WARSASH MARITIME ACADEMY

THE LEARNING RESOURCE FOR MARINE ENGINEERS

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Marinediesels.co.uk deals with the construction, operation, running and maintenance of large slow speed two stroke crosshead diesel engines such as Sulzer, MAN B&W and Mitsubishi, and medium speed four stroke trunk piston diesel engines such as Wartsila, Pielstick, Sulzer, MAK etc., as found in the majority of ocean going merchant vessels. Learn about problems which can be encountered such as scavenge fires and crankcase explosions, and how to prevent them. Find out how the engine power is calculated using the Mean Indicated Pressure, discover how the engine starts using compressed air and how Turbocharging works.

Contents

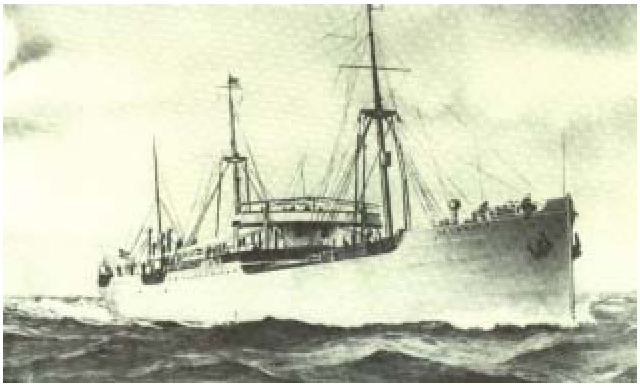
OPERATIONAL INFORMATIONS

MARINE DIESEL ENGINES - THE BASICS

The 4 Stroke Diesel Cycle

Nickolaus Otto invented the 4 stroke cycle in 1862. More details of how the four stroke spark ignition cycle works, together with pictures of Otto's first engines can be found here.

In 1892 Rudolph Diesel invented the compression ignition engine, now named after him. The first working engine was built at the Augsburg Maschinenfabrik (now part of the MAN B&W group) in 1897. The single cylinder engine was used to power stationary machinery. It weighed five tonnes and produced 20 hp at 172 rpm! The engine operated at 26.2% efficiency, a very significant improvement on the 20% achieved by the best petrol engines of the time.

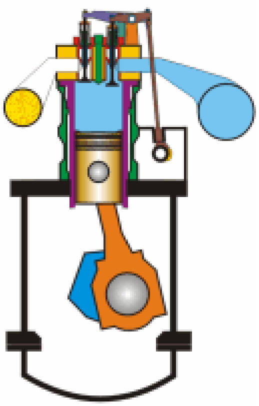


In 1912 the first ocean going vessel to have diesel engines installed was the Selandia. The engines were 8 cylinder 4 strokes. An idea of their size can be got from the man standing by the engine controls half way down the engine.

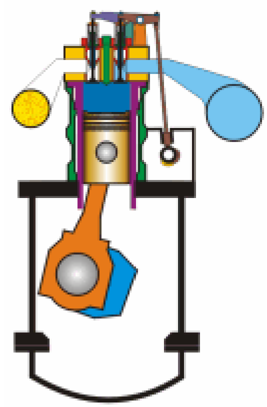
The four stroke cycle is so called because it takes four strokes of the piston to complete the processes needed to convert the energy in the fuel into work. Because the engine is reciprocating, this means that the piston must move up and down the cylinder twice, and therefore the crankshaft must revolve twice.

The four strokes of the piston are known as the induction stroke, the compression stroke, the power stroke, and the exhaust stroke. Students sometimes remember this as "suck, squeeze, bang, blow."

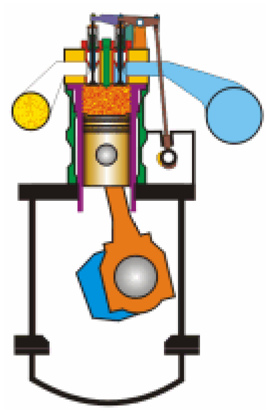
1. INDUCTION: The crankshaft is rotating clockwise and the piston is moving down the cylinder. The inlet valve is open and a fresh charge of air is being drawn or pushed into the cylinder by the turbocharger.



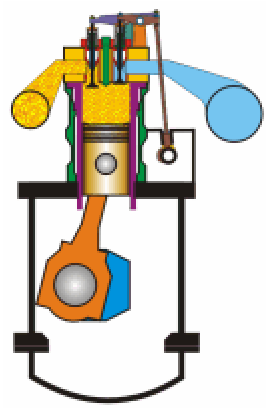
2. COMPRESSION: The inlet valve has closed and the charge of air is being compressed by the piston as it moves up the cylinder. Because energy is being transferred into the air, its pressure and temperature increase. By the time the piston is approaching the top of the cylinder (known as Top Dead Centre or TDC) the pressure is over 100 bar and the temperature over 500°.



3. POWER: Just before TDC fuel is injected into the cylinder by the fuel injector. The fuel is "atomised" into tiny droplets. Because they are very small these droplets heat up very quickly and start to burn as the piston passes over TDC. The expanding gas from the fuel burning in the oxygen forces the piston down the cylinder, turning the crankshaft. It is during this stroke that work energy is being put into the engine; during the other 3 strokes of the piston, the engine is having to do the work.

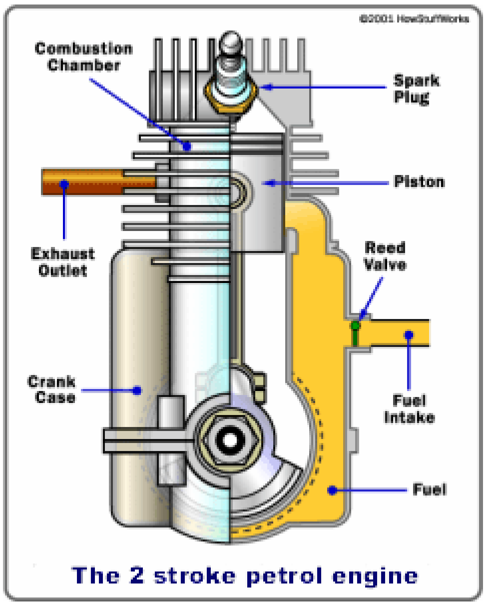


4. EXHAUST: As the piston approaches the bottom of the cylinder (known as Bottom Dead Centre or BDC) the exhaust valve starts to open. As the piston now moves up the cylinder, the hot gases (consisting mostly of nitrogen, carbon dioxide, water vapour and unused oxygen) are expelled from the cylinder.



As the Piston approaches TDC again the inlet valve starts to open and the cycle repeats itself.

The 2 Stroke Diesel Cycle

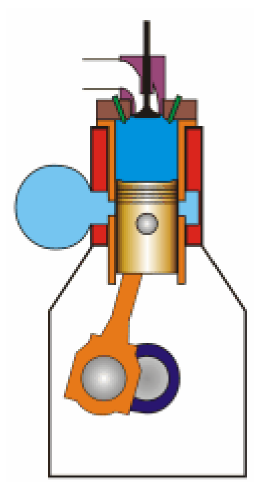


It may surprise you to learn that the biggest diesel engines in use operate on the two stroke principle. If you have experience of the two stroke petrol engine you will know that it causes more pollution than a four stroke petrol engine. This is because oil is mixed with the petrol to lubricate the crankshaft bearings, and a lot of unburnt petrol/oil/air mixture is discharged to the atmosphere.

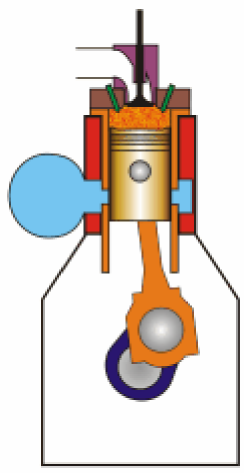
The two stroke Diesel engine does not mix fuel or oil with the combustion air. The crankshaft bearings are lubricated from pressurised oil in the same way as a four stroke engine.

The two stroke cycle is so called because it takes two strokes of the piston to complete the processes needed to convert the energy in the fuel into work. Because the engine is reciprocating, this means that the piston must move up and down the cylinder, and therefore the crankshaft must revolve once.

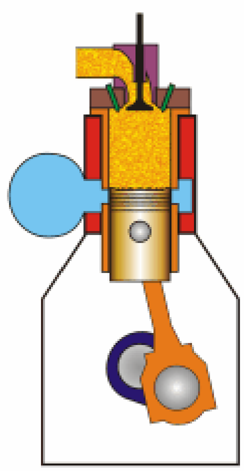
1. The crankshaft is revolving clockwise and the piston is moving up the cylinder, compressing the charge of air. Because energy is being transferred into the air, its pressure and temperature increase. By the time the piston is approaching the top of the cylinder (known as Top Dead Center or TDC) the pressure is over 100 bar and the temperature over 500°C.



2. Just before TDC fuel is injected into the cylinder by the fuel injector. The fuel is "atomised" into tiny droplets. Because they are very small these droplets heat up very quickly and start to burn as the piston passes over TDC. The expanding gas from the fuel burning in the oxygen forces the piston down the cylinder, turning the crankshaft. It is during this stroke that work energy is being put into the engine; during the upward stroke of the piston, the engine is having to do the work.

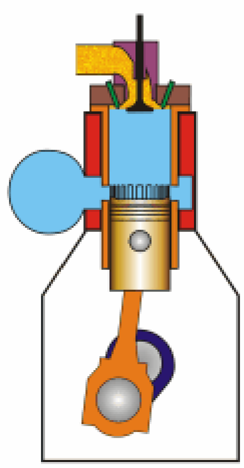


3. As the piston moves down the cylinder, the useful energy from the burning fuel is expended. At about 110° after TDC the exhaust valve opens and the hot exhaust gas (consisting mostly of nitrogen, carbon dioxide, water vapour and unused oxygen) begin to leave the cylinder.

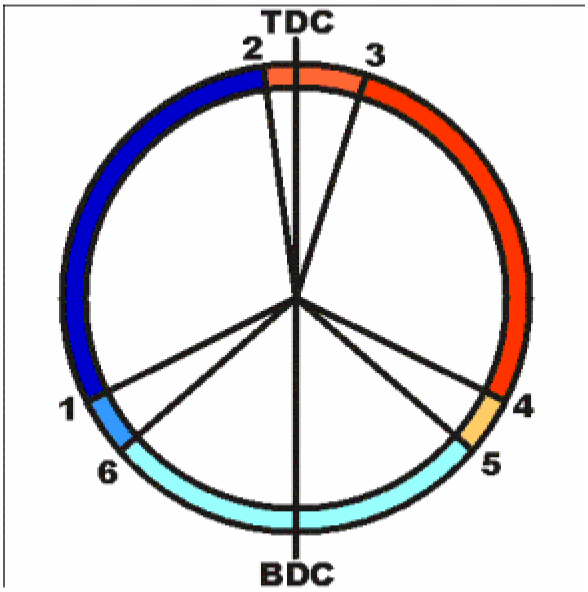


4. At about 140° after TDC the piston uncovers a set of ports known as scavenge ports. Pressurised air enters the cylinder via these ports and pushes the remaining exhaust gas from the cylinder in a process known as "scavenging".

The piston now goes past Bottom Dead Centre and starts moving up the cylinder, closing off the scavenge ports. The exhaust valve then closes and compression begins.



The two stroke cycle can also be illustrated on a timing diagram.



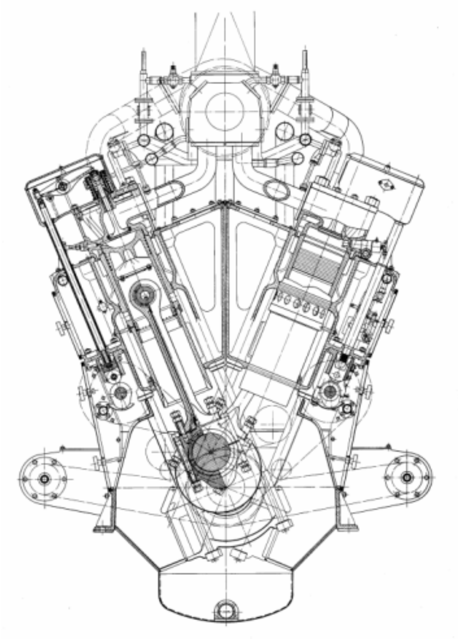
1 -2 Compression	1. approx 110º BTDC
2 - 3 Fuel Injection	2. approx 10º BTDC
3 - 4 Power	3. approx 12º ATDC
4 - 5 Exhaust Blowdown	4. approx 110º ATDC
5 - 6 Scavenging	5. approx 140º ATDC
6 - 1 Post Scavenging	6. approx 140º BTDC

In the 2 stroke trunk piston engine, the side thrust caused by the angularity of the connecting rod is transmitted to the liner by the piston skirt or trunk. It is therefore known as a 2 Stroke Trunk Piston Engine. The skirt of the piston also acts to seal the scavenge air ports when the engine is at TDC. This prevents the scavenge air from pressurising the crankcase.

Herein lies the disadvantage of this type of engine: although it has a low overall height, lubricating oil splashed up from the crankcase to lubricate the liner can find its way into the scavenge space, causing fouling and a risk of a scavenge fire. There is also the likelihood of liner and piston skirt wear, allowing air into the crankcase. This can supply the required oxygen for a crankcase explosion should a hot spot develop. The crankcase oil must have additives which can cope with contamination from products of combustion, and the acids formed during combustion due to the sulphur in the fuel.

This design of two stroke is generally only used for the smaller lower powered 2 stroke engines - up to about 5000kW for a V16 engine with a 280mm bore and 320mm stroke.

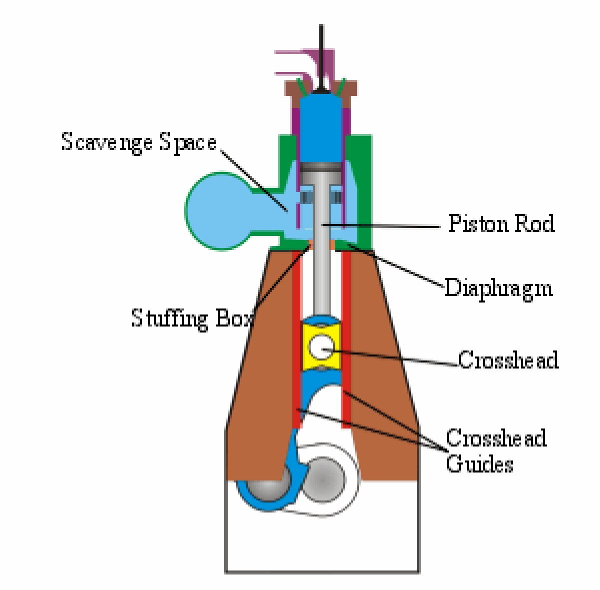
Detroit diesels manufacture 2 stroke trunk piston engines as do Wichmann and General Motors. Sulzer used to produce a model which is sometimes found at sea as did Brons. A cross sectional drawing of their type GV engine is shown below.



The 2 Stroke Crosshead Engine

The 2 stroke diesel crosshead engine works on exactly the same principle and cycle as the 2 stroke diesel trunk piston engine.

The disadvantages of the two stroke diesel trunk piston engine are that although it has a low overall height, lubricating oil splashed up from the crankcase to lubricate the liner can find its way into the scavenge space, causing fouling and a risk of a scavenge fire. There is also the likelihood of liner and piston skirt wear, allowing air into the crankcase. This can supply the required oxygen for a crankcase explosion should a hot spot develop. The crankcase oil must have additives which can cope with contamination from products of combustion, and the acids formed during combustion due to the sulphur in the fuel.



The majority of 2 stroke engines encountered at sea are of the "crosshead" type. In this type of engine the combustion space (formed by the cylinder liner, piston and cylinder head), and the scavenge space are separated from the crankcase by the diaphragm plate.

