MARC047

Manage a propulsion unit using appropriate engine systems and support services

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MARINE ENGINE & PROPULSION SYSTEMS

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Principles of Diesel Engines

1.1 Common terminology

Before beginning this module, let's look at some terms relating to internal combustion:

Force – is the influence which tends to change the motion or direction of a body at rest or in motion. A simple explanation is pushing or pulling. From the above, applying a force would either:

- Start moving a body from rest or bring a moving body to rest
- Increase or decrease the speed of a moving body
- Change the direction of motion of a moving body

Force is measured in newtons (N)

Work – is the use of energy to overcome resistance. The amount of work done is from moving an applied force through a distance. The unit of measurement of doing work is the joule. The force is measured in newtons (N) and the distance is measured in meters (m). From the formula Work = Force x Distance, work would be in newton meters (Nm). To prevent confusion between 'work' and 'torque', the unit given to the formula for work is joule.

One newton meter = one joule

Torque – is when force tends to cause a movement about a point. Torque is also called a turning or twisting effort. Torque= Force x Distance. Torque is the **force exerted**, but not **moved,** over distance. Force is measured in newtons (N) and distance is measured in meters (m). Torque is therefore measured in newton meters (Nm). As an example, the force on the piston of an engine exerts a turning moment on the crankshaft.

Power – is the amount of work done or energy expanded in a given time. Also expressed as the capacity to do work. Watt (W) is the unit measurement for power. A watt is the power used when energy is expanded or work done at the rate of one joule per second.

$$\textbf{Power} = \frac{\textbf{Force x Distance}}{\textbf{Time in seconds}}$$

As a force is in newtons (N), distance in meters (m), and time in seconds (s), the answer will be in newton meters per second or joules per second. (1 newton meter = 1 joule). However, as one joule per second = one watt, the final answer will be in watts. Power of an engine is measured in kilowatts (kW) rather than watts (W). 1000W = 1kW.

Thermal efficiency – is the ratio of work done at the flywheel to the amount of energy contained in the fuel. Thermal efficiency is expressed as a percentage.

Calorific value – Fuel contains a specific amount of heat energy or heat value which is released when the fuel is burnt. This is the calorific value of the fuel. It is measured in joules per kilogram of fuel.

Volumetric efficiency – is the ratio between the swept volume of a cylinder and the actual volume of air drawn in during the induction stroke. The efficiency varies considerably, depending on the design and operating conditions but especially with engine speed. A turbo charged engine will have a higher volumetric efficiency (in excess of 100%) than that of a normally aspirated engine (less than 100%). Swept volume is the volume in the cylinder between TDC and BDC of the piston.

Turbulence – also called swirl, is the circular movement of the air as it enters the combustion chamber. The swirling motion or turbulence is encouraged by design considerations as it enhances flame propagation and is especially important at light engine loads. It is a desirable characteristic in the flow of air into the cylinder. In most engines, a rapidly swirling motion is deliberately induced and the violent movement helps ensure even mixing of the fuel and air. It also speeds up the combustion process once the fuel has ignited.

Scavenging – is the term used for eliminating the burnt exhaust gases from a cylinder. The incoming air removes, or scavenges, as much of the burnt gases as possible. Valve overlap assists in the scavenging process.

Compression ratio – is the ratio between the volume of the air before and after it has been subject to compression. A compression ratio of 12:1 means that during the pistons travel from the lowest to the highest point in the cylinder, the air has been compressed to one twelfth of its original volume. A diesel engine needs a high compression ratio to get a sufficient heat in the compressed air to ignite the fuel.

$$\text{Compression ratio} = \frac{\text{piston displacement + clearance volume}}{\text{Clearance volume}}$$

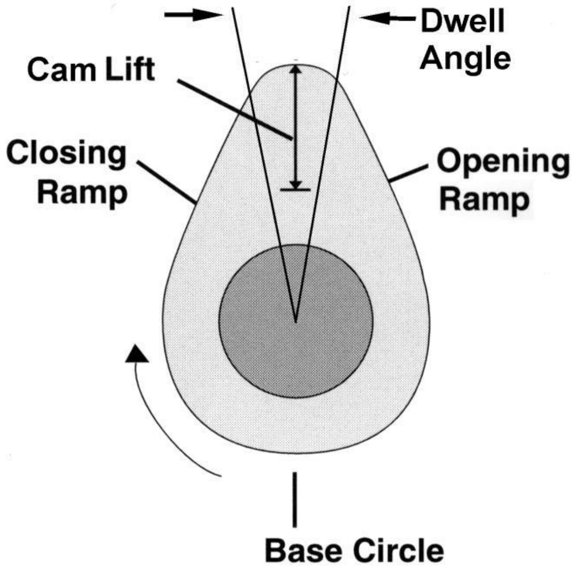
Valve overlap – is the period which both the inlet valve and exhaust valve are open at the same time. The inlet valve opens before top dead centre (TDC), say at 10° and the exhaust valve closes after TDC, say at 35°. The opening of the inlet valve overlaps the closing of the exhaust valve. The overlap in this case would be 35°. The purpose of valve overlap is to ensure that exhaust gases are discharged from the cylinder and the cylinder receives a fresh charge of air to make it more efficient when combustion next takes place. It also has a cooling effect.

Valve rotators – are devices which cause a valve to rotate each time it opens. It can be fitted to either end of the valve spring. Its purpose is to ensure even wear and prevent exhaust valves from burn out.

Dwell – is the angle that the valve remains in the fully open position. The profile of the lobe of the cam causes the valve to open until the lobe flattens out. The valve stays in this fully open position which is the angle of dwell until the other side of the lobe is reached when the valve starts to close.

Cam lift – is the distance from the peak of the lobe of a cam to its axis minus the distance from the back of the cam to its axis. Another description would be the distance the valve opens plus the valve lash or tappet clearance measurement.

Cam profile



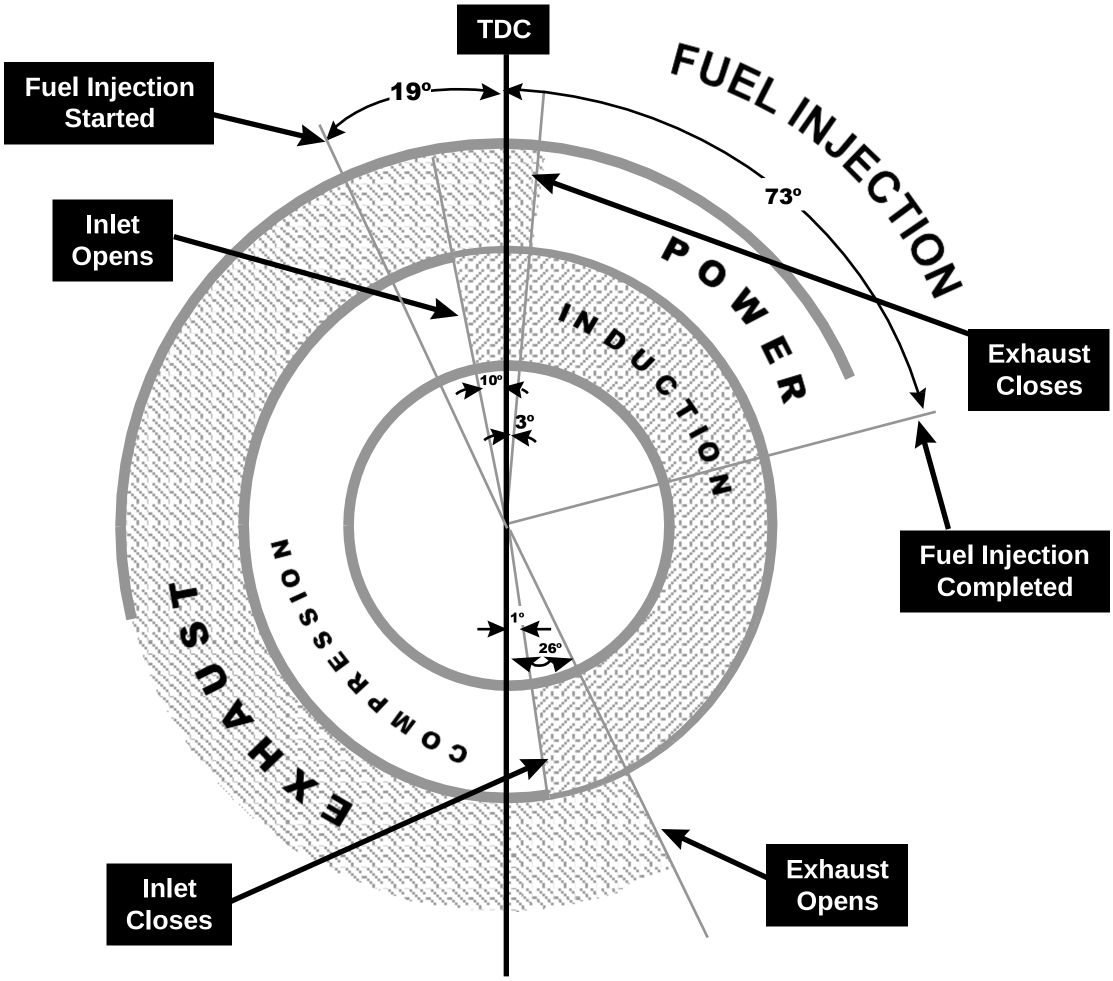
1.2 Operating principles of engines

There are two types of diesel engines, a four stroke cycle and a two stroke cycle.

Four stroke cycle diesel engine

In a four stroke cycle engine, four strokes of the piston are required to complete one cycle. The four strokes are induction, compression, power and exhaust. The actual opening and closing of the inlet and exhaust valves and the period of injection of the fuel can be taken from the timing diagram. Timing diagrams will vary between engine models and manufacturers.

Four stroke timing diagram



The above diagram is for a Caterpillar series 3600 turbo charged after cooled engine. As can be seen from the timing diagram, the induction stroke commences when the inlet valve opens 10° before TDC when air is drawn into the cylinder as the piston moves down. The inlet valve closes 1° before BDC.

The air is now trapped in the cylinder and as the piston rises on the compression stroke, the air is compressed. As the air is compressed, it rises in temperature. When the piston reaches 19° before TDC, the injection of fuel commences and continues until 73° after TDC.

The heat in the compressed air ignites the fuel and combustion takes place. The gases expand forcing the piston down on the power stroke.

The exhaust valves opens at 26° before BDC and the exhaust gases commence and are discharged as the piston rises on the exhaust stroke. Most of the exhaust gases have been discharged as the piston nears TDC. However, at 10° before TDC, the inlet valve opens and air enters the cylinder and helps discharge any remaining exhaust gases until the exhaust valve closes at 3° after TDC.

The whole cycle is then repeated.

Both the exhaust valve and inlet valve are open from 10° before TDC to 3° after TDC, an overlap of 13°. This is referred to as “valve overlap” and ensures that all the exhaust gases are discharged from the cylinder and the cylinder receives a fresh charge of air to make it more efficient when combustion next takes place.

Therefore there is one power stroke for every cycle or two revolutions of the crankshaft.

Two stroke cycle diesel engine

In a two stroke cycle engine, two strokes of the piston are required to complete one cycle.

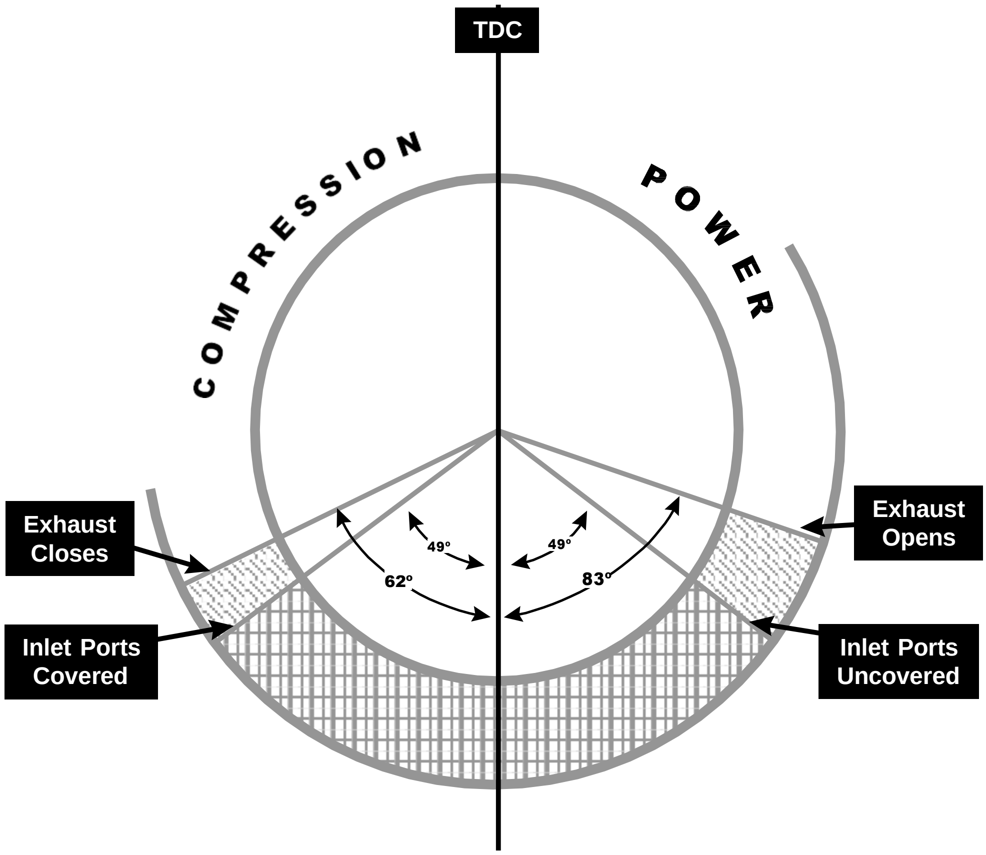
The two strokes are compression and power. The events of compression, injection of the fuel, combustion and expansion of the gases take place in the same order as the four stroke engine, but the exhaust of the burnt gases and the induction of air take place at the bottom of its stroke. This is the chief difference between the two stroke cycle and the four stroke cycle.

There are variations in two stroke cycle engines. The type described here is the most common to be found in marine engines. It has inlet ports and exhaust valves.

In this two stroke cycle engine, all the valves are exhaust. The inlet holes or ports are in the lower section of the cylinder liner wall.

The piston uncovers the inlet ports as it moves down the cylinder. The piston covers the inlet ports as it moves up the cylinder. This action has the same effect as a valve opening and closing.

An engine driven scavenge blower is fitted and the incoming air is blown into the cylinder through the inlet ports when they are uncovered by the piston.



Two stroke timing diagram.

The above timing diagram is for a Detroit Diesel model 16V-149 turbo charged inter cooled engine. As can be seen from the timing diagram above, induction commences at 49° before BDC when the piston has uncovered the inlet ports. Air is forced into the cylinder by the scavenge blower as the piston moves down to BDC and back up again until it covers the inlet ports at 49° after BDC.

As the piston rises, the exhaust valve closes at 62° after BDC. The air is now trapped in the cylinder and the piston rises on the compression stroke. As the air is compressed, it rises in temperature.

Fuel is injected before TDC and continues after TDC. Detroit Diesel do not give the period of injection as this will vary depending upon the engine speed, the load and the size of the injectors. The camshaft contains the exhaust valve cams as well as the unit injector cams. Therefore, if the exhaust valve timing is correct, the unit injector timing will be correct providing the injector follower is adjusted to a definite height in relation to the unit injector. A special gauge is supplied to set this height.

The heat in the compressed air ignites the fuel and combustion takes place. The gases expand forcing the piston down on the power stroke.

The exhaust valve opens at 83° before BDC allowing the burned gases to escape into the exhaust manifold. However, at 49° before BDC, the inlet ports are uncovered by the piston and air enters the cylinder and helps discharge any remaining exhaust gases until the exhaust valve closes at 62° after BDC.

The whole cycle is then repeated.

There is one power stroke for every one revolution of the crankshaft.

1.3 Combustion chambers

Combustion chamber design, which includes the shape of the cylinder head, the shape of the top of the piston and the air flow through the inlet ports, is one of the most important factors in efficient operation of the diesel engine. Because of the very short space of time available in a diesel engine in which the fuel and air can mix, various methods have been devised in an attempt to give improved mixing and combustion.

Combustion chambers can be of several designs but all are concerned in creating turbulence to the air during the compression stroke. In the diesel engine, the fuel is in the form of fine particles sprayed into the cylinder after the air has been compressed. To secure complete combustion, each particle of fuel must be surrounded by sufficient air. The mixing of the air and fuel is greatly assisted by the combustion chamber air turbulence.

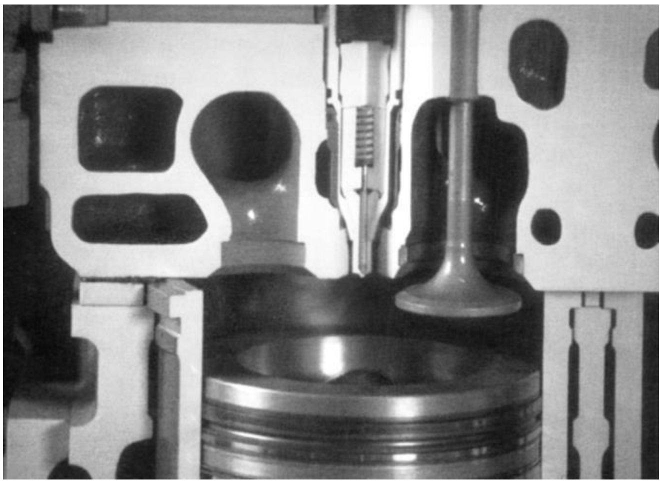
Some engines have helical inlet ports to provide additional swirl.

Generally, combustion systems can be classified as direct and indirect injection types.

- Direct injection
- Indirect injection, the two most common types being
- Turbulence chamber
- Pre – combustion chamber

The larger, slow speed engines and medium speed engines do not have the same difficulty in achieving good combustion as small high speed engines.

Direct injection



Direct injection combustion chamber

With direct injection, the fuel is injected directly into the combustion chamber which is usually formed by a cavity in the piston crown.

This cavity is carefully shaped to promote air swirl and the direction of the injector nozzle ensures that rapid mixing of the fuel and air assists complete combustion.

Advantages - It is claimed that direct injection gives higher thermal efficiency with lower fuel consumption. This is brought about by the fact that no heat is lost or power wasted in pumping air through a restricted opening into the separate chamber or in discharging the gases from the chamber. This gives easier starting and generally this type of engine does not require a starting aid device, such as glow plugs.

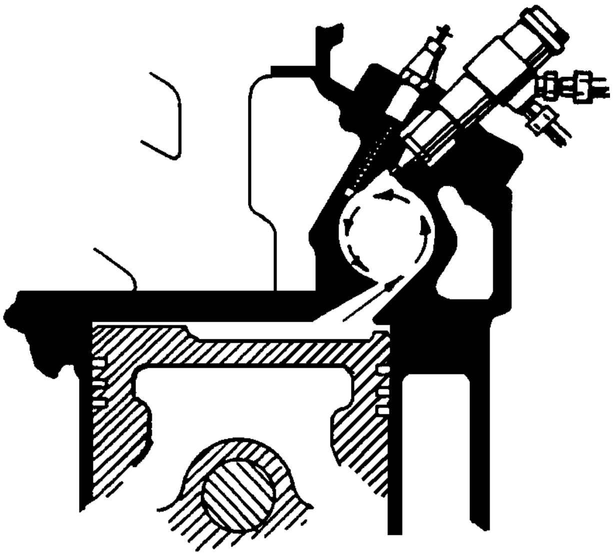
Disadvantages - This kind of injection is prone to “diesel knock”.

Indirect injection

Pre-combustion piston

The indirect injection or separate chamber system is where a separate small chamber is connected to the main chamber by a narrow passage or orifice.

The pre-combustion chamber and the turbulence chamber (also called a compression swirl chamber) work on the same principle. The main physical difference is the location and size of the connecting passage.



Swirl Chamber

With pre-combustion chambers only about 30% of the combustion air is forced into the chamber, fuel is injected and primary burning takes place in the chamber. This prevents too sudden a rise in pressure which can contribute to the so called ‘diesel knock’. The burning mixture of fuel and air is vigorously expelled through the connecting passage into the main combustion chamber or cylinder where an excess of air permits combustion to be completed.

Advantages - lower injection pressures can be used, resulting in less wear of injector nozzles; simpler design of nozzle equipment, which are easier to maintain, and smoother idling of the engine. Engine manufacturers may in some instances use either design in their range, depending on operating requirements.

Disadvantages - not as efficient as direct injection. It can also be prone to pre-combustion burn-out.

1.4 Valve timing

Valve timing is the critical relationship between the position of the crankshaft and the opening and closing of the inlet valves and exhaust valves. The valve train is geared or has a chain drive with sprockets on the camshaft and crankshaft.

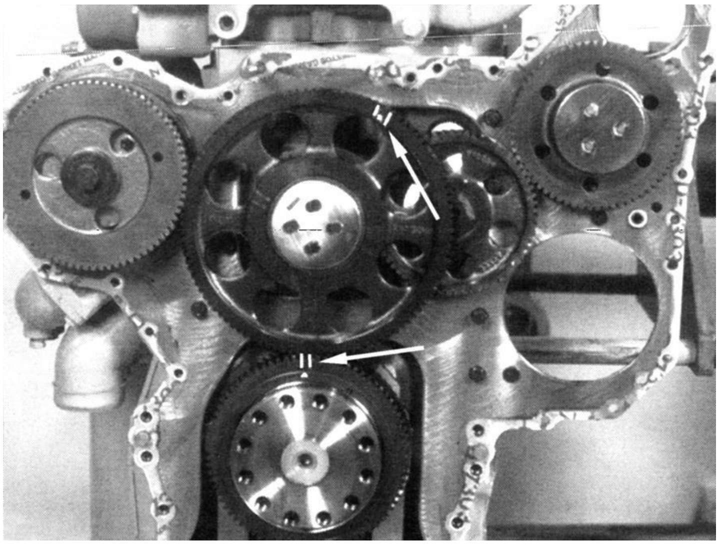
Any slight variation from the correct timing setting will result in loss of power and overheating. Any large variation and the engine will not start.

To accurately check the valve timing, it will be necessary to remove the timing cover to gain access to the timing gears.

The gears or sprockets are fitted to the crankshaft and camshaft by keys so they can only be fitted in one position. However, they can be incorrectly lined up to each other.

The operators manual will indicate what the timing marks look like and in the case of chains, what the sprockets should line up with. Typical lining up marks for gears are shown below:

Gear lining up marks



When timing has been found to be correct, the tappet clearances (also referred to as valve lash) should be checked. Whenever the cylinder head is overhauled, the valves are reconditioned or replaced, or the valve operating mechanism is replaced or disturbed in any way, the tappet clearance must be adjusted. Also when the cylinder head has been re-tightened after the initial run in period.

When the valve and valve operating gear heats up in service, the clearance between the rocker arm and the valve stem decreases. If insufficient clearance is allowed, the valve will be prevented from seating. The correct clearance will be specified by the engine manufacturer. In the Operators Manual, some manufacturers state clearances for when the engine is at its normal operating temperature, others when the engine is cold, while some give both.

Clearances will vary as much as 0.128 mm (0.005”) between a cold and the normal operating temperature of an engine. Usually, an exhaust valve will have a greater clearance than an inlet valve because of their different operating temperatures. Too much clearance will cause excessive wear, noisy operation and altered valve timing, that is, late opening and early closing. If the clearance is insufficient and the valve does not seat properly, it will result in:

- loss of compression through valve leakage
- burning and eroding of the valve and seat, and
- general overheating.

In the extreme, it is possible that the piston could strike the valve resulting in a bent valve stem, damaged piston or worse if the valve or piston should break.

When the valve operating mechanism is disturbed in any way, the engine is cold, but only a hot tappet clearance is given, the tappet clearance must be checked. If *required, a further adjustment when the engine is at its normal operating temperature.*

The most common form of adjustment for tappet clearance is by means of a screw and lock nut located in one end of the rocker arm. The clearance is measured by means of a feeler gauge between the valve stem and rocker arm when the valve is in the fully closed position. This is usually done when the piston, under the valve being adjusted, is on top dead centre at the end of the compression stroke.

An easy way to identify the above is as follows:

On a six cylinder engine with a firing order of 1 5 3 6 2 4, turn the engine over in the direction of rotation. When the inlet valve and exhaust valves are rocking on number 6 cylinder (ie. the piston finishing its exhaust stroke and starting its induction stroke) adjust the inlet and exhaust valve clearances on number 1 cylinder which will just be completing its compression stroke and commencing its power stroke.

On the crankshaft, the bottom end journals on numbers 1 and 6 are 180° to each other, 2 and 5 are 180° to each other, and 3 and 4 are 180° to each other.

What you are doing is adjusting number 1 tappets while number 6 is rocking, then adjust number 5 because it is the next one in the firing order to be on top dead centre while number 2 is rocking, adjust number 3 while number 4 is rocking, adjust number 6 while number 1 is rocking, adjust number 2 while number 5 is rocking, and adjust number 4 while number 3 is rocking.

On a Detroit Diesel, the exhaust valve/s can be adjusted on the cylinder on which the unit injector follower is fully depressed. This means that fuel injection is taking place so it is at the end of the compression stroke and the beginning of the power stroke.

1.5 Timing a fuel injection pump

Early injection

If the injection occurs too early on the compression stroke, it will result in high peak pressures. This will subject the engine to unsafe stresses caused by the tendency of the pressure to reverse the rotation of the engine and evidence by excessive detonation which is known as diesel knock.

Late injection

Retarded injection or late burning gives incomplete combustion causing too low a power output and overheating.

Timing instructions

It will be necessary to follow the manufacturers instructions in the Owners Manual to time the fuel pump to the engine as different methods are employed.

Timing principle

The principle is that fuel injection commences on the compression stroke just before top dead center. With a four stroke, the piston also comes up to top dead center on the exhaust stroke. Make sure it is on the compression stroke.

As with timing inlet and exhaust valves, the fuel injection pump must be timed to inject fuel at the correct angle on the compression stroke. This means that the gear driven shaft to the pump must also be lined up in the gear wheel train. Otherwise, difficulty might be experienced in lining up the holes in the drive coupling.

Timing engine to pump

The flywheel is usually marked with a TDC and with an injection mark that is before the TDC mark when turning the engine over in the direction of rotation. Turn the engine over in the direction of rotation until its number 1 cylinder is on the compression stroke and the injection mark is lined up.

The fuel injection pump must also be lined up on number 1 element or port at the commencement of injection. The Owners Manual will identify the position of the lining up marks as brands of pumps differ. When the lining up marks on the pump correspond, the drive couplings can be bolted together.

Alternative method of timing

To make it easier still, some manufacturers make provision for locking the fuel injector pump shaft at a position **corresponding to top dead center** for number 1 cylinder. A further pin is then located in a hole in the camshaft timing gear that is top dead center for number 1 cylinder. The drive couplings can then be bolted together and the pins removed.

As the pin is located in a hole in the camshaft, it can only be on the compression stroke on a four stroke engine.

Checking the timing of a fuel pump

The timing may be checked as follows:

1. Remove the delivery valve and spring from number 1 element in the fuel injection pump.

2. Open the throttle to the full position. *(If the throttle is left at the stop position, the slot in the plunger will be in line with the spill port and no fuel will be delivered.)*

3. Rotate the engine in its operating direction until number 1 cylinder is on the compression stroke. Keep rotating the engine slowly and when the mark on the flywheel, indicating the start of injection is lined up with the timing indicator mark, fuel will immediately start to rise from where the delivery valve was removed. *(This will mean the top of the plunger has just covered the inlet and spill ports and injection is starting).*

4. If fuel starts to rise before or after the timing marks are in line, the fuel pump timing is out and will have to be adjusted.

Detroit Diesel unit injector

On a Detroit Diesel, the cam that actuates the unit injector is on the same shaft as the cams for the exhaust valves. If the exhaust valves are correctly timed, that is they open and close at the correct angles, then the unit injector timing must be correct. It is then only a matter of adjusting the unit injector follower to get the correct height in relation to the unit injector body. A special gauge is supplied for this purpose.

Cummins PT injector

On the Cummins PT system, it is only a matter of setting the clearance between the rocker arm and the injector.

1.6 Turbo charging

A turbo charger (sometimes called a turbo blower) can be fitted to both two and four stroke engines to increase the volumetric efficiency and thus their power output.

Advantages

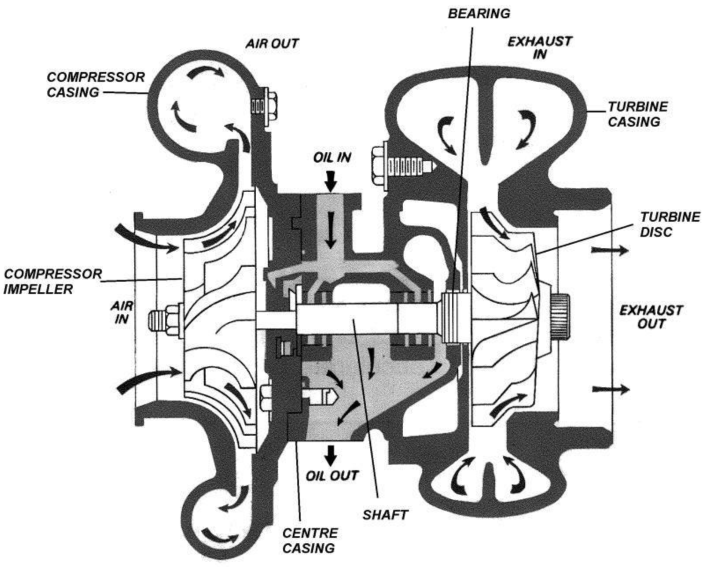
The advantage of a turbo charger is that fuel consumption is lower than that of a normally aspirated engine of the same power output.

In addition, the turbo charger utilises the exhaust gases of the engine so no power from the engine is required to drive it.

The turbo charger causes a larger mass of air into the cylinder to that of a same cubic capacity normally aspirated engine. This allows for a proportional increase in the amount of fuel that can be injected and burnt in the cylinder thereby providing an increase in the power output of the engine.

Components of a turbo charger

The components of a turbo charger are shown below.



Turbo charger

Rotor assembly – It has a rotor shaft which has exhaust gas turbine blades on one end and air compressor blades on the other end.

