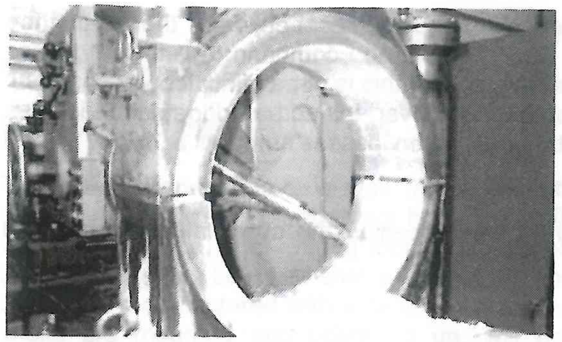


In large bearings, the casting is usually carried out by centrifugal or spin casting where the cleaned and tinned shells (so the white metal will bond) are placed in a horizontal holding device supported in a lathe or similar equipment. An accurately machined plate at each end of the bearing maintains its position and prevents the alloy from running out. The molten metal is poured into a funnel feeding into a centre hole in one of the plates.

When the shell is securely clamped, the lathe is turned up to a predetermined speed (depending on the size of the bearing but between 100 and 400 rpm) and a predetermined amount of alloy is poured into the funnel. Immediately after casting, a water or air water spray is used to cool the shell.

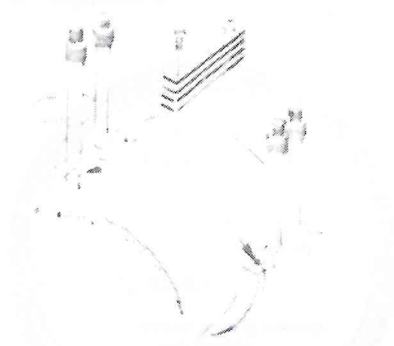
In theory the operation is simple but there are critical factors: preparation of shell, speed of rotation, thickness of lining, pouring temperature and rate of cooling.





After manufacture, the surface is inspected for porosity. The bearings are machined under torque and final inspected by class.

Thickwall Main Bearings: Clearance and Weardown

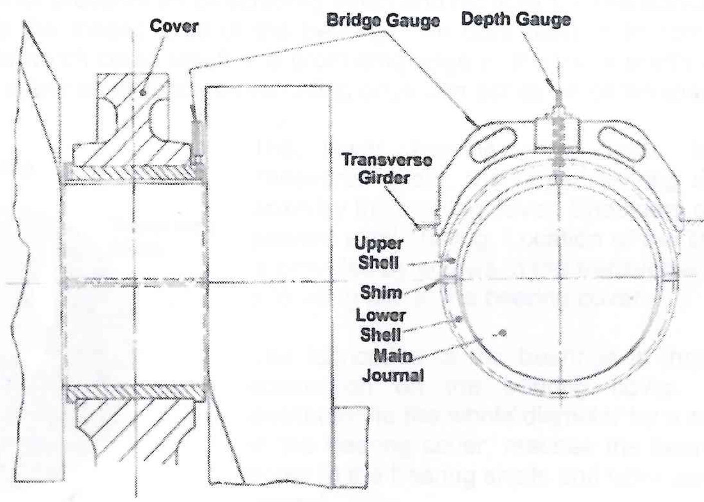


The clearance in the bearing is set by inserting shims between the two bearing halves. It is very important that the shims are of equal thickness on both sides of the bearing. Clearance varies but main and bottom end bearings are usually about 0.5mm for a large bore (680 - 900) main engine with a maximum allowable of about 0.8mm.

As the bearing wears with use, so the clearance increases. This can be adjusted back to the recommended value by altering the thickness of the shims fitted between the two bearing halves.

However, on crankshaft main bearings as the bearings wear down, so the alignment of the crankshaft alters. This could lead to the situation, whereby the clearance in the bearing is within limits, but, because of the weardown, the crankshaft is out of alignment to a degree that would cause excessive stressing due to bending during operation.

For this reason it is normal on engines fitted with thick wall main bearings to measure the wear down as well as the clearance.



The wear down is measured by measuring the distance between the top of the transverse girder and the crankshaft main journal, and comparing it with the values given in the acceptance report. On the Sulzer RND this is not a difficult operation, as it does not require the removal of the top bearing cover, Instead a bridge gauge locates on the transverse girder and a depth gauge then passes through a drilling in the bearing shell on to the journal.

The gauge locates at the back of the bearing behind the cover as shown on the previous page.

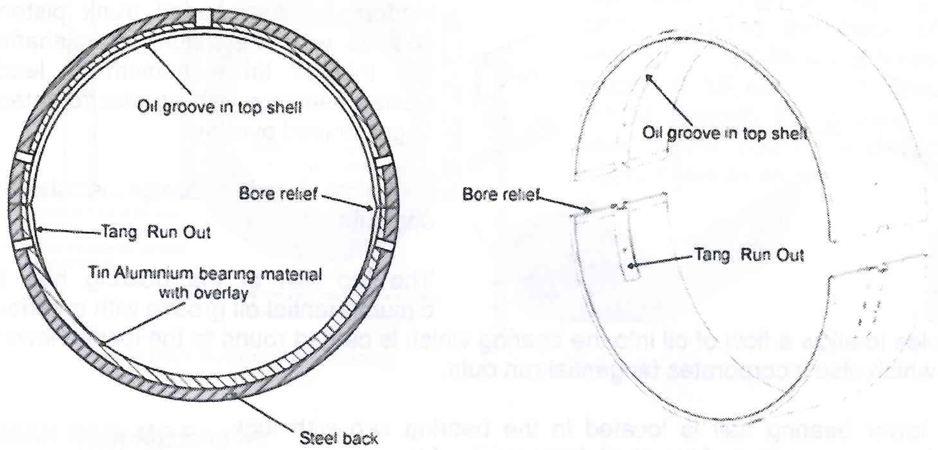
Chapter 9: Bearing Design

Main Bearings

Slow Speed Crosshead Engines

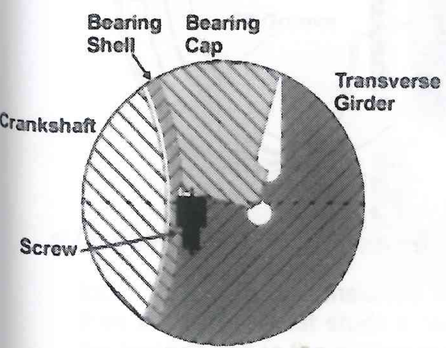
Thin shell bearings have a wall thickness between 2% and 2.5% of the journal diameter. The steel back does not have the sufficient stiffness to support the cast-on white metal alone. The bearing must therefore be supported rigidly over its full length to prevent fretting between shell and housing and failure of the bearing material. The bearing is manufactured with a circumferential overlength (crush/nip) which, when the shells are mounted and tightened up, will produce the required radial pressure between the shell and the bearing housing.

The maximum/minimum top clearance in thin shell bearings is predetermined and is non adjustable



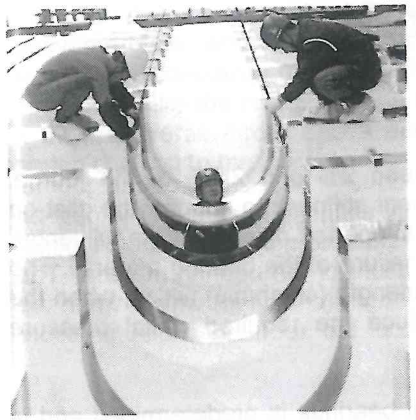
MAIN BEARING SHELLS

Plain bearings are manufactured as steel shells with a bearing surface of white metal or tin aluminium. The bearing surface is furnished with a centrally placed oil supply groove and other design features such as tangential run-outs and bore reliefs. The tangential runout prevents an oil scraping effect and reduces the resistance to the flow of oil towards the loaded area of the bearing. The bore relief is to compensate for misalignments which could result in a protruding edge of the lower shell's mating face to that of the upper shell. Such a protruding edge can act as an oil scraper and cause oil starvation.



The lower bearing shell rests in bedplate transverse girder, the upper bearing shell is held down by the bearing cover. Shoulders on each end prevent axial shifting. Location of the bearing shell is provided by screws in the transverse girder or by a locating pin in the bearing cover.

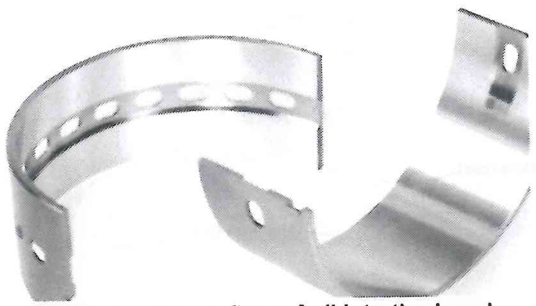
The lubrication of the bearings is through the oil connection on the bearing cover. The oil is distributed to the whole diameter by a radial groove in the bearing cover, reaches the bearing through bores in the bearing shells and lubricates bearing & journal.



The photograph shows the Installation of main bearings in a RTA96 bedplate.

The oil supply to the bearing is through a pipe to the bearing cap.

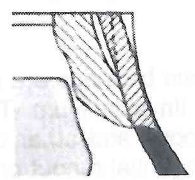
Medium Speed Trunk Piston Engines



Modern medium speed trunk piston engines with underslung crankshafts use thinwall tin aluminium or lead bronze bearings with an electroplated or galvanised overlay.

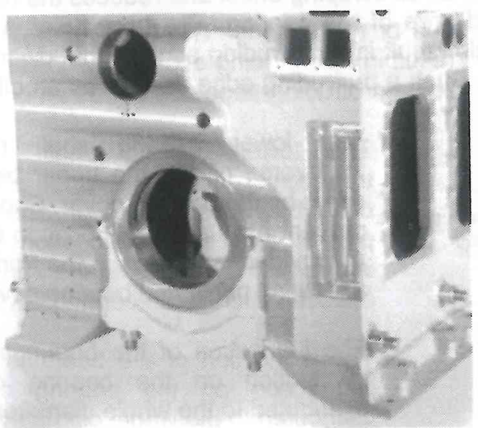
A typical bearing design is shown opposite.

The top half of the bearing has a circumferential oil groove with a series of holes to allow a flow of oil into the bearing which is carried round to the loaded lower half which also incorporates tangential run outs.



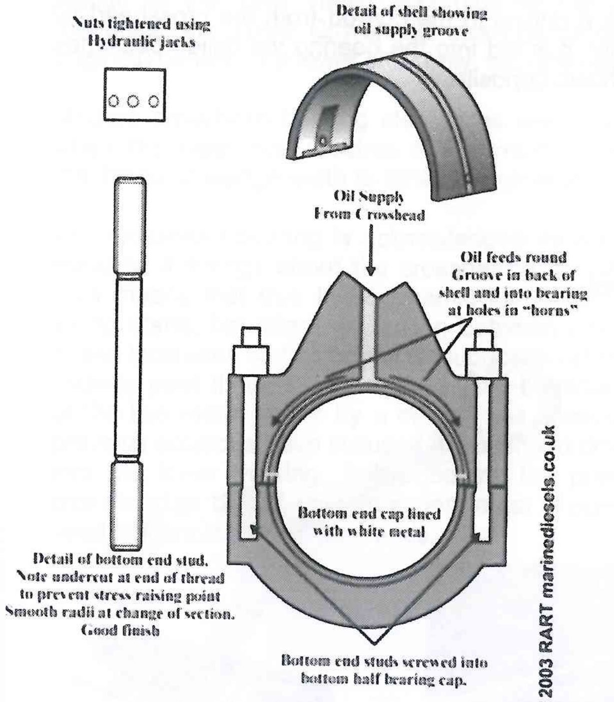
The lower bearing half is located in the bearing cap with lugs which prevent rotation of the shell during assembly.

The oil supply is via drillings in the engine block to the top bearing housing. In the photo shown the oil supply groove in the main bearing housing can clearly be seen.



Bottom End Bearings

Slow Speed Crosshead Engines



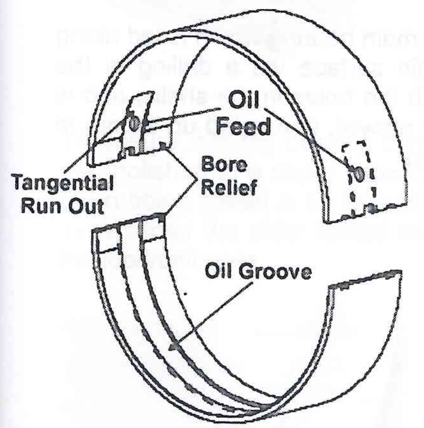
Sulzer RTA Bottom End Bearing

Sulzer RTA

The Sulzer RTA engine has only one bearing shell located in the conrod bearing housing. The bearing cap is lined with white metal. No shims are used, and the clearance is manufactured into the bearing.

The loaded half of the bearing is of thin shell design lined with white metal and has an oil supply groove running around the back of the bearing. Oil fed from the crosshead supply at 12 bar is led down the conrod, around the groove in the back of the bearing and into the supply holes as shown.

MAN B&W MC Engine

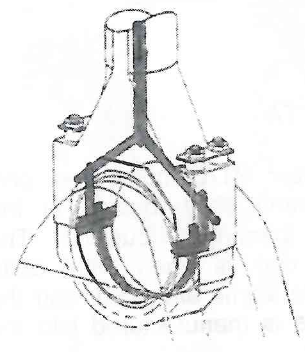


MAN B&W MC Engine Bottom End Shells

The MAN B&W MC engine uses thinwall bearing shells lined with white metal or shells lined with tin-aluminium and a flashlayer of tin for upper and lower bearing halves. The shells are manufactured with a circumferential overlength (crush/nip) which, when the shells are mounted and tightened up, will produce the required radial pressure between the shell and the bearing housing.

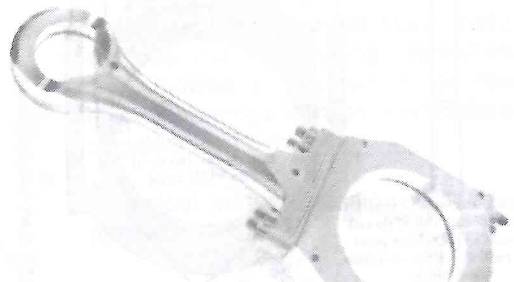
The crankpin bearing shells are retained in position by means of screws fitted in the bearing housings.

The bearing assembly has two or four tensioning studs, depending on the engine type. Crankpin bearing assemblies with four studs must be tensioned in parallel, for example first the two forward studs and then the two aftmost studs it two or three steps. This procedure is to avoid a twist of the bearing cap to the mating face on the connecting rod.



The Oil supply to the bottom end bearing comes down a drilling in the conrod from the crosshead oil supply. It is led into the bearing via drilled passages as shown opposite.

Medium Speed Trunk Piston Engines



The bottom end bearings for a modern trunk piston engine will be thinwall tin aluminium or lead bronze shells with an electroplated or galvanised overlay. The top half of the bearing is loaded for the majority of the cycle, although for a short period between inlet and exhaust strokes the load is transferred to the lower half.

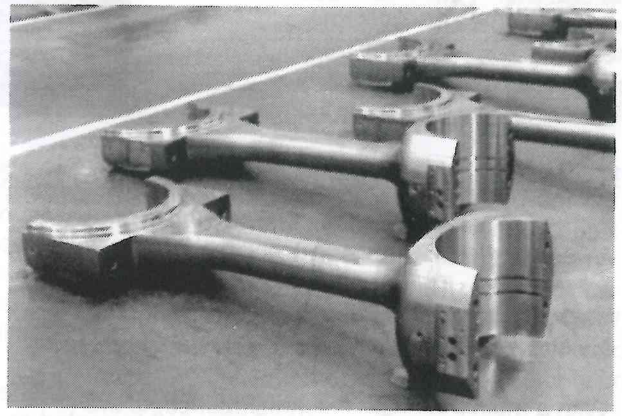
Oil is supplied to the bearing from the oil supply to the main bearing which is led along drillings in the crankshaft and exits onto the crankpin surface via a drilling in the crankpin journal. The oil then exits the bearing through the holes in the shells, and is fed round a groove in the bearing housing (see photo above), and is led up a bore in the con rod to the top end bearing and to cool the piston.

Crosshead Bearings

Crosshead bearing shells are of tin aluminium on a steel backing with a white metal overlay. White Babbitt metal and lead bronze have also been used in the past. The design of the shell varies according to the age of the engine and the engine manufacturer. Some Crosshead bearings (Sulzer RTA and some MAN B&W MC engines) consist of a lower shell only, with the bearing caps lined with white metal.

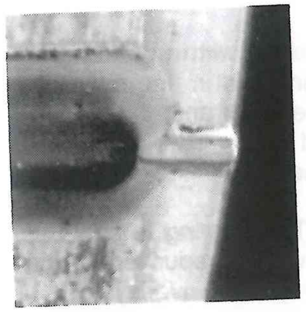
Modern crosshead bearing clearances are non adjustable. The bearing is replaced when the clearance reaches a maximum. This coincides with a reduction in the machined oil wedge width to 50% of original or the wearing away of the overlay.

The crosshead bearing is acknowledged as a difficult bearing to lubricate effectively because it swings about the crosshead pin changing direction twice per revolution. This means that true hydrodynamic lubrication cannot be built up. Instead, as the swing starts, boundary lubrication between pin and bearing occurs. As the rubbing speed increases so hydrodynamic lubrication starts, but as the bearing swings past the midway point it starts to slow down and boundary lubrication starts again. Separation of the two metal layers by a oil film has always been a problem for designers, and previous solutions have included a crosshead driven oil pump to boost the oil pressure into the lower bearing. Sulzer boosts the pressure of the lube oil supply to the crosshead to 12 bar. using a separate set of pumps; this oil at higher pressure is also used to lubricate the bottom ends.