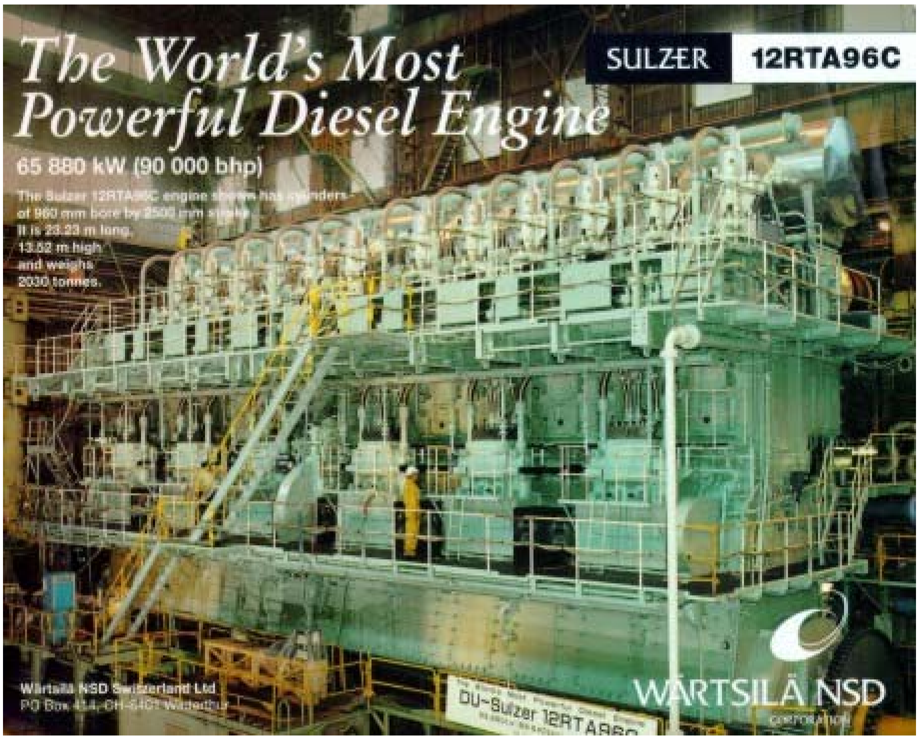
The piston rod is bolted to the piston and passes through a stuffing box mounted in the diaphragm plate. The stuffing box provides a seal between the two spaces, stopping oil from being carried up to the scavenge space, and scavenge air leaking into the crankcase.

The foot of the piston rod is bolted to the crosshead pin. The top end of the connecting rod swings about the cosshead pin, as the downward load from the expanding gas applies a turning force to the crankshaft.

To ensure that the crosshead reciprocates in alignment with the piston in the cylinder, guide shoes are attached either side of the crosshead pin. These shoes are lined with white metal, a bearing material and they reciprocate against the crosshead guides, which are bolted to the frame of the engine. The crosshead guides are located inbetween each cylinder.

Using the crosshead design of engine allows engines to be built with very long strokes - which means the engine can burn a greater quantity of fuel/stroke and develop more power. The fuel used can be of a lower grade than that used in a trunk piston engine, with a higher sulphur content, whilst high alkalinity cylinder oils with a different specification to that of the crankcase oil are used to lubricate the cylinder liner and piston rings and combat the effects of acid attack.

The most powerful diesel engines in the world are two stroke crosshead engines. Some of these engines have cylinder bores approaching 1metre with a stroke of over 2.5 metres. The crankshaft can weigh over 300 tons, with the engine weighing in excess of 2000 tons.


The World's Most
Powerful Diesel Engine
SULZER
12RTA96C
65 880 kW (90 000 bhp)
It is 23.23 m long,
and weighs
2030 tonnes.
Wärtsilä NSD Switzerland Ltd
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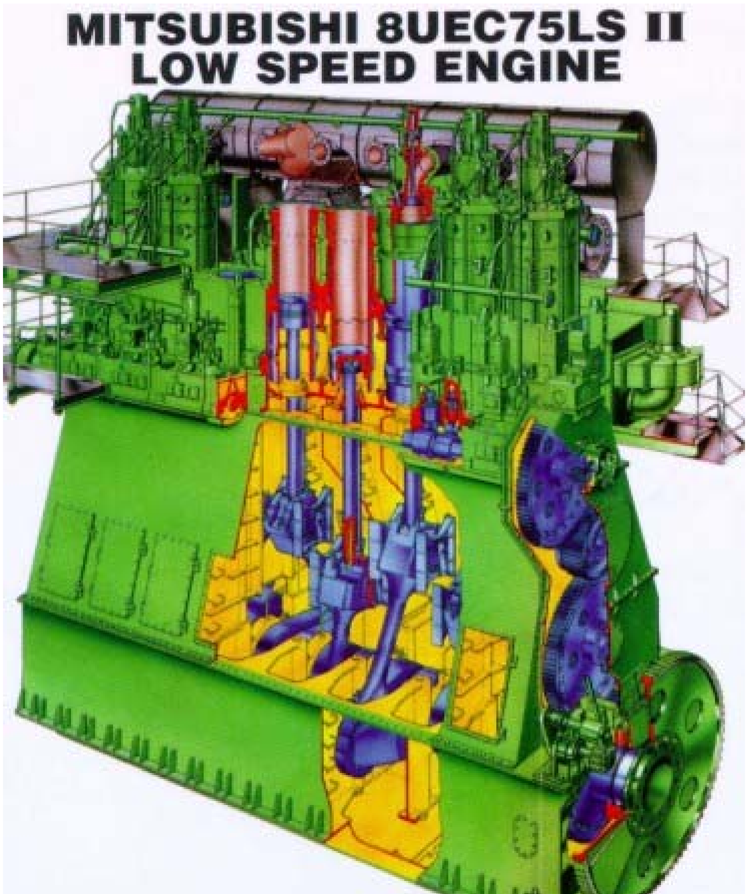
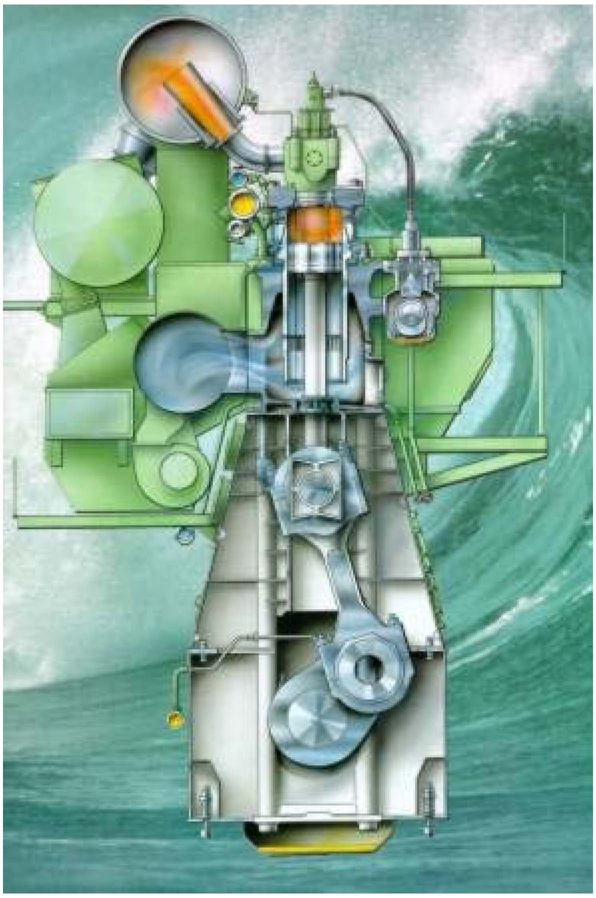

MITSUBISHI 8UEC75LS II
LOW SPEED ENGINE

Uniflow and Loop Scavenging

Scavenging is the process whereby air at a pressure greater than that of atmospheric presuure is used to push the exhaust gas out of the cylinder of an engine. Unlike the 4 stroke engine, a two stroke diesel engine does not use the piston to push out the exhaust gas, instead, air enters the cylinder around bottom dead centre and sweeps or scavenges the exhaust gas from the cylinder.

2 stroke engines with an exhaust valve mounted in the cylinder head are known as uniflow scavenged engines. This is because the flow of scavenging air is in one (uni) direction.

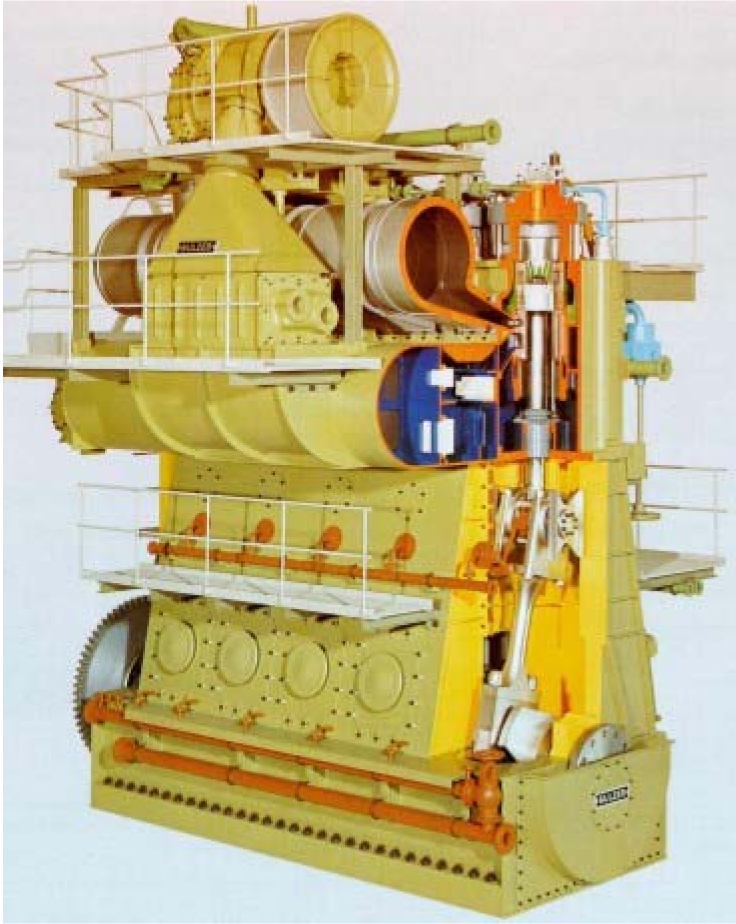


MAN B&W MC series uniflow scavenged engine

Some 2 stroke engines do not have exhaust valves; As well as scavenge ports in the cylinder liner, they are fitted with exhaust ports located just above the scavenge ports. As the piston uncovers the exhaust ports on the power stroke, the exhaust gas starts to leave the cylinder. When the scavenge ports are uncovered, scavenge air loops around the cylinder and pushes the remaining exhaust gas out of the cylinder. This type of engine is known as a loop scavenged engine. Note that the piston skirt is much longer than that for a uniflow scavenged engine. This is because the skirt has to seal the scavenge and exhaust ports when the piston is at TDC.

Although simpler in construction with less moving parts, these engines are not as efficient or as powerful as uniflow scavenged engines. The scavenging of the cylinder is not 100%, and thus less fuel can be burnt per stroke.

All modern large 2 stroke crosshead engines now being built are of the uniflow scavenged type.



SULZER RLA Loop Scavenged Engine

The Cooling Water System

Although there is an abundance of free sea water available, marine diesel engines do not use it directly to keep the hottest parts of the engine cool. This is because of the corrosion which would be caused in the cooling water spaces, and the salts which would be deposited on the cooling surfaces interfering with the heat flow.

Instead, the water circulated around the engine is fresh water (or better still, distilled water) which is then itself cooled using sea water. This fresh water is treated with chemicals to keep it slightly alkaline (to prevent corrosion) and to prevent scale formation. Of course, if distilled water, which some ships can make from sea water using evaporators, is used then there is a reduced risk of scale formation.

The cooling water pump which may be engine driven or be a separate electrically driven pump pushes the water around the circuit. After passing through the engine, where it removes the heat from the cylinder liners, cylinder heads, exhaust valves and sometimes the turbochargers, it is cooled by seawater and then returns to the engine. The temperature of the cooling water is closely controlled using a three way control valve. If the water is allowed to get too cold then it will cause thermal shocking which may lead to component failure and will also allow water and acids to condense on the cylinder bores washing away the lubricating film and causing corrosion. If it gets too hot then it will not remove the heat effectively causing excessive wear and there is a greater danger of scale formation. For this reason the cooling water outlet temperature is usually maintained at about 78-82°C. Because it is at a higher temperature than the cooling water used for other purposes (known as the LT cooling), the water for cooling the engine is known as the HT (High Temperature) cooling water.

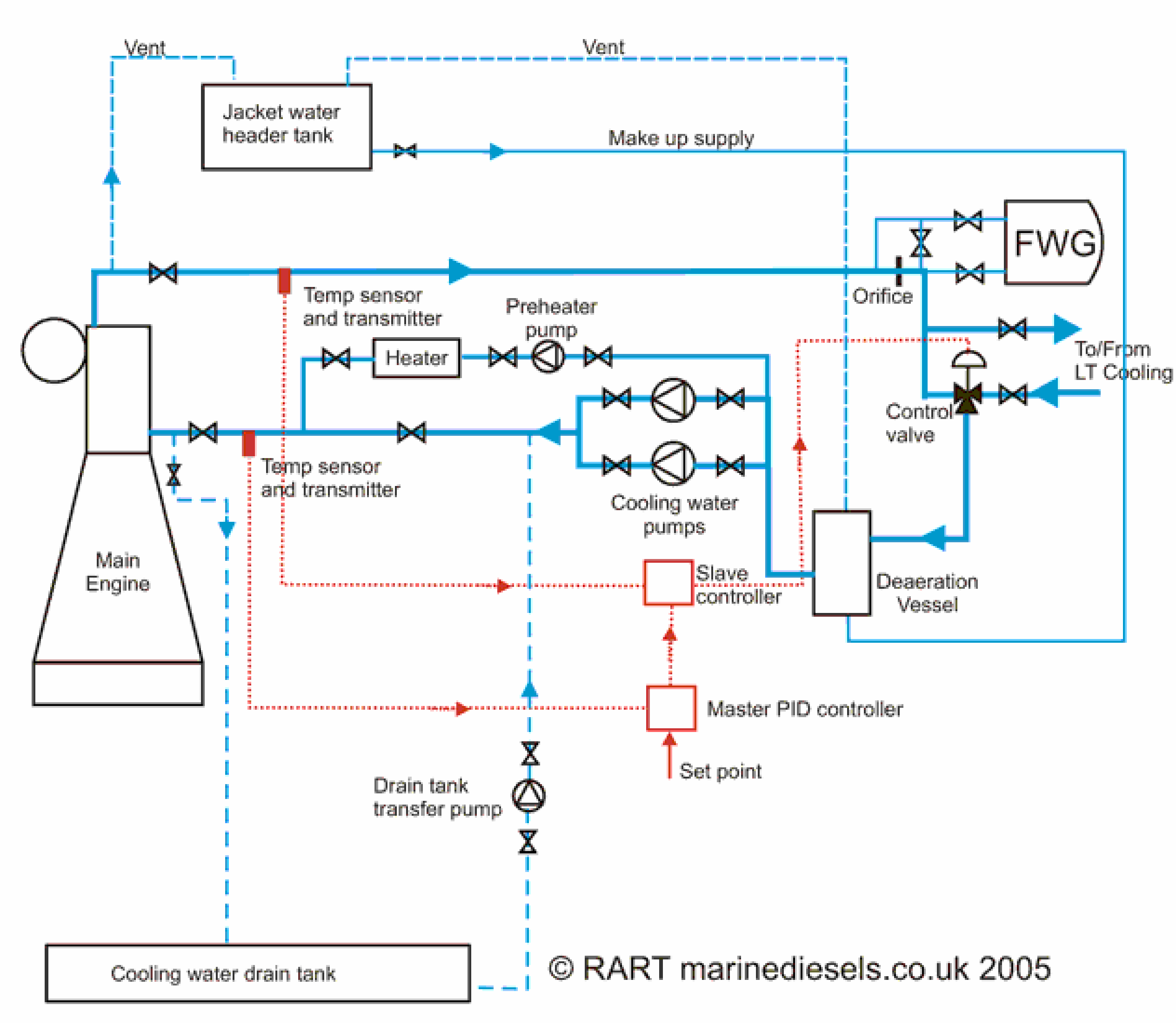
Cooling can be achieved by using a dedicated cooler or by mixing in some of the water from the LT cooling circuit. The LT cooling water is then cooled in the sea water coolers. The temperature is controlled using cascade control which monitors both the inlet and outlet temperatures from the engine. This allows a fast response to any change in temperature due to a change in engine load.