Casings – The exhaust gas turbine blades are housed in a casing which is attached to the exhaust manifold and to the exhaust pipe. Some casings are fresh water cooled to minimise the heat radiated out into the engine space. This allows for a cooler engine space, cooler air entering the engine air intake and therefore more power again. A nozzle ring is fitted inside the casing to direct the flow of exhaust gases to the turbine blades. The air compressor blades are also housed in a casing which has an air cleaner on the intake side and is connected to the intake manifold on the discharge side. Where an engine is after cooled, the discharge side is connected to the after cooler which is then connected to the intake manifold. Both the above casings are attached to a centre casing which contains the bearings, seals and method of lubrication.

Bearings and lubrication – The shaft may rotate in white metal bearings which can be lubricated from the engine driven oil pump. This method of lubrication also allows the oil to remove some of the heat in the turbo charger. One bearing locates the shaft and takes the small residual thrust, the other bearing allows the shaft to move longitudinally to accommodate the differential thermal expansion of casings and shafting. Alternatively, the smaller turbo chargers usually incorporate a ball bearing for positioning at the compressor end a roller bearing to accommodate axial expansion at the turbine end of a rotor shaft. The bearings may have their own reservoir which forms part of the turbo charger. These reservoirs usually have round oil level sight glasses with two horizontal lines marked to indicate the high and low levels. Seals are fitted to retain the oil.

Operation of the turbo charger on a diesel engine

In a four stroke engine, exhaust gases flow from each cylinder into the exhaust manifold and then past the turbine blades of the turbo charger. With the engine running at full speed, the turbo charger can obtain speeds up to 100,000 revolutions per minute (rpm).

The air compressor blades will revolve at the same speed. Air is drawn through the air cleaner and forced under pressure into the intake manifold. When the inlet valve opens on the induction stroke, with the piston descending in its cylinder, air is forced into the cylinder.

It is necessary to reduce the turbo charger speed in stages or slowly for two reasons:

1. If the engine speed is reduced from full engine speed to stop quickly and the bearings of the turbo charger are lubricated by the main engine driven lubricating oil pump, the engine, on stopping, will cease to supply the lubricating oil to the turbo charger bearings. Because of its high speed, it will take some time for the turbo charger to come to rest and the bearings could be damaged.

2. The exhaust gas side of the turbo charger operates at a very high temperature. It is preferable to reduce the temperature gradually rather than quickly to prevent unequal contraction of the turbo charger parts as it slows down.

Monitoring the performance

Normally, as part of the purchase of a new engine, the engine distributor or dealer will do an installation and pre-run check. The following will be recorded:

- The speed of the turbo charger at a nominated engine speed.
- Air flow in.
- Air flow out.
- Air pressure after the compressor blades.
- Exhaust gas flow.

The flow of air going into the turbo charger is important. The air is taken from the engine room so sufficient ventilation to the engine room is required to ensure there is enough for the engine as well as cooling the engine room.

The exhaust gas flow is also important. It ensures the installation of the exhaust piping is within limits and not restricting the performance of the engine.As the above is recorded, checks can always be carried out and readings compared with the initial ones.

1.7 After coolers (Charge air coolers)

An after cooler is also called an inter cooler or a charge air cooler.

An after cooler is fitted where an engine is turbo charged, however it is not necessary to fit one. Therefore an engine can be turbo charged or can be turbo charged and after cooled.

The reduction in air temperature will increase the density of the inlet air resulting in more air entering the cylinder. More fuel can then be injected and burnt, giving increased power.

The after cooler is fitted between the air compressor side of the turbo charger and the air intake manifold on the engine.

In the after cooler, air passes over the outside of the tubes while the engine cooling water or sea water passes through the tubes usually in the opposite direction (contra flow). Fin plates are attached to the outside of the tubes to increase the surface area for the air, thereby giving a better transfer of heat.

Maintenance

- Sea water flowing through the tubes will tend to leave deposits in less time that if fresh water was used. The end covers can be removed and a wire brush pushed and pulled through the tubes. If the scale is not removed by the brush, the tube nest will have to be chemically cleaned.
- **On the air side, usually no maintenance is required if the air cleaner is doing its job and the filter is changed regularly.**
- A leaking tube will cause the cooling water to pass into the air side. Depending on the design, the air may enter at the bottom and leave at the top to prevent water carrying over with the air. A drain cock is fitted at the bottom.
- **As the air passes through the after cooler, its temperature may be reduced until it is below the saturation temperature. Heavy condensation of water vapour may then follow, this water being carried into the engine. If this is a problem, a water separator can be mounted between the after cooler and the air inlet manifold.**

Fuel Supply, Injection and Control

2.1 Fuel system for an in line pump

The following description applies to free standing fuel tanks, a multi element (in line) injector pump, and to engines on flexible mountings. There will be variations, especially if the fuel tanks form part of the vessel’s structure but the principles and safety features remain the same.

Vent pipe - is fitted to the top of the fuel tank at the highest point when the vessel is in normal trim. This is to prevent an air lock developing. An air lock is when the tank is being filled, air or vapours become trapped in the top of the tank, are compressed, and when the pressure exceeds the filling pressure, fuel is forced out of the vent or filling pipes and a spill occurs.

The smaller vent pipes terminate in a gooseneck, the end of which must be higher than the filling point.

The end of the vent pipe has an anti-flash wire gauze fitted to it. If the fuel vapours from the vent pipe ignite, the flames cannot penetrate the gauze and ignite the contents in the tank providing the size of the holes in the gauze are not too large.

Before a combustible substance will take fire, its temperature must first be raised to its point of ignition, and, if after it has ignited the temperature is reduced in some way below this point, the flame will be extinguished. A moderate flame can be extinguished by passing a current of air over it, for instance, blowing out a candle.

The reason for this is that more air than is required for combustion is supplied to the burning gas, the surplus tending to cool the flame below its point of ignition. In a similar way, gauze, which is a good conductor of heat, prevents the passage of flame, since it loses its heat very rapidly, and the flame upon coming into contact with it, is cooled below the point of ignition; consequently, no flame appears on the other side of the gauze. A good example is placing a lighted match under the gauze. The flame will not penetrate the gauze.

The purpose of the vent pipe is to:

1. allow the escape of air and vapours when the tank is being filled so it is not pressurised;

2. allow air into the tank when fuel is being consumed so a partial vacuum is not placed on the tank thereby stopping the engine; and

3. allow normal expansion and contraction of the fuel due to temperature change.

Filling pipe - is fitted to the top of the tank and it is preferable that it be piped continuously to deck level. It does not have to be piped to the deck, if in the event of an overflow, the fuel will not run onto a hot surface and ignite. The end of the pipe is to be fitted with a sealed cap or plug.

Drain valve - is fitted to the lowest part of the tank. Its purpose is to drain water or sediment from the tank. A plug or cap is fitted so, if the valve vibrates open, the fuel is not lost or causes a fire risk.

Water can be in the tank:

1. via coming with the fuel supply

2. condensation due to the level in the tank being kept low for a lengthy period

3. through the deck fitting due to it not being secured and rain or a wave entering

4. being mistaken for a water tank

Fuel contents gauge - There are a number of methods in which to measure the amount of fuel in the tank. If the tank is fitted with a gauge glass, the cocks or valves must be of the self closing type. To take a reading, open the cocks or valves against a spring or lift a weighted handle and, on letting go, it will automatically close. If the glass breaks or the plastic tube perishes, it prevents all the fuel in the tank running into the bilges or in the case of a fire, prevents all the fuel in the tank feeding the fire.

If a sounding rod is used, a striking pad must be fitted to the bottom of the tank to prevent damage to the tank itself through repeated soundings.

Inspection opening - is fitted in a position or a number may be fitted to provide access to the whole tank. It allows the tank to be cleaned and inspected.

Baffle - They are fitted to prevent free surface effect. This affects the stability of the vessel and in extreme cases can cause vessels to capsize.

Fuel pick up - is fitted above the bottom of the tank. This is to allow a safety margin so as to reduce the amount of any water or sediment flowing to the fuel filter. A valve or cock must be fitted directly to the tank.

Emergency fuel shut off - This is fitted to allow the fuel to be shut off outside the engine room in the case of an emergency. It can be fitted anywhere in the metallic fuel line. It cannot be fitted after the flexible fuel line. Where fuel tanks are fitted outside the engine room and the fuel shut offs are easily accessible, emergency shuts offs are not required.

An extended spindle can be fitted to the fuel shut off valve so it can be operated from outside the engine room. The fuel shut off and the emergency fuel shut off are then the one valve.

Filter/water trap - They can be a combined unit or separate units. The unit provides a secondary means of filtering the fuel from sediment and impurities while the water trap removes any moisture or water. The fuel pump and injectors have very small clearances and any impurities or water in the fuel will cause them to seize. (The fuel acts as a lubricant). In addition, moisture could cause corrosion to those finely machined components.

Sometimes additional filters are fitted to the system.

Fuel return - Excess fuel from the injectors is returned to the tank. It is good practice to operate from one tank at a time and the excess fuel returned to this tank. In this case, the fuel return valve of the tank not being used must be closed. In small vessels it is not practical to operate off one tank as the vessel would develop a list, therefore engines receive their fuel from the port and starboard fuel tanks.

Fuel lift pump - Unless there is a day tank where the fuel is fed by gravity to the engine, it will be necessary to have a fuel lift pump to get the fuel from the tanks to the fuel pump. A fuel lift pump can be a gear, diaphragm or plunger type.

Fuel injection pump - It accurately meters the fuel and delivers it under high pressure at a precise moment to the spray nozzle of the fuel injector.

Fuel injector - It is a spring loaded valve located in the cylinder head and allows the fuel, under pressure from the fuel pump, to enter the combustion space. It enters in an atomised form to allow it to mix completely with the hot compressed air so that ignition can take place with efficient combustion. Excess fuel is returned to the tank.

Fuel transfer pumps

Unless the vessel's fuel tanks are positioned above the level of the engine or a day tank is installed at sufficient height, fuel cannot be gravity fed to the engine's fuel injection pump. To assist in drawing fuel from the tank/s a fuel transfer pump is fitted between the tank/s and the fuel injection pump. Fuel transfer pumps are also commonly referred to as transfer, lift and charge pumps.

Diaphragm type transfer pump

The diaphragm type transfer pump is mechanically driven by a special lobe on the camshaft. The lobe pushes against the lever causing the diaphragm to be pulled down against a spring pressure, creating a partial vacuum.

A first check valve opens and draws in fuel, filling the chamber between the diaphragm and check valves. As the lever moves off the lobe of the cam, the diaphragm spring pushes the diaphragm up, closing the first check valve forcing fuel through a second check valve and into the fuel pump. An external lever is provided to permit manual operation of the pump for priming purposes.

The pump will deliver more fuel than is required. The fuel not being used will build up pressure in the line between the fuel pump and the fuel transfer pump causing the second check valve to close. The downward movement of the diaphragm will allow more fuel to enter through the first check valve into the chamber. The first check valve will close and as the return spring cannot overcome the pressure in the line between the fuel pump and the second check valve, the lever will be held off the cam until more fuel is required.

This diaphragm pump could be attached to the side of the fuel pump and actuated by a cam on the camshaft for the fuel pump. Alternatively, it may be attached to the block and actuated by a cam on the main camshaft.

Plunger type transfer pump

The plunger type fuel transfer pump is mechanically driven by a special lobe on the camshaft. The lobe pushes against the plunger in the fuel transfer pump to create the pumping action. Check valves control the direction of fuel flow, and prevent fuel bleed back during engine shut down.

As the high point on the cam lobe rotates away from the fuel transfer pump, the spring forces the piston towards the camshaft. The pressure of the fuel in the piston bore closes the first check valve and opens a second check valve forcing fuel to the low pressure supply line. As the piston moves, a third check valve opens and fuel is drawn into the spring cavity.

As the high point of the cam lobe rotates towards the fuel transfer pump, the plunger and piston are forced towards the inlet. The pressure of the fuel on the spring side of the piston causes the third check valve to close and first check valve to open, allowing the fuel in the spring cavity to flow to the other side of the piston.

A second plunger allows manual priming and bleeding of air from the system. When the plunger is depressed, the first check valve prevents back flow forcing fuel through the second check valve. When the plunger is released, the spring forces the plunger outward. This action creates a suction that causes the second check valve to close and the fuel is drawn through the open first and third check valves.

If the pump supplies more fuel than is required, the fuel will build up the pressure in the line between the plunger pump and the fuel pump. The pressure build up will hold the plunger stationary against the plunger spring an away from the arm, effectively stopping pump operation until more fuel is required.

Gear type transfer pump

This pump consists of two meshed gears in a closely fitted housing. It has inlet and outlet ports opposite one another. One gear is driven by the power source and in turn drives the other. As the gear teeth separate and travel past the inlet port, a partial vacuum is formed. Fuel entering the inlet port is carried to the outlet port in pumping chambers formed between the gear teeth and the housing. As the gear teeth mesh at the outlet there is no place for the fuel to go but out.

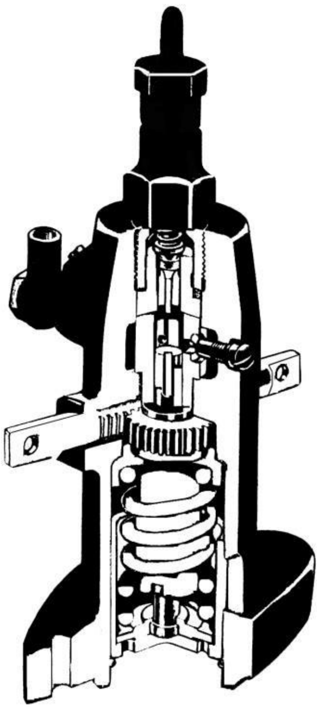
Vane type transfer pump

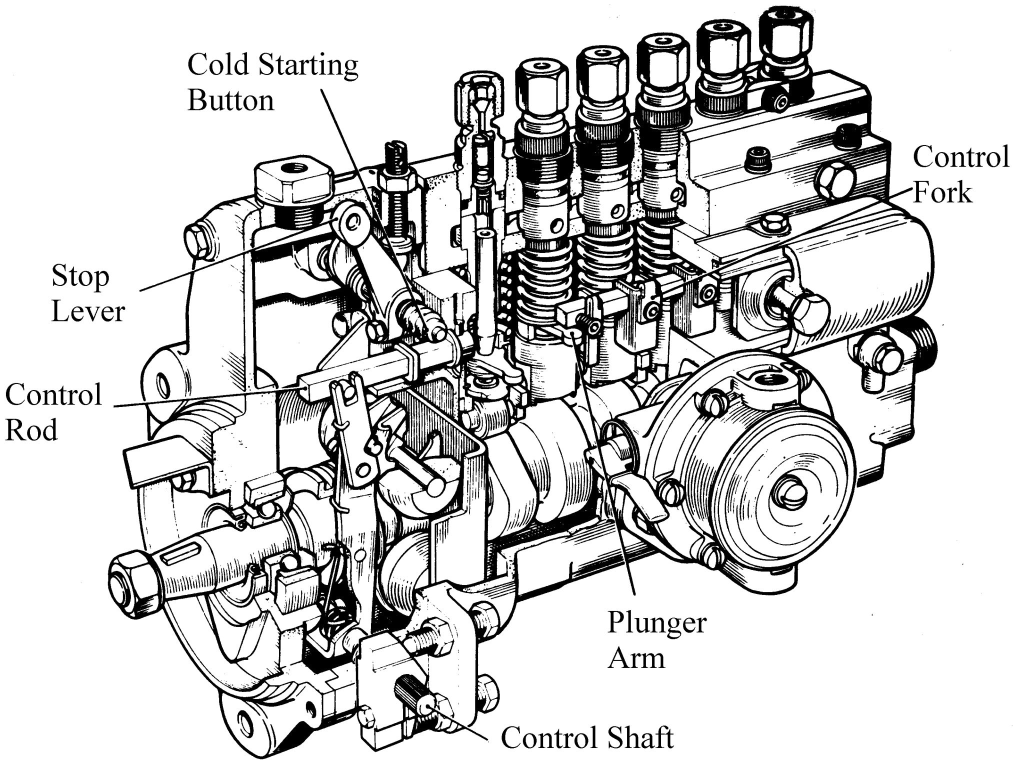
In the vane type pump, a slotted rotor driven by a drive shaft rotates between closely fitted side plates, and inside of an elliptical or circle shaped ring. Polished, hardened vanes slide in and out of the rotor slots and follow the ring contour by centrifugal force. Between succeeding vanes, pumping chambers are formed which carry oil from inlet to the outlet. A partial vacuum is created at the inlet as the space between the vanes open. Fuel is squeezed out of the outlet as the pumping chamber size decreases.

2.2 Jerk type fuel injection pump

A jerk type fuel injection pump can have a separate unit for each cylinder or multi-elements where a number of pump elements and a camshaft are housed in the one casing.

Single element jerk type fuel injection pump

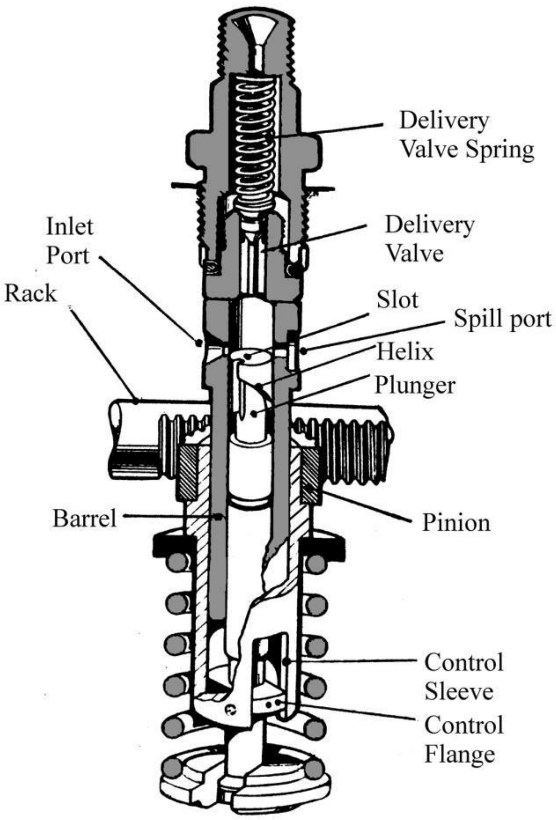




Multi element or in line fuel injection pump

In general, jerk type fuel injection pumps comprise

- barrel
- delivery valve
- rack and pinion
- camshaft and
- spring



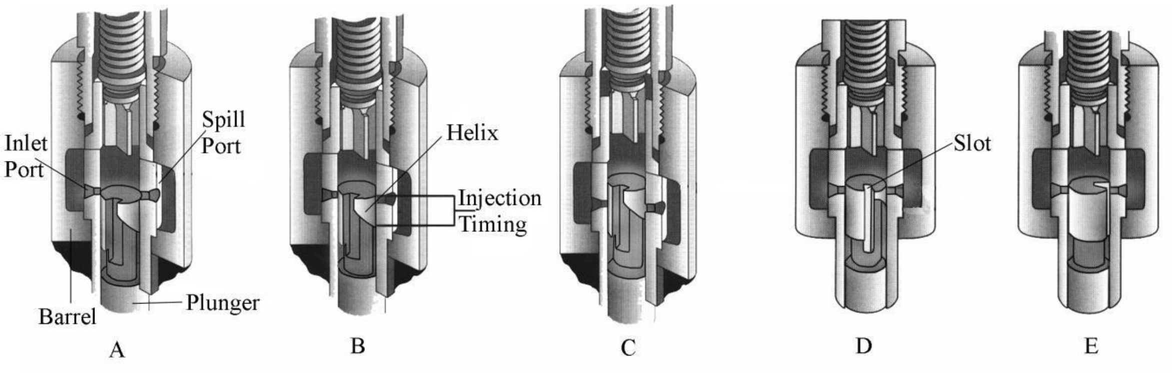
Fuel injection pump element

Barrel and delivery valve – Each barrel is locked into the housing in such a way that the upper section, which contains two ports placed at 180 degrees as known as the intake port and spill port, is completely immersed in fuel supplied by the fuel by the fuel lift pump. The barrel is closed at its upper end by a spring loaded pressure valve known as a delivery valve. An injector pipe is connected between here and the injector.

Plunger – The plunger which operates within the barrel is driven on its upward stoke by a roller tappet operating on a camshaft. Contact is kept between the plunger and the tappet by means of a spring which operates in a similar fashion to an inlet or exhaust valve spring. The plunger has a slot and a helix cut into it near the top.

Rack and Pinion – A rack is fitted to the pump to engage with a pinion on the outside of a sleeve. The sleeve fits over the plunger and has slots engaging with keys. This allows the plunger to be rotated by the fuel rack as the plunger moves up and down. The end of the fuel rack is attached to the governor.

Operation



Fuel metering principle

When the top of the plunger is below the inlet and spill ports, low pressure fuel flows through the inlet and spill ports into the barrel. It fills the space above the top of the plunger to the closed delivery valve and also down the slot of the plunger and into the space below the helix.

The cam pushes the plunger up and injection commences when the top of the plunger covers the inlet and spill ports. As the plunger moves up, the trapped fuel is delivered under high pressure through the delivery valve to the injector until the helical grove on the plunger uncovers the spill port.

This allows the fuel pressure above the plunger to fall to the suction pressure through the vertical slot. The plunger will rise further to complete its stroke but no fuel will be pumped. As the lobe of the cam goes past top dead centre, the spring will cause the plunger to return to the bottom of its stroke.

To vary the amount of fuel injected into the cylinder, the plunger is rotated by the fuel rack and this causes the helical groove to uncover the spill port earlier or later depending on whether less or more fuel is required.

The fuel rack is attached to the governor. If the propeller comes out of the water the engine starts to speed up, the governor reacts by moving the fuel rack, causing the helical groove to uncover the spill port earlier or cuts off the fuel altogether. As the propeller comes back into the water, the engine starts to slow down and the opposite occurs.

To cut off the fuel to stop the engine, the plunger is rotated by the rack until the vertical slot is in line with the spill port so no fuel is delivered as the plunger moves up.

Calibration and timing of a multi-element fuel injection pump

In a multi element pump, each element is calibrated and timed on a test rig. To calibrate a pump, each element is connected up to a calibrated test tube. The pump is run and then each test tube is checked to ensure that each element has delivered the same amount of fuel. Each element is timed to ensure that injection commences at the precise time in the stroke.

If the injection occurs too early on the compression stroke, it will result in high peak pressures and will subject the engine to unsafe stresses. This is caused by the tendency of the pressure to reverse the rotation of the engine and evidence by excessive detonation which is known as diesel knock.

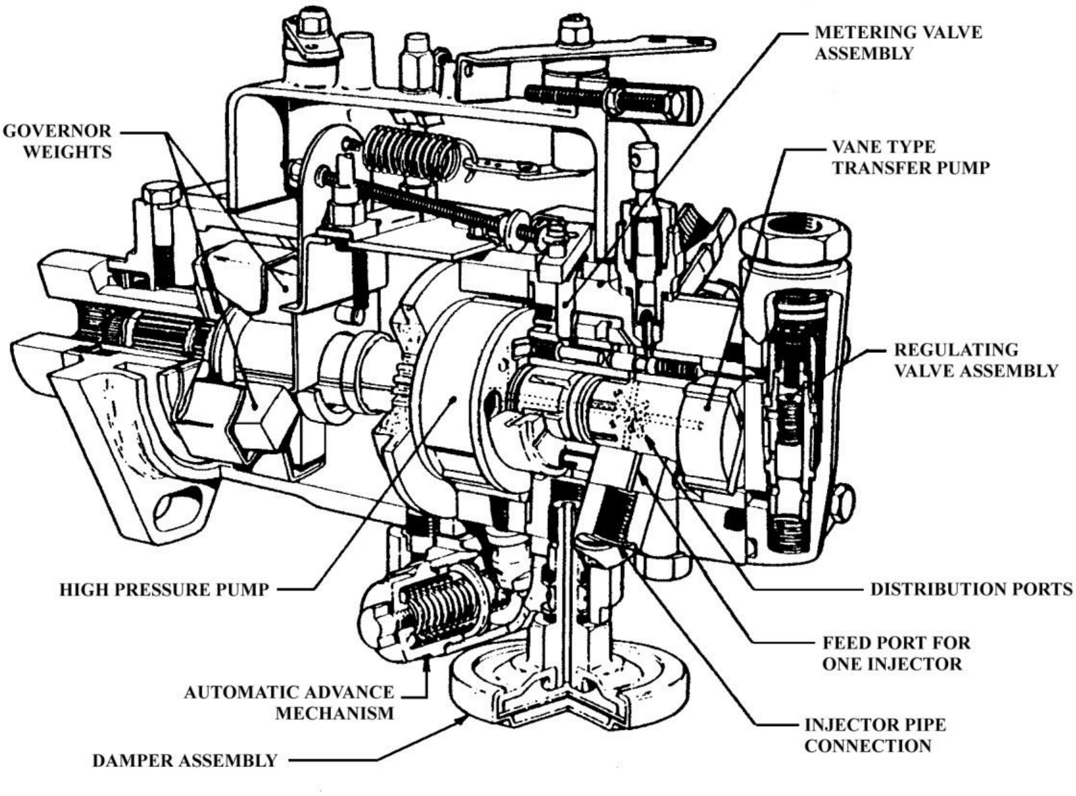
Fuel Injection Pump Systems

Distributor Pump

The distributor pump incorporates a single pumping element and automatic metering system. This will make it unnecessary to calibrate and balance a number of pumping elements which is the case of multi-element pumps.

The main components of the distributor pump are:

- internal transfer pump
- metering valve
- governor
- rotor and cam ring assembly (pumping element)
- timing advance mechanism
- maximum fuel delivery adjustment



Distributor type fuel injection pump

Operation

The fuel transfer pump (or fuel lift pump) draws the fuel from the fuel tank through a pre-filter and pumps it to a filter head into a combined filter/water separator where any contaminants and water are removed.

The fuel then is pumped to the distributor pump which pressurises, controls timing, distributes and meters an amount of high pressure fuel to the injectors.

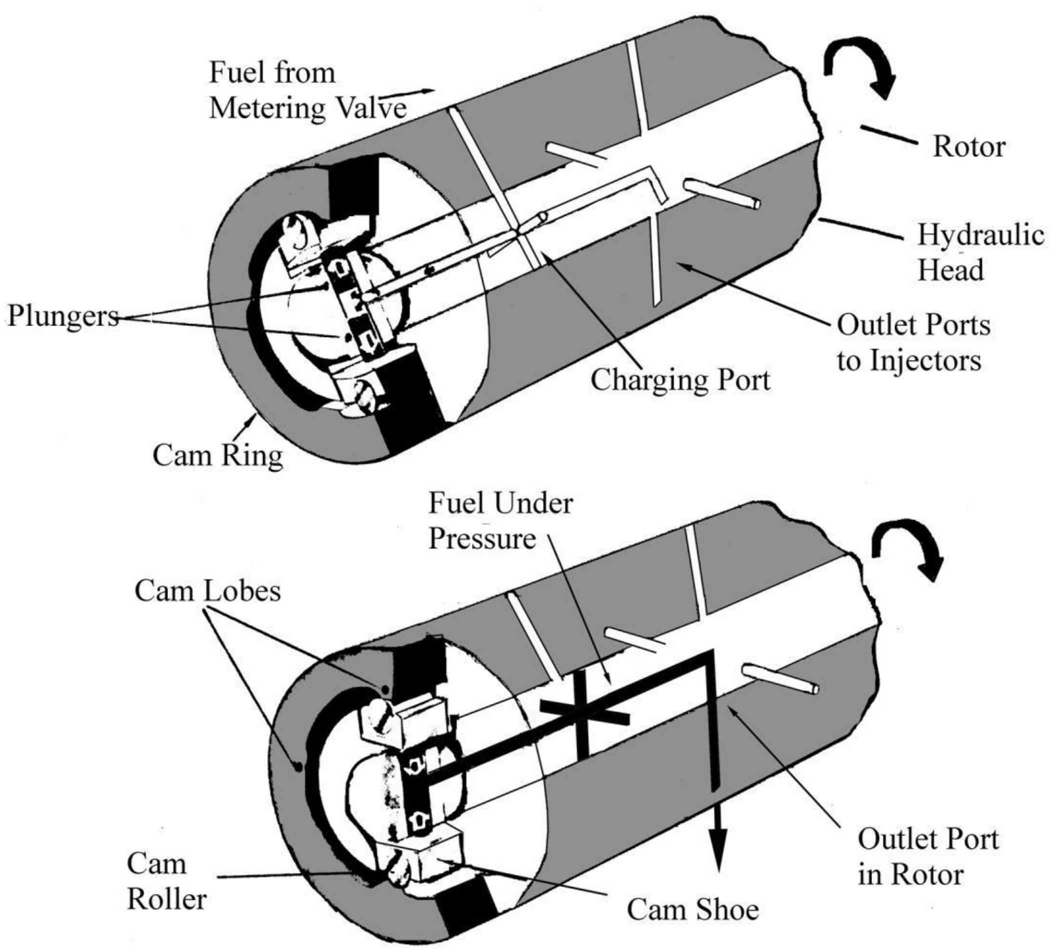
The distributor pump uses an internal transfer pump to increase the fuel pressure in relation to engine speed. Fuel then flows through a solenoid valve to the timing advance and the annular groove surrounding the rotor.

A metering valve determines the amount of fuel made available to the pumping section of the rotor. Fuel flow is either increased or decreased depending on rotation of the metering valve by the governor. A mechanical shut down lever can also be used to move the metering valve to the closed position, stopping fuel flow to the injectors and the remainder of the engine.

The governor is connected to both the engine throttle and the metering valve, controlling the fuel flow in relation to movement in the engine throttle.

Fuel from the metering valve flows through a metering port into the charging port in the rotor. As the rotor revolves these two ports fall out of alignment, trapping fuel in the rotor. As the rotor continues to revolve the fuel is placed under increasing pressure and eventually the rotor's charging port aligns with delivery ports and the fuel escapes to the injector.

Rotors and ports



Cummins pressure time fuel injection pump

The PT (pressure/time) fuel system has been developed and refined by Cummins over a long period.

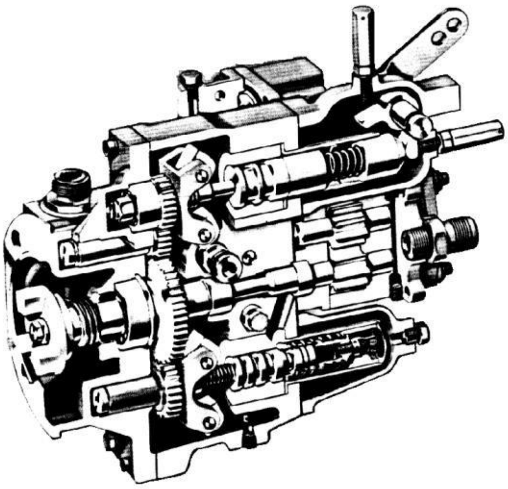
The PT system uses injectors which meter and inject the fuel. Metering is based on a pressure/time principle.