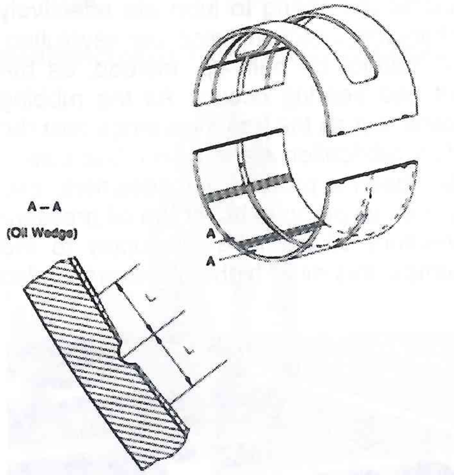


To ensure that the bearing can operate with the minimum of wear, the pin is ground and polished to a super smooth finish. The pin is made with a large diameter so that the rubbing speed is as fast as possible, and a continuous lower bearing surface has superseded the older forked crosshead which gives a greater surface area, reducing the load/unit area.

The lower half of the bearing takes the load. To help with the distribution of oil over the loaded half of the bearing, grooves are machined in the shell which also assists with the build up of a hydrodynamic film. Sometimes the grooves stop short of the edge of the bearing as can be seen in this shell from an earlier RTA with a forked type crosshead. (opposite) The idea behind this is that if the groove extended to the edge of the bearing, the oil pressure keeping the surfaces apart would be lost.



On some shells however, the grooves do extend to the edge. The grooves are of reduced section at the edge of the bearing. This allows a flow of oil to maintain a cooling effect and reduces any likelihood of reducing the oil pressure.



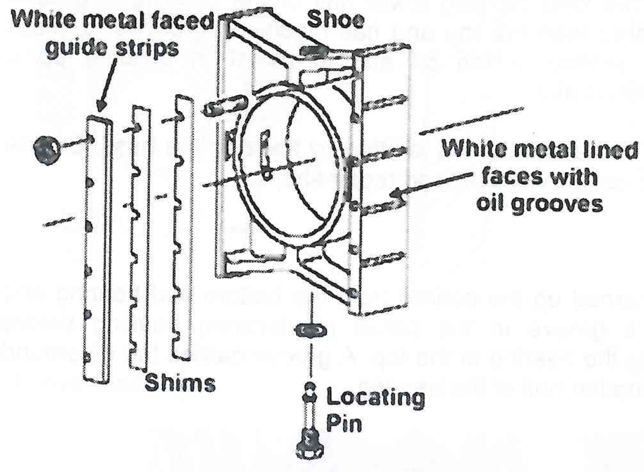
On the MAN_B&W MC engine crosshead bearing, the oil grooves extend right to the edge of the bearing shell. Unlike Sulzer, MAN do not boost the oil pressure to the crosshead; it is supplied at normal LO pressure (approx 2.5 bar, but dependent on engine type). The geometry is designed in such a way that all the loaded area of the pin and bearing are flushed with cooling oil twice, every engine cycle. This is because 90% of the circulated oil has the sole purpose of cooling the bearings.

With a main bearing, oil is pumped into the upper shell and it will cool the upper part of the journal. Since the shaft is rotating, it is cooled on all sides and because the oil film thickness is very small in the loaded part, the shaft will cool the loaded bearing half as well. A crosshead bearing is only oscillating and the lower shell is always loaded. The cooling oil must be injected between shaft (crosshead pin) and lower bearing..

In contrast, the modern Sulzer crosshead has a plain lower bearing without channels. In order to inject oil between pin and bearing, they have to supply oil at a much higher pressure. The injection will take place at around 20 degrees crank angle before TDC, where the cylinder pressure is still low and upward inertia forces on piston is still high. There is a short interval, in which the bearing pressure is lower than the oil pressure.

Crosshead Guide Shoes (Slippers)

The guide shoes, which are mounted on the fore and aft ends of the crosshead reciprocate in the guides and transfer the side component of thrust into the engine frame, so that the reciprocating motion of piston/piston rod via the connecting rod is converted into a rotational movement of the crankshaft.



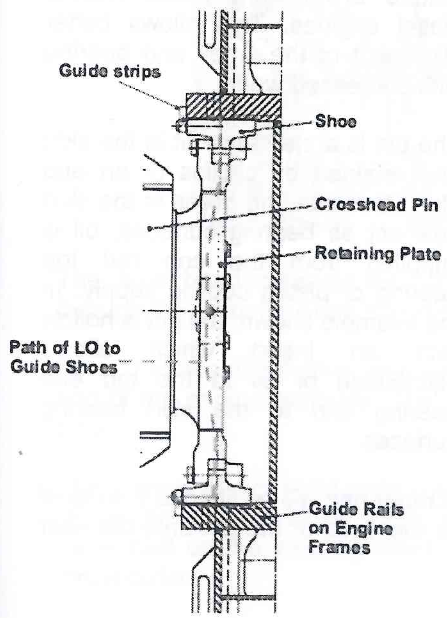
MAN B&W Guide Shoe Assembly

MAN B&W MC

The guide shoe is positioned relatively to the crosshead pin with a locating pin screwed into the guide shoe, the end of which protrudes into a hole in the crosshead pin and restricts the rotational movement of the crosshead pin.

The guide strips are bolted on to the inner side of the guide shoes and ensure the correct position of the piston rod in the fore-and-aft direction. This alignment and the clearance between the guide strips and guide is adjusted with shims.

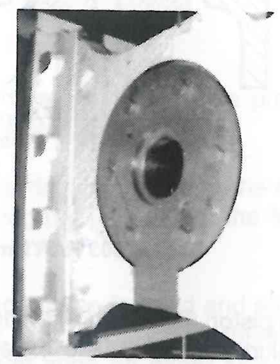
The sliding surfaces of the guide shoes and guide strips are provided with cast on white metal with machined oil supply grooves and wedges.



SULZER RTA Guide Shoe Arrangement

SULZER RTA

A similar arrangement to the MAN B&W, except a retaining cover which allows limited movement locates the guide shoe assembly on the crosshead pin.



Oil is supplied to the crosshead for lubrication and piston cooling by a swinging arm (Sulzer) or a telescopic pipe (MAN B&W)

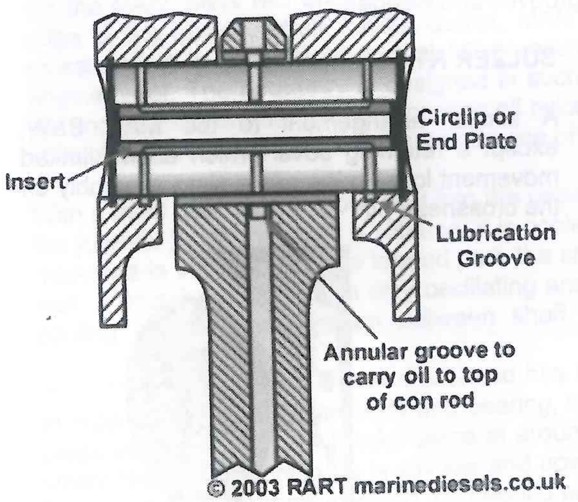
Piston Pin Bearings

The main load on the piston pin bearing on a trunk piston engine is on the lower half of the bearing, and like the crosshead on the two stroke engine, the lubrication is boundary-hydrodynamic-boundary as the conrod swings about the piston pin, changing direction twice per revolution.

The bearing consists of a bush lined with tin aluminium or lead bronze. The load carrying lower half of the bush is of greater surface area than the top and has machined grooves to assist with the spread of the oil and to assist in building up a hydrodynamic film.

The bush is an interference fit in the conrod and is fitted by freezing the bush. Engine builders recommend that this is done by specialised repair shops.

Oil is carried up the conrod from the bottom end bearing and round a groove in the piston pin bearing housing before entering the bearing at the top. A groove carries the oil around to the loaded half of the bearing.



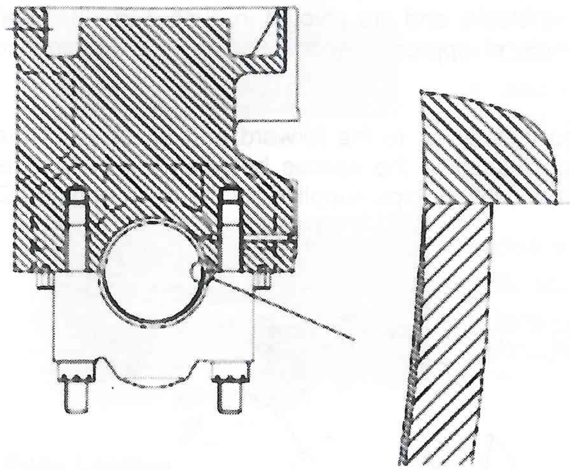
The floating piston pin is a common feature of medium speed marine diesel engines. This allows better alignment of the small end bearing with decreased wear.

The pin is a clearance fit in the skirt and retained by circlips or an end plate. Because the bores in the skirt now act as bearing surfaces, oil is supplied from the con rod top bearing or piston cooling supply. In the example shown, the pin is hollow with an insert which allows distribution of oil to the top end bearing and to the skirt bearing surfaces.

On a piston fitted with a floating piston pin, the oil scraper ring will be fitted at the top of the skirt, to remove the excess oil passing through the ends of the pin onto the liner wall.

Camshaft Bearings

Fig. 2 One-Shell Assembly

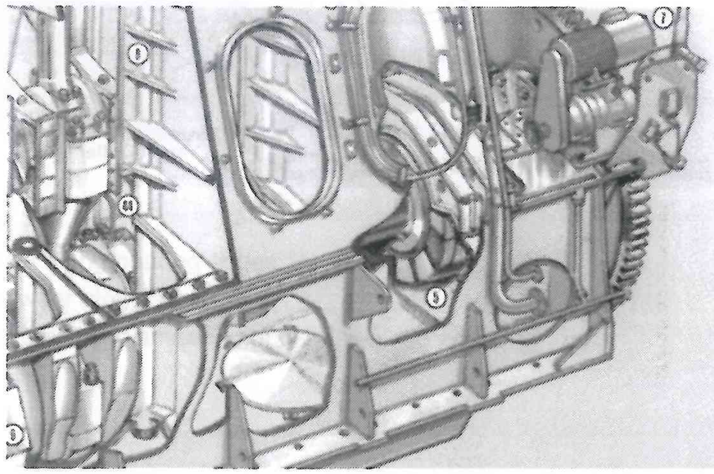


Can be one or two shell design.

Slow-speed engine camshaft bearings are usually of the underslung journal types operating in white-metal lined bearing shells.

Medium speed engine camshaft bearings can be similar to those found in slow-speed engines. Sometimes, however, roller or needle roller bearings may be used.

Thrust Bearings



The thrust bearing serves the purpose of transmitting the axial thrust of the propeller through the propeller shaft and intermediate shaft to the ship's hull.

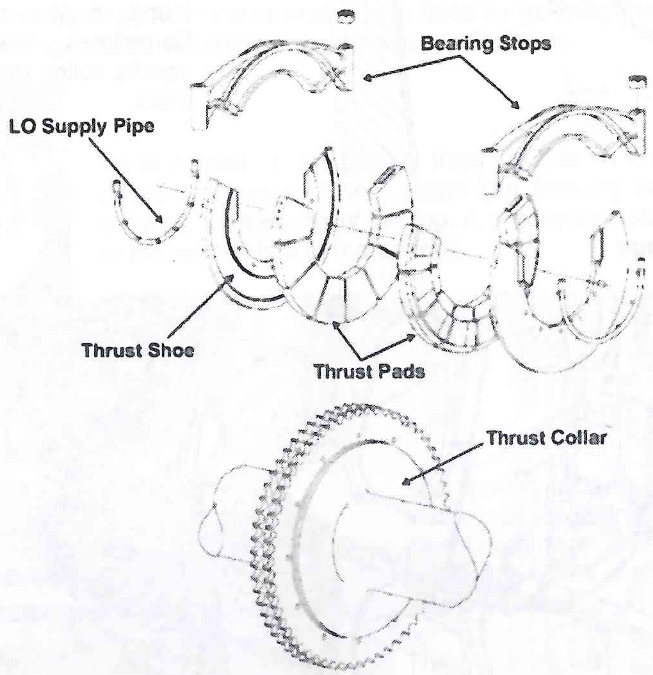
On a 2 stroke direct drive reversing engine the thrust bearing is situated at the driving end of the engine bedplate. The thrust bearing is a tilting-pad bearing of the Michell type.

There are seven or eight pads (segments) placed on each of the forward and aft sides of the thrust collar which forms part of the crankshaft. The pads which have white metal cast on the wearing faces are mounted in a thrust shoe on either side of the thrust collar.

The thrust shoes rest on surfaces in the thrust bearing housing which forms part of the two transverse girders either side of the thrust bearing and are held in place circumferentially by stops.

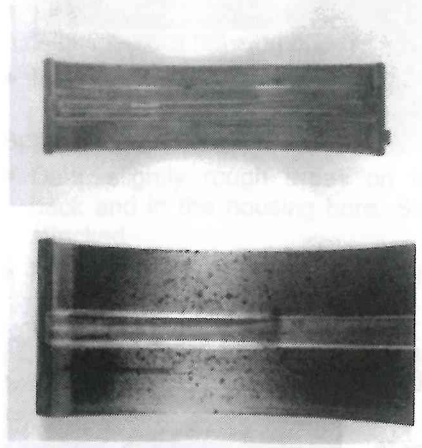
The pads can be compared to sliding blocks and are pivoted in such a manner that they can individually take up the angle of approach necessary for a hydrodynamic lubricating wedge.

The lubricating/cooling oil is sprayed directly on to the forward and aft sides of the thrust collar by means of nozzles positioned in the spaces between the pads. The nozzles are mounted on a semicircular delivery pipe supplied by the main engine LO pumps.



Chapter 10: Bearing Faults

Scoring



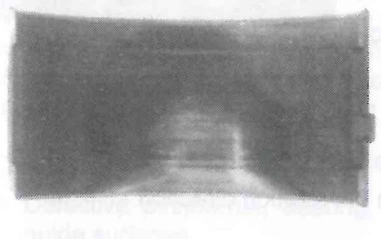
Causes:

- Contaminated lubricating oil.
- Inadequate cleaning of the engine parts prior to assembly, (oil ducts of engine block, crankshaft, conrod).
- Oxides from corrosive attack in bearings.

Appearance:

- Scratches in circumferential direction.
- Indentations on the running surface with foreign matter embedded in the centre.

Edge Loading



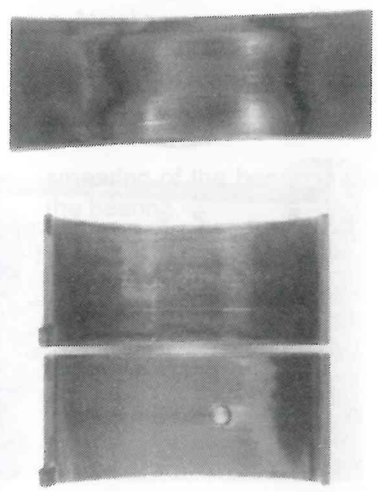
Causes:

- Conical grinding of journal.
- Conical housing bore.
- Crankshaft fillet too large.
- Crankshaft not well balanced.

Appearance:

- Shiny traces along bearing edges.
- Excessive wear along edges.
- Possibly rupture and smearing of overlay along edges.

Corrosion

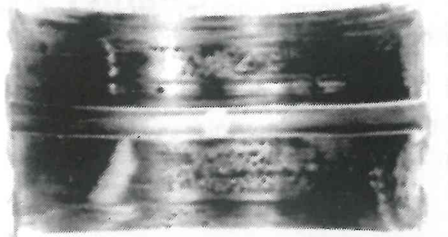


Causes:

- Chemically aggressive oil or additives.
- Contamination of the lubricating oil with alkaline or acidic substances.
- Aggressive combustion residues (heavy fuel oil) in lubricating oil.
- Exceedingly long oil change intervals.
- High water content of oil.

Appearance:

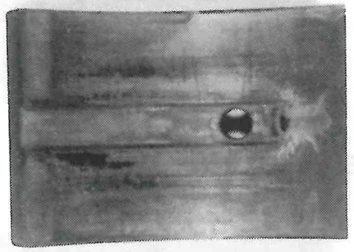
- Rough, porous or velvety running surface, most often darkened.
- Pitted Surface
- Removal of overlay over wide areas with discoloured transition zones.
- In extreme cases attacked lead bronze.



Erosion

Causes:

- local drop of the oil pressure below the vaporization pressure, leading to the formation of oil bubbles. These collapse when carried into a higher pressure region, initiating a shockwave.
- Turbulence in the incoming oil flow, in particular in areas where flow direction in groove is opposite to pin
- rotation
- Turbulence due to sharp transition from groove to bearing surface.



Appearance:

- Lance-shaped erosion with sharply defined fringes beside oil groove
- Mushroom-shaped erosions after groove runout in pin rotation direction.
- Possible erosion of groove edges.

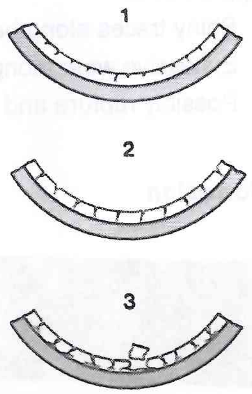
Fatigue

Causes:

- Local overload because of generally high bearing load.
- Local overload by uneven loading.

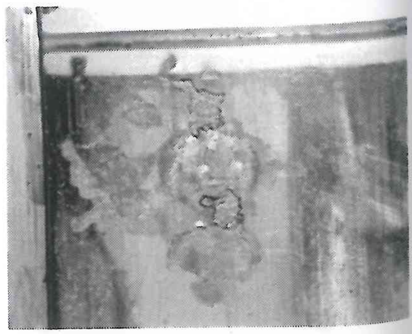
Appearance:

- Cracks, a network of cracks, "cobblestones" in the material.
- Parts of lining broken out.



Fine cracks develop at first on the bearing surface. They propagate toward the steel support shell.