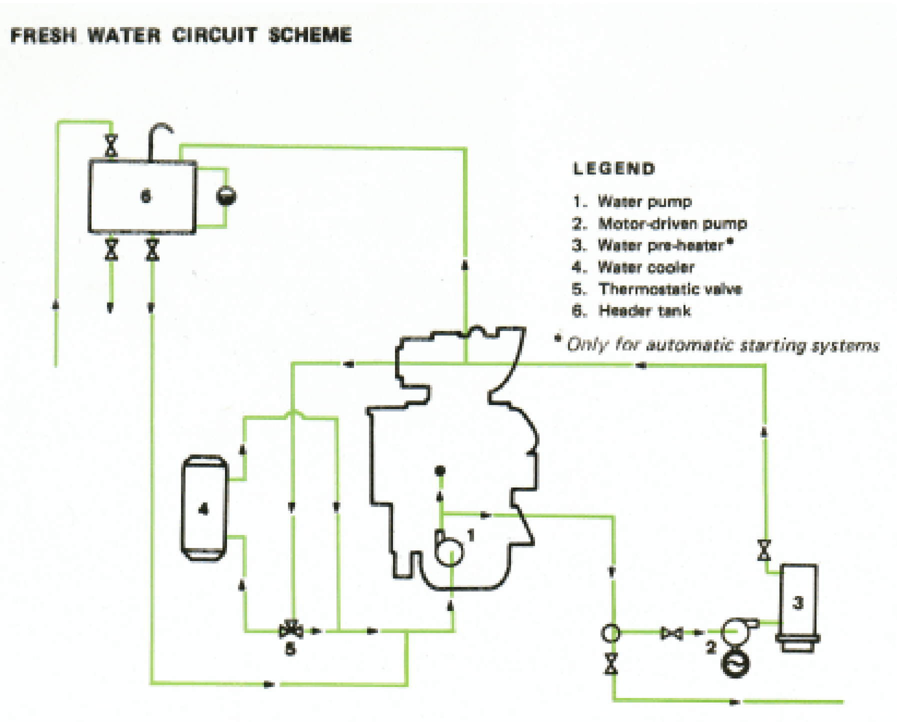
To make up for any leaks in the system there is a header tank, which automatically makes up any deficiency. Vents from the system are also led to this header tank to allow for any expansion in the system and to get rid of any air (if you are familiar with a domestic central heating system then you will see the similarities). The header tank is relatively small, and usually placed high in the engine room. It is deliberately made to be manually replenished, and is fitted with a low level alarm. This is so that any major leak would be noticed immediately. Under normal conditions, the tank is checked once per watch, and if it needs topping up, then the amount logged.

The system will also contain a heater which is to keep the cooling water hot when the engine is stopped, or to allow the temperature to be raised to a suitable level prior to starting. Some ships use a central cooling system, whereby the same cooling water is circulated through the main engine(s) and the alternator engines. This system has the advantage whereby the engines which are stopped are kept warm ready for immediate starting by the engines which are running.

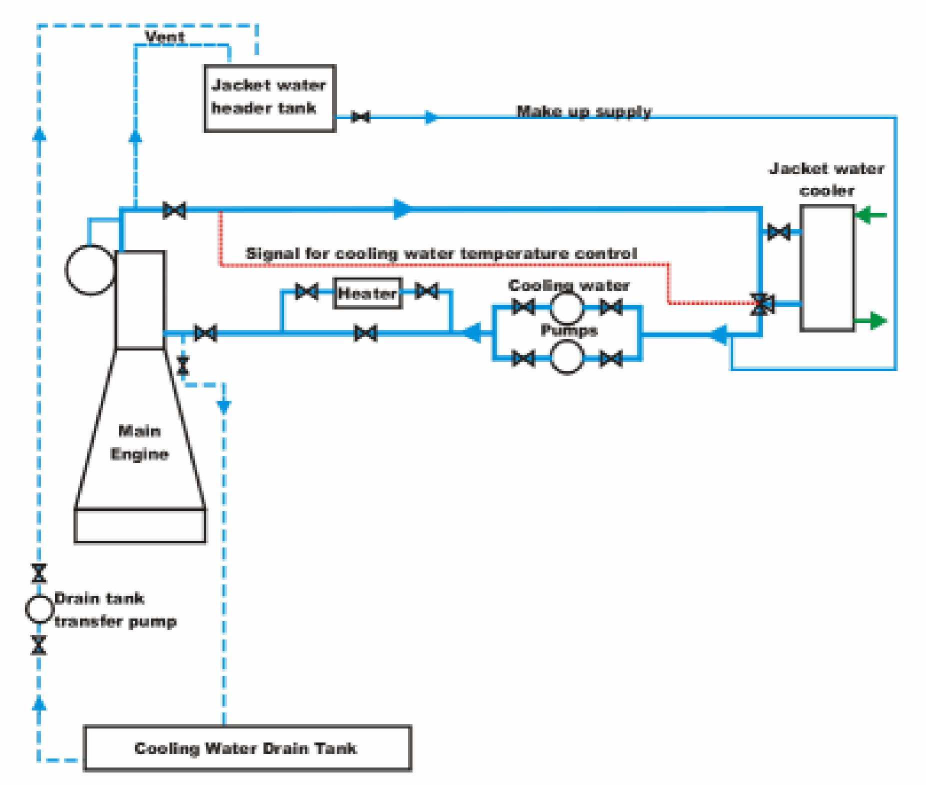
A fresh water generator (FWG) which is used to produce fresh water from sea water is also incorporated.

A drain tank has been included. This is for when the engine is drained down for maintenance purposes. Because of the quantities of water involved and the chemical treatment, it is not economically viable or environmentally responsible to dump the treated water overboard each time. This way the water can be re used.





This system shows a typical cooling water circuit for a single medium speed engine with an engine driven main pump and an electrically driven auxiliary circ pump and heater for keeping the engine warm when stopped.



In this diagram a simple circulation system for an engine. It is similar to the main diagram, but this time a dedicated HT cooler is used.

HT Cooling Water System

To keep the system hot when the ship is in port, a steam heater is used. The water is pumped through the heater using a small circ pump.

There are two HT cooling pumps fitted. These are centrifugal pumps which maintain the cooling water circulating pressure at about 4 Bar.

The fresh water generator (or evaporator) uses the heat from the main engines in the cooling water to produce fresh water from sea water. The pressure in the evaporator is below atmospheric (i.e. a vacuum) so that the water boils at a lower temperature (about 65°C). On a large passenger vessel the evaporators can produce 500 tons/day. This version is for a container ship and can produce 30 tons/day.

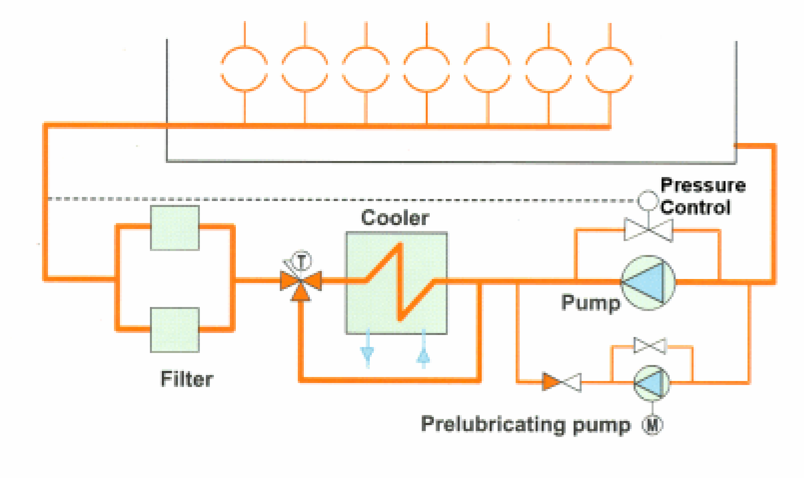
The temperature of the cooling water is controlled automatically by a 3 way valve. If no cooling is required (when the engine is stopped) then the valve allows water to circulate through the valve back to the pumps.

If cooling is required, then water is diverted to the Low Temperature (LT) system and replaced with cool water from the LT system. The LT water is cooled using sea water in plate coolers.

Any air is removed in the dearation vessel before the water is led to the HT pumps.

To make up for any leaks in the system there is a header tank, which automatically makes up any deficiency. Vents from the system are also led to this header tank to allow for any expansion in the system and to get rid of any air. The header tank is relatively small, and usually placed high in the engine room. It is deliberately made to be manually replenished, and is fitted with a low level alarm. This is so that any major leak would be noticed immediately. Under normal conditions, the tank is checked once per watch, and if it needs topping up, then the amount logged.

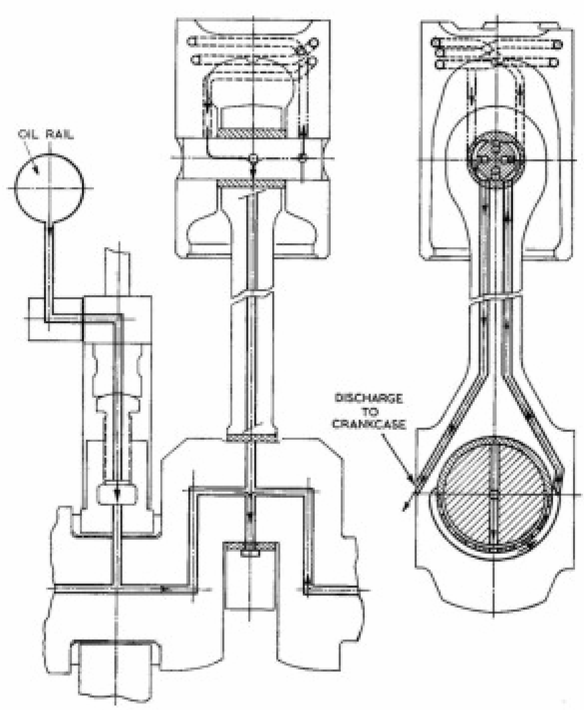
The Lubricating Oil System



Lubricating oil for a marine diesel engine achieves two objectives; it must cool and lubricate.

The oil is taken from the drain tank usually underneath the engine by a screw type pump. It is cooled, filtered and supplied to the engine via the oil inlet pipe or inlet rail at a pressure of about 4 bar. On a medium speed 4 stroke engine the oil is supplied to the main bearings through drillings in the engine frame to the crankshaft main bearings. Drillings in the crankshaft then take the oil to the crankpin or bottom end bearings. The oil is then led up the connecting rod to the piston or gudgeon pin and from there to the piston cooling before returning to the crankcase

Oil is also supplied to lubricate the rocker gear operating the inlet and exhaust valves, and to the camshaft and camshaft drive.



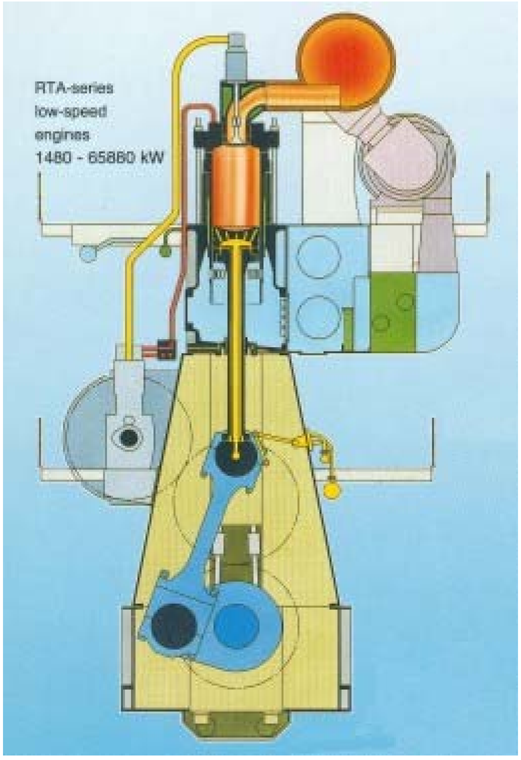
The oil then drains from the crankcase into the drain tank or sump.

The oil in the drain tank is being constantly circulated through a centrifugal purifier. This is to remove any water and products of combustion plus any foreign particles which may be in the oil.

The cylinder liner must be lubricated as well. This is so there will be a film of oil between the piston rings and the liner and also so that any acid produced by combustion of the fuel is neutralised by the oil and does not cause corrosion. Some of this lubrication will be supplied by so called "splash lubrication" which is the oil splashed up into the liner by the rotating crankshaft. However larger medium speed marine diesel engines also use separate pumps to supply oil under pressure to the cylinder liner.

The oil is led through drillings onto the liner surface where grooves distribute it circumferentially around the liner, and the piston rings spread it up and down the surface of the liner.

A pre lub pump is sometimes fitted especially to engines where the main pump is engine driven. This pump is electrically driven and circulates oil around the engine prior to starting.



On a two stroke crosshead engine lubricating oil is supplied to the main bearings and camshaft and camshaft drive. A separate supply is led via a swinging arm or a telescopic pipe to the crosshead where some of it is diverted to cool the piston (travelling up and back through the piston rod), whilst some is used to lubricate the crosshead and guides, and the rest led down a drilling in the connecting rod to the bottom end or crankpin bearing. Oil is also used to operate the hydraulic exhaust valves.

On some engines, the oil supply to the crosshead bearing is boosted in pressure to about 12 bar by a second set of pumps. This oil is also used to operate the hydraulic reversing gear for the engine.

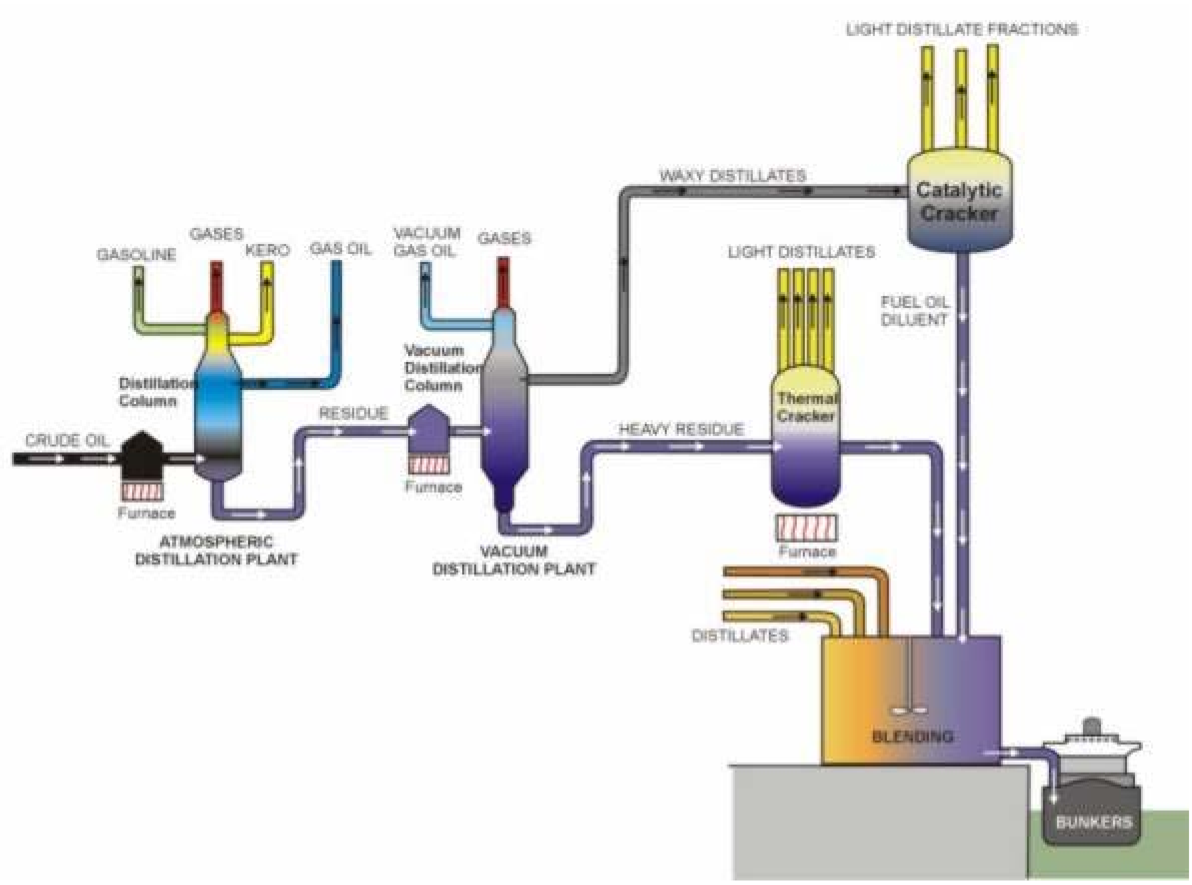
The cylinder liners on a two stroke engine are lubricated using separate injection pumps which use a different specification of oil. The oil which is led to drillings in the liner is able to deal with the acids produced by the burning of high sulphur fuels.