Pressure - Time principle and is accomplished by a fixed size opening in the injector and the pressure of the fuel supplied to the injector.

Fuel system

The fuel is drawn from the tank through a filter by the fuel pump, delivered to the injectors with 80% of the fuel being returned to the fuel tank.

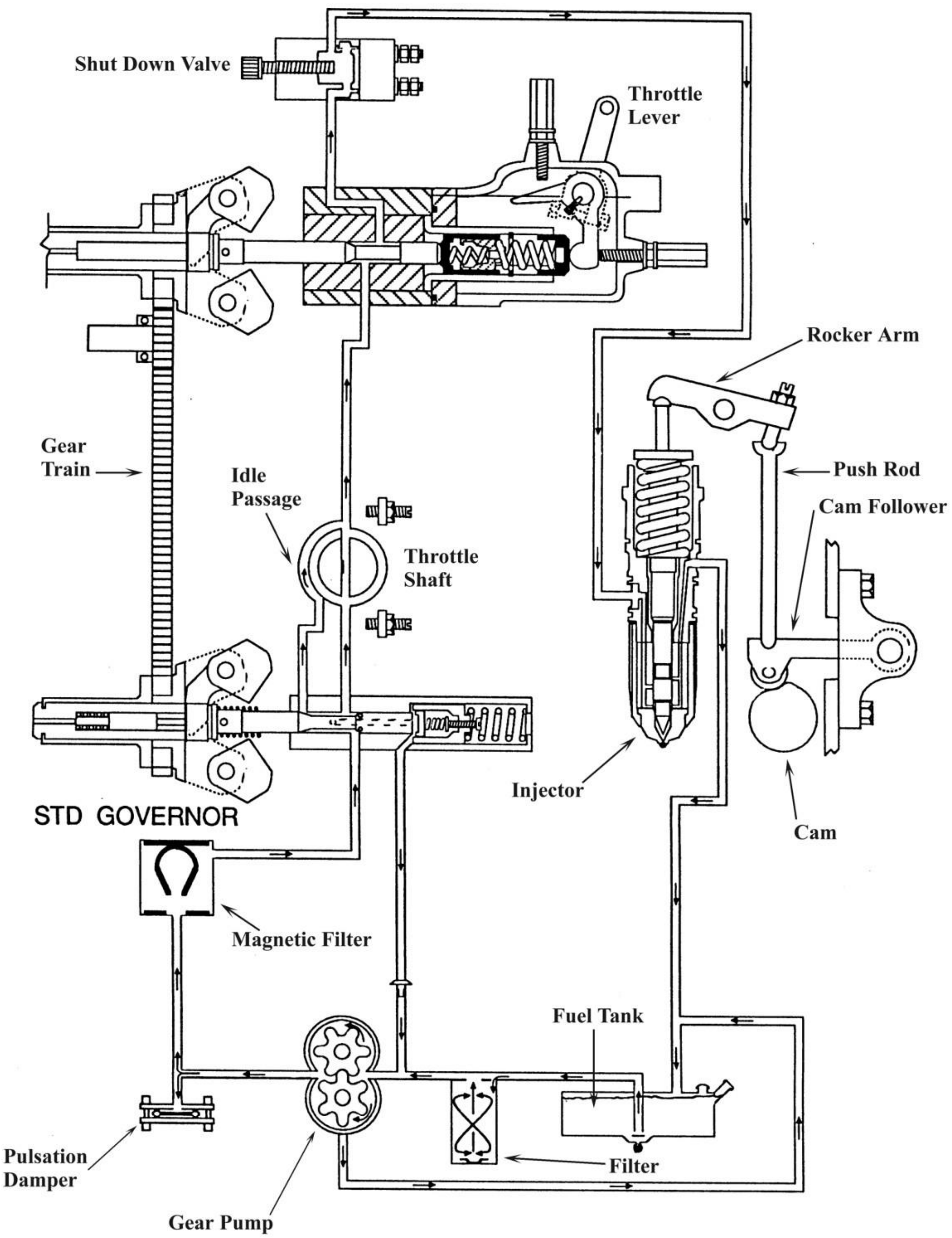
Cummins PTG-VS fuel pump



Cummins PTG-VS fuel pump

The main components of this fuel pump are:

- Gear pump
- Pulsation damper
- Magnetic filter
- A standard governor
- Throttle shaft for the standard governor
- A variable speed governor
- Shut down valve

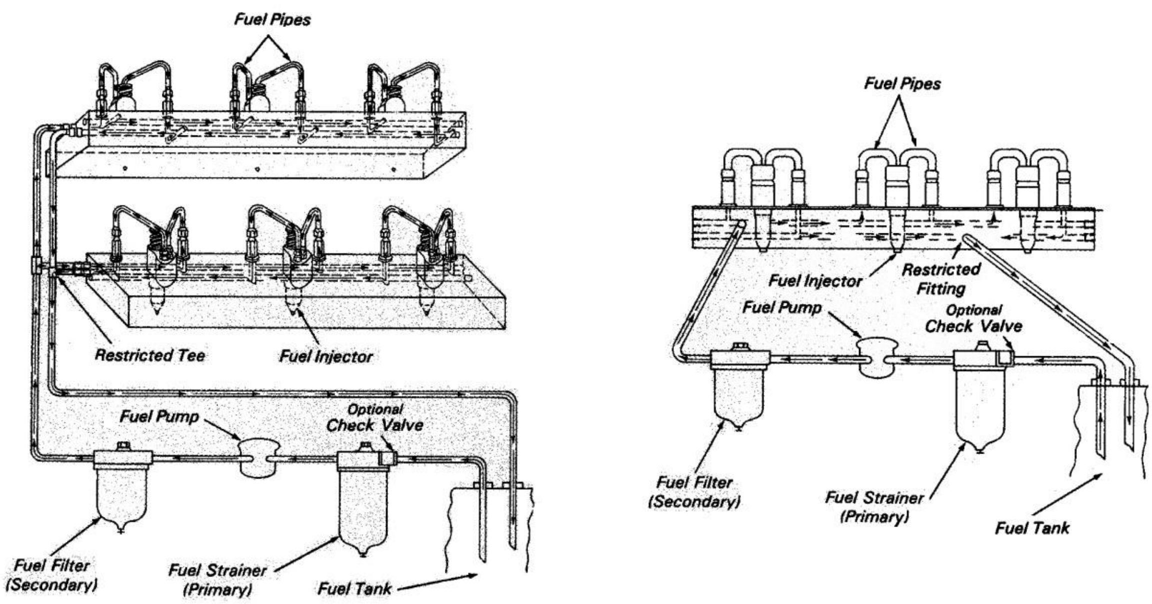


A gear pump delivers fuel under pressure through a pulsation damper, which dampens out fuel surges created by the gear pump action. A magnetic filter is used to remove any metal debris from the fuel.

The fuel flows from the magnetic filter to a standard governor which controls the engine idle speed and the fuel pressure delivered by the fuel pump. The standard governor is located in series with the variable speed governor, which is positioned in the fuel pump housing. The variable speed governor controls the fuel flow to the injectors in relation to the engine speed.

The amount of fuel which flows to the injectors is dependent upon the fuel pressure from the fuel pump and the time the feed port is allowed to remain open. Hence the “pressure - time” theory to this fuel injection pump system.

Detroit diesel mechanical unit fuel injection system



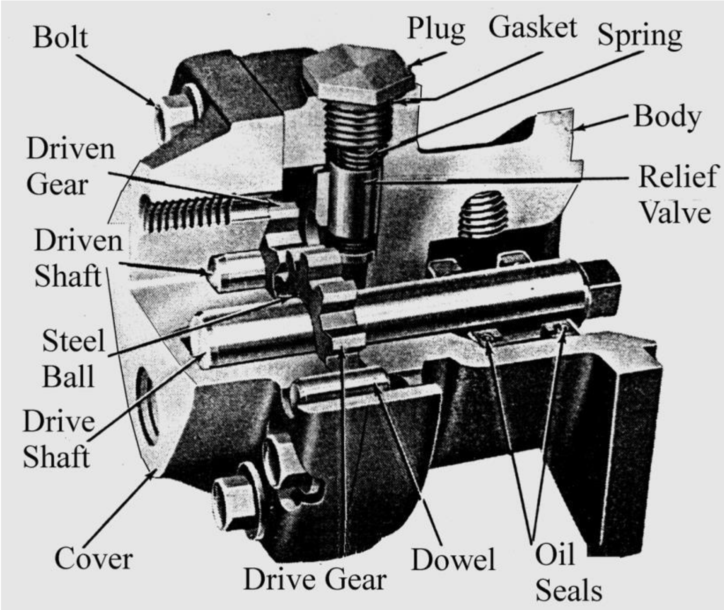
Detroit Diesel fuel system

Fuel is drawn from the supply tank through the strainer and enters the fuel pump on the inlet side. On leaving the pump under pressure, fuel is forced through the fuel filter into the fuel manifold and from there through fuel pipes to the inlet side of the unit injectors. Surplus fuel returns from the outlet side of the unit injectors through outlet fuel pipes into the return manifold, from where it flows back to the supply source.

The fuel pump is of the gear type with an in built relief valve.

A non-return valve can be installed between the fuel strainer and the source of supply to prevent fuel draining back when the engine is not running.

A restricted elbow is located at the end of the outlet manifold to maintain pressure in the fuel system between the inlet and outlet fuel passages.



Detroit diesel fuel pump

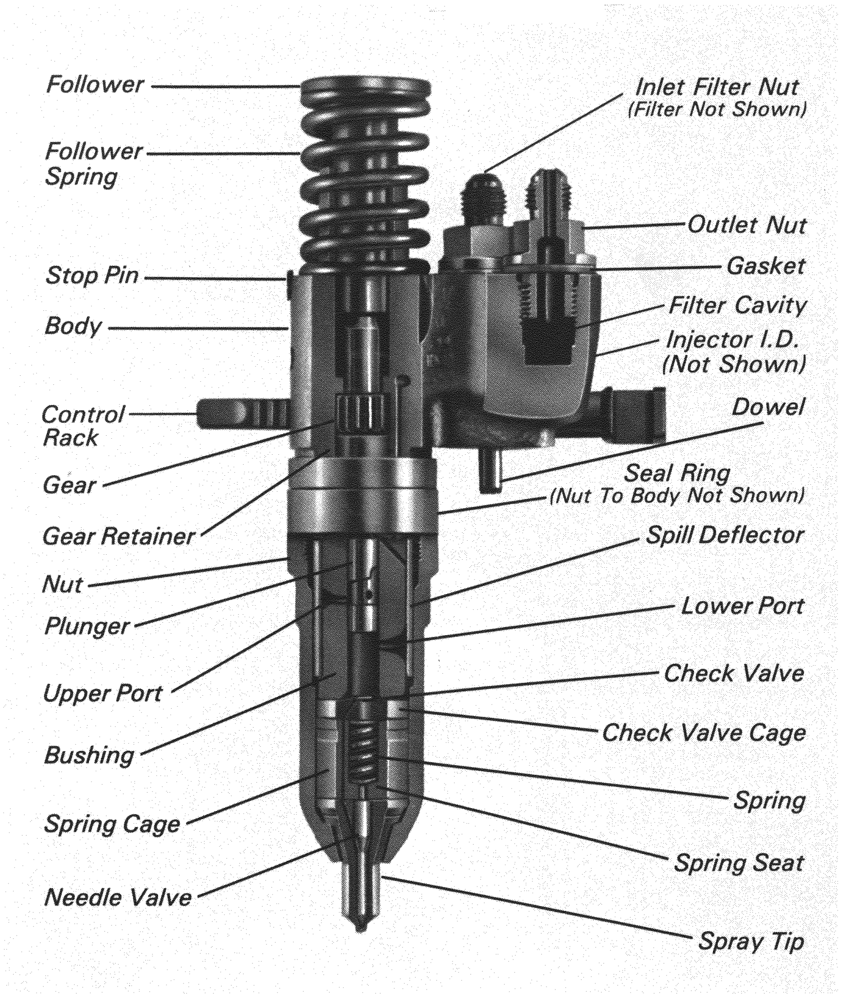
Mechanical unit injector

The unit injector is a single unit which combines all the necessary components to provide complete and independent fuel injection to each cylinder.

The unit injector performs four functions:

1. Creates the high fuel pressure needed for efficient fuel injection.
2. Meters and injects an accurate amount of fuel.
3. Atomises the fuel to assist mixture with air in the combustion chamber.
4. Times the injection of fuel into the combustion chamber

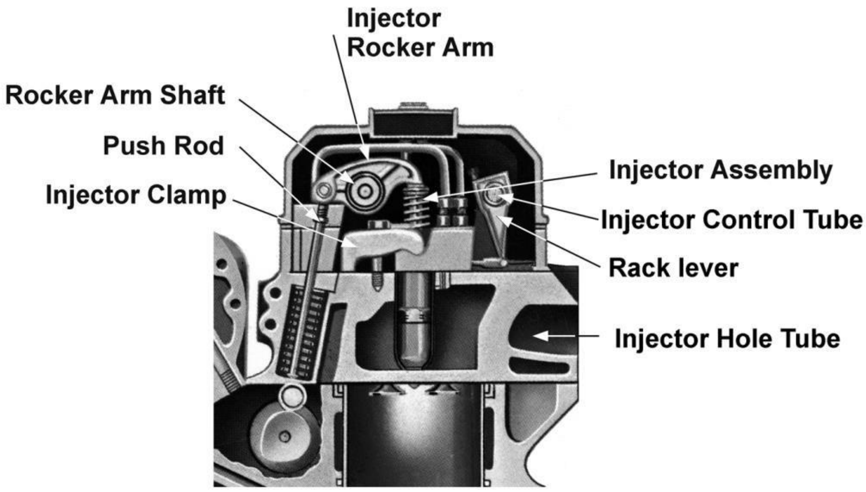
Unit injectors have the advantage that there are no high pressure fuel lines and the continuous flow of fuel serves to cool injector components while also preventing vapour pockets from forming.



Detroit Diesel Mechanical Unit Fuel Injector

Operation

Fuel enters the injector through a filter cap and element and flows into a supply chamber. Fuel also flows into space below the injector plunger. The plunger is moved by a special cam via a push rod and rocker assembly. As the plunger moves up and down inside a bushing, fuel is fed through two ports in the bushing into the supply chamber. **Fuel injection assembly, Detroit diesel 2 stroke engine.**



For engine speed the plunger can be rotated within the bushing using quadrant gear which meshes with a control rack.

Fuel metering is achieved by rotating the plunger which varies the relationship between two helices machined into the lower portion of the plunger and fuel inlet ports in the bushing. The positioning of the helices and ports control the plunger's stroke and the amount of fuel injected into the cylinder.

On the pumping stroke a portion of the fuel is forced through the lower port into the supply chamber until the lower plunger helix shuts off the port. Fuel trapped below the plunger is then forced through a central hole in the plunger and so through the upper port into the supply chamber until that port is closed by the upper plunger helix. With both ports closed fuel pressure builds up during the remainder of the plunger stroke until it is sufficient to lift the injector valve from its seat, at which point injection commences.

The spray tip incorporates a check-valve whose function is to prevent fuel dribble into the combustion chamber after the injection cut-off point should the injector valve fail to return to its seat.

On the injector plunger's return stroke, the high pressure area inside the bushing is again filled with fresh fuel through the two inlet ports. This maintains a constant circulation of cool fuel which helps in reducing injector temperatures and effectively removes all traces of air.

Excess fuel is fed back to the fuel return manifold and subsequently, the fuel tank, through the injector outlet opening which contains a filter element similar to the one on the fuel inlet side. When the control rack is pulled back to the cut-off position the upper port is not closed by the helix until after the lower port is uncovered. Consequently, all fuel is passed back to the supply chamber and no injection takes place.

When the control rack is in the full injection position, the upper port is shut off shortly after the lower port has been closed by the position of the helix. This rack position is set to give maximum effective plunger stroke and maximum fuel delivery. As previously mentioned, intermediate throttle positions are provided by the relative position of the helical contours to the inlet ports so that both the effective stroke of the plunger and the commencement timing of the injection are altered.

Electronic unit injector

Major engine manufacturers also supply electronically controlled engines. An example of an electronic control is Detroit Diesel Electronic Controls (DDEC). These engines employ an electronic unit injector.

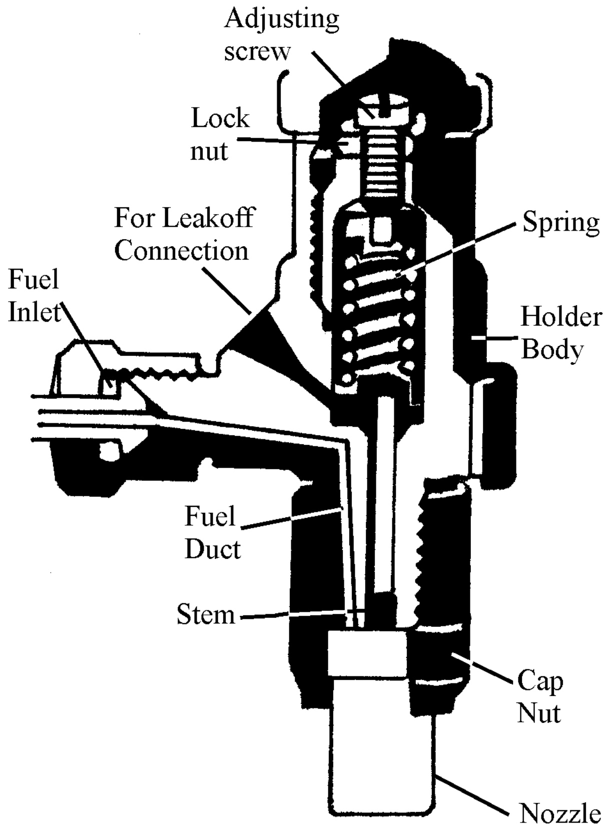
- The electronic unit injector (EUI) is built on their patented mechanical unit injector design.
- The design simplifies the plunger and bushing. It also replaces the mechanical rack with an electronic solenoid.
- It allows precise metering and injection timing.

- The amount of fuel injected and the timing are determined by information fed into the microprocessor (Electronic Control Module) from sensors located on the engine.

Fuel injector assembly

A fuel injector is a spring controlled valve located in the engine cylinder head and allows the fuel, under pressure from the fuel pump, to enter the cylinder. It enters in an atomised form to allow it to mix completely with the hot compressed air so that ignition can take place with efficient combustion.

Fuel injector

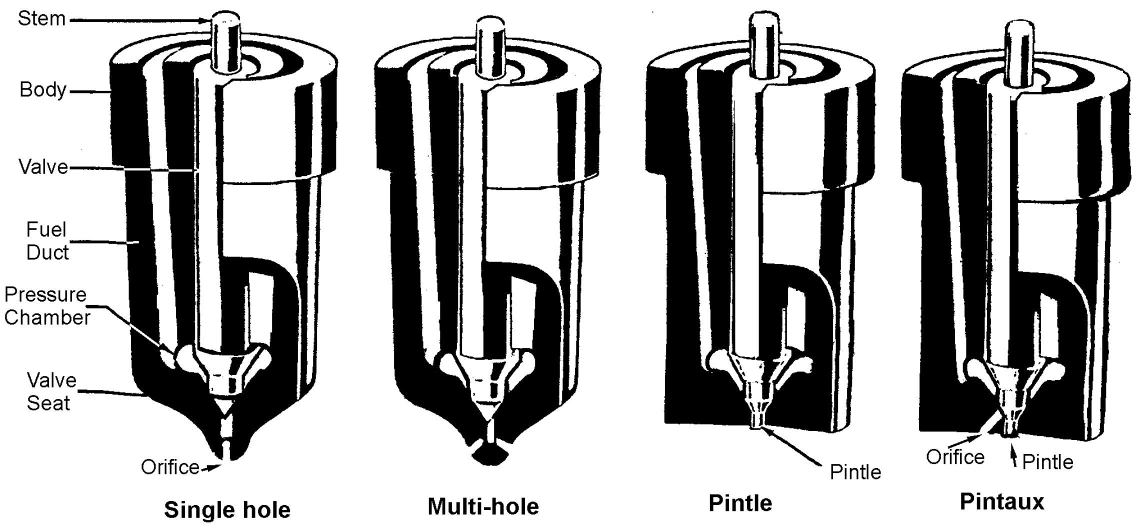


Spray nozzle assembly

The fuel injector consists of a nozzle body and valve. The nozzle body incorporates the valve seat and has holes or orifices in it to atomise the fuel. The valve must seal effectively on the valve seat to allow for a clean cut off of fuel to the cylinder. A leaking valve causes misfiring and irregular speed, particularly on light loads. The valve and nozzle body are lapped to form a mated assembly. Therefore the valve and nozzle body cannot be exchanged individually. A nozzle cap attaches the nozzle to the body of the injector.

Types of spray nozzles

There are different types of spray nozzles. The type of spray nozzle used depends upon the design of the combustion chamber and the angle of the injector. It must spray the fuel so that it mixes completely with the hot compressed air for efficient combustion to take place. Four types of spray nozzles are the single hole, multi-hole, pintle and pintaux.



Types of spray nozzles

The single and multi-hole spray nozzles are similar in that when the valve opens, the fuel ejected can be directed through one hole in the case of the single spray nozzle or through any number of holes at any angle in the case of the multi-hole spray nozzle.

The pintle and pintaux are also similar. A pintle on the valve projects past the valve seat and slightly past the end of the nozzle. There is a slight but exact clearance between the pintle and the injection hole. The pintle size and shape can be varied so as to meet any spray pattern requirement. The pintle prevents the formation of carbon deposits in the injection hole. Pintle nozzles are used in engines with adequate air turbulence such as pre-combustion chambers or turbulence chambers.

When the fuel pressure opens the valve, the pintle causes a conical spray pattern. It also allows a relatively small proportion of the fuel to be injected as the valve starts to open, followed by the bulk of the fuel thereby slowing down the pressure rise in the cylinder bringing about smoother combustion and engine running. The pintaux differs in that it has a hole at an angle where fuel sprays out separately from the conical pattern for pilot injection.

Nozzle holder or body - A nozzle holder forms the body of the injector. It is fitted with a flange to secure it to the cylinder head. It has drilled passages for the fuel to flow to the valve and for the leak off from the valve stem.

Spring and adjustment screw - The valve is held on its seat by a spring operating on a steel spindle. The compression of the spring can be adjusted by a screw and a locknut so that the valve opens at the recommended pressure.

Cap nut - A cap nut is screwed onto the top of the nozzle holder to enclose the adjustment screw and to seal the unit.

2.4 Injector operation

The fuel injector pump delivers a set amount of fuel under pressure to the fuel injector.

The pressure causes the valve to open against the spring and the fuel to spray into the cylinder.

When the helix on the plunger of the fuel injector pump uncovers the spill port, the pressure of the fuel drops quickly and the spring in the fuel injector causes the valve to shut.

The delivery valve in the fuel pump also closes and fuel is maintained in the injector pipe.

The needle valve is a neat fit in the nozzle and fuel flows through the small clearance to lubricate it. This fuel is called leak off and is returned to the fuel tank.

CAUTION:
Injectors deliver extremely high pressures. You should exercise due care when dealing with this equipment as there is a clear risk of serious and permanent injury.

2.5 Rectifying injector faults

Any injector problem at sea can be rectified by replacing the injector with a spare. However the candidate is required to know how the following faults can be identified and rectified.

Incorrect opening pressure

Too low an opening pressure will cause the valve to chatter on its seat. Fuel will be injected into the cylinder earlier. It is caused by insufficient compression on the spring. Too high an opening pressure will cause the valve to hammer on its seat. Fuel will be injected into the cylinder later. It is caused by too much compression on the spring.

The spring adjusting screw has a lock nut which may have slackened off causing insufficient compression on the spring. The spring may break. Replace the spring. The correct opening pressure can only be obtained by placing the injector in a test rig and adjusting the tension on the spring until the correct opening pressure is obtained. Whilst on the test rig, the spray pattern of the fuel leaving the nozzle can also be checked.

Distorted spray form

Spray nozzle orifices are partially clogged. Spray nozzles should be cleaned by first soaking them in either kerosene or clean fuel to soften the dirt. The spray holes or orifices can be cleaned with a pointed piece of wood. Do not use a piece of wire.

Dripping injector

The valve is not sealing on its seat. Grind it in with the finest grade of grinding compound. Excessive grinding causes the valve to seat too deeply in its seat causing a lagging of the fuel admission which results in late combustion and therefore loss of power.

In addition, the valve stem may be bent and this will cause the valve not to seal on its seat and the valve stem will be tight in the nozzle body. The valve and nozzle body are lapped to form a mated assembly. Therefore the valve and nozzle body cannot be exchanged individually. Replace with a new valve and nozzle body. The opening pressure will then have to be adjusted.

Dirt between the valve and its seating

Spray nozzles should be cleaned by first soaking them in either kerosene or clean fuel to soften the dirt. Do not use anything metallic or abrasive to clean them. Grind it in with the finest grade of grinding compound. Excessive grinding causes the valve to seat too deeply in its seat causing a lagging of the fuel admission which results in late combustion and therefore loss of power.

Injector valve sticking in the nozzle body

The valve stem may be bent and this will cause the valve stem to be tight in the nozzle body and the valve not to seal on its seat. The valve and nozzle body are lapped to form a mated assembly. Therefore the valve and nozzle body cannot be exchanged individually. Replace with a new valve and nozzle body. The opening pressure will then have to be adjusted.

Alternately, there may be dirt between the valve stem and the nozzle body. It may be possible to clean the dirt away and reuse the assembly. If however, there has been grit passing through the fuel injector, it is most likely that there is pick up on the valve stem and body thereby scoring them. *Pick up is when metal from one part is transferred to its mating part and scores or grooves it.* Further operation in this condition could cause the valve stem to seize in the nozzle body. Any pick up on the valve stem and nozzle body will require the assembly to be replaced.

Too much fuel escaping at the leak off pipe

Caused by excessive clearance between the valve stem and the nozzle body resulting from wear or pick up from dirty fuel or corrosion by water contaminated fuel. A fine clearance is required to maintain the fuel pressure and allow some fuel to pass by to lubricate. Replace the valve and nozzle assembly.

2.6 Exhaust emissions

Exhaust emissions can be related to the operation and condition of the engine.

Black smoke

Indicates a fuel or air problem. For efficient combustion, the ratio of fuel to air must be maintained otherwise incomplete combustion will take place resulting in black smoke.

- Blocked or partially blocked air cleaner
- Turbo charger not attaining sufficient speed
- Poor compression
- Incorrect fuel pump timing, Faulty fuel pump
- Incorrect valve timing
- Faulty fuel injectors - dirty nozzle, incorrect opening pressure, excessive leak off, valve not seating in body
- Engine overloaded

Blue smoke

Indicates that lubricating oil is being burnt. Caused by:

- Worn, broken or sticking piston rings and/or worn cylinder liner bores
- Worn valve guides
- Valve stem seals leaking
- Turbo charger seals leaking
- Oil bath type air cleaner overfull

White smoke

or white exhaust vapour indicates water or moisture.

- Water in the fuel
- Moisture in the air
- Cold cylinder liner bores and combustion space when first starting engine
- Leaking cylinder head gasket between cylinder and cooling water passage.

2.7 Governors

The power requirements of an engine may vary continually due to fluctuating loads, therefore some means must be provided to control the amount of fuel required to hold the engine speed reasonably constant during such load fluctuations. To accomplish this control, a governor is fitted to the engine.

There are a number of different types of governors, but only two will be mentioned.

Constant speed governor

It is used to maintain the engine at the same speed. For example an auxiliary engine driving a generator may have a fixed speed of 1800 rpm. The electrical load will vary. If the load is increased, more fuel is required otherwise the speed will drop. The drop in speed will cause the governor to alter the fuel pump to supply more fuel so the 1800 rpm is maintained.

Variable speed governor

It is used to maintain a set idling speed, a maximum speed and any desired speed between these limits regardless of any load change. The desired speed is set by a speed control lever or wheel. This type of governor is used on propulsion engines and a simple mechanical and hydraulic type are described herein.

Mechanical and hydraulic governors

Mechanical governors are limited as to their sensitivity due to the fact that the governor flyweights must not only limit the speed, but also perform the physical work of moving the fuel control mechanism.

In addition, speed droop is inherent in them, so they are incapable of maintaining constant speed with varying load without manual adjustment.

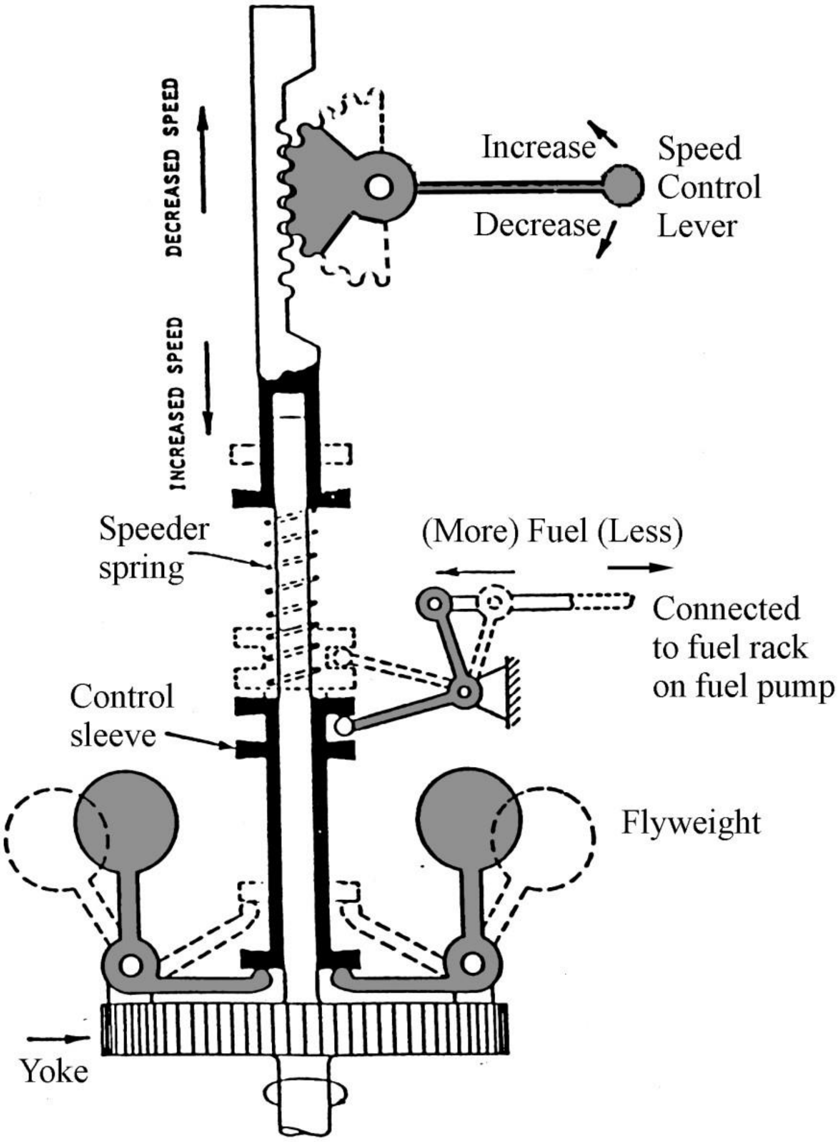
*The steady decrease in the speed of an engine caused by an increase in load from no load condition to full load, without change in the adjustment of the governor is known as "**speed droop**".*

*A governor which regulates the engine speed so that there is zero speed droop is termed "**isochronism**".*

A hydraulic governor of the proper design is not only isochronous but is extremely sensitive because the governor flyweights are used to limit speed only, the work of moving the fuel control mechanism being performed hydraulically.