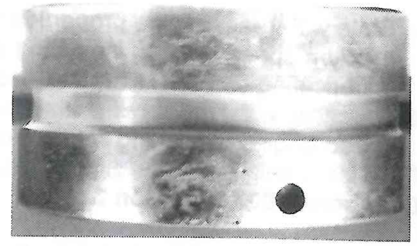
Ultimately, parts of the lining material break out.



Fretting

Causes:

- Insufficient crush of the bearing shells caused by too large a housing bore.
- Bolts not torqued according to specifications.



Appearance:

- Dark, slightly rough areas on the bearing back and in the housing bore. Steel surface attacked
- Pitting on the bearing back and in housing bore.

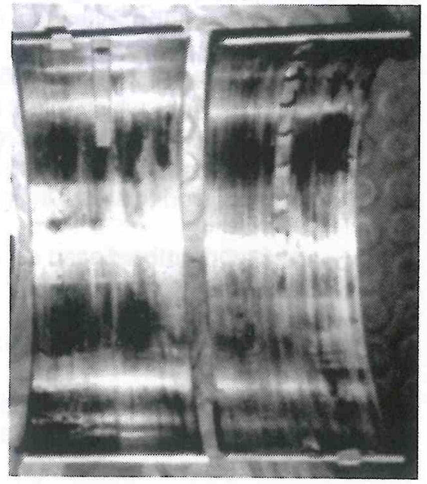
NOTE:
Once fretting has occurred in the bearing housing, the only remedy is to line the housing and rebore.

Wiping

Wiping of the overlay manifests itself by parts of the overlay being smeared out. Wiping of overlay can take place when running in a new bearing; however, if the wiping is excessive, the cause must be found and rectified. One of the major causes of wiping is pin/journal surface roughness.
White metal wiping is due to metal contact between the sliding surfaces which causes increased frictional heat, resulting in plastic deformation of the bearing metal

Causes:

- Defective pin/journal, bearing, or crosshead guide surfaces.
- Scraped bearing or guide shoe surfaces.
- Hard particles trapped between the housing bore and the back of the shell.
- Fretting on the back of the shell and in the housing bore.
- Increased pin/journal surface roughness caused by hard particles or corrosion.
- Inadequate lube oil supply.
- Misalignment.
- Overloading.



Appearance:

smearing of the bearing material. In severe cases the molten white metal runs out of the bearing.

Chapter 11: Chief Engineer Exam Questions

December 2007 Question 7

a. State with reasons, the properties required of a lubricating oil for a trunk piston type, medium speed engine, indicating why some properties differ from those required of a lubricating oil used in the crankcase of a crosshead diesel engine. (6)
b. Describe, with the aid of a sketch, the lubrication system of a trunk piston medium speed engine explaining how impurities in the lubricating oil are removed. (10)

December 2007 Question 3

a. Explain the purpose of a lubricating oil system backflush filter. (4)
b. Describe a lubricating oil system backflushing filter, explaining how it operates. (12)

July 2005 Question 6, March 2003 Question 7

a. Describe the causes and effects of bacterial attack on crankcase lubricating oil. (6)
b. Explain how bacterial attack on crankcase oil may be detected. (4)
c. Describe how a crankcase lubricating oil system may be returned to service following bacterial attack of the lubricating oil. (6)

March 2004 Question 8

While surveying a bottom end bearing under an Approved Planned Maintenance Scheme (APMS) damage is discovered on the bearing surface. As Chief Engineer Officer, write a report to the company office/Classification Society detailing the damage and the action taken.

October 2003 Question 2

With reference to a main engine bottom end bearing:
a. describe FIVE faults which might be found on the bearing and/or the crankpin during a survey inspection, indicating a possible cause for each fault; (10)
b. describe the procedure for checking and adjusting a bottom end bearing clearance. (6)

October 2002 Question 1

With reference to crossheads:
a. state why the lubricating oil supply pressure is higher than that required for the main bearings; (2)
b. state, with reasons THREE possible causes of top end bearing failure; (6)
c. describe the procedure for checking the top end bearing and crosshead guide clearances. (8)

October 2001 Question 4

A report on the analysis of the main crosshead engine crankcase lubricating oil indicates the following contaminants or property changes. In EACH of the following cases give reasons for the possible causes of the contamination or property change, explaining how the actual cause would be detected;
a. the presence of fresh water; (4)
b. white metal fragments; (4)
c. reduced alkalinity reserve; (4)
d. reduced anti oxidation reserve. (4)

Chapter 12: Second Engineer Exam Questions

December 2007 Question 6

With reference to trunk piston engines:
a. state, with reasons, the required properties of a crankcase oil; (8)
b. state, with reasons, a suitable mesh size for the crankcase lubricating oil filter elements; (4)
c. explain why the surfaces of journals and crankpins for this type of engine crankshaft may be nitride hardened.(4)

July 2007 Question 1

a. Explain how distillate fuel dilution of the crankcase oil can occur and the early symptoms. (4)
b. Explain the effect of fuel dilution on the lube oil, the damage which may be caused to the engine and the danger to personnel if it is not detected. (6)
c. Describe an on board test to confirm fuel dilution. (2)
d. Describe the action to be taken if fuel dilution is confirmed. (4)

March 2007 Question 6

With reference to diesel engine lubrication:
a. state, with reasons, what properties are required for a lubricating oil used in the crankcase of a trunk piston engine; (6)
b. explain why continuous centrifuging of a crankcase lubricating oil is normally carried out; (4)
c. explain how bacterial attack of a crankcase lubricating oil takes place, indicating the effect of bacterial attack on the properties of the lubricating oil. (6)

July 2006 Question 5, March 2003 Question 8, December 2004 Question 5

a. State how a representative sample of used lubricating oil is obtained from the main engine system for analysis. (3)
b. Describe THREE on-board tests for lubricating oil, stating how often EACH test should be carried out. (9)
c. Explain how the condition of lubricating oil may be assessed on board, if no testing equipment is available. (4)

April 2006 Question 4

a. Sketch a lubrication system for a crosshead engine, showing how the oil is supplied to the main bearings, bottom end bearings, crosshead bearings, piston cooling spaces and turbocharger bearings. (8)
b. Explain why booster pumps are sometimes used for supplying lubricating oil to the crosshead. (4)
c. Explain why a separate lubrication system is sometimes provided for the camshaft. (4)

October 2004 Question 4

a. Sketch a main engine lubrication system. (6)
b. Sketch a cylinder lubrication system for a crosshead engine, explaining how the cylinder is supplied with the desired amount of lubricant to each injection point. (6)
c. Explain why the cylinder lubricant of a crosshead engine differs in its properties from the lubricant used for the crankcase system.

July 2004 Question 4

a. Sketch a lubrication system suitable for a main engine. (5)
b. Describe the function of EACH device fitted in the lubrication system sketched in Q4(a). (5)
c. In the event of water being discovered in the main engine lubricating system, explain the possible causes of the contamination, describing how the cause of the contamination may be located. (6)

July 2003 Question 4, December 2002 Question 1, July 2001 Question 4

With reference to diesel engine lubricating oil:
a. explain why oil employed in the crankcase of a trunk piston engine differs in its properties from that employed in the crankcase of a crosshead engine; (5)
b. explain the effects of *bacterial attack* on crankcase oil, describing the possible consequences of such an attack on engine parts; (6)
c. explain the action which must be taken to prevent engine damage and subsequent attack, if bacterial attack of the crankcase oil is detected. (5)

December 2001 Question 5

a. Explain why obtaining lubricating oil samples from the main engine system and turbocharger systems are essential. (4)
b. State, with reasons, FOUR desirable properties required of a crankcase lubricating oil for a crosshead engine. (4)
c. Explain why crankcase lubricating oil for a trunk piston engine differs from that for a crosshead engine. (4)
d. Describe TWO shipboard tests which may be carried out on crankcase lubricating oil. (4)

Clutches, Couplings and Gearing

Contents

Chapter 1: Flexible Couplings

These couplings are torsionally flexible and are fitted between engine and gearbox, or gearbox and shaft to dampen out the torque fluctuations and reduce the effects of shock loading on gears and engine components.

The fluctuations are caused by the firing of cylinders, causing a loading and unloading of the gear teeth, resulting in tooth damage.

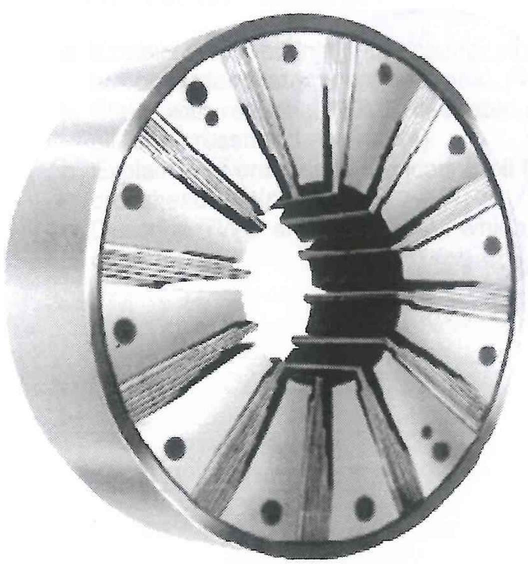
They may use rubber blocks or diaphragms. Nitrile rubber is common and also provides electrical insulation between driver and driven members.

They may be integral with an air or oil operated clutch or installed separately, all types reducing noise and vibration.

Flexible couplings also allow slight misalignment between engine and gearbox or gearbox and shaft, but problems may arise due to this misalignment as there is no rigid relationship between input and output shafts. Any stated tolerance on a coupling should not be regarded as a margin of error when installing.
Some couplings allow for angular and lateral displacement arising from temperature changes or deflexion of machinery or seating. Others may be chosen to provide torsional flexibility only.

Typical examples of a flexible coupling are the Geislinger type and the Vulcan coupling.

The Geislinger Coupling

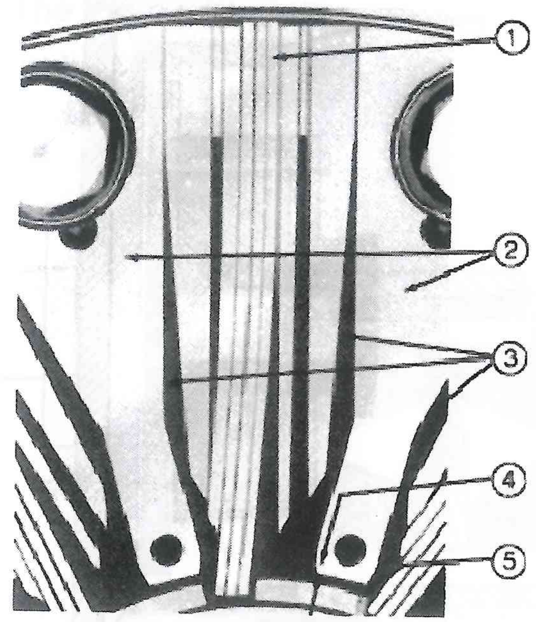


The coupling consists of primary and secondary sections. Between these, groups of leaf spring packs are arranged, which are clamped at their outer ends.

These spring packs - together with the primary and secondary sections - form chambers, which are filled with pressurized engine oil.

If the exterior section vibrates in relation to the inner section, the leaf springs are bent and press oil from one chamber to another retarding the relative movement of the two parts and thus damping the torsional vibration.

The elasticity is determined by careful selection of the leaf springs and the damping factor by the gap between primary and secondary sections.



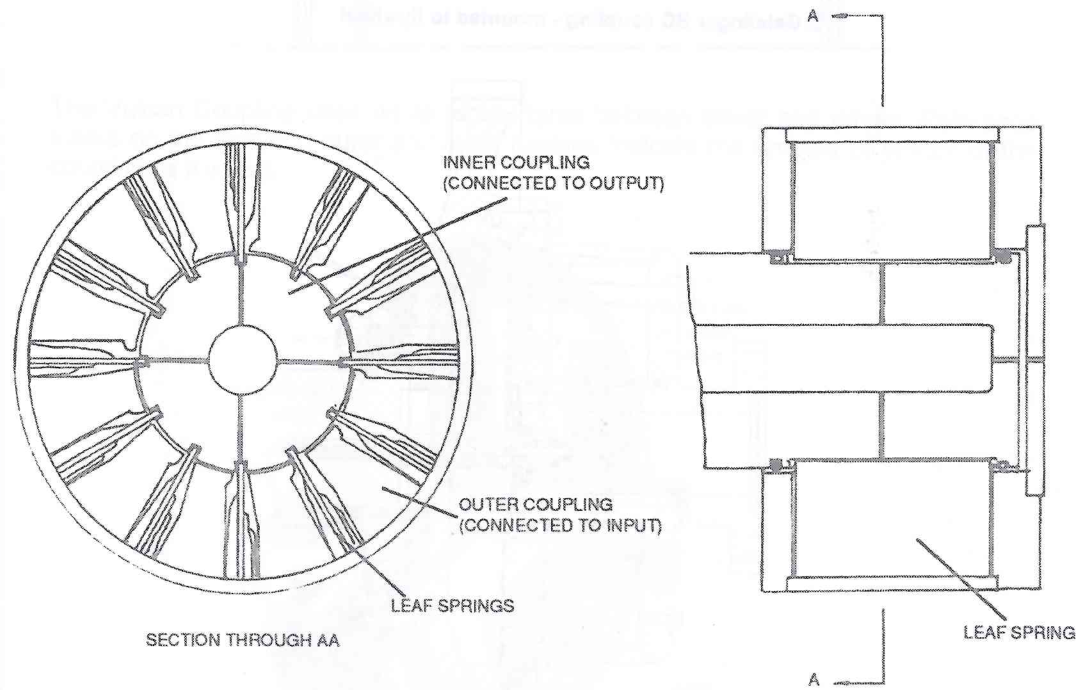
Shown left is a close-up view of a typical leaf spring group (1) from a Geislinger Coupling. The springs are being deflected due to a torque load in a counter-clockwise direction.

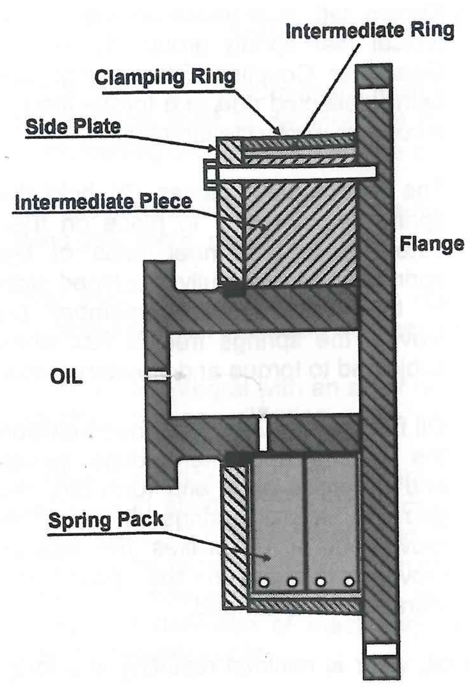
The intermediate pieces (2) hold the spring packs tightly in place on their outer ends. The inner ends of the springs fit into carefully machined slots in the coupling inner member (5) leaving the springs free to flex when subjected to torque and vibratory loads.

Oil fills the cavities (3) formed between the springs and intermediate pieces and is forced back and forth thru the gap (4) as the springs deflect. This movement of oil brakes the relative movement between the parts and vibrations are damped.

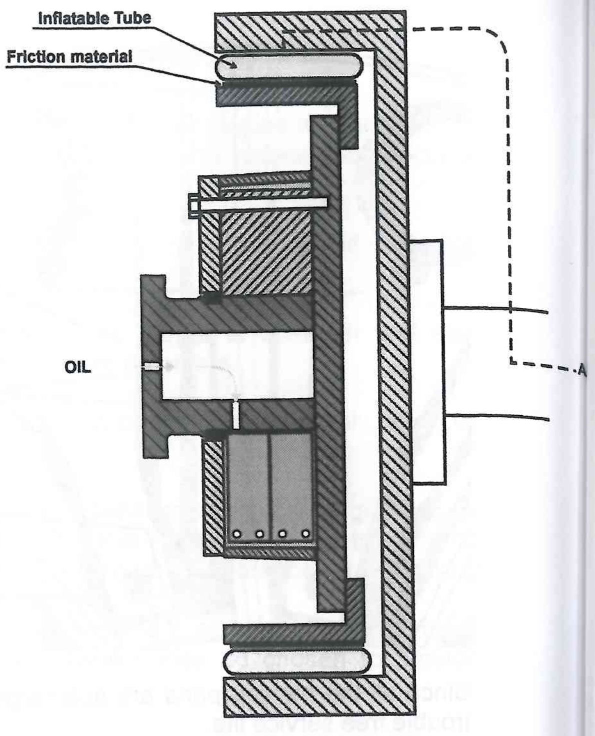
Since all the moving parts are submerged in oil, wear is minimal resulting in a long, trouble free service life.

To protect the springs from overstrain, their deflection is limited by means of buffers.