Oil grooves in a cylinder liner

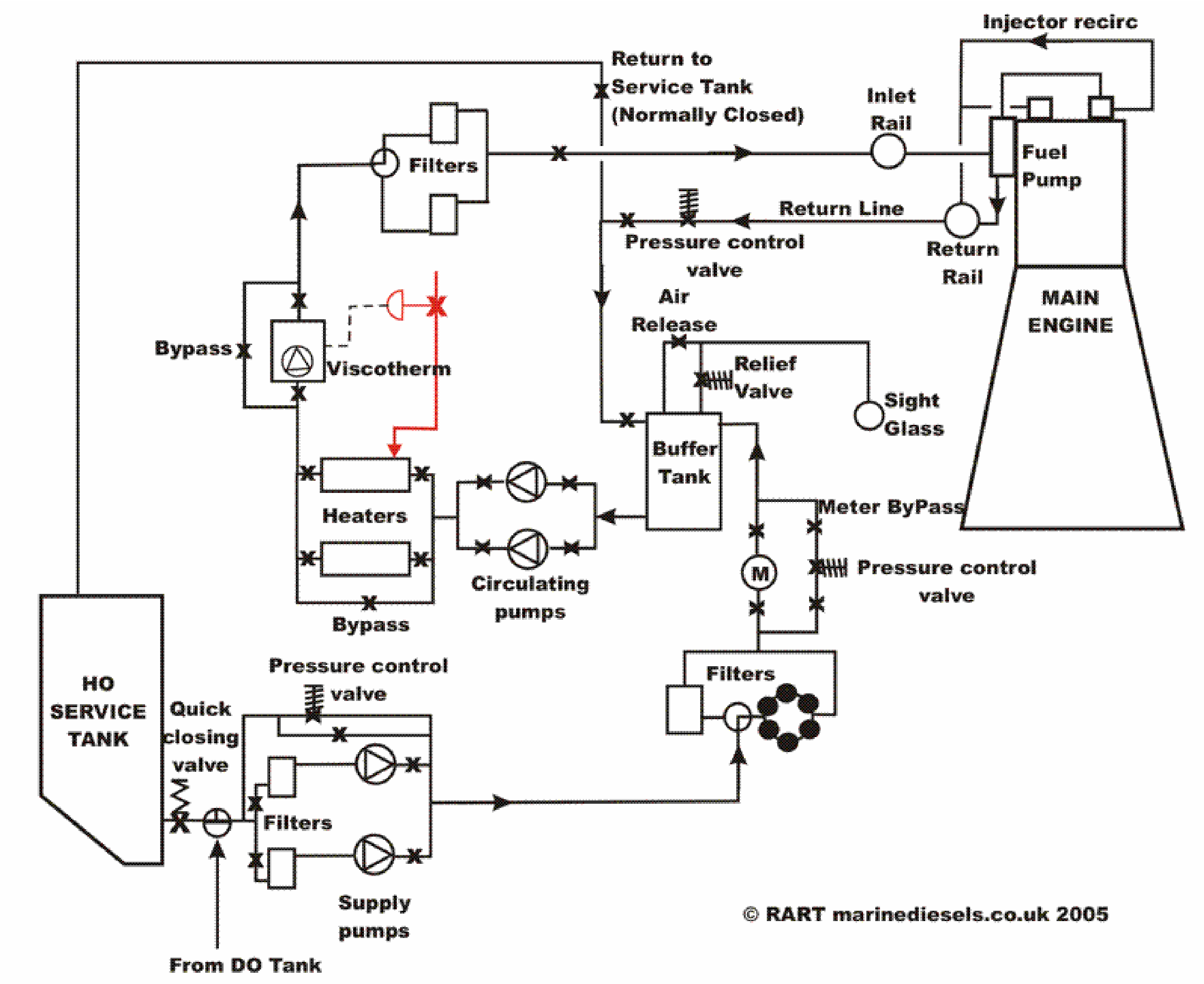
Cylinder Lubricators

Fuel Oil System

Marine diesel engines are designed to burn heavy residual fuel. This is made up of the residues after the lighter and more costly fuels and gases have been taken out of the crude oil at the refinery. The graphic below illustrates the process.



The diagram below shows a Fuel oil supply system for a large 2 stroke crosshead engine. However the set up is typical of any fuel system for a marine diesel engine operating on heavy residual fuel.



Engine Fuel Pump and Injectors

From the main engine inlet rail the fuel enters each fuel pump (one per cylinder). The fuel pump delivers the fuel at high pressure (250bar +) to the fuel injector(s).

The lower connection on the fuel pump is the fuel return. More than the required fuel is delivered to the pump. The excess is recirculated back to the buffer (mixing) tank.

The fuel injectors deliver the atomised fuel to the cylinder. When not injecting fuel, the injectors recirculate back to the fuel return.

Pressure Control Valve

To maintain the fuel oil pressure at the required setting (on this system about 8 bar) there is a backpressure control valve fitted on the return line.

FO Buffer Tank or Mixing Column

The fuel then passes to a mixing column or buffer tank where it mixes with fuel returned from the engine.

The mixing column is fitted with a relief valve and an air release (see below) and the outlets from these are led via a sight glass to the fuel oil drain tank.

Fuel Meter

The fuel is pumped via a meter so that the quantity of fuel used can be monitored and the specific fuel consumption of the engine calculated.

In the case that the meter has to be bypassed, then the fuel is led across a pressure retaining valve.

Backflushing Filters

From the supply pumps the fuel passes to a set of backflushing filters (25 micron). The pods contain the filter elements. When the filters start to clog up, a differential pressure sensor initiates a backflushing routine so that the filters clean themselves. The backflushing oil with the sediment from the filters drains to the fuel oil drain tank from which it can be recovered and purified.

The filter can be taken off line for cleaning, when a mesh type filter is put into operation.

Heavy Oil-Diesel Oil Change Over Valve

The fuel system can be changed over so that the engine can be run on diesel fuel. This is normally done if work is to be carried out on the main engine fuel pumps, or before going for a refit. It can be also changed over if there was a fault with the fuel oil heating plant.

It used to be normal practise to change to diesel fuel for manoeuvring purposes. Modern methods of fuel oil recirculation to keep the fuel hot at the injectors has now made this practise redundant

The change over valve can be operated automatically from a switch in the engine control room or by the handwheel on top of the valve.

Suction Filters, Supply Pumps and Pressure Control Valve

Before the fuel enters the supply pumps a suction filter removes any particles which could cause damage. There are two filters, one for each pump. Made from a fine metal gauze, they can be cleaned as necessary and reused.

The supply pumps raise the pressure to about 7 bar. To keep the discharge pressure constant, a pressure regulating valve is used.

There is also a manual bypass which can be used should the regulating valve develop a fault.

Quick Closing Valve

Fuel is drawn the service tank through a quick closing valve. These can be closed remotely in case of emergency (e.g. fire). This can be done with simple pull wires, hydraulically, or in this case by compressed air.

The fuel then passes via the change over valve through a set of filters into the supply pumps.

Fuel Oil Circulating Pumps

From the buffer tank fuel oil circulating pumps pressurise the fuel to about 8 bar through the heaters and to the engine.

Heaters and Viscosity Control

The oil is heated by steam (although thermal oil or electric heaters are used on other systems). The temperature of the oil is controlled by a viscosity measuring device. The viscosity must be maintained at the correct level for injection. On this particular system it is set at 16 Centistokes.

The viscosity controller in this particular case is an electronic device. It measures the damping of a vibration signal. The more viscous the fuel the less the vibration is damped.

The output from this signal is sent to the heater control valve.

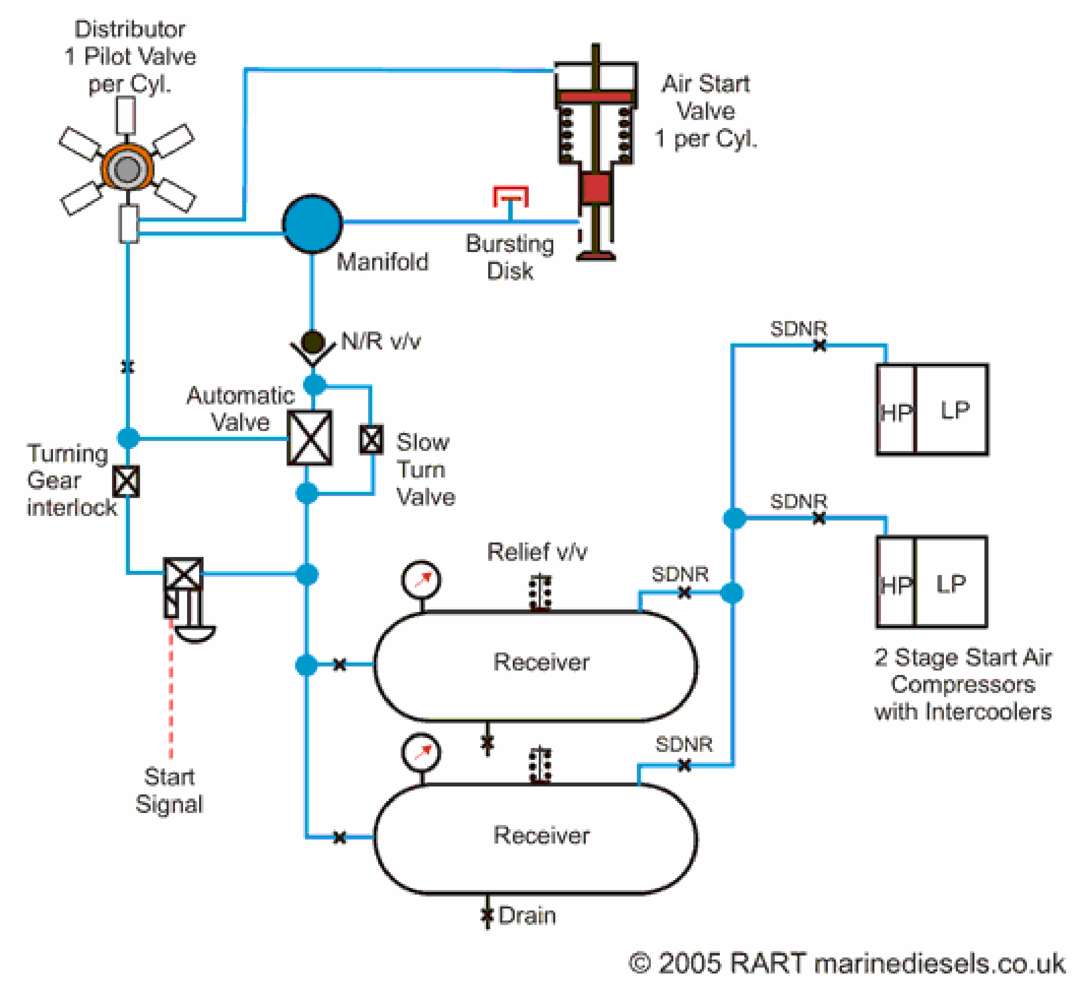
Final Filters

After the heater and before finally going to the main engine inlet rail the fuel passes through a final set of filters to ensure that it is free of abrasive contaminants which could damage the fuel pumps, injectors and cylinder liner.

The Air Start System

Large marine diesel engines use high pressure compressed air to start them. The air flows into the cylinder when the piston is moving down the cylinder on the power stroke. To minimise the risk of an air start explosion, fuel is not injected into the cylinder whilst the air is being admitted.

Air start systems vary in their design and can be quite complex. There will be a means to start the engine locally as well as from a remote location (The Bridge or the engine control room). This system is not representative of one type of engine but is simplified to give a basic understanding.

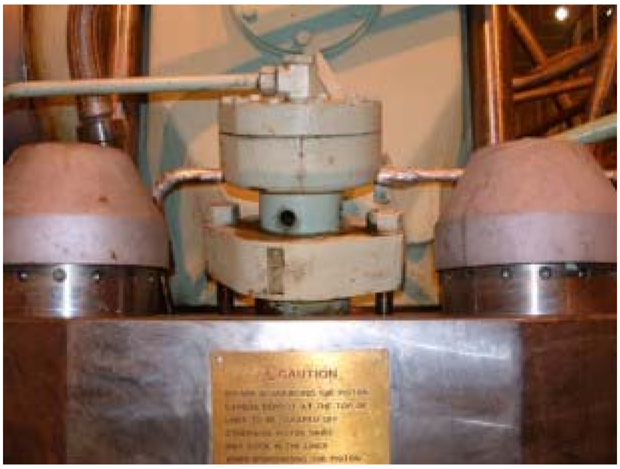


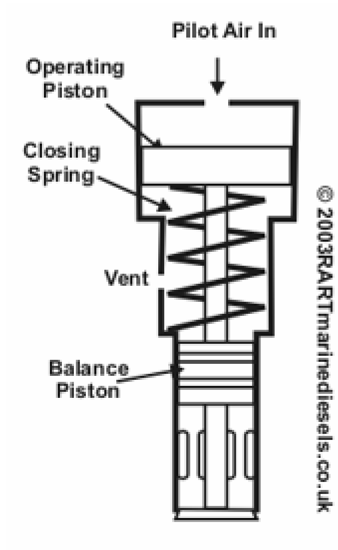
Air Start System

The Air Start Distributor

The air distributor normally consists of a series of pilot valves, one for each cylinder arranged radially around a cam. Timed to the engine and driven from the camshaft, the distributor opens the main air start valves in the correct sequence.

The Air Start Valve





Air Start Valve

The air start valve is located in the cylinder head. When it is opened by the air signal from the distributor, compressed air at 30 bar flows into the cylinder, forcing the piston down.

The Bursting Disk

The connection to each air start valve is fitted with a protection device. This can be either a flame trap or a bursting disk.

The flame trap will prevent any combustion in the cylinder passing to the air start line and causing an explosion, whereas a bursting disk will limit any pressure rise by bursting.

The Automatic Valve

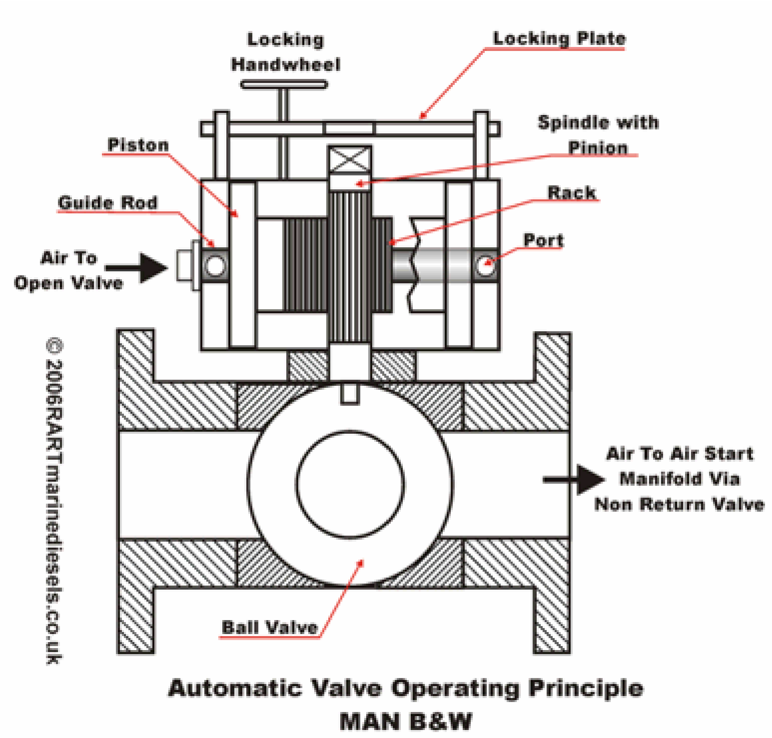
The automatic valve is only open whilst an air start is taking place. It incorporates a non return valve to prevent any explosion in the air start system getting back to the air receivers. A slow turn valve is incorporated in the smaller bore pipework to the side of the valve. This is used to turn the engine slowly before starting, to prevent damage which could be caused if liquid had found it's way into the cylinder.

The valve shown in the photos and the diagram opposite is from an MAN B&W slow speed two stroke. The valve itself is a simple ball valve which is turned through 90° by pneumatic actuator. The actuator consists of a central spindle with gear teeth machined onto it. This is rotated by two racks which are driven by pistons.

Two guide rods which maintain the alignment of the pistons and racks are bored to allow air to either side of the pistons. (only one guide rod is shown on the diagram)

When a start signal is given, the space behind the pistons is pressurised and they move together, rotating the spindle and opening the ball valve.

At the end of the start sequence air is admitted through the second guide rod (not shown) pressurising the space between the pistons, moving them apart and closing the valve.



The Turning Gear Interlock

The turning gear interlock is a control valve which will not allow starting air to operate the system when the turning gear is engaged.

The Air Receiver

Two air start receivers are fitted. The total capacity of the receivers must be sufficient to start the engine 12 times alternating between ahead and astern without recharging the receivers. In the case of a unidirectional engine, then the capacity must be sufficient for 6 starts.

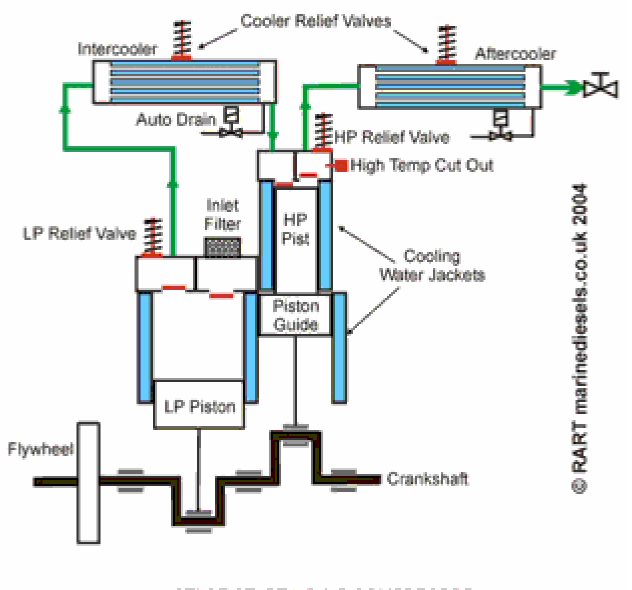
The air receiver will be fitted with a relief valve to limit the pressure rise to 10% of design pressure. A pressure gauge and a drain must also be fitted. A manhole gives access to the receiver for inspection purposes.