A mechanical governor cannot make any adjustment to the fuel supply until the engine speed has changed ie. they cannot anticipate, they can only correct.

Mechanical variable speed governor



Mechanical variable speed governor

The governor is engine driven which causes the flyweights to rotate. When the engine is operating at normal speed, the centrifugal force acts on the rotating flyweights and is balanced by the vertical speeder spring force. The control sleeve remains stationary.

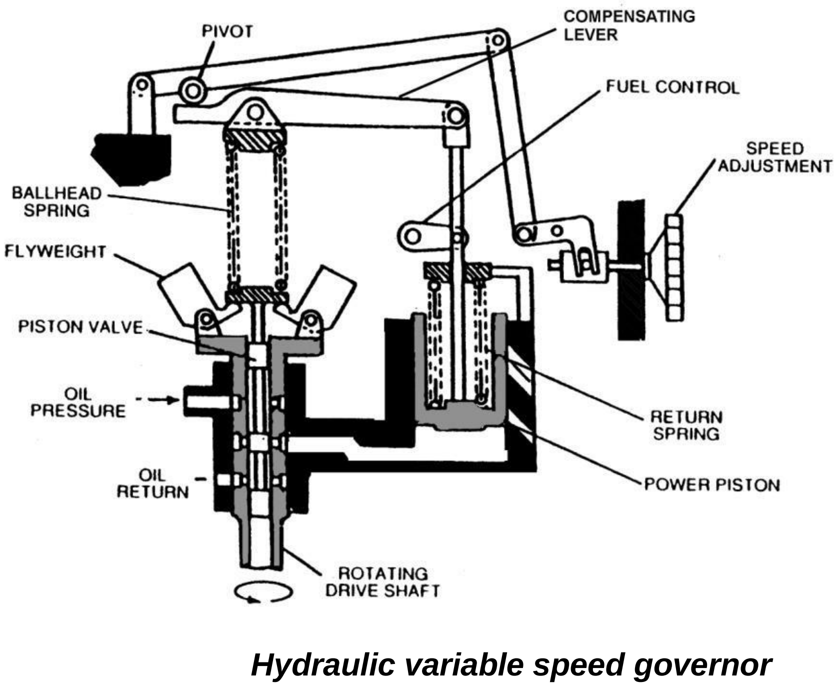
If the engine load decreases, the engine speed increases (ie. the propeller coming out of the water). The centrifugal force acting on the flyweights also increases causing the flyweights to move outwards and the control sleeve upwards.

This moves the fuel rack so less fuel is delivered. The upward movement in the control sleeve increases the compression in the speeder spring and hence the speeder spring force. This increased spring force and the control sleeve remains stationary in the new position.

If the engine speed decreases (ie. the propeller going back into the water), the opposite to the above occurs. Thus the control sleeve moves up and down as the engine speed fluctuates because of load variations.

The normal operating speed of the engine can be manually adjusted by increasing or decreasing the speeder spring compression and hence the speeder spring force by the speed control lever. The governor is engine driven which causes the flyweights to rotate.

Hydraulic variable speed governor



Hydraulic variable speed governor

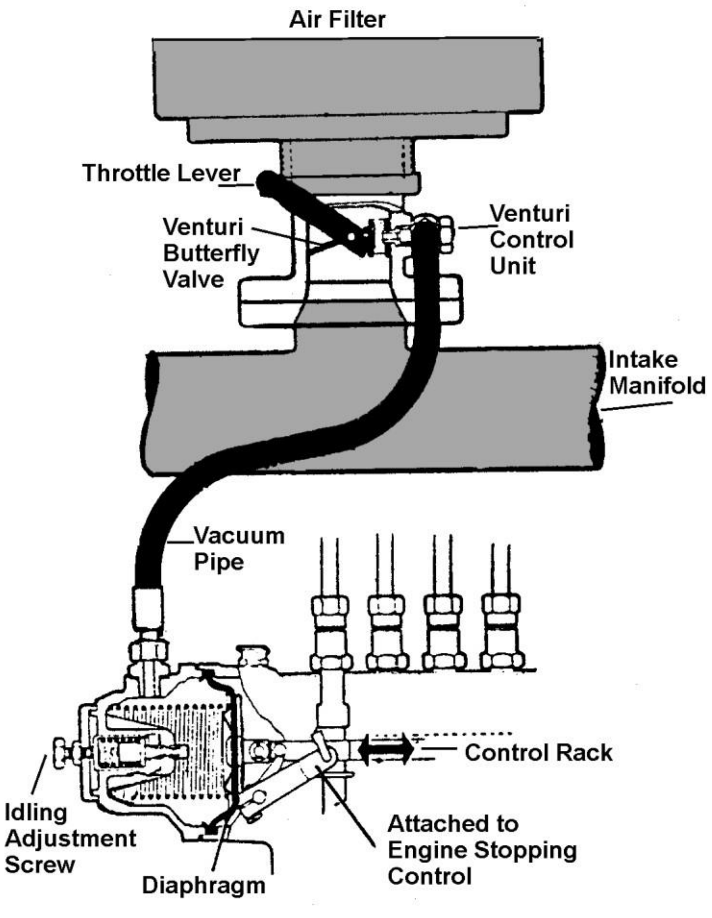
When the engine is operating at normal speed, the centrifugal force acts on the rotating flyweights and is balanced by the vertical ballhead spring force and the piston valve remains stationary.

If the engine load increases, the engine speed decreases, the centrifugal force acting on the flyweights also decreases causing the flyweights to move inwards and the ballhead spring to move the piston valve downwards. The piston valve, on moving downwards, will admit oil under the power piston. This pushes the power piston upwards, compressing the return spring and moving the fuel control towards more fuel. The movement of the compensating lever slightly decreases the force on the ballhead spring and returns the piston valve to its neutral position.

The normal operating speed of the engine can be manually adjusted on the speed adjustment wheel. To increase the engine speed, the force on the ballhead spring is increased causing the piston valve to admit more oil under the power piston which in turn increases the supply of fuel.

The compensating lever is fitted to stop the governor from hunting. Hunting is when the speed is below or above the control speed, the governor will continue to adjust the fuel control. To avoid hunting, a governor mechanism must anticipate the return to normal speed and must stop changing the fuel control setting slightly before the new setting, required for sustaining the control speed, has been reached.

Pneumatic Governor



The pneumatic governor operates on the well known fact that air passing through a pipe tends to create a vacuum in a part of smaller diameter. The engine suction through a venturi (a tube with a narrowing throat or constriction designed to increase the velocity of the gas or fluid passing through it) provides the necessary suction and in turn operates a diaphragm control connected directly to the control rack of the fuel injection pump.

The pneumatic governor consists of two main parts:

1. The venturi air flow control unit mounted between the air induction manifold of the engine and the air intake filter; and

2. The diaphragm unit mounted on the end of the fuel pump housing.

The venturi unit - has a butterfly valve fitted at its throat and is actuated by the throttle. The butterfly valve is limited by stops for both the idle and maximum speeds. A vacuum pipe is taken from the same center line as the butterfly valve to the diaphragm unit.

The diaphragm unit - has a diaphragm, a light spring dampening out any oscillations and keeping the fuel pump control rack in the full open position. A manually operated lever is fitted to the control rack and is used to stop the engine by drawing the control rack into the stop or no fuel position.

Operation

The operation of the governor is as follows:

When the engine is at rest, the lever is released and the spring forces the control rack into the full load position. By setting the excess fuel device rack allowed to move automatically to the extent of its travel, placing the fuel pump plungers into starting position (maximum fuel delivery). The engine is ready to start.

(*The excess fuel device is located at the opposite end of the fuel control rack and consists of a plunger, or latch, which when released, allows the rack to move as previously stated. As soon as the engine starts and the governor takes charge, this device resumes its normal load position automatically, preventing the control rack from again going to the starting position*).

The manual control is set to running position and the engine started.

When the engine starts and is idling, the butterfly valve is almost closed. A high vacuum is immediately created in the corresponding pipe and airtight compartment in the diaphragm unit.

The air in the adjoining compartment is at atmospheric pressure; therefore the pressure on this side of the diaphragm is higher than that existing in vacuum compartment. This causes the diaphragm to move the control rack towards the stop position until the engine is running at the predetermined idling speed.

When the throttle is operated to increase the engine speed the butterfly valve is opened wider, this decreases the velocity of the air passing the mouth of the connecting tube.

The result is an increase of pressure in the vacuum compartment of the diaphragm unit with the spring forcing the diaphragm and the control rack towards the maximum speed position, so increasing the amount of fuel delivered to the engine.

Fluctuations can exist in the induction manifold. To dampen these fluctuations, an additional adjustable spring controlling the diaphragm is fitted. This auxiliary spring comes into operation at predetermined speeds and can be adjusted by a screw to suit the engine requirements.

This governor is extremely sensitive and efficient but has the bad fault that should any leakage occur that will tend to destroy the vacuum, the governing effect will be lost and the engine may race.

Drive

Governors are driven by some part of the engine that rotates. It may be off the camshaft, or be mounted on the scavenge blower and driven by the upper blower rotor or be attached to the end of the fuel pump, or enclosed in the fuel pump housing, or by some other method.

Lubrication

Mechanical governors are lubricated by oil splash. Oil entering the governor is directed by the revolving flyweights to the various moving parts requiring lubricating.

Faults

Governor difficulties are usually indicated by speed variations of the engine. However, speed fluctuations are not necessarily caused by the governor and, therefore, when improper speed variations become evident, the unit should be checked for excessive load, misfiring or bind in the governor operating linkage.

Dirty oil is a cause of hydraulic governor troubles.

Remote control of governors

Some hydraulic governors are equipped with a reversible synchronising motor which is mounted on the governor cover. This motor makes a close adjustment of the engine speed possible by remote control and is especially valuable for synchronising two generators from a central control panel or bridge control.

Electrical / hydraulic governors

The Electric Fuel Control (EFC) governor is an electrical sensing system that can be adjusted for isochronous engine speed droop. This governor will provide rapid fuel rate changes to improve the transient response to the load change.

It consists of:

Magnetic 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.

Governor control - The governor control is an all electric solid state module which compares the pulses (electric signal) from the magnetic pick-up with a speed control reference point. A current output is supplied to the actuator which rotates the actuator shaft to control the fuel flow to the engine.

Actuator - The actuator is an electromagnetic rotary solenoid valve, the turning action of the shaft regulates the fuel pressure and therefore determines the engine speed and power. (In other governors, there are variations in that they still have an electromagnetic solenoid valve but it is not a rotary type, and it still controls the fuel pressure).

2.8 Testing and setting a mechanical variable speed governor

All governors are properly adjusted before leaving the factory. However, if the governor has been recondition or replaced, minor adjustment might be required.

As the procedure for adjustment vary between makes and models of governors, the Owners Manual should be followed.

Caution - To prevent maladjustment, it is the practice of some manufacturers to seal the governor mechanism after it has been adjusted on the test bed, and, if the seal is broken, to decline responsibility for failure in performance.

Interference with the tension of the governor springs may cause the speed of the engine to rise beyond the safety limit. Interference with the maximum fuel stop may result in the injection of too much fuel, thus causing excessive exhaust smoke and overheating.

Adjustments

The usual adjustments are for the maximum no-load speed and the idling speed, although there maybe a number of steps to affect a setting.

Adjustments should only be made after the engine has reached normal operating temperature. An accurate tachometer should be used for the engine speed.

Maximum no-load speed

A stop is used to limit the compression of the governor spring which determines the maximum speed of the engine. This adjustment will only affect the maximum speed and have no effect on intermediate speed control positions. Set the throttle at full speed and when it is running at this speed, turn the adjusting screw so that the maximum speed, as recommended by the manufacturer, is obtained. Tighten the lock nut on the adjustment screw.

Idling speed

A stop is used to limit the travel of the fuel pump rack so that the slot in the plunger does not line up with the spill port and stop the engine.

With the throttle in the idle position, loosen the lock nut and turn the adjusting screw until the engine is running at the manufacturers' recommended idling speed. Tighten the lock nut.

Fuel Storage and Handling Systems

3.1 Survey requirements for fuel storage tanks

The survey requirements for vessels are as follows:

For fuel storage tanks and piping systems:

Less than 35 metres:

Annual survey	Inspection of all pipe arrangements
Twelve year survey	All fuel oil tanks.

35 metres and over:

Annual survey	Inspection of all pipe arrangements
Five year survey	Deep tanks and double bottom tanks used exclusively for fuel oil, to be examined externally and tested to a head sufficient to give the maximum pressure that can be experienced in service
Other intervals	One deep tank and one double bottom tank used exclusively for fuel oil to be surveyed internally every 5 years starting when the vessel is 10 years old. All such deep tanks and double bottom tanks to be surveyed by the time the vessel is 25 years old.

It should be noted that a surveyor does have the discretion to survey fuel oil tanks of the vessel not due for survey if he considers such action is warranted.

Survey should not be confused with maintenance.

A responsible owner will have a maintenance program which involves opening up, inspection and repair, or refurbishment at lesser intervals than required by the survey authority.

This is especially important with the present problems of microbial infection of diesel fuel. Presence of such infection will dictate that that fuel tanks be inspected at regular intervals. In such cases of infection the inspecting surveyor will use his discretionary powers and require tanks to be opened for internal inspection at less than the specified intervals. 3.2 Fuel storage and handling
Fuel storage arrangements on board are largely dependent on the intended service of the vessel and location of refuelling stations within the area of operation of the vessel. Typical arrangements are:

1. Short distance
Tanks port and starboard within the machinery space. These may be free standing or form part of the hull structure plus a smaller tank for direct supply to the main engine and generator engines. Fuel from the larger tanks is transferred to the smaller tank as required.

2. Medium distance
A bunker or deep tank divided into port and starboard tanks forward of the machinery space the aft bulkhead of the tank being the machinery space forward bulkhead, with a small tank as in 1 OR

Two small tanks both capable of supplying the main engine and generator engines, each with independent lines to the main and generator engines. The tanks would be used alternately.

3. Long distance
as in 2, but with the addition of a double bottom fuel tank/s.

Components of a fuel system

The components of a fuel system are:

- the fuel tanks
- piping
- valves and fittings;
- pumps (power or hand)

Fuel tanks

Fuel tanks may form part of the hull structure, be free standing and substantially constructed of carbon steel, stainless steel, copper or marine grade aluminium.

Their function is storage of the fuel or as a daily service tank/s topped up from the storage tanks. The tanks shall be provided with a manhole or hand hole to enable the tank to be cleaned and inspected. Each tank needs to have ventilation pipe of a size to prevent generation of pressure in the tank.

Piping

Comprises the system of pipes installed to take fuel on board, transfer the fuel between tanks and supply the main auxiliary engines

Valves

Valves are located on the fuel tanks and at strategic parts in the piping system and are opened and shut as required to allow the fuel to be pumped between tanks and to the engines. Valves on fuel tanks have to be capable of remote operation from a safe place outside the machinery space so that the fuel can be shut off if a fire occurs in the machinery space. A drain valve is also fitted on each tank to remove any water that may have accumulated in the tank.

Fittings

Filters uses are self explanatory. Gauge glasses or fuel indicators fitted to tanks provide an indication of the amount of fuel in a tank. Gauge glasses shall be fitted with self closing valves or cocks. This is to prevent the tank draining through the cock into the bilges if the glass is broken.

Pumps

Pumps are used for transferring fuel between tanks. There may be a separate pump to supply fuel at pressure to the engines. Stop valves are to be provided on the suction and delivery sides of power operated pumps. If the closed discharge pressure exceeds the maximum design pressure of the system a relief valve discharging back to the suction side of the pump shall be fitted.

Pumps located below decks shall be provided with a means to stop the pump from a safe place outside the space.

Loading Fuel

The USL Code requires all fuel filling stations to be fitted outside of the machinery spaces and so arranged that any overflow cannot come into contact with any hot surface. Fuel is normally supplied to small vessels from road tanker/s. Therefore the amount of fuel required can be measured by the fuel meter in the tanker discharge line, and spillage should not be a problem. The basic precautions to be carried out are:

No smoking signs to be placed on the ship and on the wharf in the vicinity of the ship and tanker.

When filling has been completed a container should be supplied to catch spillage when the fuel supply line is disconnected. This action is not required if both the tanker and the ship have non drip "camloc" fittings on their piping connectors.

Venting

As noted previously each tank shall have ventilation pipe of a size to prevent generation of pressure in the tank.

Transferring fuel

The piping system should be as flexible as possible in being able to pump fuel direct from any one tank to another and therefore the system of pump/s, piping and valves should be designed to this end.

Draining

Draining can only be carried out if there is space in other fuel tanks to take the fuel from the tank being drained, or it is to be pumped a shore reception facility. If the tank is a double bottom tank or deep tank, it can only be drained to the height the end of the suction pipe is above the tank bottom. For tanks whose bottom is clear of any structure (e.g. free standing), the valve for draining water from the bottom of the tank can be opened and the remaining fuel drained into a receptacle.

3.3 Shut down devices

For all fuel systems the USL Code requires a means to be provided outside a propulsion machinery space, (in an accessible position not likely to be isolated by a fire in the space), to shut off the fuel to the main and auxiliary engines by means of a fire safe valve or cock.

In practice this means that a valve or cock required to be fitted to each tank outlet can be operated from a safe position outside the space by means of an extended spindle, or some other method of remote operation.

Any fuel transfer or a cargo oil pump which is located below deck in a machinery space shall be provided with a means to stop the pump from both inside and outside the space.

3.4 Causes of fuel contamination

Fuel contamination can be caused by:

- dirt
- moisture (water) or
- microbial infection.

Dirt

Dirt can arise from dirty fuel taken on when bunkering. It is difficult to prevent as the receiver of the fuel has no way of knowing if the fuel is clean or dirty when being loaded. Effective filtration of fuel prior to use in the engine/s is necessary. In new vessels it may be that the tanks were not thoroughly cleaned prior to commissioning. Ensure the tanks are thoroughly cleaned.

Water/Moisture

Water can be in the fuel taken on when bunkering; an analysis of the fuel can indicate if the water content is excessive; a figure of around 0.1 to 0.2 % by volume is acceptable. Moisture in the air space of the fuel tank condensing. Drain off of any water in the tank/s on a daily basis.

Microbial infection

This is a common problem in diesel and similar grades of fuel. Tests are available to identify the presence of microbes and the fuel supplier can be asked to supply a fuel which does not exceed defined standards of contamination. It can occur due to taking infected fuel on board, and is aggravated by failing to regularly drain fuel tanks of any water that has accumulated in them.

The microbes can only propagate in the presence of water and feed on the fuel at the interface between the water and oil. The waste they generate is deposited as a black slimy sludge. On board a vessel their presence is first detected in the fuel filters which clog up more frequently.

In some cases the slime gets past the filters and causes the fuel pump plungers or the injector nozzle valves to malfunction due to rusting or partial blockage. Elimination of the bacteria is difficult.

Fuel can be treated by chemicals but as noted above regular drainage of water from the fuel tanks is essential to keep it under control. In case of severe contamination it may be necessary to clean out and disinfect all affected tanks and fuel lines.

3.5 Gas Free Situations

Gas Free can be defined as when the atmosphere in an enclosed space or tank is the same as that of the outside ambient air. Enclosed spaces or tanks are required to be gas free to allow personnel to enter without danger, for the purpose of survey/inspection, maintenance or repair work.

When the tank is considered to be gas free an authorised inspector should test the space to verify the gas free condition and issue a certificate declaring it to be so. The standard method of making a space "gas free" is to ventilate the space for a period of time either by forced or extractive ventilation. However additional requirements may be necessary depending on the usage of the space.

Some methods adopted to gas free spaces are as follows:

Fuel tanks carrying diesel fuel

The tank should be completely emptied of fuel. Smoking or naked lights in the space containing the tank prohibited. Warning notices should be placed at all entrances to the space. The door or closure on any manhole or inspection opening should be removed. A portable ventilation fan preferably one to which flexible ducting can be connected. This should be situated near the tank opening, the loose end of the flexible ducting placed into the tank and ventilation commenced.

Special fans with ducting are readily available for this work. Fans can be driven by enclosed electric motor or compressed air drive. Gases will escape through the vent piping and through the manhole. Dilution of the gases and the flashpoint of diesel fuel is such that there is little danger of fire or explosion. The time required to ventilate depends on the size of the tank and fan. However 3-4 hours should be considered the minimum.

Ballast deep, double bottom and peak tanks

Tanks used for ballast may be full or empty. An empty tank should never be entered without gas freeing, especially if it has been empty for a long time (a week or more). The air becomes stagnant and any rusting that has occurred reduces the oxygen content and pockets of carbon dioxide may have formed at lower levels.

A gas free certificate must be obtained.

Many gases in confined spaces have an anaesthetic action at quite low concentrations and humans exposed to the gases experience the usual sequential effects of an anaesthetic (or narcotic effect) such as drowsiness, loss of control, lack of judgement, delirium and eventually loss of consciousness. When personnel enter a tank a watch should be maintained at the entrance to the tank and the watch keeper maintain constant communication with the person/s in the tank to ensure they are and remain safe.

Notwithstanding the issue of a gas free certificate ventilation of the tank should be maintained whilst personnel are in the tank. If personnel do suffer symptoms of anaesthesia as described, the watch keeper should call for help and rescue should only be attempted by persons wearing breathing apparatus.

3.6 Flash point

The flash point of a fuel is the lowest temperature at which the vapour arising from the fuel gives off a flammable mixture that will just ignite (flash) when a flame is momentarily applied under defined test conditions.

The flash point is determined under laboratory conditions using various apparatus of long standing, eg. the Cleveland; the Abel-Pensky; the Pensky-Martens apparatus The first determines the open flash point of a fuel and the latter two the closed flash point.

The open flash point is slightly higher than the closed flash point.

The flashpoint is an indication of the volatility of a fuel and determines the degree of fire hazard associated with the fuel. The IMDG Code mentioned earlier, classes flammable liquids as Class 3. The class is divided into sub-groups: 1 is the (highest hazard) to 3 the (lowest hazard) according to their flashpoints, thus:

Class 3.1: Low flashpoint group of liquids having a flashpoint below -18^{0}C

Class 3.2: Intermediate flashpoint group of liquids having a flashpoint of -18^{0}C and up to, but not including 23^{0}C

Class 3.3: High flashpoint group of liquids having a flashpoint of 23^{0}C up to and including 61^{0}C

Liquids having a flashpoint above 61^{0}C are not considered to be dangerous by virtue of their fire hazard. However, vapours from Class 3 liquids are hazardous. If inhaled, they have a varying narcotic effect. Prolonged inhalation may lead to unconsciousness and possibly death. Flash point should not be confused with the ignition temperature.

Ignition temperature is the temperature to which an explosive vapour-air mixture must be heated to cause actual explosion. There is no relationship between the flashpoint and the ignition temperature.

Lubricating Oil Systems

4.1 Engine Lubricating System Components

The following describes the function of components in an engine lubricating system including:

- pumps
- relief and regulating valves
- full flow and bypass filters, magnetic filters
- heat exchangers and
- purifiers

Oil pumps

Lubricating oil pumps are of the positive displacement type. They can be gear, rotor or vane type.

They are engine driven in the smaller engines and thereby have the disadvantage that it takes several vital seconds for the oil to be pumped through the engine when it is started. Wear thereby takes place, especially on a cold engine as there is metal to metal contact until oil is received.

Larger engines have an electrically driven lubricating oil pump and the oil can be circulated for some time prior to the engine being started. The oil can also be heated to bring the temperature of the engine up and prevent serious differential expansion of the different metals.

Gear type pump

A gear type pump consists of two meshed gears in a closely fitted housing. It has inlet and outlet ports opposite one another. One gear is driven by the engine and in turning, drives the other. As the gear teeth separate and travel past the inlet, a partial vacuum is formed. Oil entering the inlet is carried to the outlet in the pumping chambers formed between the teeth and the housing. As the gear teeth mesh at the outlet, there is no place for the oil to go but out.

Rotor type pump

In a rotor type pump, there is an inner rotor driven by the engine. The inner rotor has a number of cam like lobes which mesh with mating parts in a rotor ring. The inner rotor causes the rotor ring to revolve within a housing. In the housing, there is an inlet and outlet port at 90° to each other. Oil entering the inlet is carried to the outlet by pumping chambers formed between the cam lobes. As the inner rotor and rotor ring are meshed at the outlet, there is no place for the oil to go but out.

Vane type pump

In a vane type pump a slotted driven by a driveshaft rotates between closely fitted side plates, and inside of an elliptical or circle shaped ring. Polished, hardened vanes slide in and out of the rotor slots and follow the ring contour by centrifugal force.

Between succeeding vanes, pumping chambers are formed which carry oil from the inlet to the outlet. A partial vacuum is created at the inlet as the space between the vanes open. Oil is squeezed out at the outlet as the pumping chamber size decreases.

Relief valve

As the oil pumps are of the positive displacement type, a relief valve must be fitted to protect the pumps and the lubricating oil system from excess pressure. The relief valve is usually incorporated in the pump body but can be fitted externally to the pump. Upon opening, the relief valve will cause oil to discharge back to the suction side of the pump or back to the sump.

When started, a cold engine will have a high oil pressure which will cause the relief valve to open. The engine's oil pressure drops as the engine reaches its normal operating temperature and the oil thins out. This results in the relief valve closing.

Regulating valve

A pressure regulating valve is fitted to the system to maintain a pre-determined oil pressure in the system. The spring pressure can be adjusted to set the valve at the pre-determined pressure. The valve would normally be opened when the engine is at its normal operating temperature with the excess pressure being discharged back to the sump. Any drop in oil pressure caused by wear in the engine or in the pump, is automatically compensated by the pressure regulating valve until the spring causes the valve to shut completely.

Filters

An engine may have one or more oil filters of the following types:

Full flow element type filter

The full flow filter requires all the oil to pass through it before entering the bearings, etc. As all oil flowing to the engine must pass through this filter, a by-pass valve is incorporated in the design to prevent oil starvation in the event of the filter element becoming blocked.

The operation of the valve is that when the outlet pressure of the filter is below that of the inlet pressure by a predetermined amount, the by-pass valve will open allowing oil to continue to the bearings, etc. A typical opening pressure would be 124 to 145 kPa (18 to 21 psi). Whilst the oil now flowing will not be filtered, this if preferable to insufficient oil. To prevent this undesirable situation happening, change the filter element at the periods recommended by the engine manufacturer or more regularly if operating conditions are not normal.

Bypass element type filter

The bypass filter continually filters a small portion of the lubricating oil that is bled off and is returned to the sump. The main portion of the oil goes to the engine. (Other types return the oil back into the flow to the cooler). Eventually all of the oil passes through the filter.

Centrifugal type filter

This filter is a unit which does not employ an element. It can be used by itself or in conjunction with replacement element filters. These are centrifugal type filters and may be driven by the oil pressure or direct from the engine. Any solids in the oil are flung by a revolving drum to the sides of the rotor, where they will remain until the unit is dismantled for cleaning. Washing in a suitable cleaner is all that is required to put the unit back into service.

Magnetic filter

A magnetic oil filter is used to remove small particles of metal usually from the result of wear. A new or overhauled engine will shed minute particles of metal until it beds in. A magnetic filter is therefore beneficial in this instance. Regular inspections of the filter may also draw early attention to a problem.

The magnetic filter cannot be used on its own as it will not filter out the non metallic foreign particles.

The filter is a full flow type without a by-pass valve. It is so designed that metal particles fill horizontal gaps between the iron rings from the top and working downwards but still leave vertical spaces for the oil to flow.

The element consists of a permanent magnet enclosed by a non-magnetic cylinder. A number of iron rings fit over and are attached to the cylinder. There are small gaps between the iron rings to attract the metallic particles. The element is situated in a non-magnetic casing.

The oil flow into the top of the filter and out at the bottom. Metallic particles are attracted and fill the horizontal gaps between the iron rings.

To clean the filter, the cover is taken off and the element is removed. One half of the iron rings are removed at a time to avoid demagnetisation and cleaned.

Notes

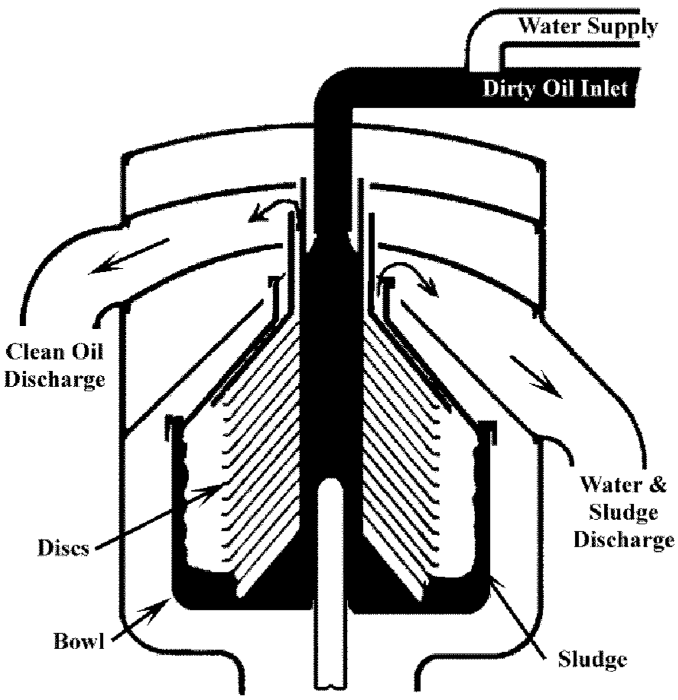
Some engines are fitted with a full flow filter that removes the larger foreign particles without restricting the normal flow of oil plus a bypass filter to remove the minute particles of foreign particles that may be present.