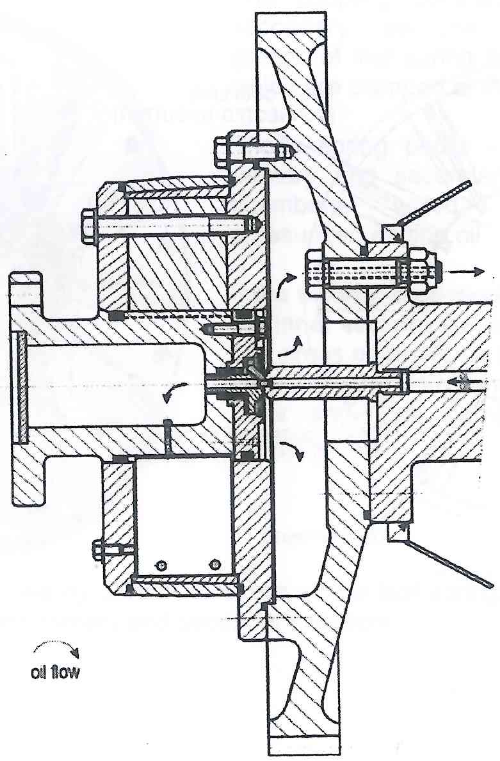


GEISLINGER COUPLING - PRINCIPLE



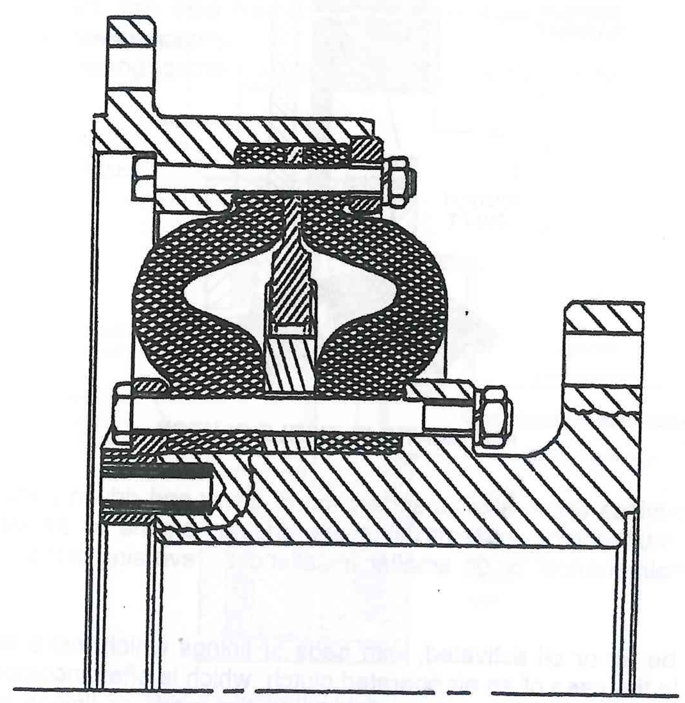
GEISLINGER COUPLING WITH AIR CLUTCH

Geislinger BC coupling - mounted to flywheel

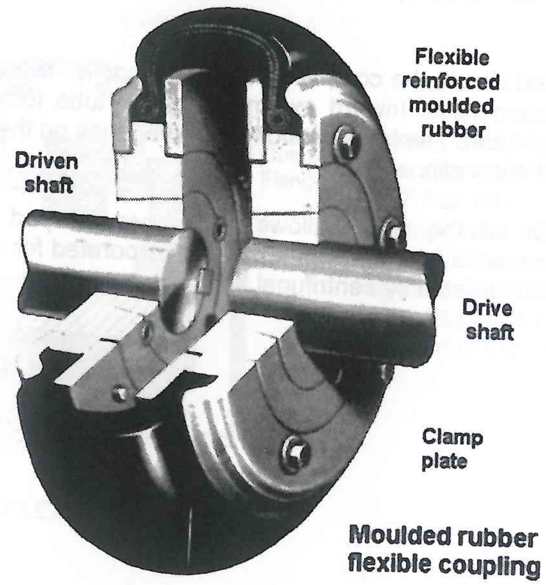


The Vulcan Coupling

Vulcan Coupling

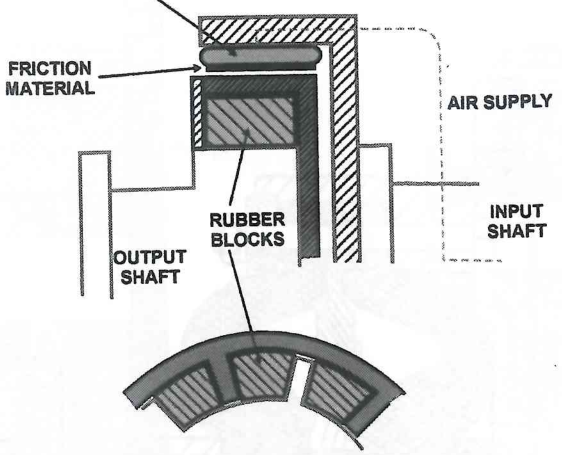


The Vulcan Coupling uses nitrile rubber tyres between driver and driven. Reference marks on the tyre and outer and inner casings indicate the amount of stretch of the coupling as it wears.



Moulded rubber flexible coupling

Chapter 2: Clutches



PNEUMATIC FLEXIBLE CLUTCH

Clutches are devices which allow a separation of driver and driven components,. The advantage in multi-engine systems is in allowing an engine to be disengaged for economy or maintenance, or on smaller installations, reversing without stopping the engine.

Clutches can be air or oil activated, with pads or linings which make either radial or axial contact. In the case of an air operated clutch, which is often incorporated with the flexible coupling, the application force for the friction pads or linings is supplied by compressed air in a reinforced neoprene rubber tube. The compressed air is filtered and moisture is removed by drains provided in the system. Air pressure is monitored and the low pressure alarm is important. Some form of rotary connection between the air supply pipe and the clutch is necessary, with the valve controlling the air supply to the clutch tube being operated by hand or remotely controlled by a solenoid or air pressure.

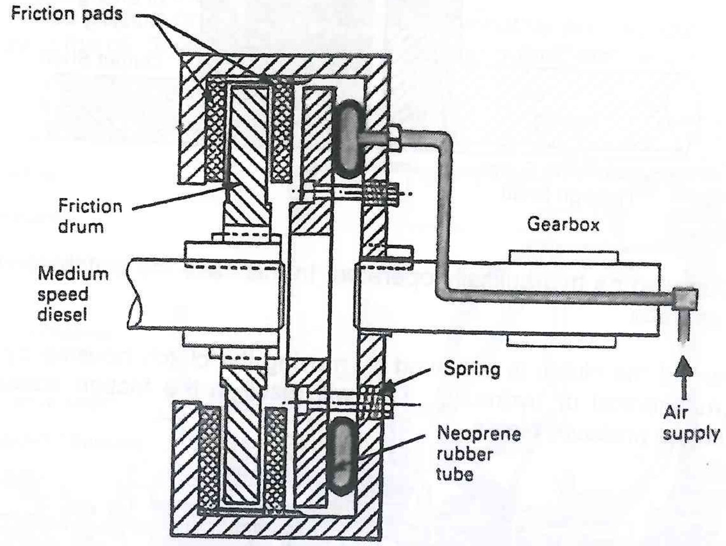
For a radial air operated clutch, the compressed air expands an actuating tube around the outside of the friction pads. Inward expansion of the tube forces the pads into contact with the friction drum. The transmission of torque relies on the air pressure and loss of pressure would allow slip.

The open construction of the clutch allows air access for pad cooling and the expanding tube compensates for wear. Springs are incorporated for disengagement of the clutch, which is also assisted by centrifugal effect.

Axial air operated clutch

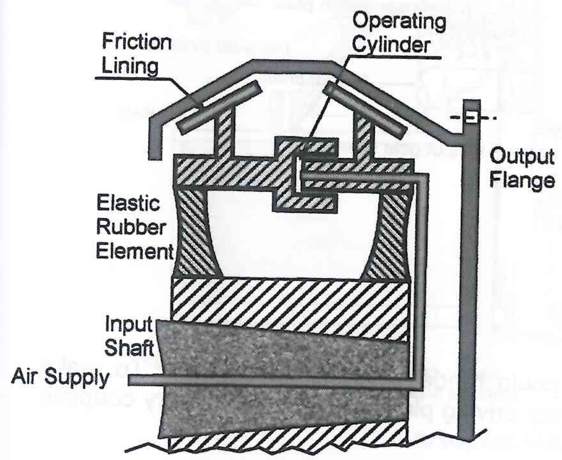
This type of clutch also uses a neoprene tube which is inflated by compressed air. Expansion of the tube produces a sandwich action between friction pads and disc. The friction disc or drum is spline mounted and therefore has axial float.

The friction pads are also free to float axially, being mated with teeth machined peripherally inside the casing.
Springs cause disengagement of the clutch when the tube is deflated.



Axial air operated clutch

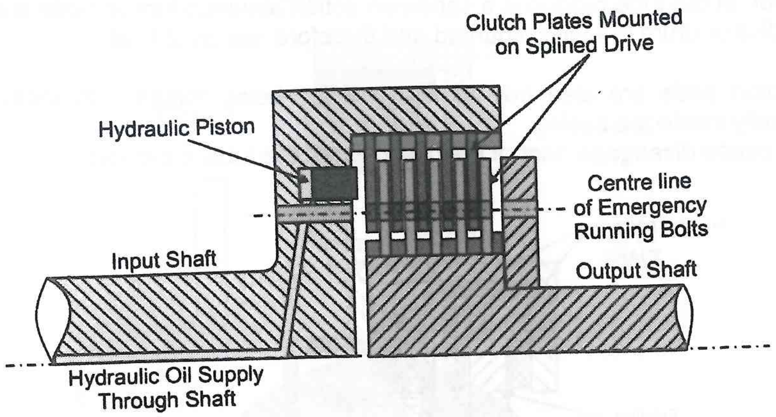
Pneumaflex Coupling



PNEUMAFLEX COUPLING

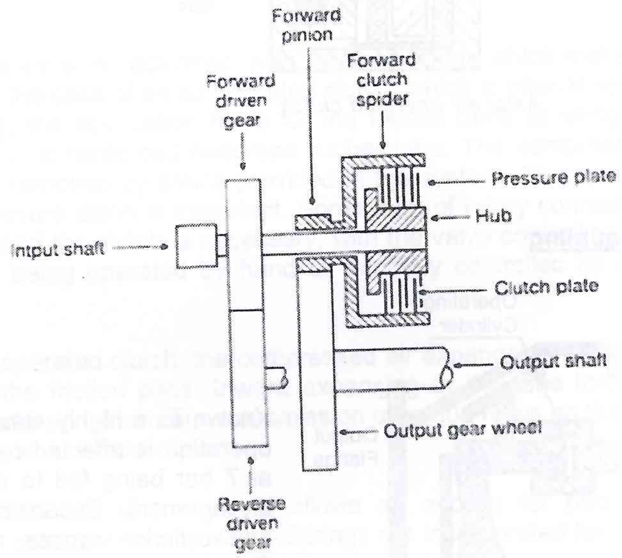
Known as a highly elastic friction clutch, operation is affected by compressed air at 7 bar being fed to an internal piston arrangement. Expansion of the piston and cylinder causes radially mounted Spiroflex rubbers to come into contact with rotating Ferodo pads. After a small amount of slip, the drive is picked up.

Hydraulically operated clutch



Clutches can also be hydraulically operated. In this case the clutch can be contained within the gearbox.

Engagement of the clutch is achieved by moving the clutch housing by means of an actuator (mechanical or hydraulic). This will result in the friction plates coming into contact with the pressure plates.



Emergency operation

Failure of the air supply or other fault could render a clutch inoperative. To make provision for this eventuality, an emergency driving plate, or set of temporary coupling bolts, is provided.

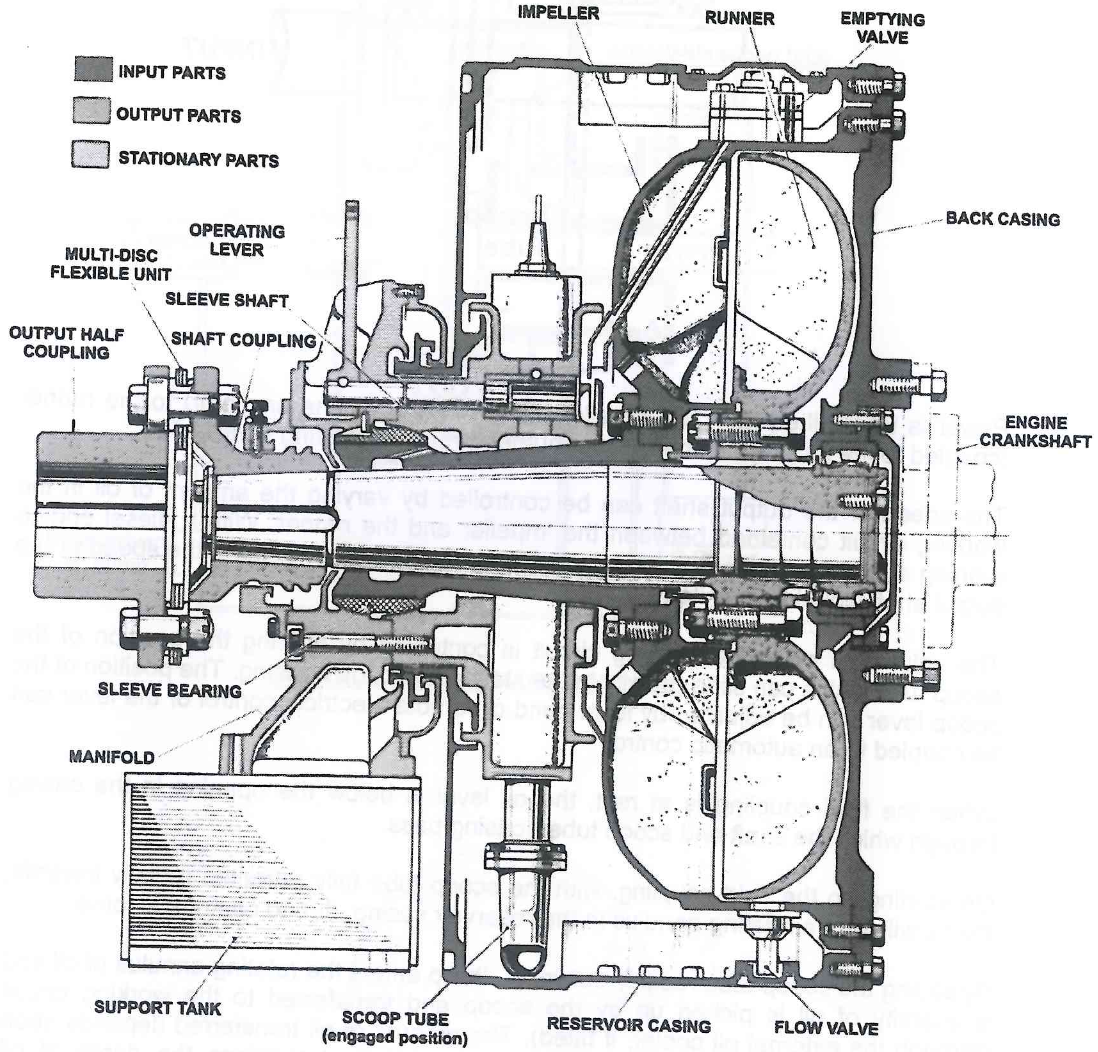
Prolonged use of the emergency solid coupling arrangement can result in serious damage to gear teeth.

Variable Speed Fluid Clutch Coupling

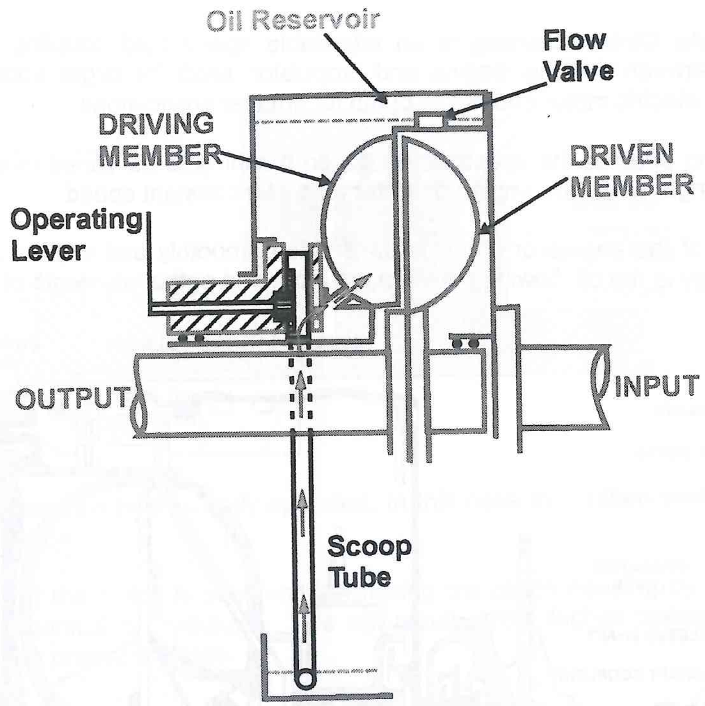
The Hydraulic Clutch Coupling is an adjustable speed fluid coupling designed for mounting between a diesel engine and propulsion shaft for larger applications, and between an electric motor and fan or pump for smaller applications.

The Coupling enables the speed of the driven machine to be varied over a wide and step-less range, whilst the engine or motor runs at a constant speed.

The power of the engine or motor is transmitted smoothly and without shock by the kinetic energy in the oil, flowing between the input and output elements of the coupling.



SINCLAIR VULCAN FLUID COUPLING



Power is transmitted from the impeller (driven by the engine or motor) to the runner (coupled to the propulsion shaft, fan or pump) through a rotating vortex of oil.

The speed of the output shaft can be controlled by varying the amount of oil in the working circuit contained between the impeller and the runner. With a diesel engine running at constant speed, the input shaft speed will be constant, but the speed of the output shaft would be infinitely variable.

The volume of oil in the working circuit is controlled by altering the position of the scoop tube which can slide radially in the stationary scoop housing. The position of the scoop lever can be adjusted by local hand or remote electrical control or the lever can be coupled to an automatic control.

When the fluid coupling is at rest, the oil level is below the opening in the casing through which the shaft and scoop tube housing pass.

On starting up the fluid coupling, with the scoop tube fully retracted radially inwards, the oil will form a rotating annulus in the reservoir casing, due to centrifugal force.

By sliding the scoop tube radially outwards, its tip enters the rotating annulus of oil and a quantity of oil is picked up by the scoop and transferred to the working circuit (through the external oil cooler, if fitted). The amount of oil transferred depends upon the radial position of the scoop tube, which in turn determines the depth of oil remaining in the reservoir casing.