The Air Compressor

Two air start compressors are normally supplied which must be capable of charging the air receivers from empty to full in one hour.

They are usually two stage reciprocating with inter and afterstage cooling. Relief valves will be fitted to each stage which will limit the pressure rise to 10% of design pressure, and a high temperature cut out or fusible plug to limit the HP discharge to 121°C.

Intercoolers are also fitted with bursting disks or relief valves on the water side.

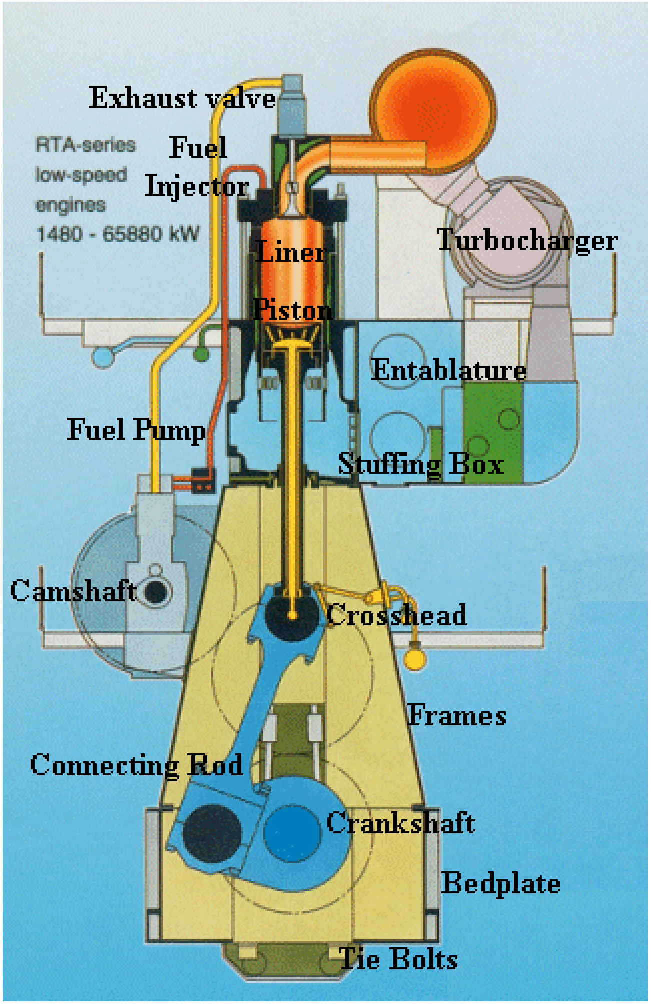


2 STAGE STARTING AIR COMPRESSOR

THE TWO STROKE CROSSHEAD ENGINE

The Two Stroke Crosshead Engine has long been the favoured main propulsive power unit for most types of merchant vessels. As the price of oil rose, developments in the design of these engines allowed them to burn the poorer residual fuels. This combined with major improvements in turbocharger design and waste heat recovery, raised their efficiency and power output, so they were able to supercede the steam turbine plants which operated at much lower efficiencies.

The number of companies which design and build these engines (along with their licensees) have reduced over the years due to take overs, amalgamations, and closure. Three companies still in business are MAN B&W (formed by the amalgamation of those two giants of the industry); The Wartsila Corporation (formally Wartsila NSD) who design and build the Sulzer engines. Mitsubishi Heavy Industries in Japan also design and build their own two stroke engine, the UE .



Due to the longevity of these engines and the professionalism of the engineers in charge of them, there are still ships sailing the globe powered by engines which are no longer built. Doxfords, Gotaverkens, Fiats are names which may bring back memories as well as the older designs of Burmeister and Wain, Sulzer, and MAN

Although the picture shown is of a Sulzer RTA engine, this website is intended to give a general insight into the design of the 2 stroke crosshead engine, and it is not my intention to pick out any particular engine for criticism, constructive or otherwise. I chose this particular picture because it was simple and clear. As a matter of fact, since this picture was published, further modifications have been made to this particular engine.

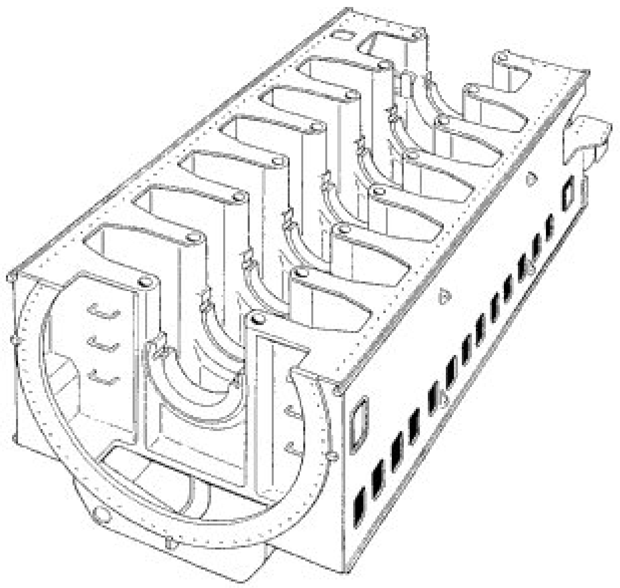
To have a look at some photos of one of the largest engines in the world click here However this is NOT the largest engine That achievement is claimed by MAN B&W who now have a 1070mm bore engine with up to 16 cylinders!!

The Bedplate

The Bedplate is the foundation on which the 2 stroke engine is built. It must be rigid enough to support the weight of the rest of the engine, and maintain the crankshaft, which sits in the bearing housings in the transverse girders, in alignment. At the same time it must be flexible enough to hog and sag with the foundation plate to which it is attached and which forms part of the ships structure.

If the bedplate was too rigid, then as the hull flexed, the holding down bolts, which secure the engine into the ship would be likely to break, and there would be a danger of the bedplate cracking.

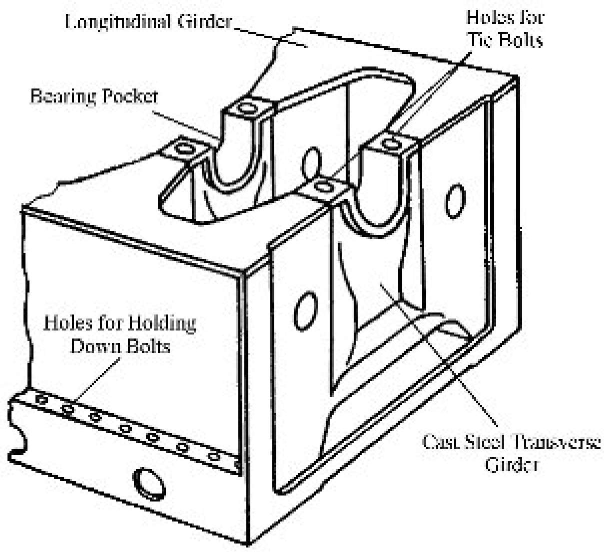
Basically the bedplate consists of two longitudinal girders which run the length of the engine. Connecting these longitudinal girders are the transverse girders which are positioned between each crankshaft throw, and either side of the thrust collar. Built into the transverse girders are the main bearing pockets for the crankshaft to run in.

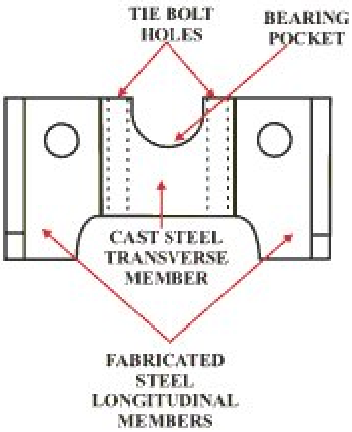


On the small bore engines, the bedplate can be made from cast iron as a single casting. Larger engines have a fabricated bedplate. This means it is welded together from steel sections, steel castings and plate. The steel is to Classification Society specifications and is a low carbon steel with a maximum carbon content of 0.23%.

Earlier fabricated bedplates had box section longitudinal girders and box section fabricated transverse girders. Problems were encountered with cracking of the transverse girders, which increased as engine powers and crankshaft throws got larger.

The modern bedplate is constructed from fabricated longitudinal girders with cast steel transverse sections containing the bearing pockets and tie bolt holes welded into place. After manufacture, the bedplate is stress relieved, the bearing pockets are line bored and landing surfaces machined.

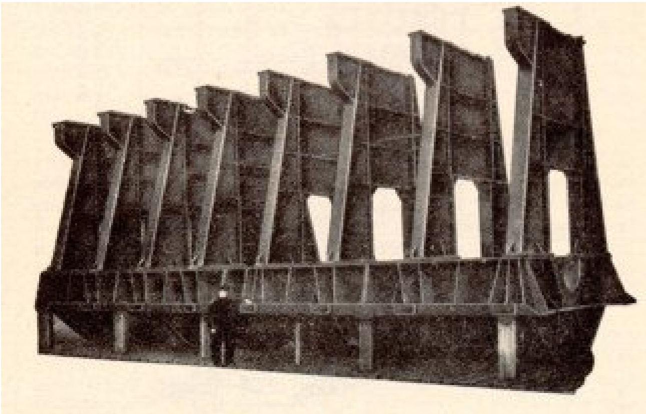


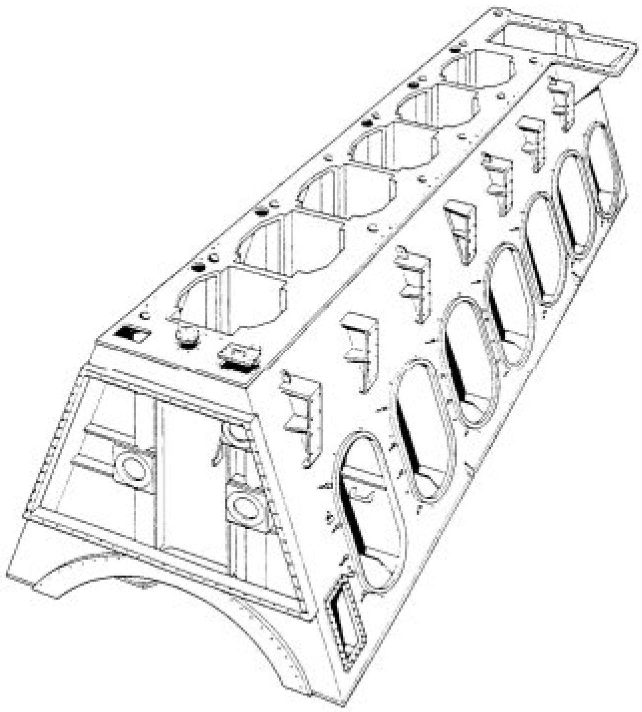


The bedplate should be inspected regularly for evidence of cracking. This can occur in the welds joining the transverse girders to the longitudinals, and under the bearing pockets, where the cracks can be radial or follow the line of the pocket. As well as faulty manufacturing techniques, causes can be uneven loading/ overloading of engine units, loose tie bolts and loose holding down bolts

The A Frames

Otherwise known as the A Frames. These carry the crosshead guides and support the engine entablature (the cylinder block). On older engines, the A frames were individually erected on the bedplate directly above the transverse girders. When boxed in with plating they formed the crankcase. The trend nowadays is to build the frame box as a separate fabricated construction and then, after stress relieving and machining the mating surfaces, to mount it on the bedplate. This has the advantage of saving weigh





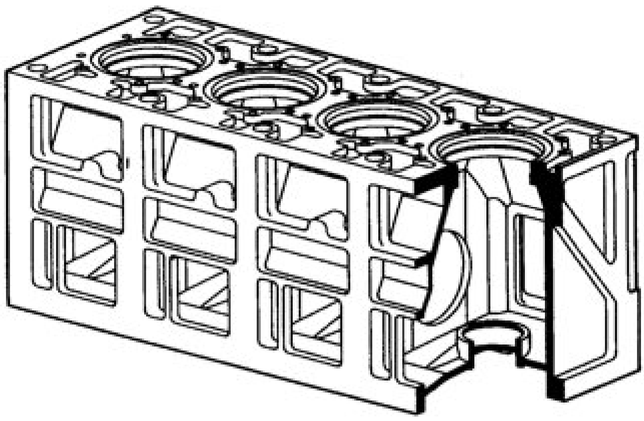
Lowering the A frame onto the bedplate. A small amount of jointing compound is used to ensure an oil tight joint

When the frames are aligned on the bed plate they are secured together by drilling and reaming and using fitted bolts.

Cracking in A frames can occur leading to misalignment and excessive wear of the running gear. Cracks can start from welds, sharp changes in section and where strengthening stringers are terminated sharply. Repairs can involve cutting the crack out, grinding and rewelding. The danger is that after repair there may still be misalignment.

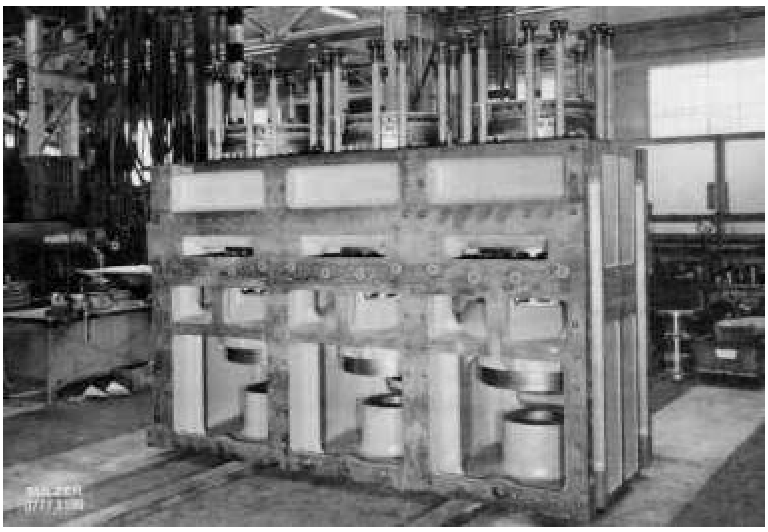
The Entablature

The entablature is the name given to the cylinder block which incorporates the scavenge air space and the cooling water spaces. It forms the housing to take the cylinder liner and is made of cast iron.



The castings are either for individual cylinders which after machining on the mating surfaces are bolted together to form the cylinder beam, or they may be cast in multi - cylinder units, which are then bolted together. The underside of the cylinder beam is machined and then it is aligned on the A frames and fastened in position using fitted bolts.

It is important to remember that the fitted bolts used to bolt the entablature, A frames and Bedplate together are for alignment and location purposes only. They are not designed to resist the firing forces which will tend to separate the three components. This is the job of the tie bolts.



In the photograph opposite, the liners can be seen in place in the entablature. Note also the diaphragm plate and the stuffing box housing.

Entablature Mounted On A Frame With Liners In Place

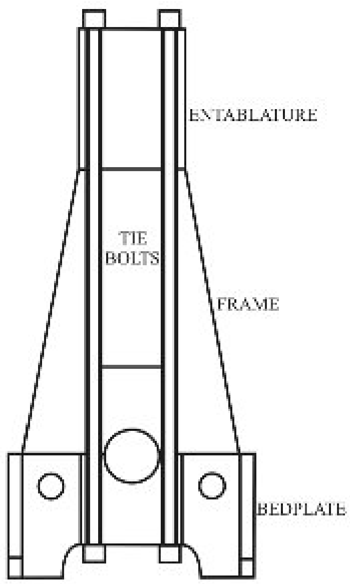
The Tie Bolts or Tie Rods

To understand the importance of the role played by the tie bolts or tie rods, it is necessary to appreciate what is happening inside the cylinder of the engine.

When the piston is just after top dead centre the pressure inside the cylinder can rise as high as 140 bar (14000kN/m2). This acts downwards through the piston rod and con-rod, pushing the crankshaft down into the bearing pockets. At the same time, the pressure acts upwards, trying to lift the cylinder cover. The cylinder head studs screwed into the entablature prevent this happening and so this upward acting force tries to lift the entablature from the frames and the frames from the bedplate, putting the fitted location bolts into tension.

As the piston moves down the cylinder the pressure in the cylinder falls, and then rises again as the piston changes direction and moves upwards on the compression stroke. This means that the fitted bolts are under are cyclic stress. Because they are not designed to withstand such stresses they would soon fail with disastrous consequences.