Some engines may be fitted with three filters. The first removes the larger foreign particles, the third removes the minute foreign particles while the second removes the intermediate foreign particles.

When changing the elements on both of the above types of filter, the engine manufacturer's recommendation as to the element number must be followed. This is to ensure that the filter has the correct degree of filtration. In addition, some elements have a built in relief valve while others don't.

Some engines are set up with dual filters but only one is used at a time. Change over to the clean, from the dirty filter, can be accomplished whilst the engine is running.

Purifier



Where a large quantity of lubricating oil is used in an engine, it is not cost effective to carry out oil changes. A purifier is therefore piped into the system to remove impurities and water so it is possible to use the oil practically indefinitely. Oils used in a purifying system are usually non-detergent oils as the purifier removes the detergent as well as the impurities.

It is preferable to install the purifier in a continuous by-pass system. The oil is drawn from the lowest part in the system, heated up to approximately
80° C, passed through the purifier and returned to the system. Heating the oil helps to separate the water from the oil.

The purifier works on centrifugal action. It has a high speed revolving bowl filled with cone shaped metal discs with holes in them. The oil is fed into the bowl at the top, and flows down the centre of the discs. Due to centrifugal force, the heavier solids are thrown out to the side of the bowl. The water and lighter solids move between the discs to their outer edge and are discharged. The clean oil, being lighter than the water, passes through the discs holes to the clean oil discharge. The heavier solids build up on the side of the bowl and regular cleaning is required. Most purifiers these days are of the self cleaning type.

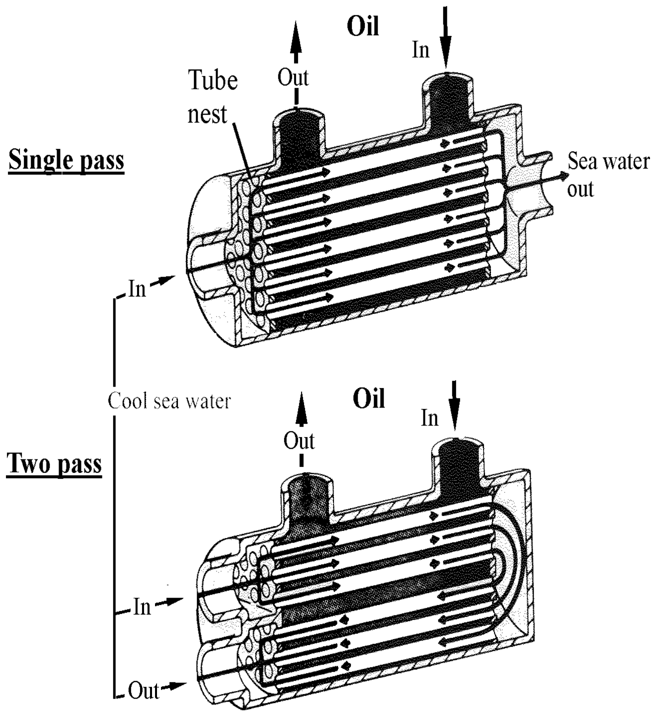
In the purifier, provision is made to water wash the oil. Hot water together with the oil is fed into the purifier. When it passes through the water seal of the bowl, the two are separated and in doing so, a washing action occurs. Water washing rids the oil of acids which are then discharged with the water.

Heat exchangers

Heat exchangers or coolers for a lubricating oil system can be of two types:

- Tube type cooler; and
- Plate type cooler.

Tube nest type oil cooler



Shell
The shell has an inlet and outlet

for the oil and contains the tube nest. Baffles are sometimes fitted to cause the oil to take advantage of all the tube surface to the maximum effect. On some coolers, means are provided on the oil inlet side to prevent direct impingement of the incoming oil on the tubes.

Tube nest
The tube nest consisting of a tube plate at either end with tubes fitted in between. One tube plate is secured at one end of the shell and allowance is made at the other end for expansion of the tube nest. This is by two “O” rings with a hole between them to indicate a leak from either the oil or the cooling medium whether it be fresh or sea water. Allowance for expansion is required due to the different rates of expansion of the metals used in the construction and prevent any undue stress on the tubes.

End covers
An end cover is fitted to each end of the shell.
Where there is a flange on each end cover, the sea water will flow in at one end and out the other end.

Where there is two flanges on one end cover, the sea water will enter and leave via this cover. A division plate will be fitted in this cover and seals against the tube nest across its diameter to separate the inlet and outlet flows. The other end cover will have no flanges. Electrolytic action - To protect the tube nest from electrolytic action, a zinc anode is fitted in the sea water inlet.

Flow of liquids - In this typical shell and tube type cooler, oil enters and leaves by the flanges on the shell and circulates around the outside of the tubes. Sea water is circulated through the tubes and enters and leaves by the end cover/s. The flow of sea water is opposite to the flow of the oil. The best efficiency is obtained by liquids moving in opposite directions to each other ie. contra-flow.

Cleaning
The sea water will leave behind more deposits than the oil. As deposits will form as scale in the tubes, it will be necessary to periodically clean them. The end covers can be removed and a wire brush pushed and drawn through each tube. This is the reason why the sea water flows through the tubes.

Plate type cooler

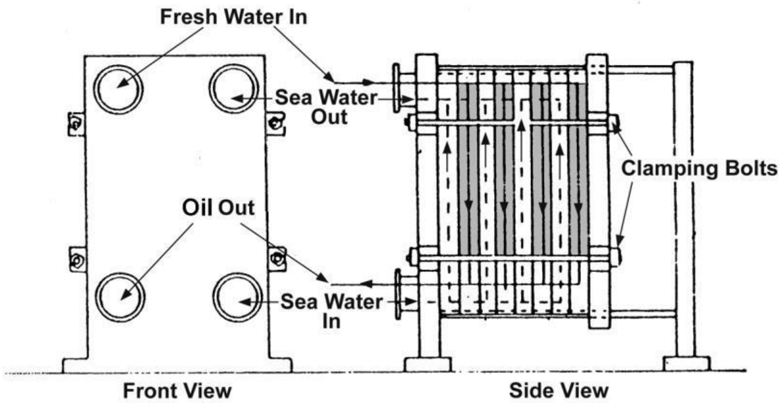


Plate construction

The plates are metal pressings corrugated with horizontal or chevron pattern corrugations. These make the plates stiffer and therefore permit the use of thinner material. They also increase the heat exchange area and produce a turbulent flow. All these factors contribute to the efficiency of heat transfer. Turbulence, as opposed to smooth flow, causes more of the liquid passing between the plates to come into contact with them. It also breaks up the boundary layer of liquid which adheres to the metal and acts as a heat barrier in smooth flow. However, turbulence can cause plate damage due to erosion.

Joining the plates
Each plate is separated from the adjacent plate with a joint material, normally nitrile rubber, which is bonded to the plate with a suitable adhesive. The joint material is positioned to stop the oil and sea water from leaking out of the cooler and to direct the flow of both liquids along their correct paths. This allows the oil to be pumped along the top of the plates and flow down every second pair of plates, returning out of the bottom outlet. The sea water flows in at the bottom of the plates and passes up the adjacent pair of plates, returning out of the top outlet. The best efficiency is obtained by liquids moving in opposite directions to each other ie. contra-flow.

Cooler assembly
All the liquid inlets and outlets are attached to the fixed end plate. The movable end sits in the horizontal carrying bars and the plates are also located and supported by these. The flow ports at the corner of the plates are arranged so that the cooling liquid and the liquid being cooled pass between alternate pairs of plates.

Cleaning
If cleaning is needed to remove deposits, use should be made of special soft brushes. Chemically cleaning may be recommended where hard deposits have accumulated. Before cleaning, coolers are isolated from the system by valves and blanks or by removing pipes and blanking the cooler flanges. Flushing is necessary after the cleaning agent has been drained from the cooler.

Advantages
Plate coolers are smaller and lighter than a tube cooler giving the same performance. No extra space is needed for dismantling (a tube cooler needs enough clearance at one end to remove the tube nest). Their higher efficiency is shown by the smaller size. Plates can be added in pairs, to increase capacity and similarly damaged plates are easily removed, if necessary without replacement. Cleaning is simple as is maintenance. Turbulent flow helps to reduce deposits which would interfere with heat transfer.

Disadvantages
In comparison with tube coolers in which leaking tubes are easily located and plugged, leaks in plates are sometimes difficult to find because the plates cannot be pressurised and inspected with the same ease as tube coolers. Deteriorating joints are also a problem; they may be difficult to remove and there are sometimes problems with bonding new joints. Tube coolers may be preferred for lubricating oil because of their pressure differential. Cost is another drawback; there are a large number of expensive joints on plate coolers and the plates are expensive.

4.2 Lubrication of a marine diesel engine

The purpose of lubricating oil is to prevent metal to metal contact. This is achieved by providing a thin film of oil between moving parts.

It removes heat caused by friction.
It overcomes wear caused by friction.
It overcomes drag caused by friction.
It carries away some of the heat caused by the combustion process.
It acts as a detergent by removing metal dust and carbon and keeps them in suspension so the filter removes them.
It assists the piston rings to seal on the cylinder liner walls, especially on the compression and power strokes where higher pressures are involved.
It prevents the metal parts from rusting which is caused by corrosive gas or moisture.

Correct type and grade of oil

The engine manufacturers in conjunction with the oil companies work together to select or produce a lubricating oil that is suitable for a particular engine. They take into account the operating conditions and the contamination problems that could arise. It is therefore essential that the correct type and grade of oil be used to prolong the engine's life. The following is an extract from the Operators Manual for a Detroit Diesel engine:

General considerations

All diesel engines require heavy-duty lubricating oils. Basic requirements of such oil are:

- Lubricating Quality
- High Heat Resistance
- Control of Contaminants

Lubricating quality

The reduction of friction and wear by maintaining an oil film between moving parts is the primary requisite of a lubricant. Film thickness and its ability to prevent metal-to-metal contact of moving parts is related to oil viscosity. The optimums for Detroit Diesel engines are SAE 40 or 30 weight.

High heat resistance

Temperature is the most important factor in determining the rate at which deterioration or oxidation of the lubricating oil will occur. The oil should have adequate thermal stability at elevated temperatures, thereby precluding formation of harmful carbonaceous and/or ash deposits.

Control of contaminants

The piston and compression rings must ride on a film of oil to minimise wear and prevent cylinder seizure. At normal rates of consumption, oil reaches a temperature zone at the upper part of the piston where rapid oxidation and carbonisation can

occur. In addition, as oil circulates through the engine, it is continuously contaminated by soot, acids, and water originating from combustion.
Until they are exhausted, detergent and dispersant additives aid in keeping sludge and varnish from depositing on engine parts. But such additives in excessive quantities can result in detrimental ash deposits. If abnormal amounts of insoluble deposits form, particularly on the piston in the compression ring area, early engine failure may occur.

Oil that is carried up the cylinder liner wall is normally consumed during engine operation. The oil and additives leave carbonaceous and/or ash deposits when subjected to the elevated temperatures of the combustion chamber. The amount of deposits is influenced by the oil composition, additive content, engine temperature, and oil consumption rate.

4.3 Additives in lubricating oil

Diesel engines require special lubricating oil, because of the diesel fuel and the higher pressures and therefore temperatures in the cylinder, compared to a petrol engine. Additives are therefore used to assist the oil in performing its duties and also in overcoming contamination problems. Listed below are some additives and why they are used:

Anti-oxidants or oxidation inhibitors

Are used to prevent varnish and sludge accumulations on engine parts. They also prevent corrosion of alloy bearings.

They decrease the amount of oxygen taken up by the oil thereby reducing formation of acidic bodies. Additive generally oxidises in preference to the oil.

Anti-corrosives, corrosion preventative or catalyst poisons

To prevent failure of alloy bearings and other metal surfaces by corrosive attack. Inhibits oxidation so that no acidic bodies are formed or enables a protective film to form on bearings or other metal surfaces. Chemical film formation on metal surfaces decreases catalytic oxidation of the oil.

Detergents

To keep engine surfaces clean and prevent deposits of all types of sludge. By chemical reaction or oxidation direction, oil soluble oxidation products are prevented from becoming insoluble and depositing on various engine parts.

Dispersants

To keep potential sludge forming insolubles in suspension to prevent their depositing on engine parts.

Agglomeration of fuel soot and insoluble oil decomposition products is prevented by breakdown into finely divided state. In colloidal form, contaminating particles remain suspended in oil.

Extreme pressure agents

To prevent unnecessary wear of moving parts as well as scuffing or scoring. By chemical reaction, film is formed on metal surfaces which prevents welding or seizure when lubricating oil film is ruptured.

Rust preventative

To prevent rust in new and overhauled engines during storage or shipment. Preferential wetting of metal surfaces through added adhesiveness. Pour point depressants. To lower pour points of lubricating oils. Wax crystals in oil coated to prevent growth and oil absorption at reduced temperatures.

Viscosity index improvers

To lower the rate of change of viscosity with temperature. Improvers are less affected by temperature change of oil. They raise viscosity at 93° C (200° F) more in proportion than at 37° C (100° F).

Foam inhibitors

To prevent formation of stable foam. Enables foam to break up quickly and disappear.

4.4 Contamination

From the following, it will be seen that due to the cause and degree of contamination, an oil change may be required at sea to enable the vessel to reach port. Therefore, sufficient engine lubricating oil should be carried on the vessel to effect an oil change.

Dust and metallic particles from wear

Atmospheric dust can enter through a faulty or dirty air cleaner, leaks in the air intake system and enter the cylinder on the induction stroke. The dust deposits itself in the oil on the cylinder wall and causes wear to the liner and piston rings. The dust can make its way to the sump if there is wear in the liner and/or rings.

It may deposit and/or form a sludge.

Metallic particles can result from metal to metal contact, especially when the engine is starting from cold and lacks lubrication for those first few seconds. It also results from normal wear. In addition, on an overhauled engine, the high spots wear off. There will also be rust and scale from storage tanks and pipes. Some engines have a magnet fitted in the sump to attract any metal particles and stop them from entering the system. An alternative is to fit a magnetic filter.

It may deposit, and/or form a sludge and accelerate oxidation.

Fuel

A leaking injector pipe situated under the rocker cover will allow fuel to drain with the oil that is returning by gravity back into the sump. A leaking diaphragm on the fuel lift pump or on some engines the seal on the fuel pump will allow fuel into the sump.

Fuel contamination will thin out the oil and it will run easily off the dip stick. There will be a rise of the level in the sump. The dip stick will also have a fuel smell. Fuel dilution of lubricating oil will cause a reduction in viscosity and flashpoint. Lowering the viscosity impairs the oils lubricating properties. Lowering the flashpoint increases the risk of a crankcase explosion.

A fuel dilution exceeding 2.5 % by volume indicates an immediate need for an oil change and corrective maintenance action.

Incomplete combustion

Lack of compression in a cylinder will result in insufficient air, a lower temperature of the compressed air causing combustion to be incomplete. An engine with worn piston rings and/or cylinder liner will allow the products of incomplete combustion into the sump. It is called blow by. A misfiring engine will also create this type of contamination from incomplete combustion.

Blow by gases in the oil will cause oxidation which could lead to corrosion and subsequent wear. A harmful varnish could adhere to engine parts. Carbon and soot will contaminate the oil. The oil will go darker in colour and a sludge could form.

(Oxidisation is when the oil is subjected to a high temperature and intimate contact with air. The products of oxidisation are acidic.)

Unburnt fuel will wash the lubricating oil off the cylinder liner bore causing liner and piston ring wear. It will dilute the oil in the sump.

Fresh or salt water leakage from cooling systems

Water created by a cold engine also contaminates the oil. A normal by-product of combustion is water and when the cylinder liner wall temperature is too low, the water will condense in the cylinder and pass the piston rings or is scraped off the cylinder liner walls, by the oil scraper ring, into the sump.

Fresh water can also enter the sump from leaking water jackets, cracked cylinder heads or liners, faulty cylinder liner seals (“O” rings), loose cylinder head or a blown head gasket from a cylinder to a cooling water passage and the water could leak into the sump when the engine is stopped.

Cooling water could enter the sump from a leak in the tube nest of the oil cooler but not while the engine is running. Whilst the engine is running, the oil pressure is greater than the cooling water pressure and any leak will cause the oil to flow into the cooling water. However, when the engine is stopped, all the oil drains into the sump.

If it is sea water cooling and the sea water line is above the cooler, it forms a head (pressure) on the sea water. It will flow through the leaking tube into the sump. If it is fresh water cooling, the fresh water in the header tank forms a head (pressure) on the fresh water. It will flow through the leaking tube into the sump.

Fresh water contamination of the lubricating oil will result in an increased level on the dipstick and a drop in the fresh water level in the header tank. Indications of a leak in the tube of the cooler cooled with sea water can be seen in oil being discharged overboard with the sea water cooling whilst the engine is running.

Indications of a leak in the tube of the cooler cooled with fresh water can be seen in oil floating on the top of the fresh water in the header tank.

Water mixing with oil will result in emulsified oil which is grey/white or sometimes described as milky in colour. Depending upon the degree of emulsification, it can clog small openings and oil passages and prevents proper circulation and heat transfer. It will also form a sludge. Corrosion will occur. The fresh water could contain glycol which, when mixed with the oil, is damaging to the engine.

4.5 Lubricating oil analysis

Regular laboratory analysis of the oil should be carried out, especially when a purifier is fitted and periodic oil changes do not take place. The oil sample tendered for analysis should be taken from the circulation system, preferably while the engine is running, so that it is a true representation of the oil. If this is not possible, it should be taken as soon as the engine is stopped.

An analysis will give valuable information as to

- the condition of the engine
- changes that have taken place to the oil due to operating conditions and
- a measure of the contaminants.

The laboratory will advise on whether the level of contaminants is acceptable or unacceptable and what steps can be taken to rid the oil of contaminants. Naturally, the problem causing the contamination must be rectified immediately.

The contaminants would include

- water
- fuel dilution
- foreign mineral matter
- carbonaceous material and
- oxidation products

The following is to be found in the Operators Manual for a Detroit Diesel engine.

Used Lube Oil Analysis Warning Values

The presence of ethylene glycol in the oil is damaging to the engine. Its presence and need for an oil change and for corrective maintenance action may be confirmed by glycol detector kits which are commercially available.

Fuel dilution of the oil may result from loose fuel connections or from prolonged engine idling. A fuel dilution exceeding 2.5 percent by volume indicates an immediate need for an oil change and corrective maintenance action. Fuel dilution may be confirmed by ASTM D-322 test procedure performed by oil suppliers or independent laboratories.

In addition to the above considerations, if any of the following occur, the oil should be changed.

The viscosity at 100° F of a used oil sample is 40 percent greater than the viscosity of the unused oil measured at the same temperature (ASTM D-445 and D-2161).

The iron content is greater than 150 parts per million.

The pentane insolubles (total contamination) exceed 1.00 percent by weight (ASTM D-893).

The total base number (TBN) is less than 1.0 (astm D-664). Note: The sulfur content of the diesel fuel used will influence the alkalinity of the lube oil. With high sulfur fuels, the oil drain interval will have to be shortened to avoid excessive acidity in the lube oil.

4.6 Engine oil changes

Time between changes

An engine manufacturer recommends the oil change intervals in engine hours in the Operators Manual. It will also state the type and grade of oil to use.

For information, Detroit Diesel recommend 150 hours for their Series 53, 71 and 92 naturally aspirated and turbo charged engines. They also recommend 500 hours for their Series 149 naturally aspirated engines and 300 hours for the Series 149 turbo charged engines. They also state that the oil change intervals may be extended if supported by used oil analysis.

It can be seen that there is a variation between oil changes.

(A used oil analysis is a measure of its contaminants. These include water, fuel dilution, oxidation products, carbonaceous material and foreign mineral matter.)

Factors affecting oil change periods

Oils are continually being improved but the operation and the operational area of the engine, its condition such as the amount of wear, contamination, efficiency of filtration are the factors that have a bearing on oil change periods.

Frequent long voyages at high speed with the resultant high engine operating temperatures, may oxidise the oil and may result in the formation of sludge and varnish.

Short runs and in cold weather do not permit thorough warming up of the engine, and water may accumulate in the crankcase from condensation of moisture produced by the burning of the fuel and cold engine parts.

Additives are used to increase the performance of the oil and some of them break down, in preference to the oil, as they perform their duty.

Some of the additives mentioned can only do so much work before they must be removed from the engine along with the undesirable side effects of combustion.

Change the oil sometime before the additives wear out. This is not possible unless an analysis is carried out. The best policy is to follow the engine manufacturers recommendations on oil and filter changes. These recommendations apply to normal engine operation. If the operational conditions of the engine are not normal, change the oil and filters more regularly.

The use of effective filters, maintaining the engine in good condition and preventing overheating of the oil, will improve the efficiency of the oil.

4.7 Faults in a lubricating oil system

The main faults in a lubricating oil system would be low oil pressure and contamination of the oil. Contamination problems have been dealt with earlier in this section.

Low oil pressure

Oil pressures will differ between types and makes of engines. As a guide, on a Detroit Diesel, normal oil pressure at 2100 rpm is 276 to 414 kPa (40 to 60 psi) with a minimum oil pressure of 207 kPa (30 psi). At 1200 rpm, it is 207 to 414 kPa (30 to 60 psi) with a minimum oil pressure of 124 kPa (18 psi).
As can be seen, a lower minimum oil pressure is acceptable at a lower speed compared to the minimum at a higher speed. This is due to the lower loadings on the bottom end bearings whilst on the power stroke.

The reduction in the normal operating pressure of lubricating oil can be a gradual process or happen instantaneously. The total loss or a significant loss of oil pressure will cause those parts under the most load to fail first. This would be the bottom end bearings due to the load placed on them during the power stroke. In an emergent situation where engine power is required, reducing the engine speed will reduce the load on the bearings. If there is still some oil pressure there, the reduction in load maybe sufficient to save them. Should the oil pressure drop instantaneously, the engine must be stopped immediately. Should there be no oil pressure within 10 to 15 seconds after starting the engine, immediately stop the engine and check the lubricating oil system.

A vessel does not have to be fitted with a low oil pressure alarm unless it is over 25 metres in length, however, most vessels are fitted with them. No mechanical, electrical or electronic piece of equipment is fully reliable, especially in a marine environment. A low pressure oil alarm may develop a fault and not indicate. The engineers, therefore, must rely on their senses to monitor the engine condition.

Insufficient level of oil in the sump

May cause a fluctuation of the oil pressure as the vessel rolls, the pump loses suction and air enters it.

Lubricating oil pump strainer clogged

Not much of a problem these days as the additives in the oil keep the foreign matter and sludge in suspension for the filter to remove.

Faulty lubricating oil pump

If the drive to the pump has sheared, there would be no oil pressure at all. The engine must be stopped immediately otherwise severe damage could occur. Should the gears or rotors of the pump be worn or have too much clearance between them and the backing plate, there will be a drop in oil pressure, usually a gradual drop will occur.

Faulty relief valve

The pressure relief valve may be stuck in the open position or its spring may have broken. A cold engine. when started, will have a high oil pressure which will cause the relief valve to open. The engine’s oil pressure drops as the engine reaches its normal operating temperature and the oil thins out. This results in the relief valve closing. Should the relief valve stick in the open position or the spring break, the oil pressure will drop below normal.

Filter partially clogged

With the filter being partially clogged, the flow of oil will gradually be restricted. Lower oil pressure will occur and be indicated on the pressure gauge until the filter by pass valve opens.

Oil temperature too high

A high oil temperature will thin the oil out causing it to flow more easily with a resulting drop in oil pressure. Could be caused by a worn engine which would have fresh water overheating as well. Alternately, it could be caused by a dirty oil cooler on the sea water side.

Faulty oil pressure gauge

A faulty oil pressure gauge could indicate a low oil pressure where in fact the actual pressure is correct. If the oil pressure gauge is suspected, try another one.

Fractured lubricating oil pipes

Will result in a gradual or sudden drop in pressure if the pipe splits.

Excessive clearance in a bearing or bearings

In a main or bottom end bearing the clearance is very small. This small clearance places a restriction on the flow of oil which causes the oil pressure. If the bearing clearance is excessive, the oil is less restricted and its pressure will drop below normal. Usually, a bottom end bearing will be the problem.

Water in the oil

Water mixing with oil will result in emulsified oil. It is grey/white or sometimes described as milky in colour. Emulsified oil loses its lubricating properties. When a certain amount of emulsification takes place, the oil pressure will drop below normal.

Fuel in the oil

Fuel contamination will thin out (dilute) the oil and it will run easily off the dip stick. There will be a rise in the level in the sump. The dip stick will also have a fuel smell. Fuel contaminated oil loses its lubricating properties and the oil pressure will drop below normal.

Cooling Systems

5.1 Fresh water cooling systems

There are two types of systems:

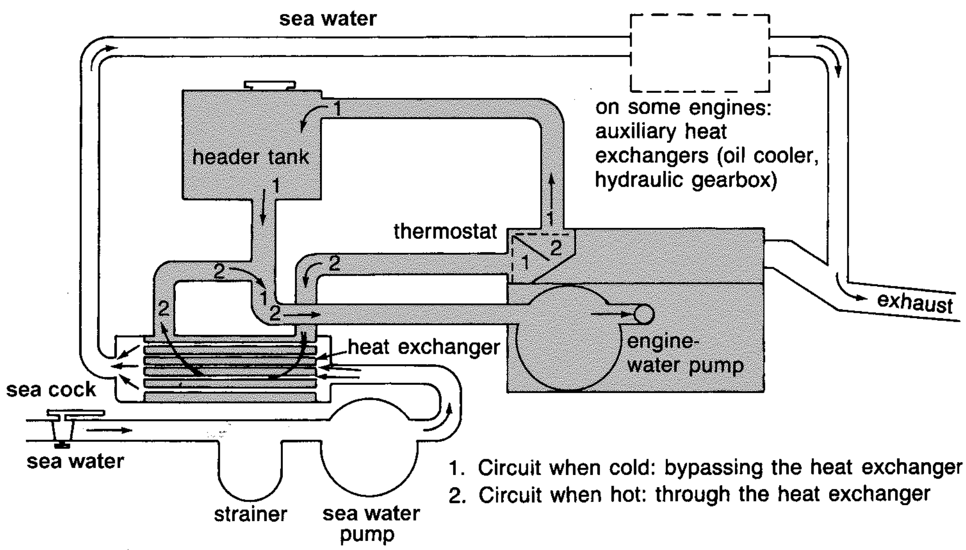
1. Tube nest cooling and
2. Keel cooling.

The purpose of the cooling water system is to maintain a constant temperature throughout the engine by removing heat from the hottest part of the engine in the vicinity of the combustion space and transferring this heat to the cooler parts.

A cooling system is designed to operate between specified temperatures which will vary between engine models and manufacturers. One example is 85° C to 90° C (185° F to 195° F) and with the 103 kPa (15 psi) pressure cap in place on the header tank, the engine can operate intermittently up to 96° C (205° F). The cooling water high temperature alarm is set at 96° C (205° F).

Tube nest cooling system

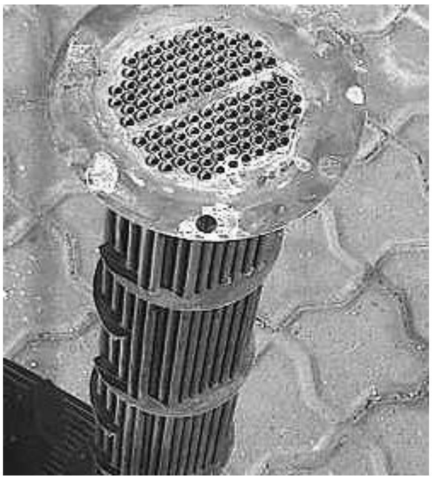
With this system two pumps are used and both are engine driven. One pump circulates sea water from the sea suction strainer through the engine mounted cooler (also referred to as a heat exchanger) . The other is used to circulate fresh water through the engine water jackets and the cooler.



Sea water cooling system

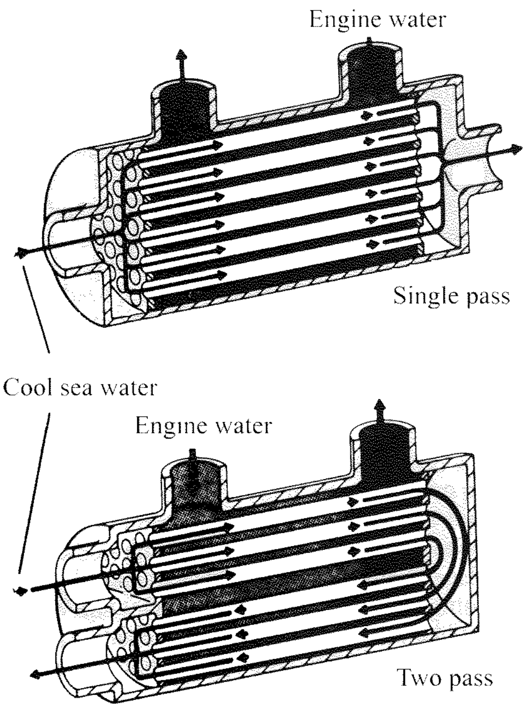
Rose or grid	The sea water intake is through a rose or grid on the vessel's hull to prevent large pieces of foreign matter entering or blocking the flow
Sea cock or valve	is attached directly to the inside of the hull so that the sea water can be shut off during maintenance or repair whilst the vessel is afloat.
Strainer	is fitted into the pipe work before the pump, to avoid small foreign matter being drawn into the system. The strainer may be fitted with a sight bowl. The strainer must be easily accessible for frequent cleaning and inspection.
Sea water pump	is driven off the engine.
Fresh water cooler	The cooler is on the discharge side of the sea water pump and is usually protected against the corrosive effect of the water by zinc blocks. As a further protection against the corrosive effect of sea water, materials used in the sea water piping system should be consistent for all parts so no electrolysis takes place.

The sea water flows through the cooler tubes, as it leaves more deposits than fresh water does. Therefore, it is easier to clean them.