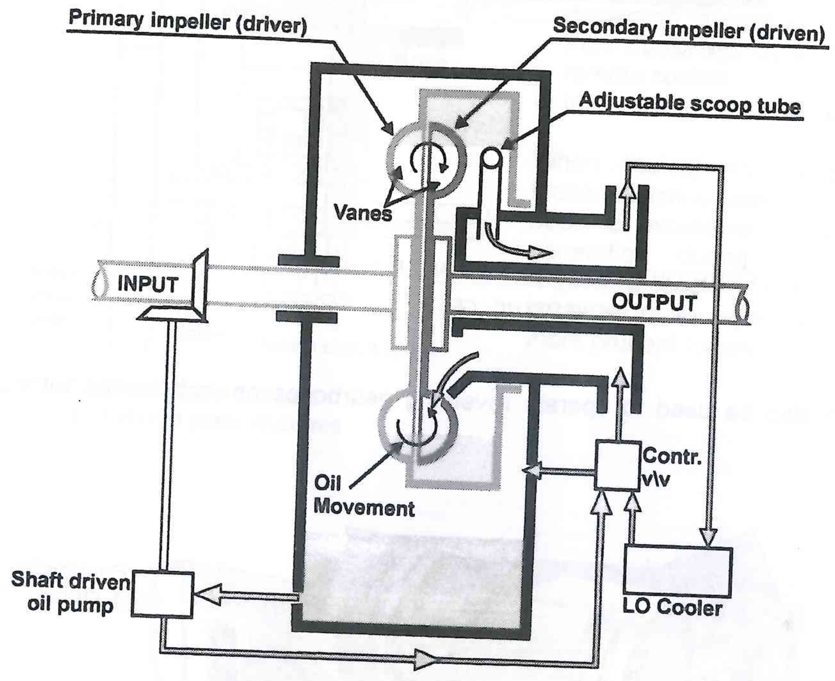
A continuous circulation of oil is maintained, as oil escapes from the working circuit through small leak-off holes into the reservoir casing all the time that the fluid coupling is running. This allows circulation of oil through an external oil cooler, if required, and

also allows the volume of oil in the working circuit to be reduced progressively as the scoop is retracted radially inwards.

It will be seen, therefore, that the amount of oil in the working circuit, and thereby the speed of the output shaft, is maintained at any desired value by the setting of the scoop tube, controlled by the external lever.

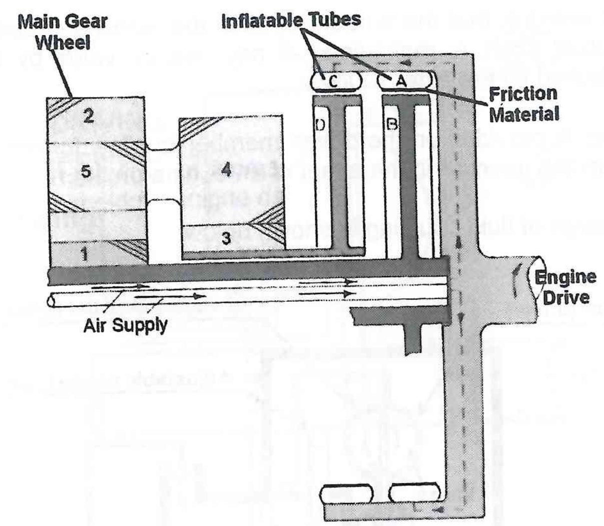
An oil dump valve is provided on the driven member to allow for rapid disengagement of the engine from the gearbox in the event of an engine problem.

An alternative design of fluid coupling is shown below:



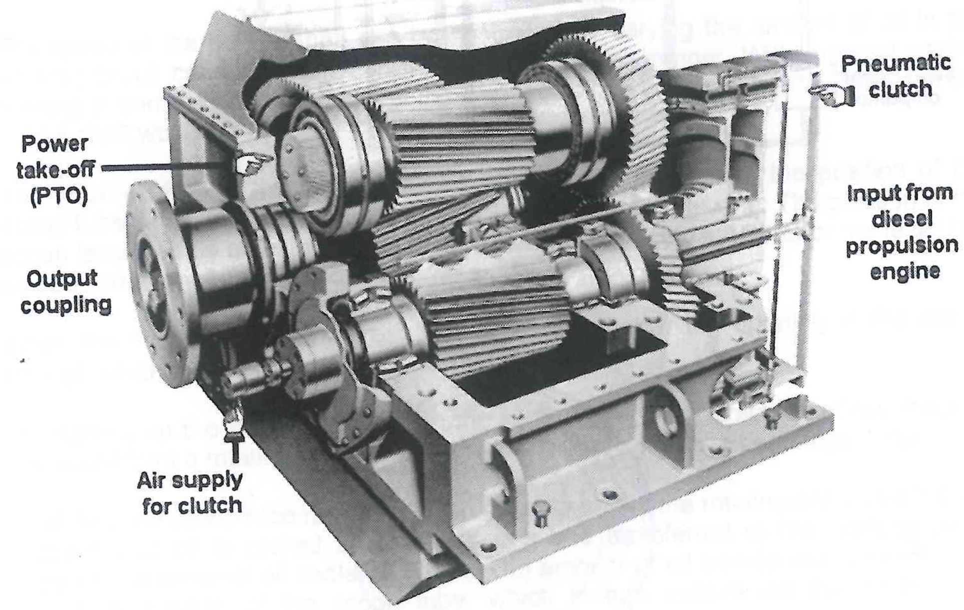
VARIABLE OUTPUT FLUID COUPLING

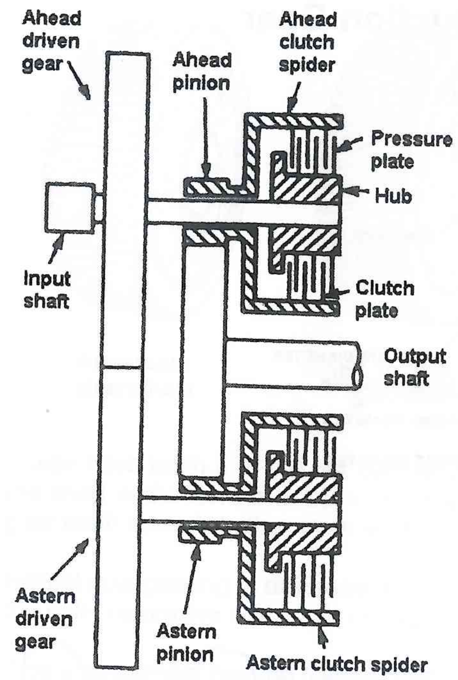
Reversing Gearboxes



FRICTION CLUTCH WITH SINGLE REDUCTION REVERSING GEAR

Clutches can also be used to operate reversing gearboxes on installations without CPPs.





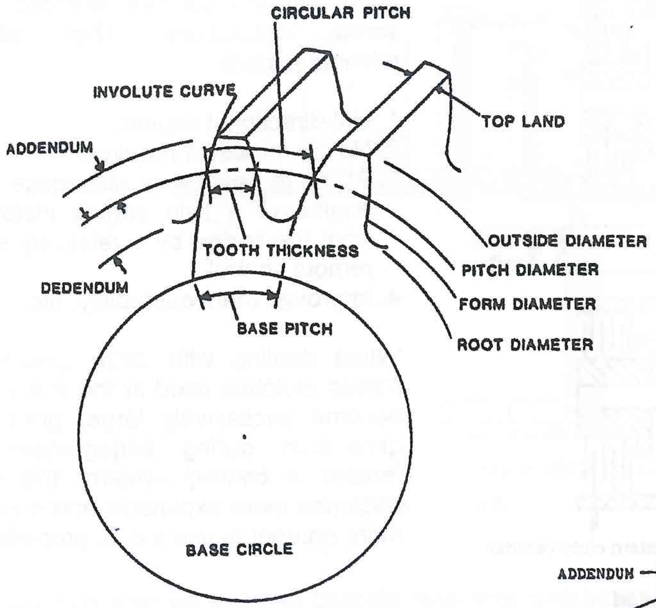
Gearbox with ahead and astern plate clutches

These gear systems are mainly restricted, at present, to powers of up to about 4800kW for twin engined single screw installations. Their obvious advantages are:

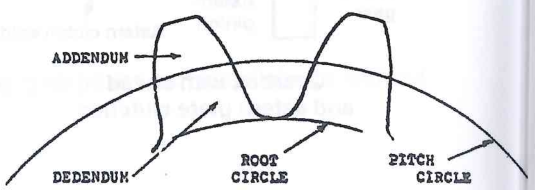
1. Uni-directional engine.
2. No c.p. propeller required.
3. Ability to engage or disengage either engine of a twin engine installation from the bridge by a relatively simple remote control.
4. Improved manoeuvrability, etc.

When dealing with large powers the friction clutches used in the system can become excessively large, great heat generation during engagement may require a cooling system, the whole becomes more expensive and it may be more prudent to use a c. p. propeller.

Chapter 3: Reduction Gear



Gear tooth nomenclature.



(b)
Gear tooth definitions

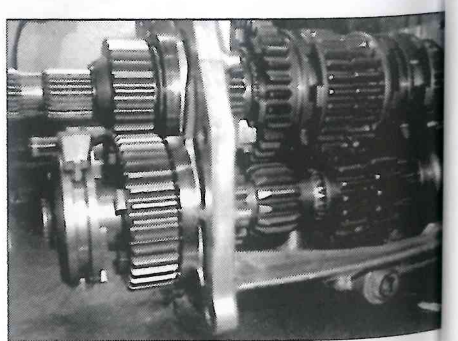
Four stroke diesel engines are designed to run efficiently at high speed.

In order to the use the power produced effectively, the diesel speed may need to be reduced to suit the particular application. Gears are also used on slow and medium speed engines to drive the camshaft and shaft generators.

This reduction in speed is carried out by means of gearing.

Two forms of gearing are used:-

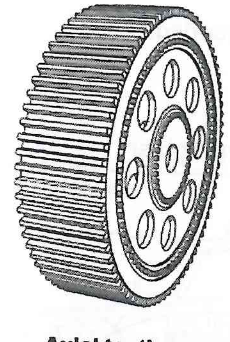
- Spur or helical.
- Epicyclic.



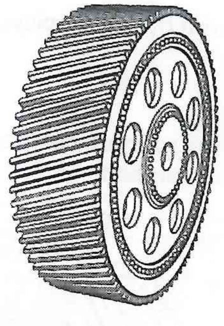
Parallel spur gearing is designed so that each gear tooth meshes simultaneously across the full axial length of the tooth. This arrangement has the following disadvantages:

- Load cannot be distributed evenly across the full face of the gear tooth.
- Only one gear tooth at a time can transmit load.
- Gears wheels mesh unevenly and noisily.

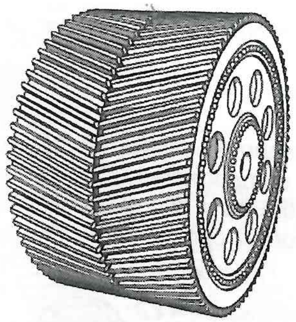
Helical gears



Axial teeth gearwheel



Single helical teeth gearwheel



Double helical teeth gearwheel

These have teeth that are not parallel to the axis of the shaft but are spiralled around the shaft in the form of a helix. Such gears are suitable for heavy loads because the gear teeth come together at an acute angle rather than at 90° as in spur gearing.

Helical spur gearing is designed so that each gear tooth remains meshed at the end of the helix before the next tooth engages at the start of the helix.

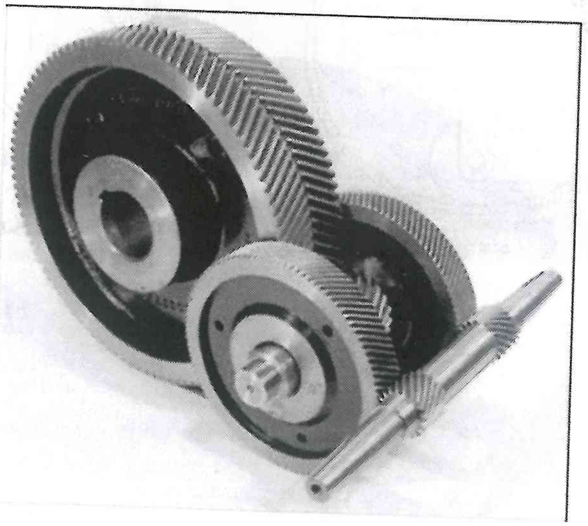
This arrangement has the following advantages:-

- Load is distributed more evenly across the full face of the gear tooth.
- More than one gear tooth is in mesh at the same time.
- Smoother and quieter operation.

Double Helical Gears

Single helical spur gearing has the disadvantage that it produces an axial thrust on the shafts and thrust bearings have to be used to keep the gears in alignment.

The axial thrusts produced by double helixes cancel each other out and produce automatic alignment.

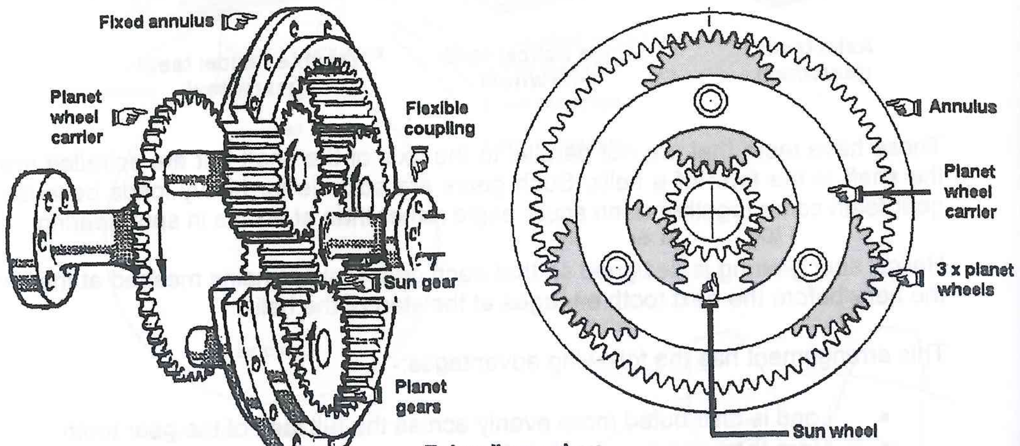


Epicyclic Gearing

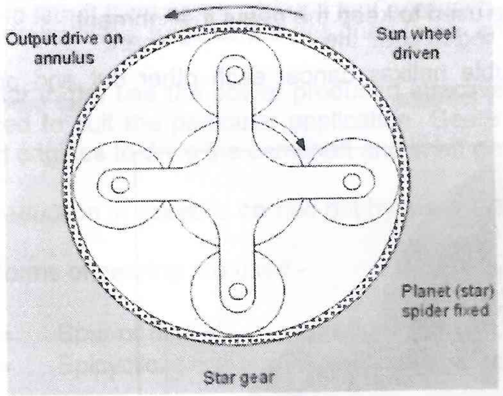
Construction costs and space can be saved by using epicyclic gearing.

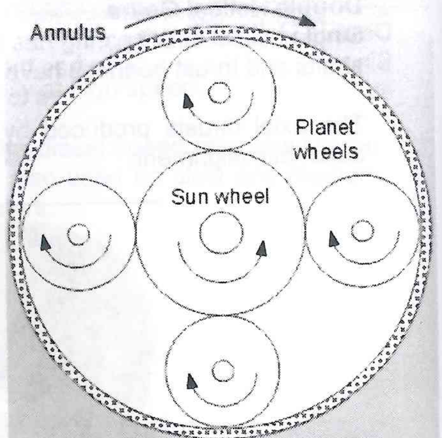
Advantages:

- Load is shared between several meshes so more compact and lighter
- Smaller components reduce noise and vibration
- Concentric input and output shafts
- Radial forces cancel each other out

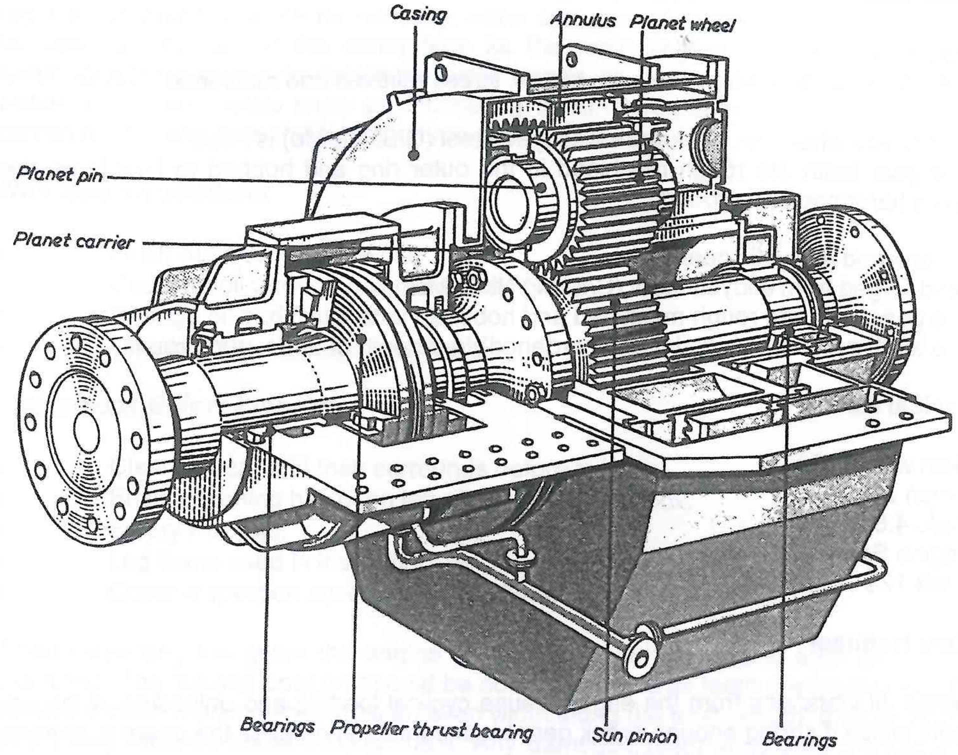


Epicyclic gearbox





SUN AND PLANET ARRANGEMENT



planetary gear for diesel drive.