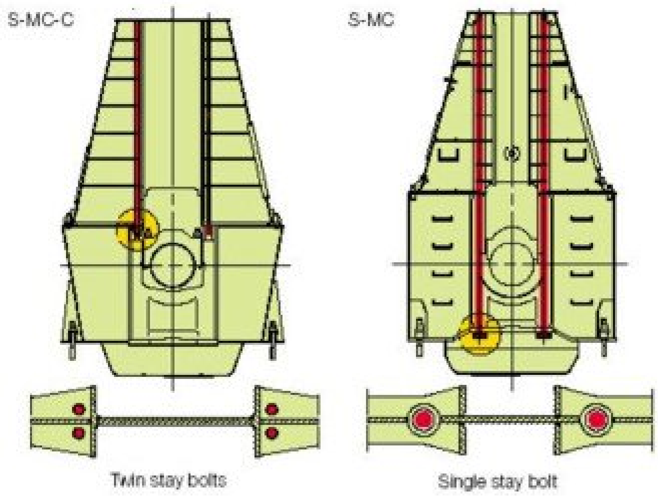
To hold the bedplate , frames and entablature firmly together in compression, and to transmit the firing forces back to the bedplate, long tie bolts are fitted through these three components and then tightened hydraulically. To prevent excessive bending moments in the transverse girders, the tie bolts are positioned as close to the centre of the crankshaft as possible. Because the tie bolts are so close to the crankshaft, some engines employ jack bolts to hold the crankshaft main bearing cap in position instead of conventional studs and nuts.

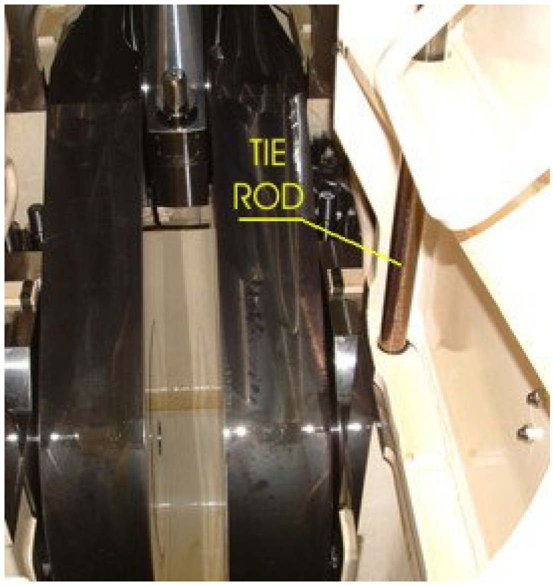


Operating the engine with loose tiebolts will cause the fitted bolts holding the bedplate, frame and entablature in alignment to stretch and break. The machined mating surfaces will rub together, corrode and wear away (this is known as fretting). Once this has happened the alignment of the engine running gear will be destroyed. Loose tie bolts will also cause the transverse girders to bend which could lead to cracking, and main bearing misalignment.

Once fretting between the mating surfaces has occurred, then tightening of the tie bolts will pull the engine out of alignment. The crosshead guides, the cylinder liner, and the stuffing box will no longer be in line and excessive wear will occur. Because the tie bolts will no longer be pulled down squarely they will be subject to forces which may lead to them breaking. If fretting has occurred, then the only solution is to remove the entablature or/and frame and machine the fretted mating surfaces (a very costly exercise).

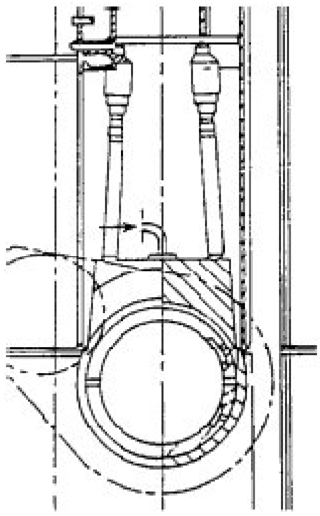
Tie bolts can break in service. To reduce the risk of this happening they must be checked for tightness; not overtightened; and the engine not overloaded. If a breakage does occur, this is not disastrous, as the engine can be operated with care for a limited period (the load on the engine may have to be reduced). The position of the fracture will dictate how the broken pieces are removed. However in the worst possible scenario where the bolt is broken at mid length, then one solution is to lift out the top half, remove the bottom nut, and then feed a loop of braided wire cable (about 7mm diameter) down the tie bolt tube, down the side of the broken tie bolt and once it emerges at the bottom a supporting piece can be fitted to the wire enabling the broken tie bolt to be withdrawn.



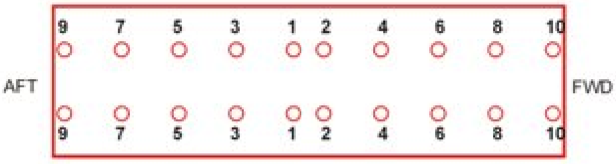


On the MAN B&W MC-C engine the tie bolts do not pass through the bedplate transverse girder in the traditional way. Instead there are two pairs of tie bolts fitted either side of the single plate A frame and screwed into the bedplate transverse girder. This, it is claimed, reduces the distortion of the bedplate during engine operation.

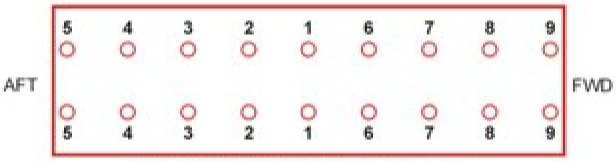
When checking the tightness of tie bolts, refer to manufacturers instructions for tightening pressures for the jacks and the order in which to carry out the check. The normal order is to start at the centre and work outwards checking the bolts in pairs. The MC -C engine with its twin tie bolts is an exception, starting at the fwd end and working aft. If the engine is fitted with bearing jacking bolts, then these must be slackened before tightening the tie bolts. Any pinch bolts fitted must also be slackened off.



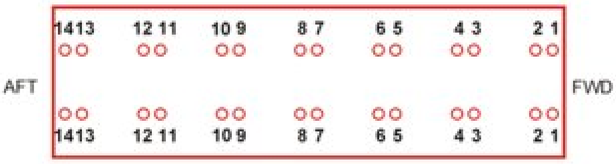
TIE BOLT TIGHTENING SEQUENCES



Sulzer RTA 96 Tightening Sequence



MAN B&W K98MC Tightening Sequence



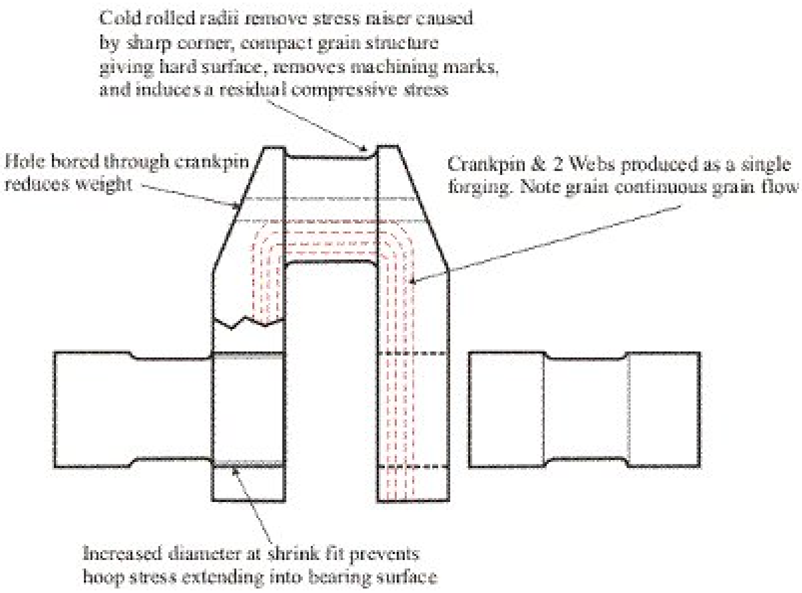
MAN B&W S50MC-C Tightening Sequence

The Crankshaft

The crankshafts on the large modern 2 stroke crosshead engines can weigh over 300 tonnes. They are too big to make as a single unit and so are constructed by joining together individual forgings. On older engines the so called fully built method was used. This consisted of forging separate webs, crankpins and main journals. The crankpins and journals were machined and matching holes bored in the webs, which were slightly smaller in diameter. The webs were heated up and the crankpins and journals fitted into the holes (which due to the heat had expanded in size). As the webs cooled down, so the diameter of the bored holes would try and shrink back to their original size. In doing so, the crankpins and journals would be gripped tightly enough to stop them being able to slip when the engine was being operated normally. This method of construction had its origins in the days of early reciprocating steam engine crankshaft manufacture, when as well as shrink fitting, dowel pins were used (mainly because the tightness of the shrink fit could not be guaranteed). THIS FITTING OF DOWEL PINS IS NEVER USED IN THE CONSTRUCTION OF DIESEL ENGINE CRANKSHAFTS. It would act as a stress raising point from which a crack could start.

Today, crankshafts for large 2 stroke crosshead engines are of the semi built type. In this method of construction the crankshaft "throws" consisting of two webs and the crankpin are made from a single forging of a 0.4% carbon steel. The webs are bored to take the separately forged and machined main journals which are fitted into the webs using the shrink fitting method described above. The shrink fit allowance is between 1/570 and 1/660 of the diameter.

The advantages of this method of construction is that by making the two webs and crankpin from a single forging the grain flow in the steel follows the web round into the crankpin and back down the other web.

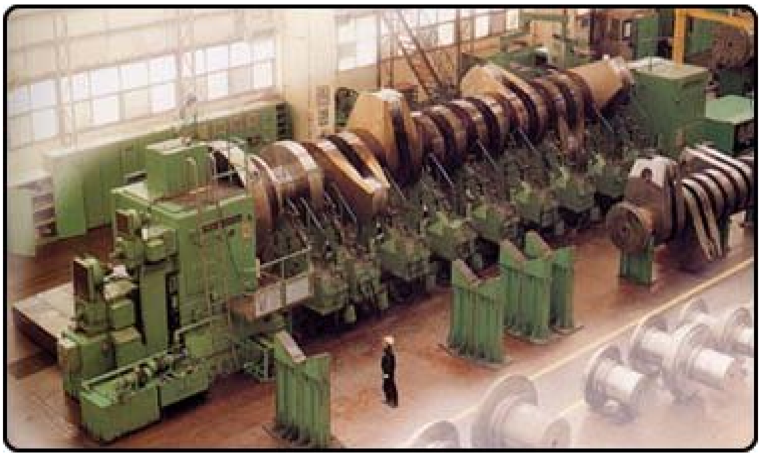


Because the crankpin and webs are a single forging, the webs can be reduced in thickness and a hole is sometimes bored through the crankpin as shown, reducing the weight without compromising strength. Note however, there is a need for a good deal of material around the holes bored to take the main journals. This is because of the large tensile hoop stress present in the material after shrink fitting. This could lead to a crack in the web if the thickness here is not adequate or if the shrink fit is too tight or if there is a flaw in the material.

Here you can see individual crankthrows awaiting machining

Heating a crank web using gas flames before inserting the main journal. Note the thickness of material around the hole for the journal.

A crankshaft being assembled vertically



A semi built crankshaft in the lathe. The man gives an idea of the size!

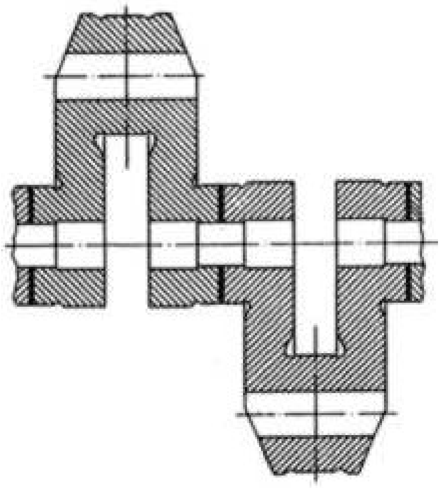
Lowering a semi built crankshaft into the bedplate.

The crankshaft in the bedplate.

The welded crankshaft

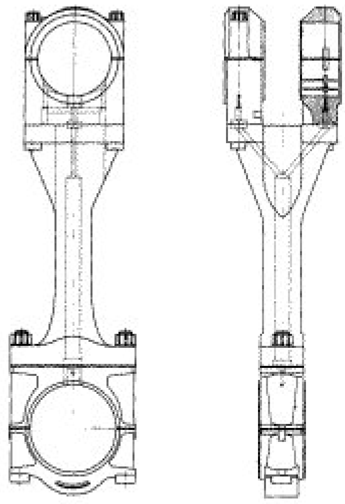
The welded crankshaft was developed in the 1980s. It was made up of a series of forgings each comprising of half a main journal, web, crankpin, second web, and half a main journal. These forgings were then welded together using a submerged arc welding process to form the crankshaft. After welding the journals were stress relieved and machined. As well as having the advantage of continuous grain flow, the webs could be made thinner (no shrink fit to accommodate), leading to a lighter shorter crankshaft.

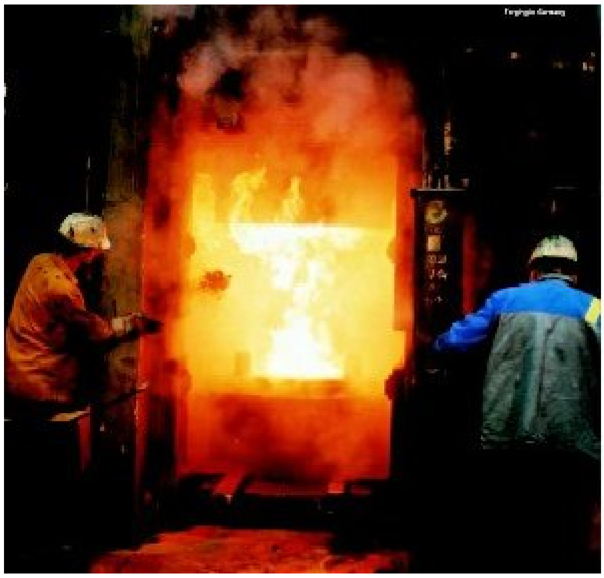
Why aren't all crankshafts produced by this method? Cost! It was very expensive and only about twenty crankshafts were produced by this method. They have performed very well in service however.



The Connecting Rod

The Connecting Rod is fitted between the crosshead and the crankshaft. It transmits the firing force, and together with the crankshaft converts the reciprocating motion to a rotary motion. Made from drop forged steel, on the older engines the bottom of the con rod terminates in a flange known as a Marine Palm which is bolted to the split bottom end (Crankpin) bearing, whilst at the top another flange is formed on which is bolted the two crosshead bearings.





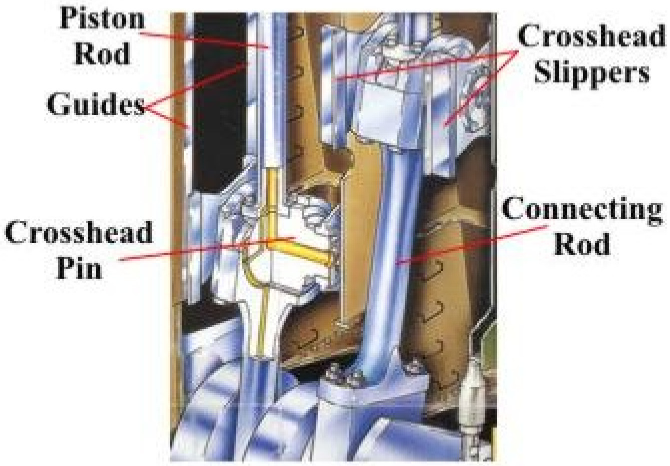
Connecting Rods on the later engines are produced as a single drop forging incorporating the top half of the crankpin bearing housing and the bottom half of the solid crosshead pin bearing housing.

On older engines the bearings were white metal thick wall bearings, scraped to fit. Clearances were adjusted by inserting or removing shims between the bearing halves. Modern bearings are of the "thinwall" type, where a thin layer of white metal or a tin aluminium alloy is bonded to a steel shell backing. The clearance on these bearings is non adjustable; When the clearance reaches a maximum the bearing is changed.

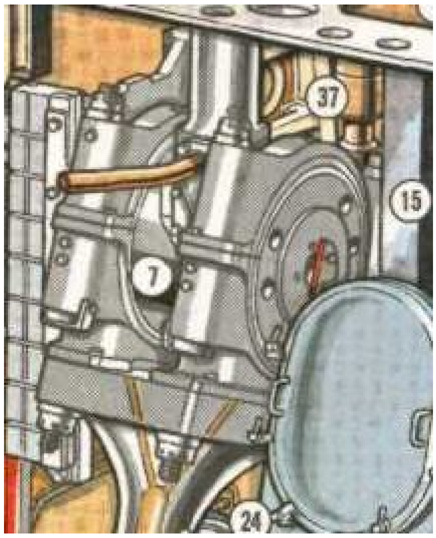
Oil to lubricate the crankpin bearing is supplied down a drilling in the con rod from the crosshead. When inspecting the crankpin bearing and journal it is good practise to check the journal for ovality because if this is excessive, a failure in the hydrodynamic lubrication can occur.

The Crosshead

The crosshead pin connects the piston rod to the connecting rod. On either side of the crosshead pin are mounted the crosshead slippers. The slippers run up and down in the crosshead guides as the piston and rod are reciprocating and prevent the top of the connecting rod from moving sideways.