Internal component of tube nest cooler

Diagram of internals of a tube nest cooler



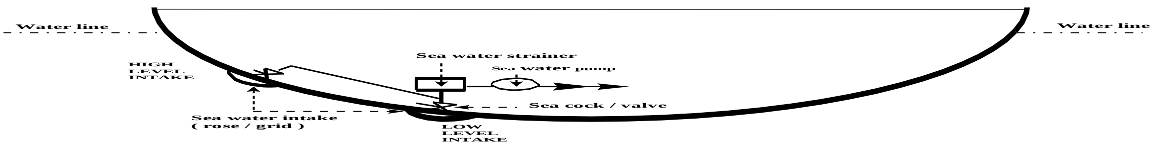
Sea water flow alternatives

Some sea water flow alternatives are as follows:

- From the sea water pump the water may be piped through an oil cooler before it goes into the fresh water cooler.
- If the engine is turbo charged and fitted with an after cooler, the sea water, after leaving the fresh water cooler may cool the incoming air in the after cooler.
- If the engine employs a wet exhaust system, a proportion or all of the sea water will then be pumped directly into the exhaust pipe.
- In a dry exhaust system, all the sea water would be pumped overboard as it leaves the fresh water cooler or, if fitted, the after cooler.

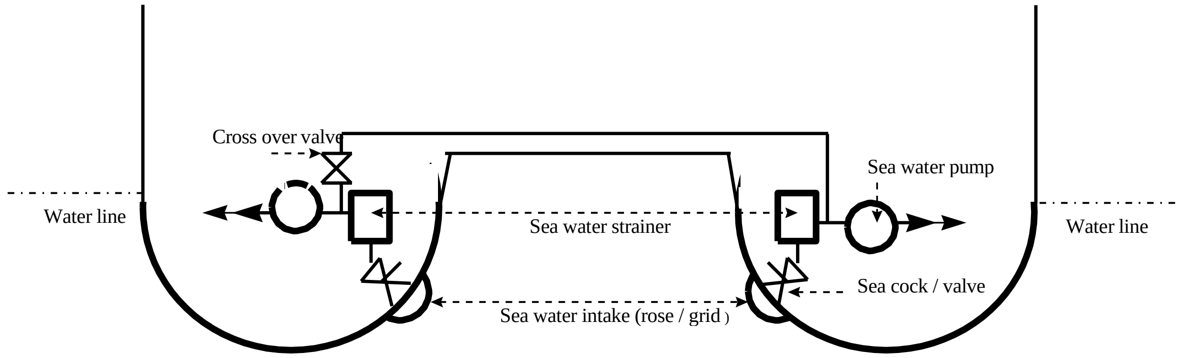
Multiple sea water intakes

On some vessels there is a high and low sea water intake valve. Only one is used at a time. The high one is used for smooth water operations where there is shallow water so that sand and mud are not sucked up into the system. The low one is used at sea so when the vessel rolls, the intake does not come out of the water. It can also be used on smooth water operations where there is deep water.



Location of multiple sea water intakes on mono hull

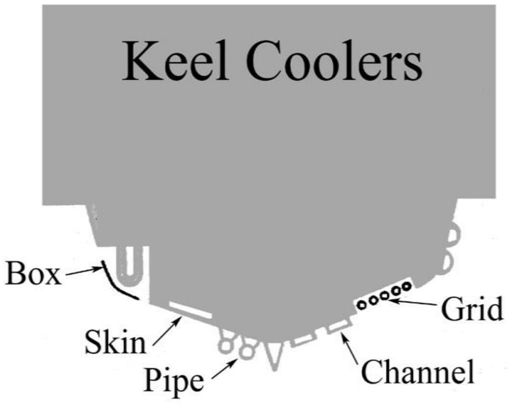
Catamaran type vessels have a sea water inlet on each hull with a cross over pipe and a valve between the two. The port and starboard engines can be operated on the sea water intake on their own side or their opposite side.



Location of multiple sea water intakes on catamaran hull

When running off the one intake is required, open up the cross connection valve before closing the intake valve that is not required. It is preferable that both intake valves are open when running both engines.

Keel cooling system



Keel cooling system

In this type of system, the fresh water is circulated through the engine jackets then through a pipe mounted externally on the hull below the waterline. The keel cooling pipes may be a channel or half a round pipe welded to the hull or may be a copper tube grid. The sea water on the outside of the keel cooling pipes cools the fresh water on the inside. The sea water pump is eliminated.

Keel cooling has the advantage that there is no external water inlet that may become clogged and restrict engine cooling.

The disadvantage is that marine growth on the pipe will impair the transfer of heat. The vessel would have to be slipped to clean the keel cooling pipe.

Fresh water system

The fresh water system is the same in both the sea water and keel cooling systems.

Fresh water pump	is engine driven.
Fresh water circulation	It circulates fresh water through the block and cylinder head. The hottest part of the engine is the combustion space. This is at the top of the cylinder liner and the inlet and exhaust valve area where combustion takes place. There are spaces around the cylinder liner and the block that are called jackets. The fresh water circulates through them. The fresh water then flows through the holes in the top of the block and corresponding holes in the cylinder head gasket and cylinder head. In the cylinder head the water circulates around the inlet and exhaust gas passages to the thermostat. The fresh water in some engines may be fed through the exhaust manifold and turbo charger. Cooling them minimises the radiant heat given off thereby keeping the engine space cooler and

	providing better engine power. Fresh water cooling of these parts does not leave the deposits that sea water cooling does.
Thermostat	A thermostat allows an engine to reach its normal operating temperature quicker, thus preventing wear. If the engine is cold, the thermostat will be in the closed position, that is, it will direct the water back to the pump. When the engine reaches its normal operating temperature the thermostat will open and direct the water to the cooler or the keel cooling pipes before going back to the suction side of the pump.
Fresh water cooler	When the thermostat is open, fresh water will flow through the tubes of the cooler to reduce its temperature and then back to the suction side of the pump.
Header tank	Also called the expansion tank. This allows for the expansion volume of the fresh water. The tank provides an adequate method of venting air and combustion gases from the fresh water system during engine operation. Since diesel engines inherently allow some combustion gases to enter the fresh water system, it will be necessary to remove these gases before they cause deterioration of the engines cooling water system's performance. Gases in the system reduce coolant flows and may result in engine failure if adequate venting capacity is not provided. In most engines the header tank is situated above the fresh water cooler to form one unit.
Venting	Initial venting of the system is critical in order to ensure that the system is completely filled with coolant. Fill the engine slowly to allow the coolant to fill from the bottom up. Quickly filling the expansion tank can fill the vent pipes with coolant and result in slow or incomplete fill of the engine. If vent cocks are fitted, they are to be used to help any air to escape. After initial filling of the system, run the engine, keep checking and if necessary top up the water level until the coolant operating temperature is reached. Any trapped air should make its way up to the header tank in the form of bubbles.
Preventing corrosion	To prevent corrosion, formation of scale and rust

	inside the water jackets in the fresh water system, an inhibitor should be used. Check with the engine manufacturer to ascertain what type of inhibitor is suitable.

Preventing Corrosion

The fresh water used for cooling may be treated with an inhibitor to protect the system. A glycol antifreeze can be used. It will raise the boiling point of the coolant and prevents vapour pockets from forming in the engine. The antifreeze also contains corrosion and rust preventative chemicals that improve engine life. Care should be taken to ensure:

- the inhibitor is the correct type for the material used in the engine
- is only used at the correct strength
- is pre-mixed prior to filling engine and
- is used when topping up the system.

The inhibitor has a maximum service life and should be replaced as recommended by the manufacturer. Where an inhibitor is used, the system may not have zinc blocks.

Electrically driven fresh water and sea water pumps

On larger engines, the fresh water and sea water pumps are driven by electric motors, as opposed to being engine driven. No thermostat is fitted, so the fresh water circulates through the engine as well as the cooler.

The advantage of an electrically driven fresh water pump is that the fresh water can be circulated through the engine and its temperature gradually raised until it reaches its normal operating temperature.

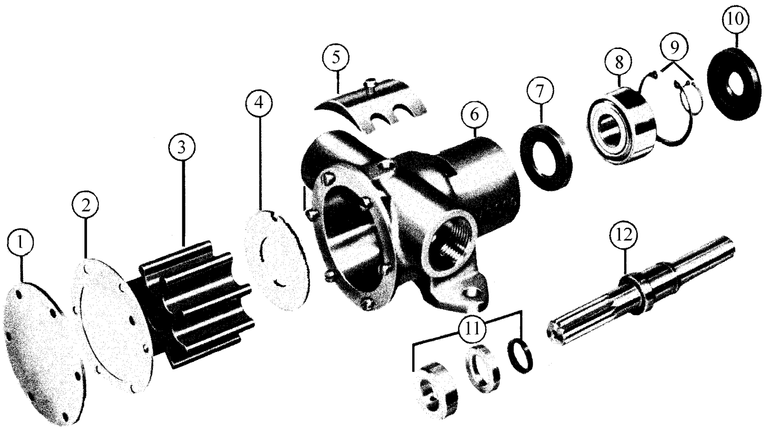
This raises the temperature of the engine so that when it is started and fires, a sudden rise in temperature is not so great. To control the temperature of the fresh water, a control valve is fitted for the sea water to by-pass the cooler until it is required.

5.2 Pumps

Generally speaking, two types of pumps are employed in cooling water systems:

- Flexible impeller type (such as the well known Jabsco pump although there are other brands) and
- Centrifugal type pump.

Flexible impeller type pump



No.	Description
1	Pump Cover
2	Gasket
3	Impeller
4	Wear plate
5	Cam (located inside pump body)
6	Pump body
7	Seal
8	Bearing
9	Retaining clips
10	Outer seal
11	Inner seal assembly
12	Pump shaft

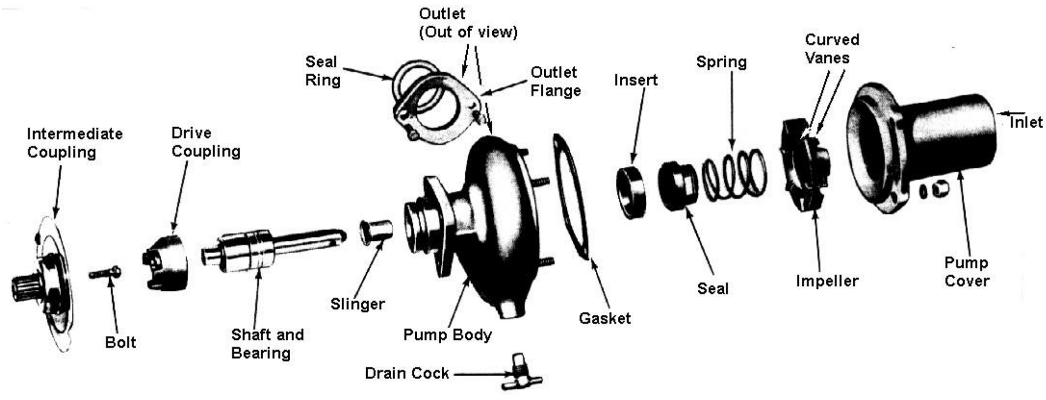
These pumps consist of a bronze casing with an inlet and outlet in the area where the offset cam and circular sections meet. The impeller is of neoprene rubber with flexible blades. The impeller rotates in the casing which is circular for approximately 240° while the remaining 120° is of a greater radius which flattens it out like an offset cam.

As the flexible impeller blades leave the offset cam and move onto the circular section, a partial vacuum is created at the inlet. *(The vacuum is so good that it is a self priming action which makes this type of pump popular as a bilge pump.)* The impeller keeps on rotating with water being drawn into the chambers between the flexible blades until they reach the start of the offset cam which causes the blades to be squeeze in and discharge the water through the outlet.

Faults

Loss of pressure is usually due to too much clearance between the impeller and the back cover allowing water to escape from the pumping chambers. If the pump is allowed to stand idle for a considerable period, the rubber impeller blades will stick to the housing and tear when the pump is started. The water flowing through the pump helps to lubricate and keep them cool. Running a pump dry will result in a damaged impeller. In a cooling water system, this would only happen if there is air in the system.

Centrifugal type pump



With a centrifugal type pump, the water enters at the centre of the impeller and is thrown radially out of the impeller by centrifugal force to the periphery from where it is discharged.

The centrifugal pump can therefore be recognised by the suction or inlet entering the centre of the pump housing and the outlet or discharge on its circumference.

The centrifugal pump consists of a shaft attached to a impeller. The impellor will have internal curved vanes if it is hollow or curved vanes on one or both sides if it is not hollow. The impeller in contained in a housing or casing with an inlet on its centre line and an outlet on the circumference.

Centrifugal type pumps are generally used for large quantities of water at low pressures. *The pressure can be increased by having a number of impellers in series, although this is not required in a cooling water system.*

It is preferable that a centrifugal pump has a positive suction (the level of liquid is above the inlet of the pump) or is used when the lift is very small. They are not self priming pumps. They are suitable for cooling water systems.

Faults

To be effective the impeller must have the minimum of clearance between the suction and discharge openings. Erosion is a problem in centrifugal pumps caused by the flow of the fluid, especially if used for sea water in shallow sandy conditions. Cavitation can also be a problem.

5.3 Faults in the cooling system

Corrosion / electrolysis in cooling water systems

Galvanic corrosion (often incorrectly referred to as “electrolysis”) is the corrosion of the more active (or less noble) member of a pair of metals in physical contact in a corrosive environment.

The more active metal is the anode, whereas the less active metal (more noble) is the cathode and does not corrode. Although the current flowing is often very small, it is a continuous process and the attack is made worse if the anode is small and the cathode large. Where the more corrodible metal is very much larger in area (eg. stainless steel bolts in an aluminium hull) galvanic corrosion may not happen.

Where corrosion on dissimilar metals occur, the particular metal that will corrode can be determined from what is known as the “Galvanic Series”. Below is a table in which the common construction metals are listed with the active (or anodic) metals at the top and the noble (or cathodic) metals at the bottom.

The Galvanic Series of Metals and Alloys in Sea Water

Active Metals (anodic)

- Magnesium and magnesium alloys
- Zinc and galvanised steel
- Aluminium
- Cadmium
- Aluminium alloys
- Iron, cast iron, mild steel
- Stainless steels (activated)
- Lead, tin, tin-lead solders
- Naval brass, high tensile brass
- Manganese bronze
- Nickel and High nickel alloys (activated)
- Copper, Admiralty brass

- Phosphor bronze, silicon bronze, gun metal
- Cupronickle
- Monel, Inconel, high nickel alloys (passivated)
- Stainless steels (passivated)
- Silver
- Titanium
- Platinum, gold graphite

Noble Metals (Cathodic)

If two metals are coupled, the metal nearer the top of the series will be the anode and suffer increased corrosion, whereas the metal nearer the bottom will be the inert cathode. Generally, the further apart the two metal are in the Galvanic Series, the worse will be the galvanic corrosion of the more active metal. Where two metals are listed close together in the series, there is little likelihood that damaging galvanic corrosion will occur.

As can be seen from the above, when two dissimilar metals are placed in sea water, galvanic action loosely referred to as electrolysis will take place.

In an engine cooling system, a number of different metals are used which are close together in the Galvanic Series. However to prevent the slight galvanic action (electrolysis) that will take place, a sacrificial anode is placed in the fresh water, if an inhibitor is not used, and sea water inlets of the cooler (heat exchanger).

Regular inspections should take place of these anodes. They should cleaned with a wire brush so they are more effective. If they are excessively eaten away, they are to be replaced. If in doubt about the condition of the anode, strike it sharply against a hard surface. A weakened anode will break.

Sea water system

General comments

In tracing faults, it is helpful to divide and follow the circuit or flow of the sea water and the fresh water cooling systems separately, and think what may go wrong with each component.

Problems causing overheating that are not directly involved in the cooling system (such as a rope around the propeller or fuel injection being late) are not covered here.

A gradual rise is where the temperature rises over a period of time. It could be caused by a gradual build up of scale on the cooling water surfaces or a strainer gradually becoming clogged.

A sudden rise in temperature could be caused by the thermostat stuck in the closed position, a pump impeller revolving on its shaft or the engine overloaded.

When the engine is hot and the fresh water level in the header tank is low, cold water should be introduced very slowly whilst the engine is running. The cold water will then be heated sufficiently before it circulates around the combustion space. Cold water suddenly coming into contact with the hot cylinder liner and cylinder head may crack them.

Sea water temperature too high

Not normally a problem in southern Australian waters, however must be considered when a vessel is operating in warmer northern waters.

The engine speed should be reduced to bring the temperature back to its normal operating temperature.

Sea water intake rose or grid

Could become clogged over a period of time so there would be a gradual increase in the fresh water cooling temperature.

Reduce the engine speed until the normal operating temperature is obtained.

Alternately, a plastic bag may get sucked onto the grid and a sudden rise in temperature would occur.

Gradually slow down the engine to reduce the heat slowly and stop the engine. With no suction holding the plastic bag on the grid and with the vessel moving through the water, the plastic bag will come away from the intake grid. Start the engine and let it idle until temperatures stabilise.

Clogged sea water strainer

Could become clogged over a period of time so there would be a gradual increase in the fresh water cooling temperature.

Reduce the engine speed gradually and stop the engine. Clean out the strainer. Start the engine and let it idle until temperature stabilises.

Alternately the vessel may have voyaged through matter which quickly clogged the strainer.

Take the above action.

Faulty impeller in sea water pump

The rubber flexible impeller in the sea water pump could be damaged. Damage usually occurs when the pump is run dry. Indications would be the pump discharge pipe would be warm and not at the same temperature as the sea water. In addition there would be no or a reduced sea water discharge overboard.

Reduce the engine speed gradually and stop the engine. Replace the impeller. Should you be at sea and have no replacement impeller, it may be possible to reach port at reduced speed if the impeller is only partially damaged and still can pump some water. Alternately, a sea water hose from the fire pump or the wash deck hose could be connected up to the system at the discharge side of the sea water pump to get the vessel back to port.

With a centrifugal type pump, the pin holding the impeller onto the shaft may have sheared. The indications would be as above. It should be possible to make up and fit a new pin.

Faulty seal in sea water pump

Sea water will leak out and will cause no problems provided it does not spray over anything, especially electrical equipment.

Seal can be replaced when the vessel gets back to port.

Air in sea water cooling system

On a lot of vessels, air is trapped in the sea water cooling system when the vessel re-enters the water after slipping.

With the engine stopped, the air can be bled off by slackening off the backing plate on a jabsco pump or loosening a join in the seawater cooling pipe on the suction side of the pump that is below the water line. If it is a jabsco pump and has run dry until the engine overheated, the rubber impeller will be severely damaged.

Insufficient speed of sea water pump

On some vessels the sea water pump is belt driven from the engine. The adjustment of the belt may cause it to slip.

Reduce the engine speed gradually and stop the engine. Adjust the belt tension. Start the engine and let it idle until temperature stabilises.

It may be that the pump does not attain sufficient speed as the driver or driven pulleys may be the wrong size.

Reduce the engine speed gradually until normal operating temperature is attained. When back in port, change the pulleys.

Dirty or fouled tubes in the cooler

The sea water discharged overboard would be restricted. It is unusual for the cooler to be completely blocked.

Reduce engine speed until normal operating temperature is attained. Stop engine and clean the cooler or return to port under reduced speed.

Electrolysis in the cooler

It would appear that the zinc anode/s have wasted and require replacing.

Leaking sea water hoses or pipes

Sea water will leak out and will cause no problems provided it does not spray over anything, especially electrical equipment.

Hose can be replaced, or a piece of rubber fastened with a hose clip, can be fitted to the leaking pipe.

Keel cooling pipes not effective due to marine growth

This causes a gradual increase in the fresh water temperature.

Reduce the engine speed gradually until the normal operating temperature is obtained. The vessel will have to be slipped to clean the keel cooling pipes.

Keel cooling pipes leaking

Corrosion or electrolysis on the keel cooling pipes could cause a leak to develop. The fresh water would flow into the sea water as the fresh water pressure is greater than the head of sea water, even when the engine is stopped, that is until the fresh water level drops to the same level as the water line of the vessel.

If the leak is not too bad, the engine can be run provided the fresh water tank is kept topped up. The vessel will have to be slipped to repair the leak.

Fresh water system

Fresh water cooling level is too low

A leak has developed in the fresh water system causing a loss of water in the header tank. It could be a leak in the piping, seal in the pump or a blown cylinder head gasket.

Reduce the engine speed gradually and if the fresh water system is the unpressurised type, very slowly top up the header tank to its correct level.

If the fresh water system is of the pressurised type, reduce the engine speed gradually and stop the engine. Let the engine cool down further before placing a rag over the header tank cap. Turn the cap anti-clockwise until it reaches the position where the pressure is released. When the pressure is released, remove the cap. Start the engine and very slowly top up the header tank to its correct level.

If there is very little water in the header tank, it is advisable to let the engine cool right down before adding fresh water.

If possible, the leak in the piping should be stopped or the pump seal replaced.

The engine can be run with a blown head gasket between the cylinder and a cooling water passage to get the vessel back to port providing the leak is not too severe and the engine is not stopped. If the engine is stopped, water could make its way into the cylinder and hydraulic the engine.

Thermostat not opening fully

The thermostat is in the closed position when the engine is cold and first started. In the closed position, the water is circulated through the engine only. As the engine reaches its operating temperature, the thermostat opens and now allows the water circulating through the engine to pass through the fresh water cooler or the keel cooling pipes. Should the thermostat stay in its closed position or not open fully, the engine will overheat. Feeling the pipe from the thermostat housing to the fresh water cooler will indicate whether or not water is flowing through it.

Reduce the engine speed gradually and stop the engine. When the engine has cooled down replace the thermostat. Start the engine. Should you be at sea and have no replacement thermostat, the engine can be run without one to get the vessel back to port.

Faulty impeller in fresh water cooling pump

The rubber flexible impeller in the fresh water pump could be damaged.

Reduce the engine speed gradually and stop the engine. Replace the impellor. Should you be at sea and have no replacement impellor, it may be possible to reach port at reduced speed if the impellor is only partially damaged and can still pump some water.

Alternately, the impeller from the sea water pump could be used if it is the same size and a sea water hose from the fire pump or the wash deck hose could be connected up to the system at the discharge side of the sea water pump to get the vessel back to port.

Faulty seal in fresh water pump

Fresh water will leak out and will cause no problems provided it does not spray over anything, especially electrical equipment, until the level in the header tank is low and overheating will start to occur. Refer to the “Fresh water cooling level is too low” heading.

Leaking fresh water hoses or pipes

Fresh water will leak out and will cause no problems provided it does not spray over anything, especially electrical equipment, until the level in the header tank is low and overheating will start to occur.

Hose can be replaced, or a piece of rubber fastened with a hose clip, can be fitted to the leaking pipe.

Build up of scale on cylinder water jackets, etc.

Fresh water contains impurities which will come out of solution at high temperatures and adhere to hot surfaces. The hottest part of the engine is in the combustion space at the top of the cylinder. Scale will deposit on the cylinder liner walls in this area, on the passages to the cylinder head and around the exhaust valve. The scale will stop the transfer of heat from the combustion process to the fresh water cooling and in the case of passages, will restrict the flow. This will be a gradual process.

Reduce the engine speed until normal operating temperature is attained. Back in port, the cooling water system will have to be chemically cleaned.

Air in fresh water cooling system

Not normally a problem when the engine is running. Air can get into the system when repairs are carried out and the cooling system is refilled. On starting the engine, bubbles will be sighted in the header tank as the air makes its way out. As the water replaces the air, the water level in the header tank will drop. As it drops, it can be topped up slowly.

5.4 Maintenance procedures

The cooling system is like any other part of machinery. It requires routine maintenance and preventative maintenance to minimise costly engine overhauling due to overheating.

The cooling water system should always be maintained at its correct level in the header tank. Inhibitors are used in the cooling water to provide corrosion protection, pH control, water softening, prevent freezing and increasing the boiling point.

The manufacturers instructions should be followed as to what type of inhibitor should be used. It is recommended that one brand of inhibitor be used as mixing different brands may have serious consequences if they are not compatible. Care should be taken to insure the inhibitor is only used at the correct strength, is pre-mixed prior to filling the engine and is used when topping up the system. The inhibitor has a maximum service life and should be replaced as recommended.

Hoses on the cooling water system tend to deteriorate due to age and heat. A hose found to be soft, is bulging or its outside surface is covered with minute cracking should be replaced immediately. It is recommended that all hoses be replaced regularly in order to avoid possible engine overhaul, water damaging electrics, inconvenience, etc. Repair leaks as they occur as they will only get worse.

Keep a regular check on the cooling water temperature. A rise in temperature could be attributed to a dirty cooler. The cooler should therefore be cleaned regularly, especially if the vessel is to proceed to an area of higher sea water temperatures.

Any anodes are to be inspected regularly, cleaned, checked for weakness and replaced if circumstances dictate.

5.5 Setting a high temperature alarm

The cooling water temperature alarm consists of a thermo switch. It has a bi-metal probe that activates contacts in a micro switch. It is usually situated in the thermostat housing. The manufacturer will state at what temperature the engine operates at and what temperature the alarm will sound.

The probe can be inserted into a container of water with a thermometer making sure they do not touch the container.

Heat and agitate the water to ensure uniform water and probe temperature. Place a meter over the contacts of the micro switch. The contacts should close when the thermometer reaches the temperature within the required tolerances. If the water is left to cool, the contacts will open.

Should the contacts not close within the required tolerances, the micro switch will have to be adjusted. However, most of them are sealed units and cannot be adjusted. A replacement would therefore have to be fitted.

Manufacturers supply a shut down device that would energise a solenoid to shut off the fuel when the cooling water temperature is at the alarm setting.

Operating a Marine Engine

6.1 Starting Methods

There are four different methods for starting marine diesel engines.

- Hand start, Battery operated starter motor, Hydraulic start & Air start

Hand start

Hand starting is usually fitted to smaller engines although some manufacturers do provide them on larger engines.

On the smaller engines, a starting handle engages in the end of the crankshaft.

The starting handle should be held with all fingers and the thumb on one side of the handle. If the thumb is placed on the opposite side to the fingers, and the engine back fires, the thumb could be broken.

The starting handle is turned until the engine has sufficient cranking speed for it to fire.

The compression pressure of a diesel engine is higher than that of a petrol engine, therefore more effort is required. To make the engine easier to turn, decompression levers may be fitted to relieve the pressure in one or a number of cylinders, not necessarily all cylinders.

A decompression device is a mechanism that is actuated by a lever, which holds the inlet or exhaust valve off its seat. This means that when the piston ascends on its compression stroke, no compression or resistance is there because the air is flowing straight out the inlet or exhaust valve (whichever one is decompressed).

The decompression lever/s are conveniently placed to the starting handle so one person can operate both:

1. The decompression lever/s are engaged
2. The engine is hand cranked until it attains sufficient cranking speed
3. The decompression lever/s are released allowing full compression pressure and
4. The engine fires.

On the larger engines, the starting handle is operated by sprockets and a chain with a ratio to provide easier turning. The decompression levers are operated by a second person. This means of starting on the larger engines is an additional emergency method. The main means is an electric starter motor.

Battery operated starter motor

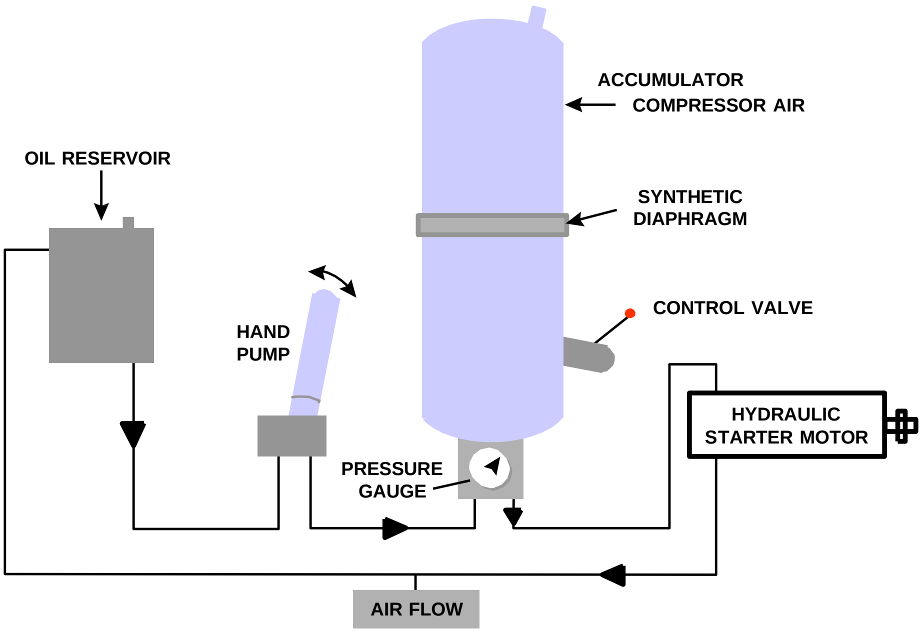
The battery operated starter motor is now commonly used on large engines of high kW power.

Due to the high compression pressures mentioned previously, starter motors draw a very high current for a short period of time. The connections on the batteries and starter motor must be clean and tight. The starting motor leads must be kept as short as possible to prevent voltage drop and the wire size must be sufficient to take the high current.

A solenoid on the starter motor is energised and causes a pinion to engage with the ring gear on the flywheel. The starter motor turns the pinion until the engine attains sufficient cranking speed to fire. On firing, centrifugal force of the pinion causes it to disengage from the ring gear.

Variations include starter motors which employ a clutch. Others have reduction gearing to enable the starter motor to rotate at high speed with comparatively low torque which is multiplied by the gear ratio.

Hydraulic starting system



A hydraulic starting system is normally used on a stationary engine that drives an emergency pump, or an engine on a vessel that needs to be started first to get all machinery running.

The hydraulic starting system consists of:

- an oil reservoir
- a hand pump
- an accumulator
- a pressure gauge
- a hydraulic driven starter motor plus
- connecting hoses and fittings

Operation

Hydraulic oil from the oil reservoir is pumped by the hand pump into the accumulator.

The accumulator is divided by a synthetic diaphragm which is filled with compressed air of around 1,400 kPa (200 psi). The diaphragm is sealed to stop the air leaking out.

The oil is pumped into the lower portion of the accumulator and increases the pressure of the air. A manually operated control valve on the bottom of the accumulator allows the oil to flow to the starter motor which rapidly accelerates the engine to a high cranking speed. The fluid returns directly to the reservoir from the starter motor.