Materials

Main gear:
Initial fabrication is from steel web plates, stress relieved and machined.

A separate wheel rim of hardened alloyed steel (C/Si/Mg/Mo) is fitted.
The gear teeth are rough machined in the outer ring and hobbed to final form, then flame hardened and ground.

Pinions and epicyclic gearing:
Solid forged from alloyed steel (C/Si/Mg/Ni/Cr/Mo)
The gear teeth are rough machined and hobbed.
The teeth are then nitrided (case hardened) to a depth of 2mm. and ground.

Typical Ratio

Main wheel 150
Pinion 31
Ratio 4.84:1
Engine Speed 620
Shaft 128

Gear Hammer

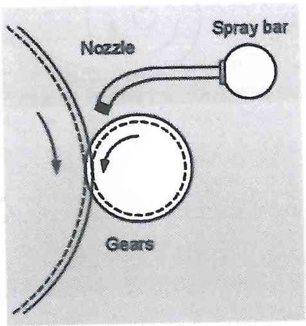
Torsional vibrations from the engine cause cyclical loading and unloading of the gear teeth which if strong enough break gear tooth contact and cause the gears to separate and close, hammering violently.

Causes
- Wear steps
- Exfoliation
- Increased surface roughness.
- Accelerated wear
- Fatigue cracks
- Possible tooth failure.

Prevented/eliminated by fitting torsional vibration dampers and flexible couplings.

Lubrication Systems

The gearbox will have its own lubricating oil circulation system with pump, filters and a cooler. The pump is usually driven by the gearbox itself and an electrically driven pump is normally used during start up. The oil is supplied under pressure to the shaft bearings and sprayers. The sprayers are located to apply oil across the width of the gear teeth just prior to the contact point.



Oil may also be supplied to a header tank above the gearbox. Following oil pump failure this will allow lubrication while the gearbox is coming to rest.

The condition of the lubricating oil is particularly important. The oil should also be regularly analysed to check for viscosity, water and wear elements. Oil samples should be sent for analysis at the same time as the main engine. This should include spectrographic analysis to determine wear metals as well as to test for water and viscosity. If wear metals show an increasing trend, ferrographic analysis should be carried out to determine the size and type of wear particles.

With New Installations

- Flush out debris before use
- Circulate oil through commissioning filters
- Change oil and filters after trials
- Check magnetic plugs and filters

Precautions Before Inspection

- Clean covers and their surrounds before removal.
- Ensure nothing has been left on top of the gearbox.
- Empty Pockets.
- Log items used in inspection: torch, camera, notebook and pen.
- Cover inspection access with polythene if left without cover.

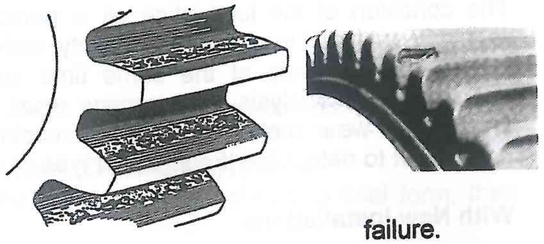
When inspecting the gears the engine should be turned slowly and each gear tooth examined. The starting position should be noted to ensure all teeth are inspected. The surface contact marking should be an even width along the tooth length. If wider at one end it may indicate some misalignment. Any damaged teeth should be marked and sketches or photographs of the damage taken for use during future inspections.

Gearing Faults

The basic failures of gears are due to:
- Overload leading to Flaking (spalling, exfoliation).
- Bending fatigue.
- Pitting.
- Adhesive wear (Scuffing)
- Abrasive wear
- Corrosion.
- Polishing.
- Cavitation.
- Electrical damage.

Cavitation and electrical damage are rare, however, electrical damage can cause small pits due to ineffective earthing or defective shaft earthing equipment.

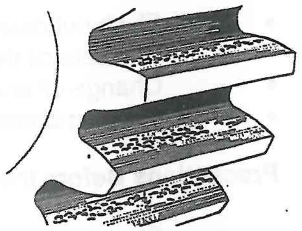
Flaking



- Caused by abnormal tooth loading
- Stresses subsurface metal
- Chips and flakes break away

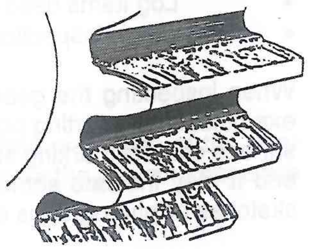
Pitting

- Common cause of gear tooth failure.
- Fatigue process initiates a crack.
- Crack propagates then a piece of metal breaks away leaving a pit.
- Surface cracks due to thin oil film.
- Cracks below surface caused by inclusions in the metal.
- Abrasive particles can cause pitting by embedding in surface forming stress raisers



Adhesive or Scuffing Wear

- Mild adhesive wear during running in as surface asperities are removed – run at reduced load.
- After running in classed as mild if it only causes wear to oxide layers
- Caused by metal to metal contact: reduced lubrication or excessive temperatures



Scuffing is severe adhesive wear. The high load between the gear teeth and the sliding material is removed from one tooth.

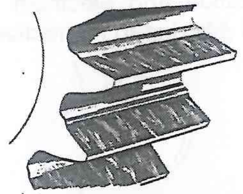
Gear oils should contain Extreme Pressure (EP) additives containing antiscuffing compounds.

Polishing

In some cases the excessive pressure (EP) additive may cause polishing of the gear teeth causing them to adopt a highly polished appearance. If this occurs a different EP additive could be required and the oil supplier should be contacted.

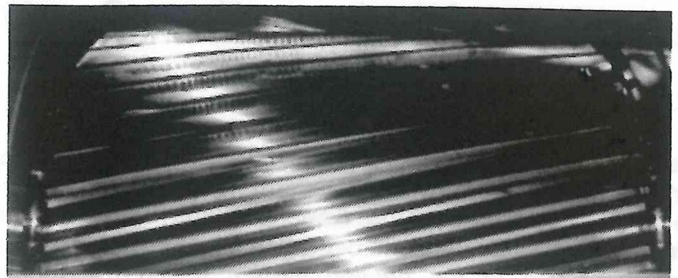
Abrasive Wear

Abrasive Wear is caused by contaminants in the oil which may occur due to the following:

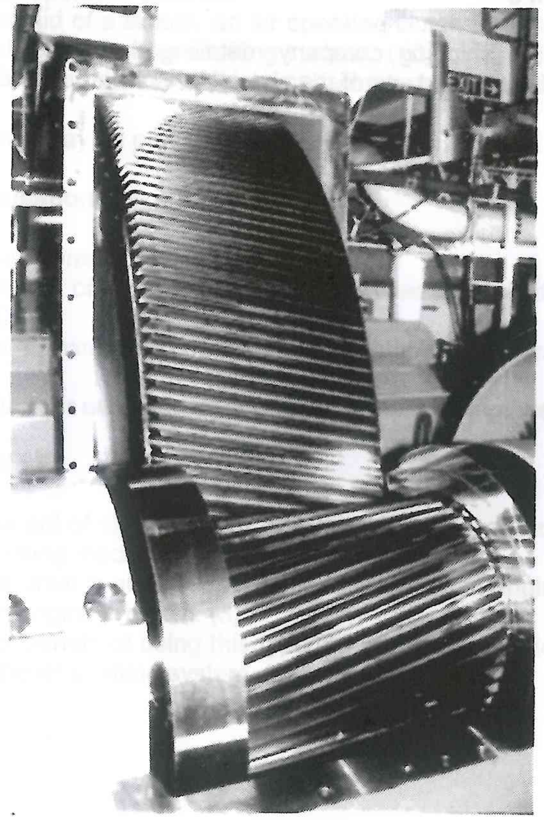


- Internally generated due to wear.
- Introduced during maintenance.
- Leaking seals or cover joints.
- Leaking breathers.

Dirt causes scoring of the teeth in the sliding direction and, as previously stated, may become embedded in the teeth and lead to stress concentrations. Breathers on the gear casing should have filters fitted and all seals and joints should be tight to prevent dirt ingress.



"Tiger Striping" on a gear pinion caused by misalignment.



Chapter 4: Chief Engineers Exam Questions

October 2006 Question 3

With reference to a medium speed engine driving a controlled pitch propeller through a reduction gear system:

a. explain the term gear hammer, the damage it can cause and what may be incorporated into the system to reduce or eliminate it; (8)
b. describe the inspection of the gearing system during the running in period, explaining what checks should be made and what defects may be found. (8)

April 2005 Question 8

Write a report to the shipping company, detailing the inspection of the gearbox following a period of prolonged use of the clutch in the emergency drive. (16)

Chapter 5: Second Engineers Exam Questions

July 2006 Question 8

With reference to medium speed engine and gearbox installation:

a. describe an oil operated clutch arrangement fitted within the gearbox; (10)
b. explain the precautions that should be taken when clutching in; (3)
c. state how the engine is protected against overspeeding in the event of clutch failure. (2)

December 2005 Question 8

With reference to air-operated clutches:

a. describe, with the aid of a sketch, an air operated clutch for a medium speed diesel drive to a gearbox and propeller shafting system; (10)
b. explain how the transmission of torsional vibrations from engine to gearbox is prevented; (4)
c. state how the drive may be provided following air supply failure. (2)

December 2004 Question 8

With reference to oil operated clutches:

a. describe, with the aid of a sketch, a clutch for a medium speed diesel engine drive to a gearbox; (10)
b. explain how the transmission of torsional vibrations from engine to gearbox is prevented; (4)
c. state the procedure for engaging the clutch after starting engines. (2)

March 2002 Question 8

a. Describe with the aid of sketches, the operating principle of a clutch in which oil is the power transmitting medium. (10)
b. Describe how the drive is arranged for rapid isolation of an engine from the gearbox in the event of an engine problem. (3)
c. Explain the major benefit of using this type of clutch for a medium speed drive to a gearbox and propeller shafting system. (3)

Governors

Contents

Chapter 1: Introduction

Terminology:

a) Speed Droop: The proportional and permanent drop in speed of an engine-governor combination with increase in engine load. It has a stabilizing effect.

b) % speed droop = $\dfrac{\text{No load RPM} - \text{Full load RPM}}{\text{Full load RPM}} \times 100$

c) Droop is required in a governor to give stability. ***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

d) Isochronous: The characteristic of holding a constant steady-state speed for any load between no-load and full-load without any speed adjustment being made. It is the same as "zero speed droop."

e) Compensation: The method by which speed droop, usually a large amount, is used for stability but only temporarily. It may be termed "temporary speed droop."

f) Deadband: The change in speed required before the governor action takes place.

g) Stability: The ability to achieve equilibrium for different loads.

h) Hunting: Temporary variation in speed until the governor settles down to a steady speed.

Note on Droop

Although a small governor droop means a small difference between the `full load' and `no load' steady rpm, it also means a rapid swing from full fuel to no fuel if a small rise in speed occurs.

When a change in load occurs an interval of time is bound to elapse before the engine torque alters to match. This delay arises from several causes: friction has to be overcome so that a small change in speed occurs before the governor takes any action; inertia of the components requires a finite time for the fuel pump rack to reach its new position and when it is in the new position no effect can begin to be felt until combustion takes place in the first cylinder to fire after the change has been made; the effect will not be complete until all the cylinders have completed a cycle.

During this period the speed is continuing to change and a sensitive governor will continue to adjust the fuel pump rack position so that over correction occurs. This will result in too large a change in speed and will be followed by a correction in the other direction. Equilibrium may be reached only after several oscillations.

A large governor droop giving a slower response to the change in speed will not have such a strong tendency to overshoot and equilibrium will be reached without a large number of rapid alterations and in many cases it will be reached in less time than with a sensitive governor.

Note on Governor Response

To make a governor more responsive, the weights are required to be smaller (inertia effects). So to provide the same flyweight output (centrifugal force) the speed of the flyweights or their spread must increase. Usually the flyweights are driven at a greater speed than the engine to achieve this.

Reducing the friction/viscosity of oil in the mechanism, will reduce the change in force required to move the pilot valve, and thus reduce dead band effects. Note that governors use ball bearings wherever possible to reduce frictional effects.

Note on Flywheel Effect

The function of the flywheel is to dampen down the speed fluctuations resulting from the individual cylinder outputs, and variations in engine speed/load changes.
The flywheel achieves this by storing the surplus kinetic energy when the speed rises, and shedding kinetic energy when the speed drops.

Kinetic energy = $\frac{1}{2} m \omega^2 k^2$
Where:

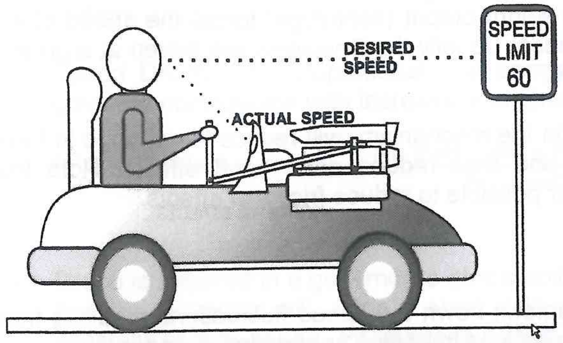
- m = mass of flywheel
- ω = angular velocity in radians per second
- k = radius of gyration

Increasing the size (mass or dimension) of the flywheel reduces engine speed fluctuations, but also increases the time taken for the engine to return to the desired speed following a load change, as the additional fuel energy must increase the rotational inertia of the whole shafting system.

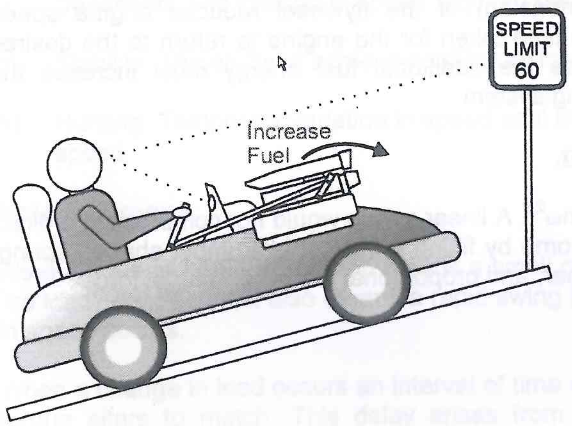
<u>Note On Shape Of Speeder Spring.</u>

Centrifugal force is proportional to $m\omega^2 r$. A linear spring would not compress in a direct relationship to speed. This is overcome by fitting a conical or trumpet shaped spring, the compression of which is non linear, and proportional to the centrifugal force

Chapter 2: Principle of the Governor

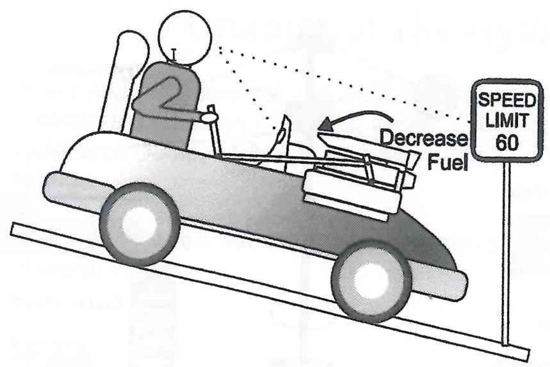


- The driver of the car is the CONTROL or GOVERNOR
- The speed limit sign is the desired speed setting.
- The speedometer senses actual speed.
- The driver compares desired speed to actual speed, if they are the same, fuel is held steady.
- If desired speed and actual speed are different, the fuel setting is adjusted by the driver to make actual speed equal desired speed.
- Fuel is held steady until a speed or load change occurs.

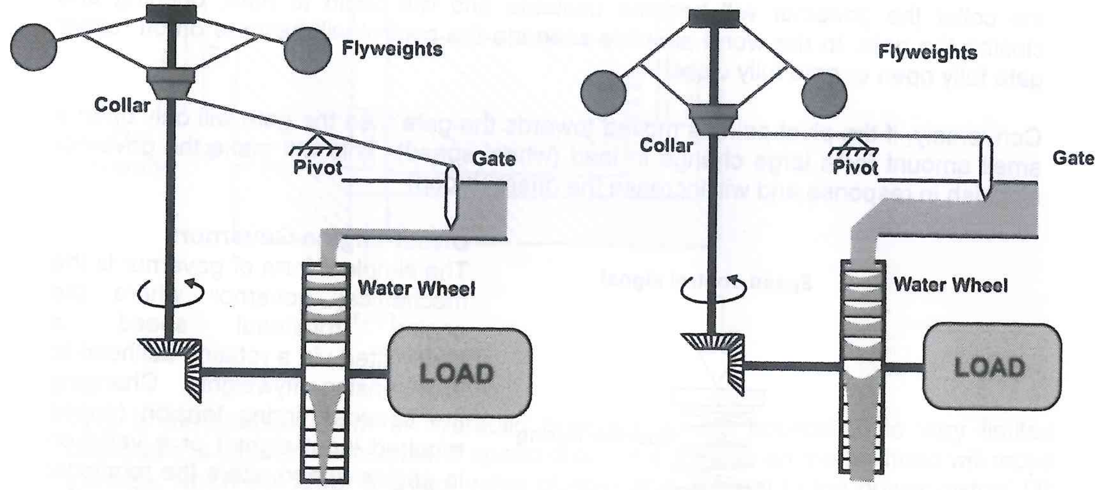


The car starts up the hill, load increases, speed decreases.

- The actual speed is less than desired speed.
- Driver increases the fuel to increase the speed, which returns the actual speed to the desired speed.
- Before the actual speed reaches the desired speed, the driver reduces the fuel to prevent overshoot of speed. This is called COMPENSATION and is adjusted to match the response time of the prime mover.
- It takes more fuel to pick up load than to maintain load.