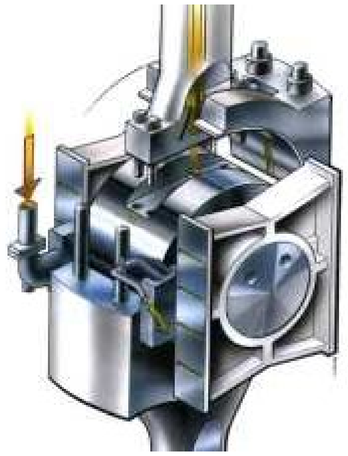
The crosshead pin sits in the crosshead bearing which is either a forked type (shown left), where the bearing housings are mounted on the top of the connecting rod either side of the piston rod, or of the continuous type (shown above and below), where the bearing housing is formed by the top of the connecting rod. On the forked type, the piston rod passes through a hole in the crosshead pin and is secured by a nut. On the continuous type, the piston rod has a foot which is bolted onto the top of the crosshead pin. Modern engines are fitted with the continuous type of bearing.



The crosshead bearing is difficult to lubricate effectively. Because the top of the connecting rod swings about the pin and changes direction each time the piston reaches mid stroke, the relative speed between bearing and pin at mid stroke is zero, accelerates to a maximum as the piston approaches top or bottom dead centre and then decelerates back to zero again as the piston approaches mid stroke and the con rod changes direction. This means that hydrodynamic lubrication, where the pin is separated from the bearing by a wedge of oil only occurs over part of the swing; i.e when the relative speed between the two components is high enough

The load on the pin is always downwards, so it is the bottom half of the bearing which is subject to wear. Because of the high loads the bearing material is a tin-aluminium alloy bonded to a steel shell. The pin is highly polished to a mirror finish.

To accommodate the high downward load and to aid effective lubrication the pin has a large diameter. This increases the relative speed between pin and bearing. The bottom halves of the bearing shells have oil gutters cut in them to assist the distribution of oil. Oil is supplied to the crosshead using a swinging arm or a telescopic pipe and is sometimes boosted in pressure to aid efficient lubrication.



The crosshead slippers are mounted on stepped journals machined either end of the crosshead pin, secured in place by end plates. The slippers float on the journals, to allow for any slight misalignment in the guides. The rubbing surfaces are white metal lined. Oil is supplied to the slipper rubbing faces from the crosshead oil supply. The slippers have gutters machined in them to assist the spread of the lube oil.

The guide surfaces are either machined into the A frames or are separately cast and machined, then bolted to the A frames. The alignment of the guides is very important as is the clearance between the guides and slippers. If this alignment is out of true or the clearances excessive then excessive wear will occur between piston rod and stuffing box and piston and cylinder liner.

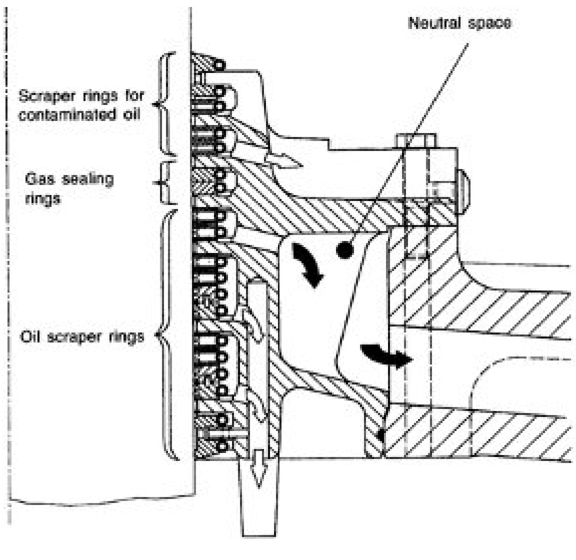
The Stuffing Box

Because the crankcase is separated from the cylinder and scavenge space by the diaphragm plate on a two stroke crosshead engine, provision must be made for the piston rod to pass through the plate without oil from the crankcase being carried upwards, or used cylinder oil contaminated from products of combustion being carried downwards. It is also highly undesirable to allow the pressurized air in the scavenge space to leak into the crankcase.

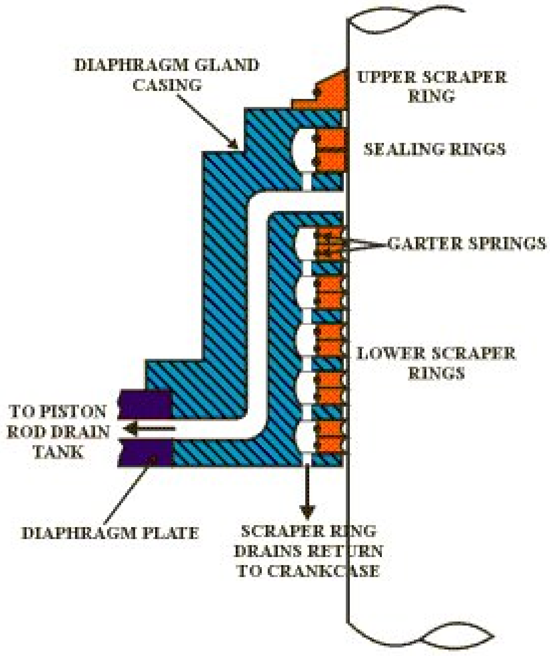
This photo of a split stuffing box showing the rings and springs was taken by Mr Dylan Wheel at the Ship Repair Exhibition at Olympia in Nov 2000.

The Piston rod passes through a stuffing box which is bolted into the diaphragm plate. The stuffing box casing which can be split vertically, as shown in the photo, contains a series of rings which are each made up of three or four segments. On the outside of each set of segments is a garter spring which provides the tension to hold the ring segments against the piston rod. There is a clearance between each segment to allow for wear. The rings are either bronze or can comprise of replaceable cast iron lamella fitted into a steel backing ring.

As the Piston rod passes up through the stuffing box, the oil from the crankcase is scraped off by the lower sets of rings and is returned via drillings to the crankcase. Any oil that passes this primary set is scraped off by another set of rings, and is led away through a drain to a tell tale open ended pipe into a tun dish outside the engine from where it drains to a recycling tank.



Stuffing box in engine



As the piston passes down through the stuffing box, the top set of scraper rings will scrape off the contaminated oil into the bottom of the scavenge space, where it is drained away via the scavenge drains. However if these rings are faulty, then the oil may drain into the recycling tank.

By observing the open ended tell tale referred to above, a guide to the condition of the rings can be ascertained. If a large quantity of oil is draining out, then the lower set of rings are faulty. If air is blowing out, then the upper rings are worn.

Oil in the recycling tank can be purified back to the crankcase. However this is not necessarily a good idea. It may be contaminated by used cylinder oil which if mixed with crankcase oil causes an increase in viscosity of the crankcase oil. calcium deposits in the bearings lead to damage and the oil may carbonise and deposit on the underside of the piston crown when used as a piston coolant. Often this contaminated oil is just landed ashore or burnt.

Regular maintenance of the stuffing box will keep it in good condition. checking garter spring tension, ring butt and axial clearances, and replacing worn rings are all part of the overhaul procedure.

Excessive wear will take place if the crosshead guides are out of alignment or if the guide clearances are excessive. Worn stuffing boxes and excessive leakage can exacerbate the incidence of scavenge fires and increase the risk of a crankcase explosion.

The Cylinder Liner

The cylinder liner forms the cylindrical space in which the piston reciprocates. The reasons for manufacturing the liner separately from the cylinder block (jacket) in which it is located are as follows;

- The liner can be manufactured using a superior material to the cylinder block. While the cylinder block is made from a grey cast iron, the liner is manufactured from a cast iron alloyed with chromium, vanadium and molybdenum. (cast iron contains graphite, a lubricant. The alloying elements help resist corrosion and improve the wear resistance at high temperatures.)

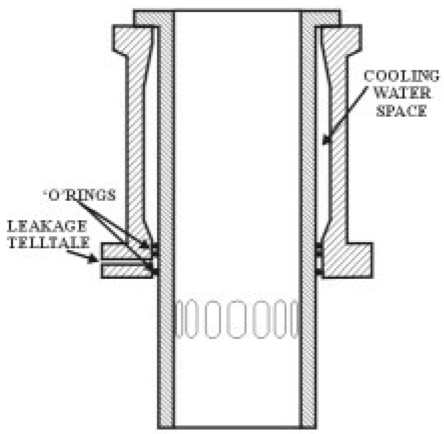
- The cylinder liner will wear with use, and therefore may have to be replaced. The cylinder jacket lasts the life of the engine.

- At working temperature, the liner is a lot hotter than the jacket. The liner will expand more and is free to expand diametrically and lengthwise. If they were cast as one piece, then unacceptable thermal stresses would be set up, causing fracture of the material.

- Less risk of defects. The more complex the casting, the more difficult to produce a homogenous casting with low residual stresses.

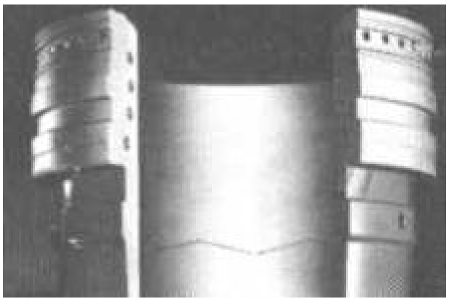
The Liner will get tend to get very hot during engine operation as the heat energy from the burning fuel is transferred to the cylinder wall. So that the temperature can be kept within acceptable limits the liner is cooled.

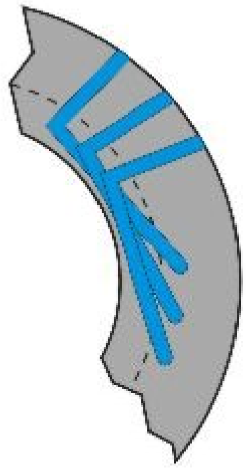
Cylinder liners from older lower powered engines had a uniform wall thickness and the cooling was achieved by circulating cooling water through a space formed between liner and jacket. The cooling water space was sealed from the scavenge space using 'O' rings and a telltale passage between the 'O' rings led to the outside of the cylinder block to show a leakage.



To increase the power of the engine for a given number of cylinders, either the efficiency of the engine must be increased or more fuel must be burnt per cycle. To burn more fuel, the volume of the combustion space must be increased, and the mass of air for combustion must be increased. Because of the resulting higher pressures in the cylinder from the combustion of this greater mass of fuel, and the larger diameters, the liner must be made thicker at the top to accommodate the higher hoop stresses, and prevent cracking of the material.

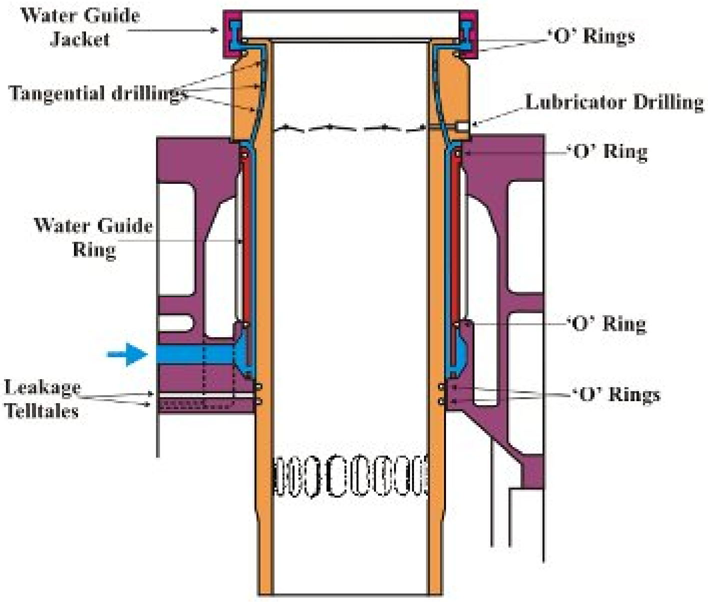
If the thickness of the material is increased, then it stands to reason that the working surface of the liner is going to increase in temperature because the cooling water is now further away. Increased surface temperature means that the material strength is reduced, and the oil film burnt away, resulting in excessive wear and increased thermal stressing.



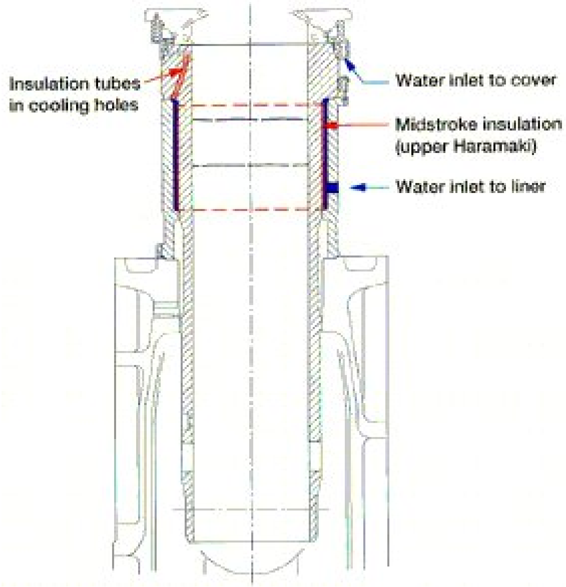


The solution is to bring the cooling water closer to the liner wall, and one method of doing this without compromising the strength of the liner is to use tangential bore cooling.

Holes are bored from the underside of the flange formed by the increase in liner diameter. The holes are bored upwards and at an angle so that they approach the internal surface of the liner at a tangent. Holes are then bored radially around the top of the liner so that they join with the tangentially bored holes.



On some large bore, long stroke engines it was found that the undercooling further down the liner was taking place. Why is this a problem? Well, the hydrogen in the fuel combines with the oxygen and burns to form water. Normally this is in the form of steam, but if it is cooled it will condense on the liner surface and wash away the lube oil film. Fuels also contain sulphur. This burns in the oxygen and the products combine with the water to form sulphuric acid. If this condenses on the liner surface (below 140º) then corrosion can take place. Once the oil film has been destroyed then wear will take place at an alarming rate. One solution is to insulate the outside of the liner so that there was a reduction in the cooling effect. On The latest engines the liner is only cooled at the very top.



The photo shows a cylinder liner with the upper and mid insulation bands known as "Haramaki".

Although Haramaki is a type of Japanese armour, the word also means literally " Stomach or Body Warmer". i.e an insulator.

Cylinder lubrication: Because the cylinder is separate from the crankcase there is no splash lubrication as on a trunk piston engine. Oil is supplied through drillings in the liner. Grooves machined in the liner from the injection points spread the oil circumferentially around the liner and the piston rings assist in spreading the oil up and down the length of the liner. The oil is of a high alkalinity which combats the acid attack from the sulphur in the fuel. The latest engines time the injection of oil using a computer which has inputs from the crankshaft position, engine load and engine speed. The correct quantity of oil can be injected by opening valves from a pressurized system, just as the piston ring pack is passing the injection point.

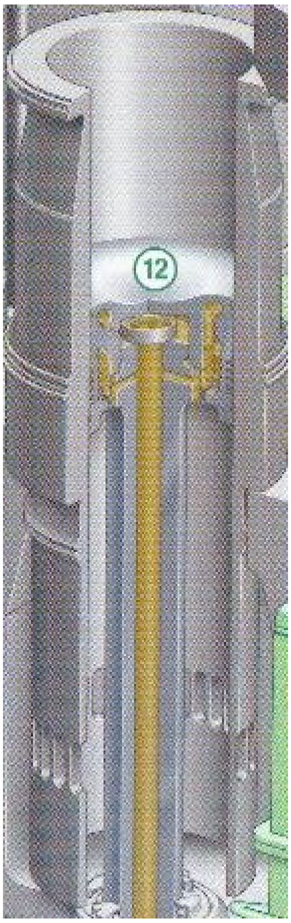
As mentioned earlier, cylinder liners will wear in service. Correct operation of the engine (not overloading, maintaining correct operating temperatures) and using the correct grade and quantity of cylinder oil will all help to extend the life of a cylinder liner. Wear rates vary, but as a general rule, for a large bore engine a wear rate of 0.05 - 0.1mm/1000 hours is acceptable. The liner should be replaced as the wear approaches 0.8 - 1% of liner diameter. The liner is gauged at regular intervals to ascertain the wear rate.

It has been known for ships to go for scrap after 20 + years of operation with some of the original liners in the engine.

As well as corrosive attack, wear is caused by abrasive particles in the cylinder (from bad filtration/purification of fuel or from particles in the air), and scuffing (also known as micro seizure or adhesive wear). Scuffing is due to a breakdown in lubrication which results in localised welding between points on the rings and liner surface with subsequent tearing of microscopic particles . This is a very severe form of wear.