Starting Procedure

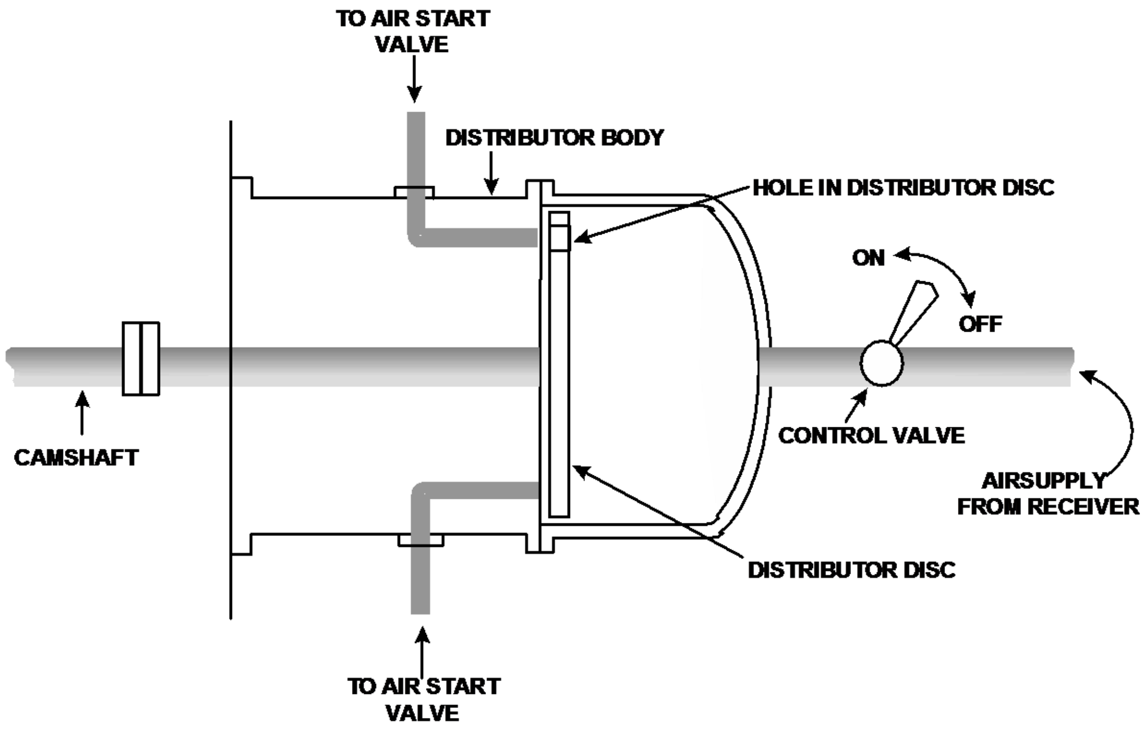
	Step

1	Ensure oil in the reservoir is at the correct level.
2	Use the hand pump to raise the pressure in the accumulator to provide adequate cranking speed to start the engine.
3	Set throttle to the start position.
4	Push the control valve lever on the accumulator to allow the pressurised oil to flow to the starter motor.
5	Close the control valve quickly when the engine starts to conserve the accumulator pressure and to prevent excessive overrunning of the starter drive clutch assembly.

Detroit Diesel have a hydraulic starting system called a hydro starter. It is basically the same as above, but uses nitrogen in the accumulator instead of compressed air. In addition, it has a engine driven pump so the system is automatically recharged after each start. It still has a hand pump so it can also be manually recharged.

There are also different types of hydraulic starter motors.

Air start method



There are a number of variations, but only the distributor type will be explained.

The principle is to allow compressed air into the cylinder to push the piston down and rotate the engine fast enough so that it fires on the fuel.

The air must be fed into the cylinder when that cylinder is on the power stroke and about 10 to 15 degrees past top dead centre. On the power stroke, both inlet and exhaust valves are closed, so the compressed air cannot escape when it is fed into the cylinder.

The air is fed into the cylinder via an air start valve situated in the cylinder head. There is normally one air start valve for each cylinder. *On some V12 and V16 engines, air start valves are only fitted to one bank of cylinders to save on costs.*

The air start valve is a spring loaded valve. It opens when compressed air is fed to it and will close when the air is shut off to it.

The air is supplied to each air start valve via an air distributor. The distributor is mounted on the end of the camshaft. It has a steel disc. A hole is drilled through the disc and as it rotates, it lines up with holes in the distributor body, the number of which are equal to the number of cylinders. Pipes are connected from these holes in the distributor body, in the firing order sequence, to each air start valve.

The air is stored in and supplied from an air receiver. A multi stage compressor is required to supply the air to the receiver. The compressor is usually connected to a diesel engine that is hand started, or by a battery operated starter motor.

Starting procedure

	Step
1	Ensure the air receiver (bottle) is fully charged with compressed air.
2	Drain off any water and oil in the air receiver.
3	Check the indicator cocks are open and bar the engine over at least one complete revolution to ensure there is no fresh water in a cylinder. Close the indicator cocks.
4	Open the stop valve on the air receiver.
5	Place the fuel lever in the start position.
6	Place the air starting lever in the start position. *Air will now flow to the cylinder that has just started its power stroke. The pressure of the air will open the air start valve and air entering the cylinder will force the piston down.*
7	The rotation of the engine will cause the distributor to shut off air to that cylinder and supply air to the next cylinder in the firing order.
8	When the engine fires, release the air starting lever. (It is usually spring loaded).
9	Shut the stop valve on the air receiver.
10	Recharge the air receiver.

6.2 Precautions with air start engines

Where the propulsion engine is fitted with a gear box, the air receiver stop valve must be closed whilst the engine is running.

The air start valves must be checked to ensure they are seating. This can be checked by placing a hand on the air pipe at each air start valve. If the valve is leaking, the hot gases of combustion will pass the valve seat and flow into the air supply pipe. A bad leak will cause the air supply pipe to glow red.

Should the air compressor be pumping oil, this oil will finish up in the air receiver and an explosion could occur.

A non-return valve is fitted in the air line between the air receiver stop valve and the distributor. This is to prevent the hot gases going back into the air receiver and possibly causing an explosion.

An air receiver is a pressure vessel and should be treated with respect. It is essential to drain any water out of it regularly to prevent internal corrosion. At the same time, oil would be drained from it, sometimes in the emulsified form, to prevent explosions. Should the oil be excessive, the air compressor should be overhauled. Survey requires the air receiver to be inspected internally and the relief valve set annually. The relief valve must be set and floated in the presence of the surveyor. A safety valve should never be altered or interfered with.

6.3 Engine protection devices

Survey requirements are that a propulsion engine shall be provided with an audible warning device to indicate a dangerous condition associated with:

(a) engine lubricating oil pressure

(b) engine jacket cooling water outlet temperature and

(c) engine gear box lubricating oil pressure.

As noted, these protection devices give off an audible warning only. Automatically shutting down a propulsion engine without any warning could result in collision, grounding, or the loss of the vessel. Crossing a bar entrance is an example.

The alarm system may have an alarm switch that must be turned on manually to put the system into operation. The danger of this system is the operator may forget to activate the system. The engine will then run in an unprotected mode. It is preferable that there be no alarm switch.

If there is an alarm switch, it is good practice to switch it on before starting the engine. It will sound until the engine is started and the minimum oil pressure registers. Similarly, it should not be switched off until the engine is stopped and the alarm sounds. This procedure checks that the pressure components of the alarm are operational.

The gear box low lubricating oil pressure alarm operates in the same fashion as the engine low oil pressure alarm.

Low oil pressure alarm

The oil pressure alarm consists of a pressure switch fitted to the pressure side of the lubricating oil system, usually into an oil gallery. The oil pressure acts on a diaphragm and spring which open the contacts in a micro switch. When the spring pressure is greater than the oil pressure, the contacts will close and sound the audible alarm.

If an alarm switch is fitted, switch it on. When the engine is started, the oil pressure switch opens as the oil pressure reaches approximately 69 kPa (10 psi) and the alarm will cease to sound.

Likewise, if the oil pressure drops below the setting of 69 kPa (10 psi), the oil pressure switch will close the circuit and sound the audible alarm.

The alarm will continue to sound until the engine is stopped or if an alarm switch is fitted, it is switched off.

High temperature fresh water alarm

The high temperature fresh water alarm consists of a thermo switch. It has a bi-metal probe that activates contacts in a micro switch. It is installed in the side of the thermostat housing.

When the engine is started and running at normal operating temperature, the contacts in the switch will be open. Should the engine coolant exceed say 96° ± 3° C (205° ± 5° F) the water temperature switch will close the electrical circuit and sound the audible alarm.

The alarm will continue to sound until the temperature drops below the above mentioned setting.

A Detroit Diesel engine has an additional sensor fitted for the protection of their engines. It will also sound the alarm on a large loss of coolant. A big and sudden loss in coolant may reduce the coolant level to below the probe in the thermostat housing. As the water is not now circulating over this probe, it will not detect the rise in temperature of the coolant. An additional sensor is fitted into the exhaust manifold outlet to detect the rise in temperature due to overheating.

The water temperature switch consists of a temperature-sensing valve and a micro-switch. The valve contacts a copper plug (heat probe) which extends into the exhaust manifold outlet. Engine coolant is directed over the power element of the valve. Should the water temperature exceed its setting, the valve will close the contacts in the micro-switch. This closes the circuit and sounds the audible alarm. If a loss of coolant occurs, the heat of the exhaust gases will be transmitted through the copper plug to the temperature-sensing valve, closing the circuit and sounding the audible alarm.

Emergency stop device

Numerous diesel engines are fitted with a manually operated emergency engine shut down device. This is mounted in the air inlet housing, to stop the engine if an abnormal condition should arise. If the engine continues to run after the engine throttle is placed in the "no fuel" position, or if combustible liquids or gases are accidentally introduced into the combustion chamber causing over speeding of the engine, the shut down device will prevent damage to the engine by cutting off the air supply and thus stopping the engine.

The shut down device consists of an air shut off valve (flap) mounted in the air inlet housing which is retained in the open position by a latch. A cable assembly is used to remotely trip the latch. The shut off valve must be manually reset on the latch for restarting the engine after the malfunction has been rectified.

6.4 Start up, operation and shut down

Start up checks

The checks and procedures to be carried out before starting an engine depend on

- whether the engine has just been repaired or overhauled and
- whether you were the last person to run the engine.

The person with the Certificate of Competency to operate the machinery of the vessel is the one who takes full responsibility and cannot transfer the blame if something goes wrong. To cover yourself, you must carry out pre-departure checks and checks whilst the vessel is under way.

The following checks apply to the main propulsion engine only and do not include any other piece of machinery or equipment that is checked during a pre-departure check.

Let us assume this is an air start engine and that the lubricating oil pump, fresh water cooling pump and the sea water pump are driven by electric motors.

Firstly, carry out all the necessary checks and procedures for starting the engine driving the alternator and putting it on the board (supplying electrical power to the vessel).

4	Checks to be made	Comments
	Make sure that all work carried out on the engine has been completed, all guards are in place and that there are no tools, materials or parts lying on the engine.	
	Ensure that there are no rags on the engine, especially in the exhaust area. Check the whole engine is free from fuel and lubricating oil.	
	Gear box is in neutral.	
	Check the fresh water in the header tank is at the correct level.	Open the relevant valves. Start up the fresh water circulating pump and ensure there are no fresh water leaks. Apply heat to the fresh water and gradually raise the temperature.
	Check the oil in the sump is at the correct level.	Open any relevant valves. Start up the lubricating oil pump and ensure there are no leaks. Apply heat to the lubricating oil and gradually raise the temperature.
	If the fuel injection pump has its own sump, check the level in the sight glass is at the	

4	Checks to be made	Comments
	upper line.	
	If a turbo charger is fitted and has its own lubricating system, check the level in the sight glass is at the upper line.	
	Grease or oil any linkages.	
	Open the indicator cocks, where fitted. *Indicator cocks are fitted to each cylinder to take indicator cards. Indicator cards allow the power of the cylinder to be assessed and identifies any problems in the cylinder*	Opening the indicator cocks on this occasion allows the compression pressure to go to atmosphere. This allows the turning gear to rotate the engine easier. If the volume of any fresh water in a cylinder exceeds the clearance volume of the cylinder, it will discharge out the indicator cock while the engine is being rotated on the turning gear. This problem will have to be rectified before continuing further.
	Engage the turning gear and switch the turning gear motor on.	
	Check the fuel filter is clean. Check there is sufficient fuel in the fuel tank for the intended voyage plus a reserve.	Open the fuel tank drain valve and drain off any sediment or water. Open the fuel tank outlet valve.
	Prime the fuel system and bleed off any air.	This is not always necessary except after a repair has been carried out to the fuel system or long periods of shut down.
	If a water separator is fitted, drain off any accumulated water.	
	Check the condition of any vee belt drives	

4	Checks to be made	Comments
	and that they are correctly tensioned.	
	Check the condition of all flexible hoses.	
	Check the movement of the hand throttle.	
	Ensure the air receiver/s are at their correct pressure.	If necessary, run the air compressor to bring them to the correct pressure. Drain off any water and/or oil from the air receiver.
	Check that the sea water strainer is clean and open the sea connection valve and the overboard discharge valve.	Start up the sea water pump and ensure there are no leaks. The sea water will by-pass the fresh water and lubricating oil coolers until the temperatures rise above the normal operating temperatures.
	Activate the alarm system.	
	When the fresh water cooling water and the lubricating oil have reached their operating temperatures, shut off the heat source.	
	Where fitted, stop the turning gear motor and disengage the turning gear.	
	Open up the air receiver stop valve to supply air to the starting air distributor.	
	Roll the engine over slowly on air at least one complete revolution to ensure there is no fresh water in any cylinder.	Any water will discharge from the indicator cocks. If there is water in a cylinder, the problem will have to be rectified before continuing further.
	Place the fuel lever in the start position.	

4	Checks to be made	Comments
	Engage the air start lever. As soon as the engine fires release the lever.	Listen for any unusual noises, especially hard metallic knocks.
	Check for fresh water, sea water, lubricating oil, fuel oil and exhaust gas leaks.	
	With the engine at its operating temperature, check the colour of the exhaust gas.	

Operational checks

It is assumed it is a manned engine room so all machinery will be monitored regularly.

4	Check:
	Engine oil pressure.
	All lubricating oil levels.
	Engine fresh water temperature.
	Fresh water level in the header tank.
	For fresh water, sea water, lubricating oil, fuel oil and exhaust gas leaks.
	Exhaust temperatures.
	All flexible hoses for leaks and possible deterioration.
	For any overheating.
	Pumps circulating fresh water, sea water and lubricating oil. Electric motors driving them.
	Listen for any unusual noises, especially hard metallic knocks.
	Maintain the log book.

Use your senses when you carry out checks.

Smell	Hot oil, exhaust gas leaks, insulation melting on electrical cables, paint on an overheated surface and overheating problems give off individual smells that can be recognised. You can smell the combustion gases of a blown head gasket if blown between the cylinder and the outside of the engine.
Hearing	You can hear an injector pipe rattling in a clip. If you don't stop it rattling, it will either wear through or fracture probably resulting in oil being sprayed onto the exhaust manifold and igniting. You can hear a metallic knock from a bottom end bearing with too much clearance. You can hear the pulsations of a blown head gasket if its blown between the cylinder and the outside of the engine.
Sight	As well as hearing the above mentioned injector pipe rattling, you can also see it rattling. Sight allows you to see most things that are wrong such as locking devices missing, excessive movement due to slackness or wear, etc. You can also see exhaust gas leaks, especially on starting an engine, before it fires. Soot deposits at a flange will also indicate an exhaust gas leak.
Feel	Placing your hand on a part will indicate its temperature. You will quickly learn what the normal temperature feels like, therefore overheating can be detected. You can feel the pulsations of a blown head gasket if its blown between the cylinder and the outside of the engine.

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Shut down procedures

It is important that engine temperatures be reduced gradually to prevent unequal contraction of the different metals found in an engine. Otherwise cracking may occur in the block or cylinder head.

If an engine is fitted with a turbo charger, it is necessary to reduce its speed in stages or slowly for two reasons:

1. **Example**: Engine speed is reduced from full engine speed to stop quickly. The bearings of the turbo charger are lubricated by the main engine driven lubricating oil pump. The engine, on stopping, will cease to supply the lubricating oil to the turbo charger bearings. Because of its high speed, it will take some time for the turbo charger to come to rest and the bearings could be damaged.

2. The exhaust gas side of the turbo charger operates at a very high temperature. It is preferable to reduce the temperature gradually rather than quickly to prevent unequal contraction of the turbo charger parts as it slows down.

When the engine has been stopped

4	Checks to be made	Comments
	Deactivate the alarm system.	
	Shut the fuel off at the tank.	
	Open the indicator cocks.	
	Engage the turning gear and start the turning gear motor.	
	Stop the sea water circulating pump. Shut the sea water intake valve. *On a lot of vessels, this valve is left in the open position from one survey to the next. This is bad and dangerous engineering practice. The purpose of the valve is to stop the ingress of sea water should a hose or pipe fail. If the valve is not worked (opened and closed) regularly, marine growth will make it difficult to close and impossible to seal.*	A number of engine rooms have flooded, whilst no one was on board, because the sea valve was left open and a pipe or hose burst. A notice should always be placed in a prominent position indicating whether the valve is opened or closed as a useful reminder in the pre-departure check.
	Shut the sea water discharge valve.	

4	Checks to be made	Comments
	Keep on circulating the fresh water and the lubricating oil and turning the engine until it cools down to the ambient temperature.	
	Switch off the turning gear motor.	
	Stop the fresh water and lubricating oil pumps and close any valves in the systems.	
	Close the indicator cocks.	
	If electrical power to the vessel is not required, shut down the engine driving the alternator.	

6.5 Identifying causes for defects

- Failure of engine to start
- Low operating power
- Exhaust emissions
- Loss of lube oil pressure
- Overheating of engines/components
- Vibration
- Fluctuation of engine revs
- Crankcase explosions

There is a large amount of information in this section. You may wish to work through certain areas at your own pace. Much of the text will be reference material to refer back to when these faults occur in your workplace.

Failure of engine to start

If the engine does not start, the causes are mainly in the supply of fuel and/or air.

Remember:

1. A full charge of air needs to enter the cylinder.

2. This air must not escape as it is being compressed. Otherwise insufficient heat is obtained to ignite the fuel.

3. Fuel must be injected in an atomised form into the cylinder at a precise moment.

4. In addition, there must be no restriction in the flow of exhaust gases.

An engine not turning over quickly when the starter motor is engaged could be caused by the following:

Cause	Comment
Battery capacity low	Check that electrolyte level is above the plates. Try to start the engine on the other bank of batteries. Failing this, try to start the engine on both banks of batteries. Never continue to use a battery if the starter motor is sluggish. High discharge rates will buckle the battery plates. Take the specific gravity of each cell of the battery. A fully charged battery would have a specific gravity reading in each cell of 1.26 where as a flat battery would give a reading of 1.10. The specific gravity reading should not vary more than 0.030 between cells. A lower reading on one cell usually indicates the battery needs replacing.
Battery connections dirty	Check that the connection to and on the battery is clean and tight. A dirty or loose connection can be identified by the heat it generates.
Bad electrical connection to starter motor	The starter motor draws the most load on the battery. This is especially so on diesel engines because of their high compression ratios. The electrical connections must therefore be tight and clean.
Faulty starter motor	The starter motor could be burnt out or the pinion is not engaging with the ring gear on the flywheel
Incorrect grade of lubricating oil	If the oil is too thick, the engine will not attain sufficient speed on the starter motor. In turn, this will not generate the amount of heat required on the compression stroke to ignite the fuel.
Engine has been overhauled and is tight	The parts of an overhauled engine are brought back to their correct clearances. In these clearances there will be a number of high spots. They will be worn away as the engine is run in. When the engine is run in, it will turn easily. The engine will not attain sufficient speed on the starter motor to generate the amount of heat required to ignite the fuel

There must be sufficient air and no restriction in the exhaust gas system:

Cause	Comment
Air cleaner restricted	The air cleaner is choked restricting all or most of the air required by the engine.

Cause	Comment
Exhaust gas restriction	Could be caused by a bucket left on the outlet of a vertical exhaust pipe to prevent rain water entering the engine; or by the automatic flap valve fitted for this purpose and is stuck in the closed position. Occasionally a baffle could come loose in a silencer and block the passage of exhaust gas.

The air must be compressed to a high enough temperature to ignite the fuel.

This is usually due to low or poor compression. Compression pressure can be checked by replacing each fuel injector in turn with a compression gauge. Poor compression throughout the engine could result from one or more of the following:

Cause	Comment
Incorrect valve timing	The inlet valve is not opening or closing at the correct moment in the cycle. This is because the engine has not been correctly timed after maintenance work has been carried out. *(The timing of the exhaust valve would be out as well.)*
Worn cylinder liner bores	Normal wear takes place on the cylinder liner where the piston rings come into contact with it. The wear is more pronounced near the combustion space where the heat burns the lubricating oil. The wear is also oval due to the thrust of the piston on the cylinder wall. The piston rings will not seal against the cylinder liner walls and, on the compression stroke, air will pass the piston rings into the crankcase.
Cold engine	The air entering the engine and the piston, cylinder liner and cylinder head are so cold that they take away the heat of the compressed air before it can reach sufficient temperature to ignite the fuel. If an engine is fitted with heater plugs, they can be utilised. Other alternatives are to use an air heater or a starting fluid to assist ignition of the fuel.

There must be fuel.

Cause	Comment
Fuel tank empty	Fuel piping could develop a leak empting the contents of the fuel tank into the bilges.
Blocked fuel feed line	The suction valve on the fuel tank could have vibrated closed or someone could have closed the emergency fuel shut off valve.
Faulty fuel lift pump	Fuel is not being delivered from the fuel tank to the engine. If of the diaphragm type, the diaphragm could be perished or damaged. The drive to the pump could be damaged.

Cause	Comment
Choked fuel filter	The fuel filter has choked up with foreign matter preventing the full flow of fuel. The filter may not have been changed at its recommended period. A bad batch of fuel may have been received. The filter would require changing at more frequent intervals than recommended until the system is clean.
Air in fuel system	Air is compressible. Fuel is not. Air in a fuel system will cause the engine to malfunction or not start. Air usually enters the fuel system when repairs are carried out or where there is a fuel leak. This air must be bled off until a bubble free fuel is obtained. Some fuel systems have a manual priming handle on the fuel lift pump or on the fuel injection pump. In addition, there are bleed valves throughout the system, such as on filters or water separators.
Faulty fuel injection pump	The fuel pump is not delivering fuel to the injectors.
Incorrect fuel pump timing	The fuel is not being delivered to the fuel injector at the precise moment in the cycle. The engine could have been overhauled and the timing of the fuel pump was incorrectly carried out.

Low operating power

Low operating power is caused by wear in the engine and combustion being incomplete. Therefore, fuel and air problems are involved. All in the following table result in lack of compression:

Cause	Comment
Restriction in air cleaner	Element is clogged restricting the flow of air into the engine. Replace element or clean air cleaner. If oil bath type, check cleanliness and level of oil.
Cylinder head gasket leaking	Could be leaking between two cylinders, between a cylinder and the outside of the engine or between a cylinder and a cooling water passage.
Fuel injector	The fuel injector body may not be sealing properly in the cylinder head allowing the compressed air to escape.
Air start valve	The air start valve may not be sealing in the cylinder head allowing the compressed air to escape.
Incorrect tappet adjustment	The tappet adjustment is such that there is no clearance between the inlet or exhaust valve stem and the rocker arm. The inlet or exhaust valve is not closing on the compression stroke. (Referred to as riding).
Sticking valves	The cam, through the cam follower, push rod and rocker arm, causes the valve to open. The spring causes the valve to shut when the cam follower moves off the lobe or peak of the cam. A sticking valve is caused by combustion being incomplete. Alternatively, the engine may have overheated. Carbon finds its way between the valve stem and guide until the spring cannot exert sufficient pressure to close the valve. A broken valve spring will not close the valve. On the compression stroke, air will pass the valve. It could be an inlet or exhaust valve.
Pitted valves and seats	The exhaust valve and seat is more prone to being pitted. Carbon, from incomplete combustion, is hammered between the valve and seat when the valve closes. On the compression stroke, air will pass the valve.
Valves not seating correctly	Can be caused by the head of the valve being bent on its stem due to the head being too thin from continual grinding. It can also be caused by exhaust gases scouring the valve face and/or valve seat in the head. On the compression stroke, air will pass the inlet or exhaust valve.
Incorrect	The inlet and exhaust valves are not opening and closing at the

Cause	Comment
valve timing	correct time in the cycle. Caused when the timing is being set. Check the timing marks are in line on the crankshaft and camshaft gearwheels or sprockets.
Worn cylinder bores	Normal wear takes place on the cylinder bores. This is especially towards top dead centre where the high temperatures of combustion tend to break down or burn the lubricating oil. The cylinder bores will also wear oval due to the thrust of the piston on the power stroke. Replace the cylinder liner.
Broken, worn or sticking piston rings	The piston rings expand and seal against the cylinder liner walls. Normal wear takes place and will in time become excessive. Piston rings are also subject to breakage in service or when installing. They will also stick in their grooves due to the carbon from incomplete combustion or overheating. In all cases air will pass the piston rings, on the combustion stroke, into the crankcase.
Piston ring gaps in line	Installation of the piston rings may have gaps which were not equally separated or the ring gaps came into line during the running of the engine. Piston ring gaps in line will cause the air from compression to enter the crankcase.
Turbo charger	Reduction in the turbo charger speed can be attributed to worn or faulty bearings or carbon build up on the exhaust gas turbine blades. This will cause a reduction in air supply to the air intake manifold resulting in a loss of engine power
Restricted fuel supply	Could be caused by fuel tank outlet valve not being fully opened. Vibration coupled with loose gland packing could cause it to start closing. The fuel tank vent pipe anti-flash gauze could be clogged. This will cause the fuel pump to pull a vacuum on the fuel tank. Open the outlet valve and tighten the gland packing. Clean the anti-flash gauze.
Faulty injector	Caused by blocked nozzle hole/s, valve not seating properly, broken spring, injector not opening at correct pressure, valve stem sticking in nozzle, leaking injector pipe, excessive fuel return. Replace the injector.
Faulty fuel pump	Caused by incorrect timing, wear between plunger and cylinder, delivery valve not seating properly, incorrect calibration, broken spring. Retime the fuel pump and if that is not the problem, replace the fuel pump.
Fuel lift pump	Fuel lift pump is not delivering sufficient fuel from the tank to the fuel pump. If of the diaphragm type, the diaphragm could be perished. In gear or plunger type pump it will most probably be wear. Overhaul the pump.

Cause	Comment
Fuel filter	Fuel filter could be blocked. Clean filter.
Water in the fuel	Drain the water from the fuel at the fuel tank and at the separator.
Restriction in flow of exhaust gases	Can be caused by excessive build up of carbon or a baffle plate in the silencer coming adrift and partially blocking the flow.
Restricted air supply	Could be caused by the fire flaps and hatch cover in the engine space being closed resulting in insufficient air flow to the engine.

Exhaust emissions

The colour of the exhaust gases can indicate problems with the engine.

Some electronic controlled fuel systems have the provision for the exhaust emissions to be monitored. It allows for the fuel metering and timing to be altered to suit the load and have the most efficient combustion possible.

Black smoke

indicates excessive fuel for the amount of air. It causes incomplete combustion and black smoke is emitted. The problem may be:

- Engine overload.
- Blocked air cleaner.
- Faulty injector/s.
- Faulty fuel pump.
- Incorrect fuel pump timing.
- Incorrect valve timing.
- Lack of compression.

Blue smoke

indicates lubricating oil is being burnt. The problem may be

- Worn cylinder liner/s.
- Worn or faulty piston rings.
- Excessive clearance in valve guides.
- Oil seals in turbo charger not sealing.
- If fitted, oil bath type air cleaner overfilled.

White exhaust vapour

indicates water or moisture. The problem may be:

- Water in the fuel.
- Moisture in the air.
- Cold cylinder liner bores when starting the engine.
- Fresh water leak into the combustion chamber.

Loss of lubricating oil pressure

The reduction in the normal operating pressure of lubricating oil can be a gradual process or happen instantaneously. The loss of oil pressure will cause those parts under the most load to fail first. This would be the bottom end bearings, due to the load placed on them on the power stroke. By reducing the engine speed, the load on the bearings is reduced. If there is still some oil pressure there, the reduction in load maybe sufficient to save them.

Should the oil pressure drop instantaneously, the engine must be stopped immediately.

Problem	Comment	Recommended action
Insufficient level of oil in the sump	May cause a fluctuation of the oil pressure as the vessel rolls, the pump could lose suction and air enters it.	Reduce speed and top up the sump to the correct level.
Lubricating oil pump strainer clogged	Not much of a problem these days as the additives in the oil keep the foreign matter and sludge in suspension for the filter to remove. Will usually be a gradual drop in pressure..	If possible, clean the strainer
Faulty lubricating oil pump	If the drive to the pump has sheared, there would be no oil pressure at all. The engine must be stopped immediately otherwise severe damage could occur.	Repair the pump.

Problem	Comment	Recommended action
	Should the gears or rotors or vanes of the pump be worn or too much clearance between them and the backing plate, there will be a drop in oil pressure, usually a gradual drop will occur.	
Faulty relief valve	The pressure relief valve may be stuck in the open position or its spring may have broken. A cold engine, when started, will have a high oil pressure which will cause the relief valve to open. The engine's oil pressure drops as the engine reaches its normal operating temperature and the oil thins out. This results in the relief valve closing. Should the relief valve stick in the open position or the spring breaks, the oil pressure will drop below normal.	Free up the sticking relief valve or replace the relief valve spring.
Filter partially blocked	With the filter being partially blocked, the flow of oil will gradually be restricted. Lower oil pressure will occur and be indicated on the pressure gauge until the filter by-pass valve opens. *Remember that most oil filters have a by-pass valve in them to prevent oil starvation in the event of the filter element becoming blocked. Whilst the oil flowing through the by-pass is not filtered, this is preferable to insufficient oil. When the by-pass valve opens, the oil pressure would return so the engineer should be aware of why the oil pressure has dropped slightly then increased.*	Replace the filter element or clean the filter (centrifugal type).
Oil temperature too high	A high oil temperature will thin the oil out causing it to run more easily with a resulting drop in oil pressure. Could be caused by a worn engine which would have fresh water overheating as well. Alternately, it could be caused by a dirty oil cooler on the sea water side.	Run the engine at a slower speed until the normal operating oil pressure is obtained and voyage home. Alternately, clean the tubes in the oil cooler.
Faulty oil pressure gauge	A faulty oil pressure gauge could indicate a low oil pressure where in fact the actual pressure is correct	If the oil pressure gauge is suspected, try another one.