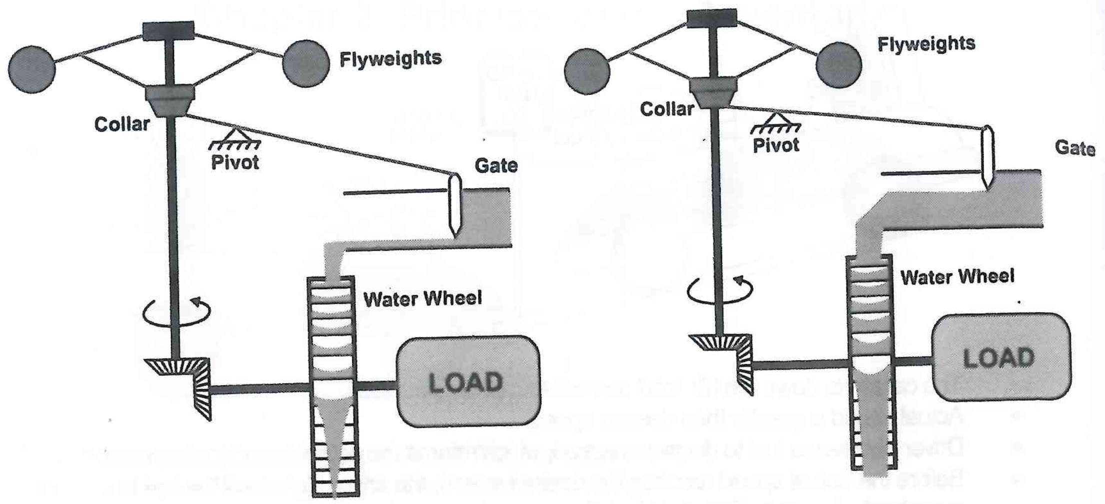
- The car starts down the hill, load decreases, speed increases.
- Actual speed is greater than desired speed.
- Driver decreases fuel to decrease speed, which returns the actual speed to desired speed.
- Before the actual speed reaches the desired speed, the driver increases the fuel to prevent overshoot of speed. This is called Compensation and is adjusted to match the response time of the prime mover.



The water wheel is running at constant speed driving a load. The load is increased, so the water wheel starts to decrease in speed. Because they are rotating more slowly the fly weights move inwards due to the decrease in centrifugal force, thus lowering the collar and opening the gate increasing the flow of water to the wheel.

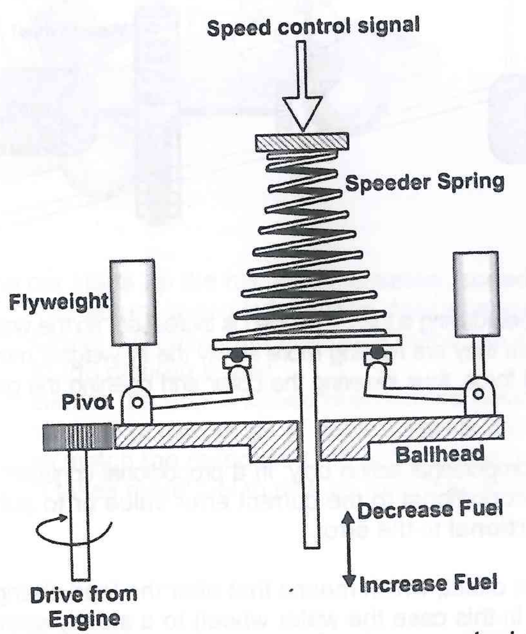
In this simple example the governor has proportional action only. In a proportional controller a change to the output is made that is proportional to the current error value or to put it another way the control effort is **proportional** to the error.

Proportional control will always have an offset, which means that after the load change the governor will return the engine (or in this case the water wheel) to a steady speed which is not the speed it originally was turning before the load change. The difference between the two speeds is the offset, or droop.



If the pivot point is moved closer to the collar, then a small change in load (and wheel speed) will lead to a large change in the position of the gate, i.e. output. This is known in control theory as increasing the proportional band. By moving the pivot too close to the collar the governor will become unstable and will begin to hunt, opening and closing the gate. In the worst possible scenario the control will become on-off: either gate fully open or gate fully closed.

Conversely, if the pivot point is moved towards the gate then the gate will only open a small amount for a large change in load (wheel speed). This will make the governor sluggish in response and will increase the offset (droop)



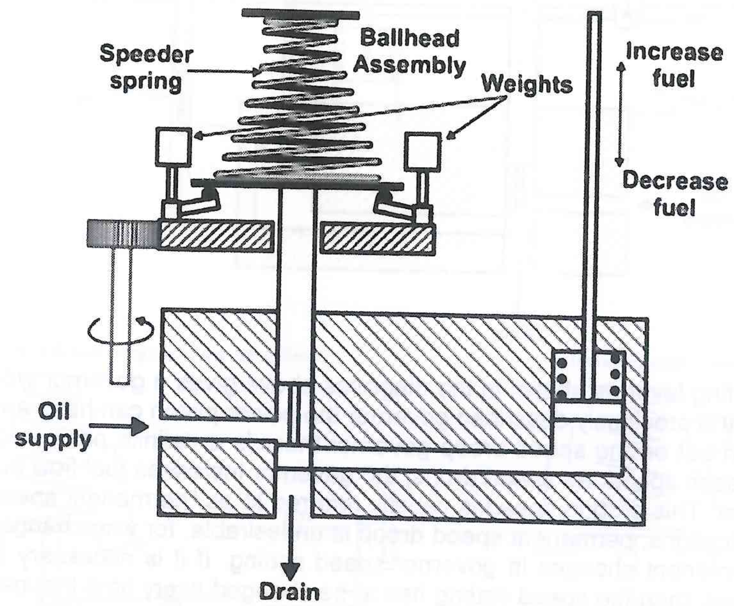
Diesel Engine Governors
The simplest form of governor is the mechanical governor where the engine rotational speed is transmitted via a rotating ballhead to the sensing flyweights. Changing the speeder spring tension (speed required input signal) or a variation in engine speed alters the rotational orbit of the weights which alters the position of the fuel racks through a mechanical linkage.

Because the position of the fuel racks will have altered the balance between flyweights and speeder spring will be achieved at a different speed. (offset) This governor also has the tendency to hunt before settling down to a steady speed. The governor has to develop the power to operate the fuel racks. Larger flyweights have a higher torque output and thus develop larger powers, but this makes the governor sluggish in operation (larger variations in speed because the governor is less sensitive). For these reasons this governor is not used.

Chapter 3: The Hydraulic Governor

In a hydraulic governor the ballhead no longer acts on the fuel linkage, but instead controls the position of a pilot valve. The pilot valve controls the flow of oil (from an integral oil pump) to and from a servo piston. The servo piston is connected to the fuel linkage.

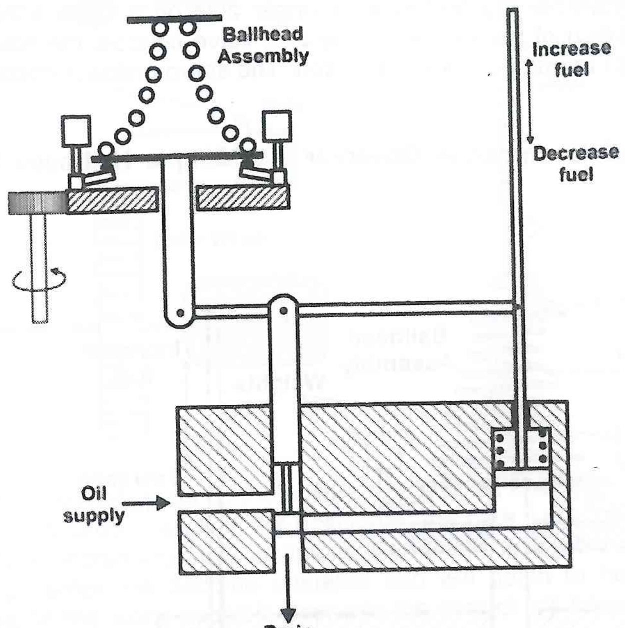
Uncompensated Isochronous Governor – A Simple Hydraulic Governor With Integral Action



This is the simplest form of hydraulic governor but its application is very limited because it is inherently unstable. If speed drops, the weights on the ballhead will move inwards, which will lower the pilot valve plunger and pass oil to the power piston. Oil will flow to this piston and increase fuel until speed returns to normal and thus bring the weights back to centre and cut off the flow. Due to even minute time delays in the system, the governor will always over travel in applications where required correction rate is fairly fast. This will cause the speed to oscillate (hunt) continuously and prevent the governor from ever reaching a stable position. Although this instability prevents the common use of this governor, this principle does have the advantage of trying to hold the same speed (isochronous) regardless of the load on the engine.

The action of this governor in trying to maintain constant engine speed is known as integral action.

Proportional Action Speed Droop Governor

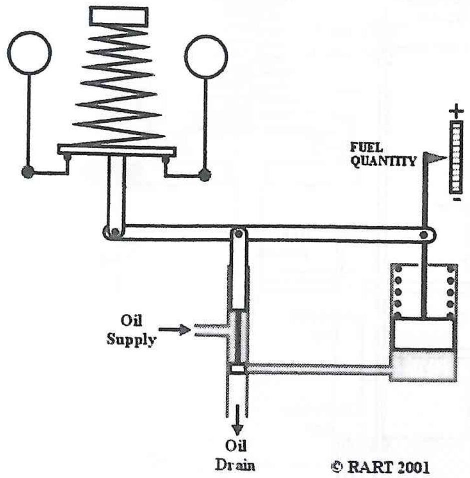


The addition of a floating lever as shown in the diagrams above gives a governor with inherent stability. On the previously described governor the power piston can have any position at equilibrium but on the speed droop governor there is a definite position of the power piston for each speed. As speed drops, the governor increases fuel flow but this drop is permanent. This drop in speed is usually referred to as "permanent speed droop." In many applications, permanent speed droop is undesirable, for with changes in load there are permanent changes in governor speed setting. If it is necessary to hold to a definite speed, then the speed setting has to be changed every time the load changes.

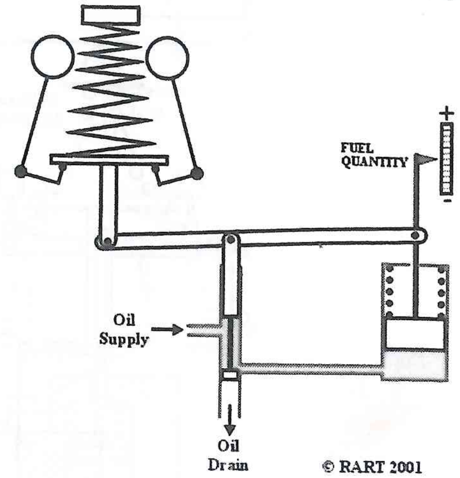
Its inherent stability and simplicity are the greatest advantages of this governor. In many cases the droop required to produce stable operation is objectionable. It has to be made adjustable in order to adapt it to different engines if minimum droop values are to be obtained.

The series of sketches illustrate that after a change in load the engine is running at a steady speed, although different from that before the load change.

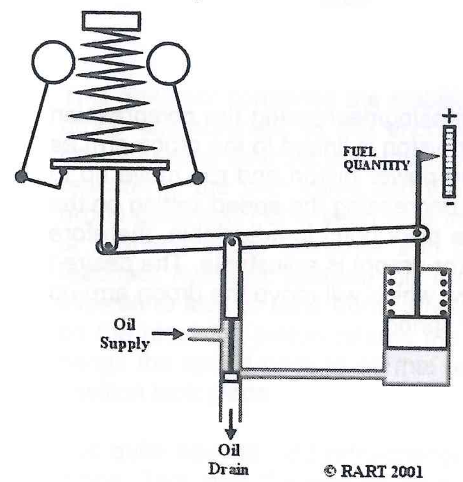
1. Engine running at constant speed



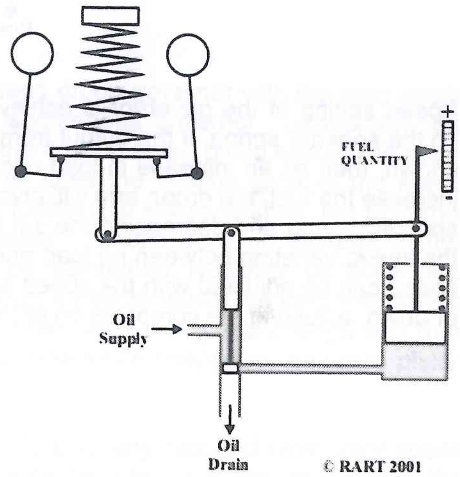
2. Decrease in speed. Weights move inwards. Oil valve opens



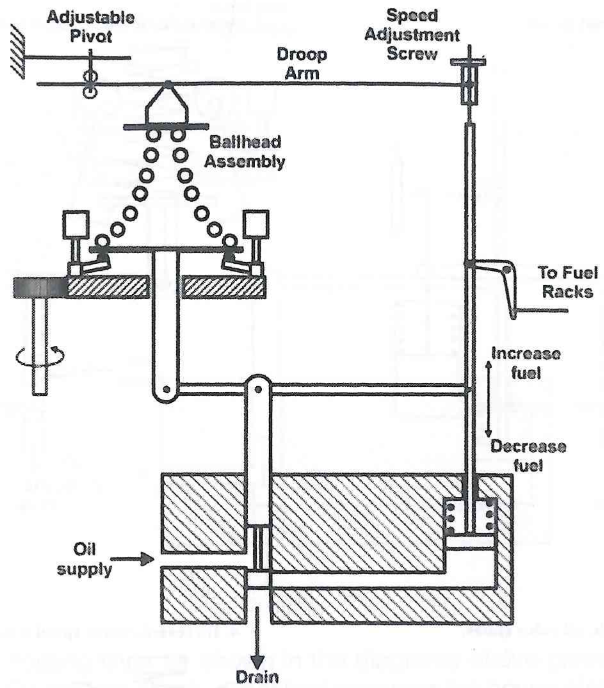
3. Fuel rack moves upwards, oil valve closes.



4. Increased engine speed moves linkage to close oil valve

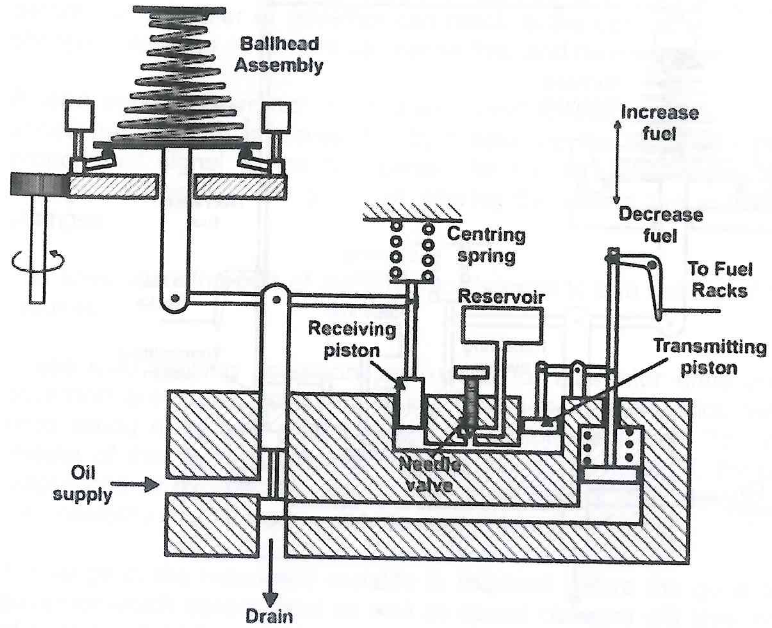


Proportional Action Governor with Adjustable Droop



Speed setting of the governor is achieved by increasing/decreasing the compression on the speeder spring. If the output from the power piston is linked to the droop arm as shown, then as an increase in load occurs and the power piston and rod move up to increase the fuel, the droop arm will pivot upwards decreasing the speed setting on the speeder spring and decreasing the set speed. The pivot point is adjustable, therefore the speed variation between no load and full load (or droop) is adjustable. The desired speed can be adjusted with the speed setting screw which will move the droop arm up or down, adjusting the compression of the speeder spring.

Isochronous Governor with Proportional + Integral Control (Compensation)



This governor combines the stability of the speed droop governor with the zero speed droop characteristic of the uncompensated isochronous governor. Temporarily, the compensating dashpot assembly, inserted in the floating lever, gives exactly the same reaction at the pilot valve and the ballhead as does the floating lever of the speed droop governor. For a short time immediately following a speed change, the governor is a speed droop governor and has its stability. If there were no leakage in this feedback hydraulic system, this droop would be maintained. However, because oil is allowed to leak to (and from) a reservoir through a needle valve, the centering spring on the receiving piston returns the piston to centre after the speed change and thus brings the speed back to normal regardless of how much change in the servo piston position took place.

It is quite easy to add ratio-changing features to give any required temporary speed droop. This, plus the needle valve, makes it quite easy to "tune" the governor to the engine.

This principle then combines the desirable features of the first two governors and omits the undesirable.

Note: **Isochronous:** From the Greek Iso meaning one and chronous meaning speed.

I.e. one speed or constant speed governor

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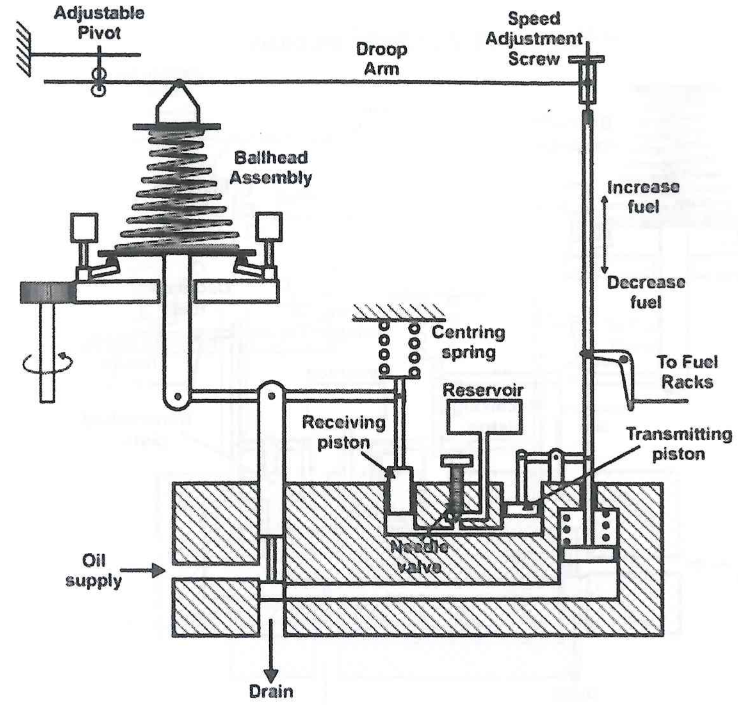
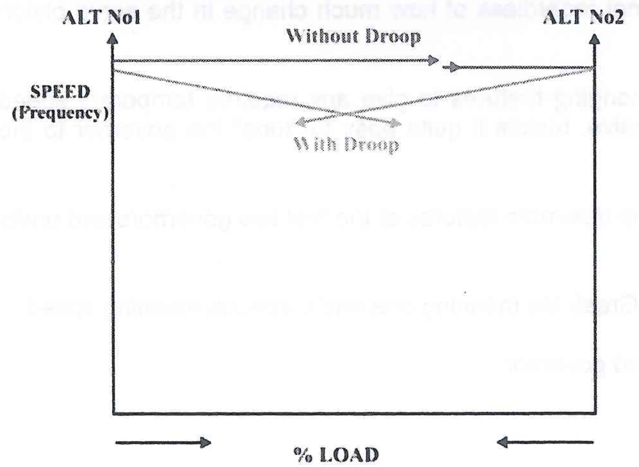


Droop can be built in to the isochronous governor as it was to the speed droop governor.

Why is Droop Needed

When two or more engines are sharing a load, e.g. generators supplying a switchboard or two or more engines driving a single propeller through a gearbox, then the governors must incorporate droop to prevent one engine trying to take all the load.



In the graph alternator No 1 is running at a faster speed than No 2. As it slows down as the load increases, the governor responds by increasing the fuel, returning the engine to its original speed, and so it takes the load from No2.

With droop, as the load increases the governor maintains a speed decrease and so the alternators share the load equally (as long as the droop setting is the same).

Chapter 4: The Load Sensing Governor

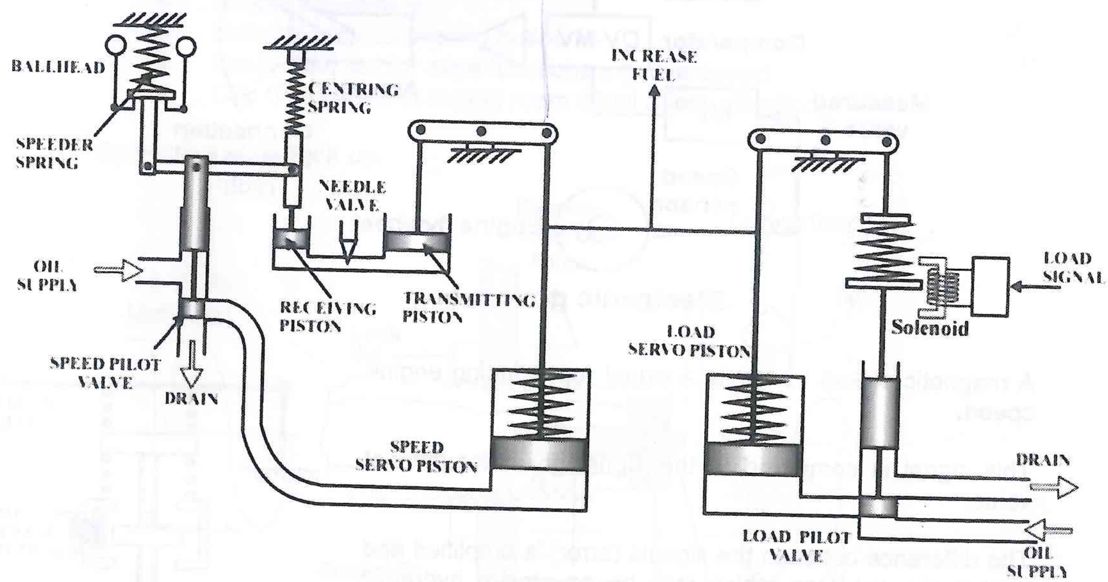
With feedback control systems, there must be a change of the measured variable, before the controller or governor can react. In the case of governors, the speed must change before the governors can sense this, and then adjust the fuel pumps.

A load sensing governor incorporates feed forward control which will anticipate a speed reduction. It achieves this by measuring the required load, and producing a proportional signal to the fuel pumps for the required torque output. Thus a load change will result in the governor altering the fuel to the engine, before the speed changes.

The speed sensing part of the governor is used to trim the signal for the exact speed required.

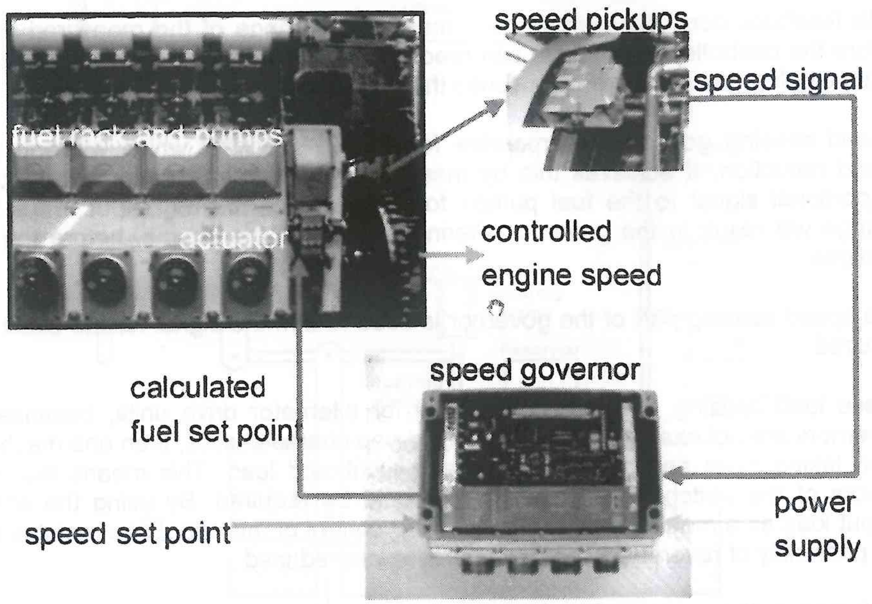
These load sensing governors are useful for alternator drive units, because if the governors are not exactly matched in their droop characteristics, then one machine will keep taking more and more of the total switchboard load. This means that regular checks of the switchboard load sharing would be required. By using the alternator output load as a measured value, then closer control of this should be maintained and the possibility of reverse power trips operating are reduced.

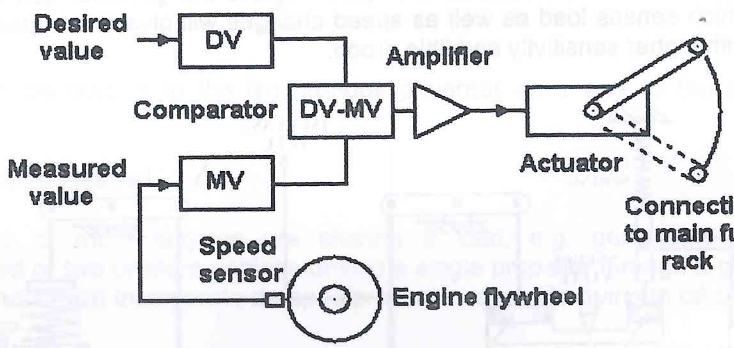
A change in the measured variable is required before the governor can respond. A governor which senses load as well as speed changes will give much greater control of speed, with higher sensitivity and little droop.



The governor shown above consists of a mechanical hydraulic speed sensing and electro-hydraulic load sensing governor. The speed and load sensing are independent of each other. The load change is sensed before a speed change so the primary governing is done by the load sensing element. The speed sensing can be classed as a fine correction facility and also a back up to the load sensing element.
The load sensing is achieved by electronic circuits which in turn control a solenoid operated pilot valve.

Chapter 5: The Electronic Governor





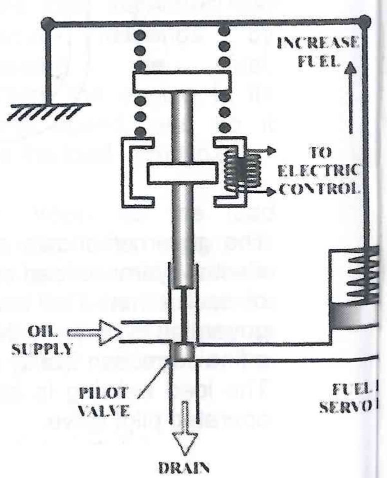
Electronic governor

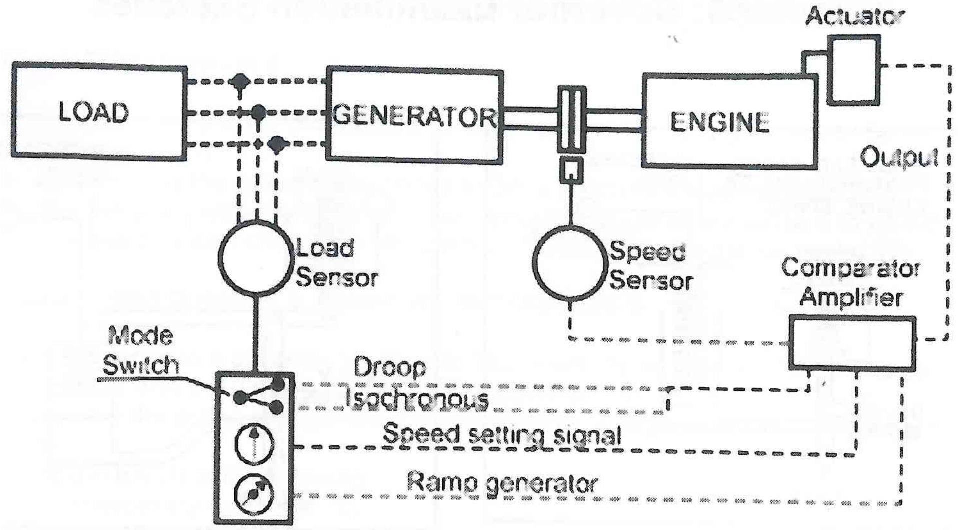
A magnetic pickup transmits a signal representing engine speed.

This signal is compared to the signal given for the set value.

The difference between the signals (error) is amplified and sent to the actuator, which may be an electro hydraulic servo valve (shown right) which converts the signal into a mechanical movement of the fuel racks.
Can be programmed to avoid running in a barred speed range and to increase the load slowly during build up to full revolutions.

Can incorporate load sharing, synchronising, power sensing etc.



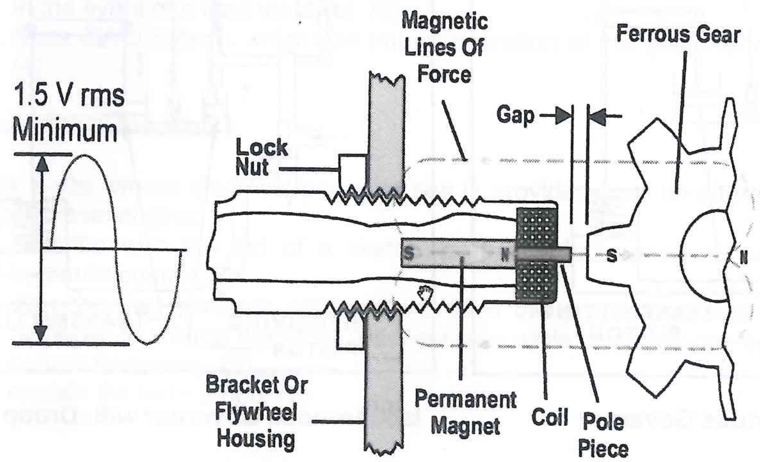


ELECTRONIC LOAD SENSING GOVERNOR

Advantages:

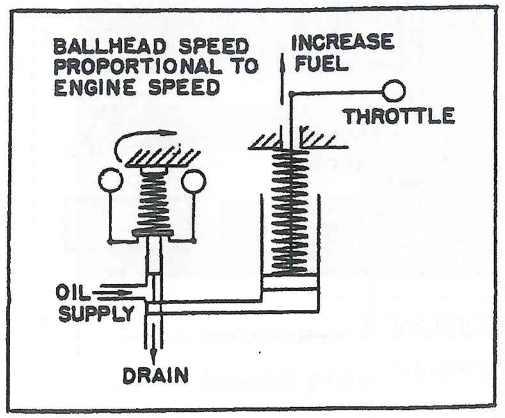
- Fast response
- No friction
- Simple installation
- Simple adjustment
- Suitable for load sharing duties
- Easily adapted for extra functions e.g. overspeed
- Can be situated in control room (Cool & less vibration)

Speed Sensing Pick up

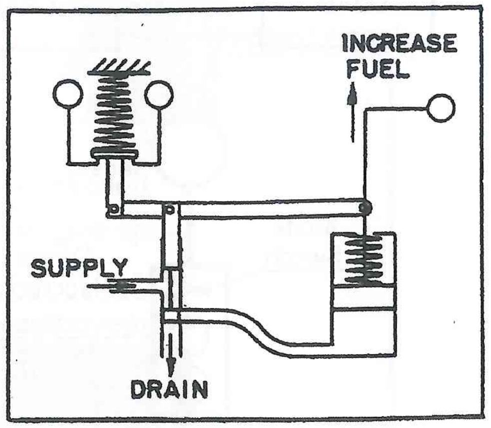


This is an electromagnetic device that is mounted in the flywheel housing. As the flywheel gear teeth pass the pick-up, an alternating current (AC) voltage is induced, one cycle for each gear tooth. This electrical signal is directly proportional to the engine speed and is fed to the governor control.

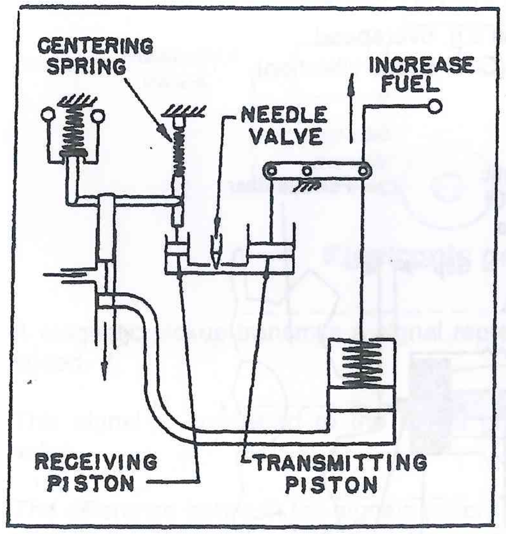
Chapter 6: Governor Examination Sketches



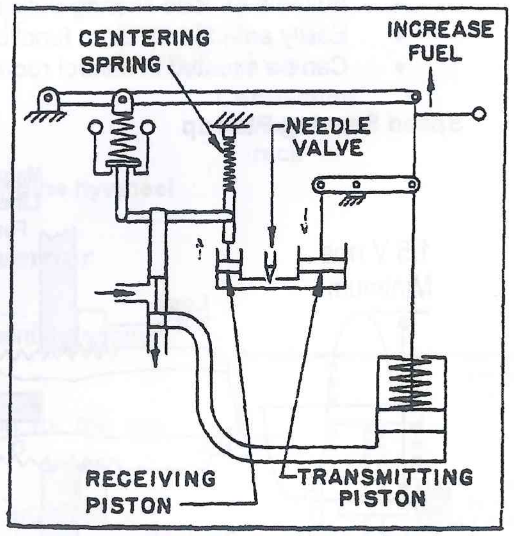
Simple Isochronous Governor



Speed Droop Governor



Isochronous Governor



Isochronous Governor with Droop

Chapter 7: Chief Engineers Exam Questions

March 2007 Question 8

a. Describe, with the aid of a sketch, an hydraulic isochronous governor suitable for a main engine. (7)
b. Describe how the governor described in Q8(a) reacts to a load increase. (6)
c. State what adjustment to the governor described in Q8(a) will cause it to be slow in response to a load change, or will prevent it from settling on the set speed. (3)

October 2005 Question 3, December 2000 Question 3

With Reference to a governor for an alternator driven by an auxiliary diesel engine:
a. describe, with the aid of a sketch, such a governor; (8)
b. describe the action of a governor in response to a large increase in electrical load; (4)
c. Explain EACH of the following:
   i) the necessity for droop; (2)
   ii) how droop is effected. (2)

December 2003 Question 5

a. Describe, with the aid of a sketch, a hydraulic governor for a medium speed auxiliary engine. (12)
b. State why it is desirable to install a hydraulic governor rather than a mechanical one. (4)

July 2003 Question 3

a. Describe, with the aid of sketches, an electronic governor suitable for a main propulsion engine. (6)
b. Explain how the governor described in Q3(a) functions to increase fuel to the engine in the event of a load increase. (6)
c. State TWO defects which can impair operation of the governor described in Q3(a) (4)

July 2002 Question 3

For a ship where electrical power at sea is provided from an alternator driven by the main diesel engine:
a. describe with the aid of a sketch, a mechanical speed sensing governor with hydraulic control; (8)
b. describe the governor action to increase the power delivered by the engine in response to a large electrical load increase while also restoring and maintaining the correct frequency; (6)
c. explain the term *droop*. (2)

Chapter 8: Second Engineers Exam Questions

July 2007 Question 2

a. Describe, with the aid of a sketch, EACH of the following:
   i. a simple isochronous hydraulic governor; (5)
   ii. a droop governor. (4)

b. Explain the action of the governors described in Q2(a) in the event of a load increase. (5)

c. Explain why *speed droop* is necessary in some governors. (2)