Problem	Comment	Recommended action
Fractured lubricating oil pipes	Will result in a gradual or sudden drop in pressure if the pipe splits.	Carry out repairs to rectify the leak.
Excessive clearance in a bearing or bearings	The small bearing clearance places a restriction on the flow of oil that causes the oil pressure. If the bearing clearance is excessive, the oil is less restricted and its pressure will drop below normal. Usually, a bottom end bearing will be the problem.	Providing the journal is all right, replace the bearing.
Water in the oil	Water mixing with oil will result in emulsified oil. It is grey/white or sometimes described as milky in colour. Emulsified oil looses its lubricating properties. When a certain amount of emulsification takes place, the oil pressure will drop below normal.	Stop the water leak and change the lubricating oil.
Fuel in the oil	Fuel contamination will thin out the oil and it will run easily off the dip stick. There will be a rise in the level in the sump. The dip stick will also have a fuel smell. Fuel contaminated oil looses its lubricating properties and the oil pressure will drop below normal.	Stop the fuel leak and change the lubricating oil.

Engine overheating

In determining the cause of an engine overheating, consideration should be given as to whether it is a gradual process or there is a sudden rise in fresh water temperature.

An engine overheating can be identified by the fresh water cooling temperature gauge, the exhaust temperature and by the operators sense of touch.

Experience can develop a sense of touch by brushing the palm of a hand lightly over the parts of the cooling water system. It enables the operator to know exactly at what temperature each part works best and enables him or her to tell when there is a difference in operating conditions.

A gradual rise is where the temperature rises over a period of time caused by:

- wear

- a gradual build up of scale on the cooling water surfaces or
- a sea water strainer gradually becoming clogged.

A sudden rise in temperature could be caused by:

- the thermostat stuck in the closed position
- a pump impeller revolving on its shaft or
- the engine overloading.

- When the engine is hot and the fresh water level in the header tank is low, cold water should be introduced very slowly whilst the engine is running. The cold water will then be heated sufficiently before it circulates around the combustion space. Cold water suddenly coming into contact with the hot cylinder liner and cylinder head may crack them. You should also refer to Section 5.3 “Fault in the cooling system” which covers a number of reasons for the engine overheating.In addition to the reasons listed in Section 5.3, you should consider the following:

Problem	Comment	Recommended action
Build up of scale on cylinder water jackets, etc.	Fresh water contains impurities and they come out of solution at high temperatures and will adhere to hot surfaces. The hottest part of the engine is in the combustion space at the top of the cylinder. Scale will deposit on the cylinder liner walls in this area, on the passages to the cylinder head and around the exhaust valve. The scale will stop the transfer of heat from the combustion process to the fresh water cooling and, in the case of passages, will restrict the flow. This will be a gradual process.	Reduce the engine speed until normal operating temperature is attained. The water passages will have to be chemically cleaned to remove the deposits.
Engine parts may be too tight causing friction	A new or overhauled engine normally runs hotter because it is tight. As the engine is run in, the high spots disappear and the engine turns easily. This reduces the operating temperature.	Reduce the engine speed so that it runs at its normal operating temperature.
Blown cylinder head gasket	Leaking between the cylinder and a cooling water passage will be indicated by bubbles in the header tank whilst the engine is running. The extent of the leak will determine the amount of bubbles. When checking for bubbles, remember the above for pressurised and unpressurised systems.	Should the piston be below top dead centre, sufficient water could flow into the cylinder and hydraulic it. The water level would drop in the header tank and the procedure would

Problem	Comment	Recommended action
	Whilst the engine is running, the pressures inside the cylinder exceeds that of the leak and the water. The heat will turn the water into steam and be discharged with the exhaust gases. However, when the engine is stopped, there is no pressure in the cylinder. The header tank is above the cylinder thereby putting pressure (a head) on the water. The water would then flow through the leak in the cylinder head gasket into the cylinder.	be the same as that above. However, remember that if the engine is stopped for a period of time, it may hydraulic the cylinder.
Low compression	Low compression causes the engine to overheat. Some of the heat in the combustion gases by-passes the piston rings and goes into the crankcase. The cooling water is not taking away the heat caused by combustion and overheating of the engine occurs.	The engine speed should be gradually reduced until the normal operating temperature is attained. Rectify the cause of low compression.
Engine overloaded	An engine that is overloaded will overheat. An engine can be overloaded by a dirty hull, a rope around the propeller, a bent propeller blade or too large a pitch propeller.	The engine speed should be reduced until the normal operating temperature is attained. To stop overheating, it would be necessary to clean the hull of marine growth, remove the rope from the propeller, straighten the propeller blade, alter the propeller pitch or replace the propeller with one of the correct pitch.
Fuel injection into cylinders may be too late	The timing of the fuel injector pump is out causing the fuel to be injected into the cylinders too late. This will cause the engine to overheat.	Reduce engine speed until normal operating temperature is attained. Stop engine and adjust fuel pump timing.

Vibration

Vibration is a back and forth movement and may only appear at certain revolutions of the engine. It is usually the result of some component being out of balance like the rotor shaft of a turbo charger.

The crankshaft of an engine can be fitted with a vibration damper or harmonic balancer. They reduce the quick increases in crankshaft speed caused by the firing impulses of the cylinders and dampens out the crankshaft vibration.

Flexible engine mounts that have lost their resilience will also cause vibration.

When the engine is not lined up with the shafting (intermediate or propeller), vibration will occur.

A damaged or bent propeller blade or a rope caught around the propeller will cause vibration.

A misfiring engine will cause vibration.

Fluctuation of engine revolutions

Fluctuations in the engine speed can be caused by the governor.

A hydraulic governor should be checked for sufficient supply of oil, that dirt has not entered the oil spaces, the linkages are not binding or have excessive wear.

A mechanical governor should be checked that the lubricant is sufficient, and that the linkages are not binding or have excessive wear.

Fluctuations in the engine speed can also be caused excessive engine load and the governor not being able to cope.

Intermittent misfiring can also cause speed fluctuation. This would usually be caused by a faulty fuel injector.

Crankcase explosions

The three components which cause fire are fuel, oxygen and heat. In an engine crankcase, there is fuel and oxygen. Only heat is required for an explosion to occur. The fuel is in the form of a mist of lubricating oil. If there is fuel contamination, the risk is higher. Heat can be supplied from a hot bearing, combustion gases passing the piston rings (blow by) or by partial seizure of a piston with its cylinder liner. When the three components come together, an explosion will occur.

An engine may be fitted with a crankcase relief valve to relieve any violent increase of pressure in the crankcase. They are so constructed as to open smartly and close promptly and decisively. Closing promptly ensures a minimum of fresh air enters the crankcase which might cause a further explosion.

A hot bearing is caused by insufficient clearance or lack of lubrication. The journal may have to be ground. A new slipper bearing would be required.

“Blow by” is caused by worn liner and/or piston rings. Replace the worn parts.

Partial seizure of a piston with its cylinder liner is caused by overheating which also causes a reduction of lubrication in the cylinder. Depending upon the degree of pick up, a severe case will require the cylinder liner and piston to be replaced.

Engine oil diluted by fuel will result in the oil thinning out and loosing its viscosity. Stop the fuel leak and replace the oil. As stated previously, oil diluted by fuel increases the chances of a crankcase explosion.

6.6 Engine room log book

An engine log book assists in trouble shooting and the maintenance of all machinery providing the relevant details are entered regularly.

Where vessels are required by law to maintain a log book, they can be used in an investigation into an incident. A log book is therefore an official document, and to be completed in accordance with the instructions given.

Where a vessel is not required to maintain a log book, it is still good engineering practice to maintain records of all service and maintenance work carried out.

A log book has the advantage that amongst other things, relevant pressures and temperatures are recorded regularly. For example, where a temperature is recorded every four hours, a pattern may emerge that it is steadily rising but the sea temperature remains constant. You would need to exercise your judgement as to why this trend may be occurring.

Engine manufacturers issue a maintenance schedule for each model of engine. The suggestions and recommendations for preventative maintenance should be followed as closely as possible to obtain long life and best performance. However, the periods between inspections are a guide only as a lot depends on the operating conditions of the engine. Certain parts may need to be inspected at more frequent intervals, whilst the condition of the parts may indicate that longer running periods may be allowed.

Therefore, records should also be kept of all maintenance carried out, the running hours and date at which it was carried out. Records should also be taken of any measurements. For example, if the piston rings are renewed, but the liners measured are found to be within tolerances stated by the manufacturer, the measurements taken shall be recorded so the rate of wear can be ascertained. It can be calculated in running hours when the wear will exceed the tolerances. The engine log will indicate the operating conditions of the engine during any particular period.

Technology is heading in the direction, and is already fitted to vessels, that computers through sensors regularly scan all important points of an engine. A read out or a print out can be given. Service intervals can be set so maintenance is only carried out when needed. The computer can tell the operating conditions of the engine and where the critical wear and tear is or has taken place.

6.7 Preventative maintenance schedule

Preventative maintenance schedules are laid down to ensure the continued trouble free performance of the engine and to maintain it in tune.

Wear will occur in any engine. It should be rectified at regular intervals rather than allow it to accumulate until the inevitable breakdown occurs.

Engine manufacturers issue a maintenance schedule for each model of engine. The suggestions and recommendations for preventative maintenance should be followed as closely as possible to obtain long life and best performance. However, the periods between inspections are a **guide only** as a lot depends on the operating conditions of the engine.

The maintenance periods are usually expressed in running hours. However, most manufacturers recognise that some engines will do less running hours in a given period than others. An engine that is not used regularly will have its own problems. Therefore manufacturers also specify time periods to overcome these problems.

On the following page, a simple maintenance schedule is shown. This schedule does not go into depth, such as when the cylinder head should be removed. The maintenance schedule indicates which part needs cleaning, changing, checking, etc. Reference should be made to the Operators Manual for detailed instructions. These instructions deal with procedures, cautionary measures and useful hints. Such instructions help to carry out the work quicker and safely.

The Chart also gives specifications for the fuel, oil, grease and coolant. It also refers to other information for more complete and detailed instructions.

The following is the maintenance recommendations for Caterpillar 3500 marine engines.

Lubrication and Maintenance Chart

Item	Procedure	Lubricant
Every 10 Service Hours		
Engine	Inspect engine for leaks and loose connections	
Engine Crankcase	Check the oil level - add oil if needed	EO
Cooling System	Maintain Coolant level	
Air Starter (if Equipped)	Check air starter lubricator oil level - add oil if needed	EO (SAE 10W)
Clutch shift collar	Lubricate 1 fitting	MPGM

Fuel and Oil Differential Pressure	Check the fuel filter and oil filter differential gauges	
Woodward UG8L Governor (if Equipped)	Maintain oil level	EO
Every 50 Service Hours		
Zinc Rods	Inspect - replace zinc rods (sea water applications)	
Every 125 Service Hours		
Shift Lever Bearings	Lubricate 2 fittings	MPGM
Pilot Bearing	Lubricate 1 fitting	MPGM
Main Shaft Bearing	Lubricate 1 fitting	MPGM
Clutch	Check - Adjust if required	
Every 250 Service Hours		
Cooling System	Add Caterpillar cooling system conditioner or replace coolant conditioner element (if Equipped)	
Batteries	Maintain electrolyte level. Clean top of batteries and cable connections	
Engine Crankcase (See Note On Reverse)	Change oil and oil filters. Take sample for S·O·S analysis. See Oil and Oil Filter Change Interval Chart	EO
Belts	Inspect all belts for wear and proper adjustment	
Hoses	Inspect all hoses for wear and loose connections	
Fuel tank	Drain water and sediment	
First Oil Change Interval		
New/Rebuilt Engines	Inspect - adjust valve lash. Observe rotation of valves. Inspect - adjust injector timing	
Every 1000 Service Hours		
Fuel System	Clean primary fuel filter. Change final fuel filters.	
Woodward UG8L Governor (if Equipped)	Change oil in Woodward governor	EO
Breather	Clean crankcase breather elements	
Governor (Air Actuator)	Lubricate 2 fittings	MPGM
Shutoff Controls	Inspect engine shutoff controls. The shutoff controls must be inspected periodically so that they will function properly when required. Only authorised personnel should perform the inspection. Contact your Caterpillar dealer.	
Every 2000 Service Hours		
Valve lash	Inspect - adjust valves. Observe valve rotation.	
Jacket Water Thermostats	Inspect - Replace if necessary.	
Turbochargers	Inspect turbochargers.	
Engine Mounts	Inspect engine mounts for damage. Check bolts for proper torque.	
Damper	Inspect damper for damage.	
Every 4000 Service Hours		
Cooling System	Drain and clean cooling system. Add coolant conditioner precharge	

6.8 Safety aspects when working on engines

Safety is a very important consideration in all industries. Your workplace is no exception. The following information is a summary of safety considerations. (You may wish to re-visit information in the “Occupational Health and Safety at Sea” module presented in the MED2 modules).

Safety, when working on engines, can be divided into a number of areas.

- Being caught in rotating machinery.
- Fire precautions.
- Oil causing slippery conditions.
- Heat causing burns or scalding.
- Ensuring satisfactory completion of work.

Being caught in rotating machinery

When you are working on an engine, ensure that the engine cannot rotate. Such an occurrence usually results in the loss of fingers. There are various ways in which an engine can be rotated, depending on the size, method of starting and number of propellers.

Advise personnel that work is being carried out on an engine. Be aware of any personnel not present at the time of the instruction, so they can be advised.

Place a warning sign or signs in the relevant positions where the engine may be rotated. *There was a case where an engineer ignored a warning sign not to start an engine (direct reversible type), started it and cut a diver, who was in the propeller aperture, to shreds.*

Disconnect the source of supply to the method of rotating the engine. eg. disconnect batteries, tie up the air receiver stop valve.

You, as the person in charge, may have someone else (a fitter or mechanic) carrying out maintenance work. Under the Occupational Health and Safety Act, you are the one responsible for any safety issues involved. Stiff penalties are prescribed.

A vessel may have one engine driving a propeller and making way through the water whilst the other engine is stopped. The vessel moving through the water can cause the stationary propeller to revolve and turn the stationary engine. In this type of situation a shaft brake would be fitted and should be applied and the turning gear engaged.

Fire precautions

You are aware that fuel dilution of the lubricating oil is taking place and suspect a leaking injector pipe under the rocker cover.

With the engine stopped, the rocker cover is removed. There is no indications of which pipe is leaking. There is no provision to bar the engine over, so it is necessary to start the engine to locate the exact position of the leak.

In starting the engine, it is possible for fuel to spray in any direction as the rocker cover is not containing it. Should it spray onto a hot surface, it could ignite. In addition, it could spray into a persons face and due to its high pressure, cause eye damage. Eye protection should be worn.

One person should start the engine and stop it as soon as it fires, while the other person locates the fuel leak.

Remember, the valve rocker gear will be operating so make sure no part of your clothing, hair, part of your body, rag in the hand can get caught.

In addition, oil will be splashed over the engine.

Oil causing slippery conditions

When working on an engine, it is difficult not to have patches of oil lying about. Oil could cause you to lose your grip or footing and sustain injury. Any spilt oil must be cleaned up immediately.

Heat causing burns or scalding

Being burnt on a hot exhaust pipe is bad enough, but being scalded by hot water is serious. The engine may have overheated. Working on the cooling water system before the engine cools down is dangerous. Equally dangerous is removing the cap on the cooling water header tank before releasing the pressure in the tank.

Ensuring satisfactory completion of work

When any work has been carried out on an engine, a check should be made to ensure that the work has been completed and that there are no tools or rags lying in, around or on top of the engine before a test run is carried out.

Completing the work means that all connections, couplings, flanges, components, etc. have been tightened up, all locking devices are in place, access doors and guards are back in place, plus oil and water levels are satisfactory.

Failure to take these precautions could result in fire, or maybe damage to the engine and injury to personnel should a component come adrift.

Gears, Transmissions and Propulsion Devices

7.1 Relevant sections NSCV & USL Code

The sections of the USL Code that deal with propulsion equipment are to be found in the parts of **Section 9 Engineering**, and specifically, among other matters:

Part 1. Preliminary:
Dealing with the application of the Section to various classes of vessels.

Part 2. General
Deals with such matters as:

- Design - Corrosion and Abnormal Loadings
- Novel Design and Unusual Materials
- Astern power
- Access to Machinery
- Machinery Identification.

Part 3.
Relates to Machinery.

- Main Engines
- Machinery Seatings
- Instrumentation
- Starting Arrangements
- Exhaust Systems
- Engine Cooling Systems
- Gear Boxes
- Propeller and Intermediate Shafting
- Stern Bearings
- Propeller Shaft Brackets
- Fuel Systems.

7.2 Components forming the transmission system

The transmission system of a vessel is the system of shafts, gearing, bearings etc. that connect the engine to the propeller. Starting from the engine end, the components and their purpose are:

For a propeller driven through reduction gear:

The reduction gear is interposed between the engine and the propeller to reduce the speed of the propeller relative to the engine speed. This is to allow the engine to run at its optimum or design speed. Propellers running at lower speeds are generally more efficient.

Note: The thrust bearing is in many cases built into the aft end of the reduction gear. What follows on thrust block/bearings are relevant to the thrust bearings in reduction gear boxes.

For a propeller direct driven by the engine:

The thrust block/bearing is a short length of shafting with a single collar with tilting white metal faced thrust pads either side of the collar.

The forward side pads resist the thrust of the propeller when operating in the ahead direction and the aft pads when going astern. The shaft is supported on both sides of the collar by bearings and all are carried in a housing bolted to the vessel frames. The pads are fitted in carriers that transmit the loads through the housing to the frames. In some vessels self aligning roller thrust bearings are used. The rollers are often angled to combine both thrust and bearing loads. The load is transmitted through the roller carriers through housing to the engine frames.

The purpose of the thrust bearing is to prevent the thrust of the propeller from being transmitted to the engine. A thrust load on the crankshaft would result in longitudinal misalignment of main bearings with the crankshaft and, crankpins with pistons and connecting rods resulting in overheating of the parts and premature wear.

The intermediate shaft is a length (or lengths) of shaft between the thrust block and tail shaft. They are required when the engine is located well forward of the stern. The shaft is supported by a bearing (or plummer block).

The propeller shaft (may also be known as the screwshaft or tubeshaft) is the final link between the engine and propeller.

It must pass through the hull of the vessel and the arrangements must be such that water cannot enter the vessel. This is done by enclosing the shaft in a tube that passes through the aft bulkhead of the engine room through the peak tank and the stern plating or frame. The outer diameter of the tube being made watertight at the aft engine room bulkhead and where it passes through the stern.

The shaft is supported in the stern tube by bearings at each end of the tube. The forward end is flanged and connects to the intermediate shaft or thrust block. At the forward end of the tube where it passes through the aft engine room bulkhead, a packing gland or mechanical seal is fitted to prevent water entering via the annulus between the tube and shaft.

The purpose of the propeller shaft is to carry the propeller. To achieve this the shaft protrudes through the stern sufficient to fasten the propeller to it.

The most common fastening arrangement is to cut a taper with keyway and key in the shaft end with a threaded extension; a matching taper and keyway is cut in the bore of the propeller. The propeller is pushed on to the shaft taper and the nut is made tight; the nut is then prevented from turning by fitting a suitable locking device.

7.3 Methods of propulsion reversal

Reversal of the thrust of a propeller can be achieved by various methods such as:

- engine reversal of rotation
- reversing rotation of the drive shafting by means of gears and clutches
- controllable pitch propellers which can change the blade pitch from full ahead to full astern
- steerable thrusters that rotate the propeller through 360^0
- Voith Schneider (VS) propellers having vertical blades that can rotate on their axis and change the direction of thrust.

Engine Reversal of Rotation

This is not common in smaller vessels. To provide engine reversal, cams for correct timing, opening and closing of inlet and exhaust valves, fuel injection, and air start have to be provided in addition to the cams for ahead operation.

For a four stroke engine, this is usually done by providing ahead and astern cams side by side on the camshaft/s and the camshaft is designed to slide longitudinally

In the normal position the ahead cams are in line with the cam followers. When astern rotation is required the camshaft is moved longitudinally and the astern cams are moved into line with the cam followers.

In many engine designs the air start distributor is separate from the camshaft but a method of cam changeover from ahead to astern operation similar to moving the camshaft is adopted.

The operating gear for changing direction is mostly mechanically operated with pneumatic assistance. Engine manufacturers each have their own particular method of achieving this. Whichever method is used, interlocks are required to ensure that fuel is injected only after the engine is turning on air in the required direction.

Reverse Reduction Gear

On most smaller engines, it is more convenient (and cheaper) to use a reverse reduction gear box rather than fit a reduction gear and reversing gear for the engine.

Various systems of gears such as, spur, bevel or epicyclic are used in combination with clutches (in the case of epicyclic gears-brake bands) to effect speed reduction and reversal.

Manufacturers use various arrangements of gears to achieve reversal.

Controllable Pitch Propellers

These have separate blades that are designed to rotate on their axis around the propeller hub. This allows the pitch of the blades to be adjusted from the normal full ahead position to zero pitch, then to full astern.

There are many types of adjusting mechanisms but all rely on oil pressure provided by an oil distribution/control box surrounding a section of the aftmost intermediate shaft or, on the aft end of the reduction gear. Oil pressure is generated by a pump driven by electric motor.

A piston rod passing down the centre of the shaft and propeller shaft actuates a servo motor in the propeller hub which, by means of sliders/cranks, turns each blade the same amount.

A control mechanism is mounted on the distribution box and operated from the wheelhouse by hydraulic, electrically/electronic, or mechanical linkage. It can also be operated in an emergency at the distribution box.

Steerable Thrusters

(other names: Azimuth thrusters, "Z" thrusters; rotatable thrusters; rudder propellers; duckpellers)

The propeller is driven by a vertical shaft through bevel gears and a swivelling arrangement allows the propeller to rotate through 360^0 thus providing thrust in any direction and dispensing with the need for a rudder.

The lower bevel gears and propeller shaft are enclosed in a pod and the vertical shaft in a trunk. In the upper part (inside the vessel) the trunk is surrounded by an outer casing and swivelling of the trunk (and propeller) is effected by a worm and wheel gearing, the wheel being fixed to the top of the trunk. The pod, trunk and outer casing is filled with oil.

The source of power is fitted by bevel gears at the top the vertical shaft and can be coupled directly to a diesel engine, electric or hydraulic motor.

Voith Schneider (VS) Propulsion

The VS propeller is a vertical axis propeller that consists of a number of blades. The blades are located vertically on a horizontal rotating disc. The disc is driven by a motor with a vertical shaft, or the drive can be changed to the horizontal by means of bevel gears in which case a diesel engine provides the power.

Each blade can be turned around its longitudinal axis by a special mechanism that feathers the blade causing a thrust in any required direction.

The mechanism is complex and fairly noisy.

Note: With conventional rudders the turning force drops away and the maximum angle of helm is generally limited to around $35^{0.}$

At greater angles, the rudder can stall and an increase in angle gives no increase in manoeuvrability. Thrusters and VS propellers provide exceptional manoeuvrability as the thrust remains virtually constant at any angle. They are used on small craft, tugs ferries and any operation where exceptional manoeuvrability is required.

7.4 Stern tube assembly

The stern tube assembly can be either

- water cooled or
- oil cooled

Water Cooled

The propeller shaft is enclosed in a tube that passes through the aft bulkhead of the engine room through the peak tank and the stern plating or frame. The outer diameter of the tube is made watertight at the aft engine room bulkhead and where it passes through the stern.

The shaft is supported in the stern tube by bearings at each end of the tube The forward end is flanged and connects to the intermediate shaft, thrust block or reduction gearing. At the forward end of the tube (where it passes through the aft engine room bulkhead) a packing gland or mechanical seal is fitted to prevent water entering via the annulus between the tube and shaft.

Oil Cooled

The oil cooled stern tube assembly is the same as the water cooled assembly except that:

- a mechanical gland or seal is fitted at the aft end of the assembly to prevent water entering the stern tube. A mechanical gland or seal can be fitted to the forward end of the tube in lieu of the standard packing gland.

- the bearings are usually white metal. The space between the shaft and tube, and in and around the bearings, is filled with oil
- an oil tank (at a designed height above the stern tube) connected by piping to the stern tube supplies a head of oil above the sea at the loaded draught. This also serves as a supply tank to the system.
- a pump to circulate the oil around the system may be provided
- valves for venting and draining are also provided

7.5 Propeller action

Propeller theory and design is a complex subject with many subtleties. The definitions that follow are generalised.

If you wish to learn more there are many text books on the subject.

Propeller Definitions

Pitch (geometric pitch)	The action of a propeller is similar to a screw rotating in a nut advances a distance equal to the pitch of the thread for each complete rotation. As a propeller rotates in a fluid medium there is some slippage and the actual advance of the propeller is less than the geometric pitch. The difference is termed the slip.
Pitch angle	(ϕ) is the pitch divided by the circumference of the propeller at a given diameter ie. Tan ϕ = pitch/Π x diameter of the propeller.
Diameter	Usually means the maximum diameter. With an even number of blades, it is the distance from the tip of one blade to the centre of the blade. Directly opposite for odd numbers, it is twice the distance from the centre of the propeller to the tip of a blade.
Cavitation	is the phenomenon resulting from pressure variations on the back (forward face) of a blade forming vapour filled cavities (bubbles). This leads to a loss of thrust and torque and increase in revolutions until the bubbles collapse. The collapse of the bubbles on the blade produces intense local pressure and can result in erosion and pitting of the blades.
Excitation	is where the natural frequency of the propeller blades is close to (or the same as) frequencies derived from single or combined sources. Examples include: • the variation in torque of the engine • variations in pressure due to a blade passing the stern • the flow of the water into the propeller • the natural hull frequency; etc. The combined result can produce resonance in the

blades which can result in unacceptable vibration of the propeller, or shafting stern of the vessel. In larger vessels propeller designs occasionally result in frequencies of the blades that generate disturbing noises. This is often referred to as a "singing" propeller.

Many of the problems associated with propellers can now be eradicated or reduced by testing propellers and models of propellers in towing and cavitation tanks.

7.6 Methods of attaching propellers

Fitting a Propeller

The most common method of attaching a propeller to the tailshaft is by machining a taper on the propeller end of the shaft and a matching taper in the bore of the propeller. The taper is usually 1 in 12.

A keyway and key is provided in the shaft with a matching keyway in the propeller. The small end of the shaft is extended and threaded to take a nut. The propeller is hardened up on the shaft taper by tightening the nut. A locking device is fitted to prevent the nut from slackening.

There are many methods of locking the nut. Most involve a setscrew or allen screw that penetrates both the nut and the propeller boss.

Removing a Propeller

The procedure for removal of a propeller is:

- When the vessel is in the drydock or on the slip, fit lifting arrangements to support propeller
- Remove rope guard and fairing piece (if any) from propeller nut, then remove locking device and nut
- Fit drawing gear (which usually consists of 2 or more long studs that screw into threaded holes) in the back of the propeller boss and a strong back.
- Place strongback over studs so that it bears on the end of the shaft and run nuts down on studs
- Tighten the nuts to increase load on studs. At some point, the load will overcome the friction between propeller and shaft taper and the propeller will slide off. If the propeller is holding, a sharp hit with a large hammer on the strongback will often produce results.

Beware that as the propeller becomes free, it can quickly slide off the propeller shaft. You should take precautions to ensure that the moving propeller does not damage the shaft. More importantly, be sure that the propeller does not fall off the shaft *causing personal injury or damage.*

Think about the safety aspects, as propellers are heavy and may have sharp edges.

7.7 Methods of alignment

Before attempting to align any shafting, it is essential that the propeller shafting bearings are checked for wear. To check the alignment of the shaft of a vessel in service, it is assumed that specialist alignment equipment (such as optical devices) are not available.

Therefore the only method is to verify that the flange couplings of the intermediate shaft are parallel and concentric by use of dial indicators (the most accurate method) and/or feeler gauges and straight edges.

Method 1: Utilising a dial indicator:

1. Inspect the intermediate shaft.
Where supported on two bearings carry out the next step.
If supported on a single bearing it will be necessary to provide a temporary support to ensure the shaft does not cant or tip. This could be a vee block carefully set under the shaft to ensure the shaft maintains the same alignment.

2. Remove the coupling bolts at either end. If a muff or muff couplings are fitted, dismantle them and slide the muff/s away from the shaft ends.

3. Using an indicator gauge, clamp the gauge on the engine/gearbox side shaft coupling. Set the pointer on the top of the intermediate shaft coupling flange and record the reading on the indicator dial. Rotate the engine gearbox shaft and take

4. readings of the dial at 90, 180 and 270 degrees. For perfect alignment the indicator reading should remain the same at all angles.

5. The procedure for a muff coupling is similar except that the indicator gauge is clamped on the shaft and the pointer set on the intermediate shaft.

Method 2: Using feeler gauges and straight edge:

1. Inspect the intermediate shaft.
Where supported on two bearings carry out the next step.
If supported on a single bearing it will be necessary to provide a temporary support to ensure the shaft does not cant or tip. This could be a vee block carefully set under the shaft to ensure the shaft maintains the same alignment.

2. Remove the coupling bolts at either end. If a muff or muff couplings are fitted, dismantle them and slide the muff/s away from the shaft ends.

3. Lay the straight edge across the outer diameters of the half couplings at 0, 90,180 and 270 degrees, any mis-alignment will show as a gap between straight edge and one half coupling. This gap can be measured by feeler gauge.

Allowable mis-alignment will depend on the diameter of the shaft. The vessels data manual or other documents will often provide the information.

As a further check:

If the coupling faces can be separated to produce a small gap, feeler gauge or taper gauge readings of the gap at 0, 90, 180 and 270 degrees will show if the faces are parallel.

7.8 Maintenance procedures

Transmission and propulsion equipment comprise of:

- gearboxes
- shafting
- shaft bearings
- stern gland
- propeller shaft.

Regular maintenance procedures and checking are as follows:

Gearboxes

- adjustment of clutches and operating mechanism
- cleaning of filters
- cleaning of oil coolers

In the drive train

- loose shaft coupling bolts (perhaps due to mis-alignment) may need to be tightened
- mis-alignment of intermediate bearings will show up by overheating of the bearing. Check alignment
- adjustment of the stern gland

Tailshaft bearings

These are not accessible. Water lubricated bearings wear, the after one more than the forward one. Problems are usually due to misalignment, but mud or grit in the after bearing can accelerate the wear. As they are not accessible nothing can be done. In extreme cases of wear this may result in premature drydocking to resolve the problem. Wear of bearings usually shows up as an increasing noise level around the stern.

Running Inspections comprise checking:

- **gear box:**

oil level; inspect for leaks around casing; ensure pins and bolts etc. in mechanical linkages are secure

- **shaft bearings:**

check oil level in bearing sump; leakage through end seals; temperature of bearing

- **stern gland:**

a leaking stern gland is a normal routine and is adjusted as a matter of course

- **propeller shaft:**

check noise level to determine whether it is increasing.