The Piston

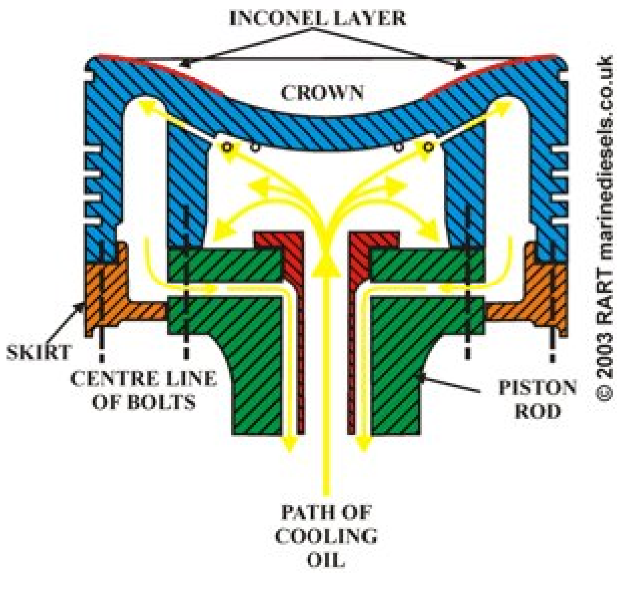
The Piston comprises of two pieces; the crown and the skirt. The crown is subject to the high temperatures in the combustion space and the surface is liable to be eroded/burnt away. For this reason the material from which the crown is made must be able to maintain its strength and resist corrosion at high temperatures. Steel, alloyed with chromium and molybdenum is used, and some pistons have a special alloy welded onto the hottest part of the crown to try and reduce the erosion caused by the burning fuel. The crown also carries the 4 or 5 piston ring grooves which may be chrome plated.



The cast iron skirt acts as a guide within the cylinder liner. It is only a short skirt on engines with an exhaust valve (known as uniflow scavenged engines), as unlike a trunk piston engine, no side thrust is transmitted to the liner (that's the job of the crosshead guides).

A forged steel piston rod is bolted to the underside of the piston. The other end of the piston rod is attached to the crosshead pin.

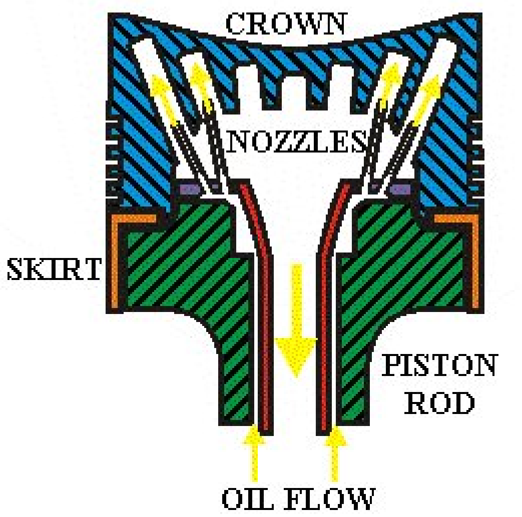
Pistons are cooled either using water or the crankcase oil. Water has a better cooling effect than oil, but there is a risk of leakage of water into the crankcase.



Modern engines have oil cooled pistons. The piston rod is utilised to carry the oil to and from the piston. The rod is hollow, and has a tube running up its centre. This gives an annular space which, with the central bore, allows a supply and return. The MAN B&W piston has an 8mm thick heat resisting layer of a hard nickel-chrome alloy called Inconel welded to the hottest part of the crown to resist the "burning" of the piston crown.

An alternative method of cooling uses a nozzle plate and nozzles. Note that the oil goes up the annular space formed between the oil tube and the bore in the piston rod, and returns down the centre.

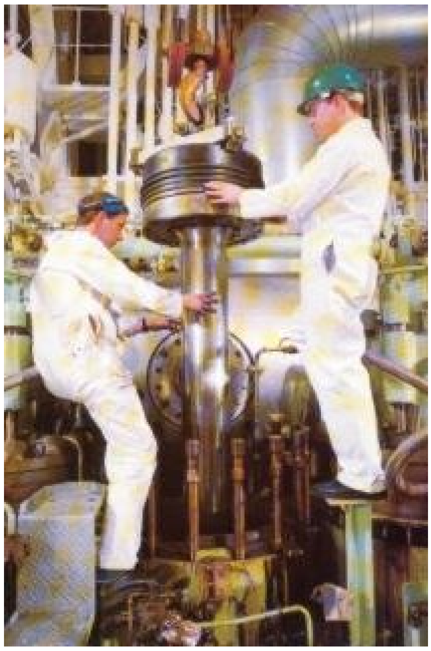
The oil is sprayed up matching bores onto the underside of the crown. This allows the crown to be made as thin as possible, to allow for maximum heat transfer while maintaining strength, and combined with the "cocktail" shaker effect caused by the reciprocating motion, gives efficient cooling



This Photo Shows the Nozzle Plate and Nozzles

This Photo Shows the Underside of the Piston Crown

When overhauling the piston it is important to check the thinning of the piston crown due to burning/erosion/corrosion. The piston should be dismantled to check the cooling space. If this is subject to a build up of carbon (in an oil cooled piston) or scale (in the case of a water cooled piston) then this may have led to thermal stressing of the piston, which in its turn can lead to cracking of the piston crown. If the cooling oil is allowed to leak into the combustion space then the consequences could be disastrous.



Piston rings

The Piston Rings are made of alloying cast iron with chromium, molybdenum, vanadium, titanium, nickel and copper. They are harder than the cylinder liner in which they run to give them a maximum life.

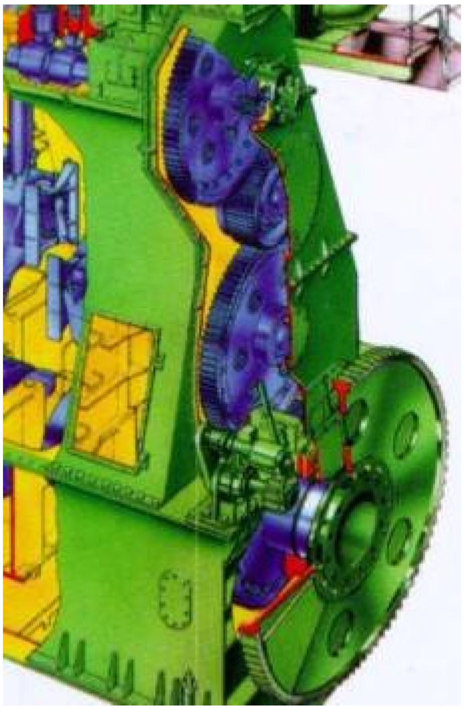
Piston rings seal the gas space by expanding outwards due to the gas pressure acting behind them. They also spread the lubricating oil up and down the cylinder liner and transfer heat to the liner walls.

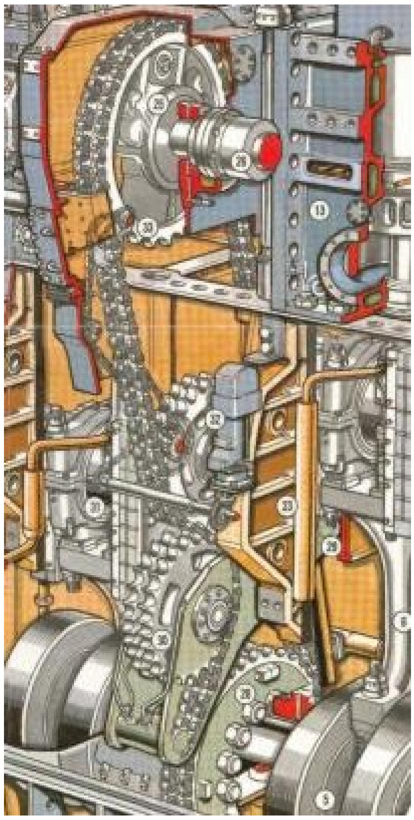
When overhauling the piston it is important to check the ring grooves for wear and the piston ring condition. The axial and butt clearances should be measured and recorded.

The Camshaft

The Camshaft carries the cams which operate the fuel pumps and exhaust valves. Because these operate once every cycle of the engine, the camshaft on a two stroke engine rotates at the same speed as the crankshaft.

It is also very important that the fuel pump and exhaust valve operate at exactly the right time, so the camshaft is driven by the crankshaft. Two methods are used, a geared drive and a chain drive.



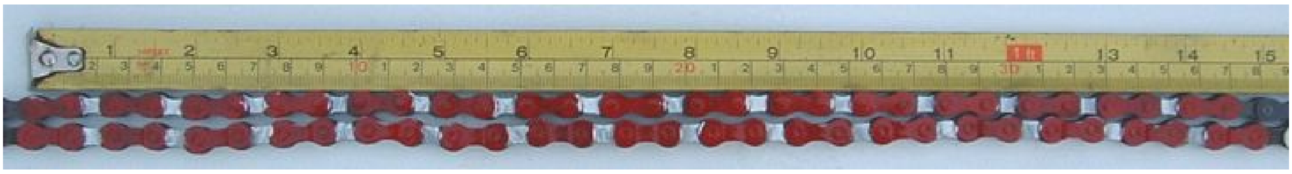


Chain drives are relatively light, narrow in width and flexible; however they elongate in service due to wear, which will affect the camshaft timing, and they have a limited life - 15 years.

Students sometimes have difficulty in visualising the effects of the elongation of a timing chain on the timing of the camshaft. This model may help in understanding what happens.

It should be made clear from the start that timing chains do NOT stretch, The factor of safety is too high. However, they wear on the bushings and rollers, and this causes elongation and thus a change in the pitch of the chain.

For the model, I used bicycle parts, two large wheels of 42 teeth and a smaller 21 tooth wheel for the jockey on the tensioner. Two chains were used; a brand new chain with a pitch of 0.5 inch (12.7mm) and an old worn chain. The percentage elongation between old and new chains is about 2.5% which is way above the max allowable on an actual engine of 1%, but because my model is not to scale, will show the effects more clearly.



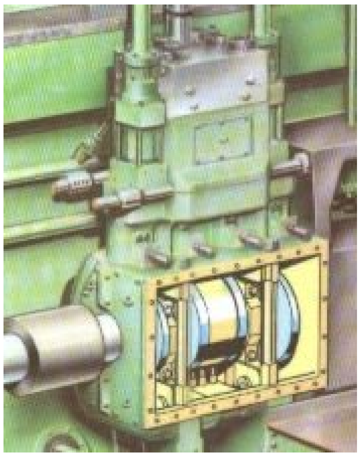
It will be noticed that a series of 29 links have been painted red and white on both chains. This is to highlight the difference in length and also to highlight why the camshaft timing alters as the chain gets longer. The 29 links spans the distance between the chain leaving the camshaft drive wheel and engaging with the crankshaft drive wheel. These points on the wheel teeth are also highlighted

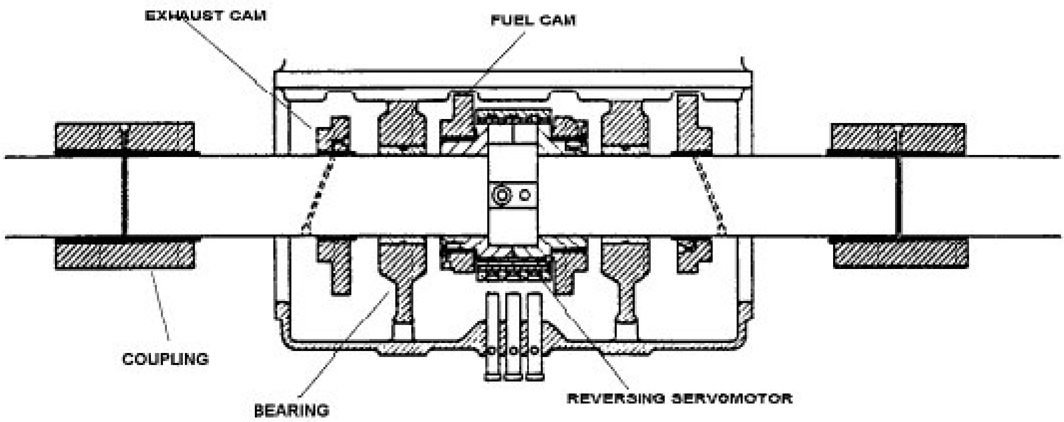
For our model the crankshaft and camshaft are turning clockwise when running in the ahead direction as indicated by the arrows. TDC of the crankshaft and camshaft for No 1 unit are indicated by the marks on the crankshaft and camshaft wheels. It can be seen that with the new chain the timing marks are correctly aligned.

As the chain gets longer so the pitch of the chain increases. BUT there is still the same number of links between the camshaft wheel and the crankshaft wheel. Because of this the camshaft chain wheel is effectively retarded when turning the crankshaft wheel in an ahead direction. This can be clearly seen from the timing marks. Because of this, chain elongation results in alteration of valve, fuel pump and air start distributor timing.

Gear drives should last the life of the engine; However, a gear train is heavier, and more expensive. If the gear wheels are misaligned, shock loading will result, which can lead to broken teeth.

The Camshaft is made in sections, each section spanning one or two cylinders. The individual cams are manufactured from steel which are heat treated to give them a very hard surface, but retaining a tough interior. The cams are expanded onto the camshaft in the correct position using either heat or hydraulic means. The couplings for joining the camshaft segments together are also expanded hydraulically, allowing for adjustment and to facilitate the replacement of a cam if necessary.





The camshaft runs in underslung white metal lined bearings, lubricated in most cases by the main engine LO system. Older B&W engines used a separate LO system for the camshaft because of the possibility of contamination by fuel oil leaking past the fuel pumps.

On engines with chain driven camshafts, as the chain elongates, the timing of the fuel pumps and exhaust valves is retarded. When this retardation reaches a certain point, the camshaft must be retimed. This is done by expanding the coupling between camshaft and drive using high pressure oil, and turning the camshaft to the correct position using a large spanner and chain block.

The Exhaust Valve

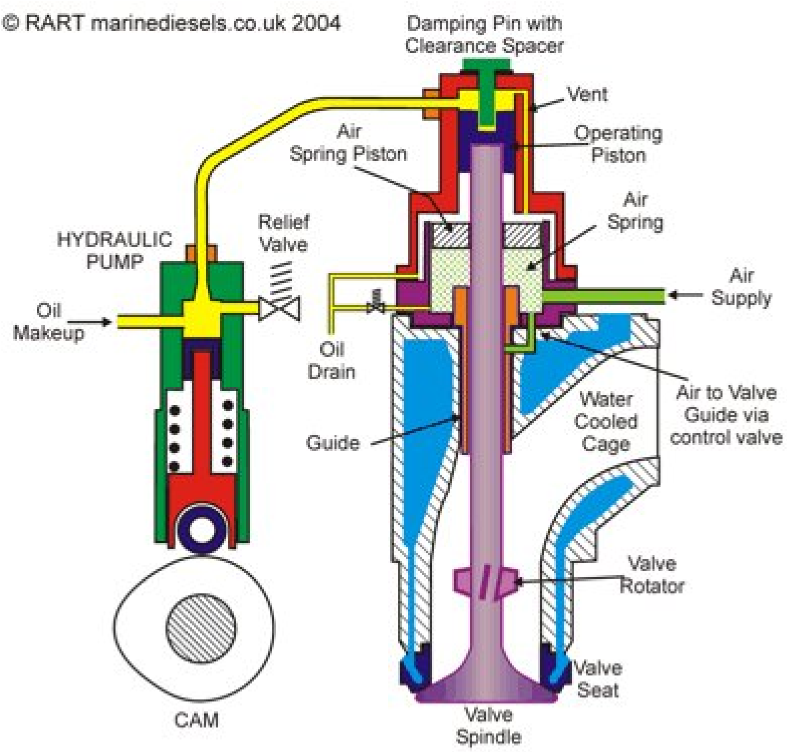
Exhaust valves open inwards into the cylinder, so that the gas pressure in the cylinder will ensure positive closing and help dislodge any build up of carbon on the valve seat.

Two stroke crosshead engines have a single exhaust valve mounted in the centre of the cylinder head. The opening and closing of the valve is controlled by a cam mounted on the camshaft. On older engines the cam follower lifts a push rod, which operates a rocker arm and opens the valve.

This has disadvantages: The push rod and rocker arm is heavy and the engine must overcome the inertia of these heavy parts. The motion of the rocker arm is an arc of a circle, which will tend to move the exhaust valve sideways, causing wear on the exhaust valve guide which locates the exhaust valve spindle. Exhaust gas can then leak up the spindle, causing overheating and accelerating wear. The springs which ensure the valve closes will weaken with use and are liable to break.

Modern two stroke crosshead engines have a hydraulically operated air sprung exhaust valve. The cam operates a hydraulic pump instead of a push rod. Oil (from the engine LO system) displaced by the pump operates a piston in the exhaust valve which pushes the valve open.

Instead of mechanical springs, the valve has an "air spring". Air at 7 bar is led via a non return valve to the underside of a piston attached to the valve spindle. As the valve opens, the air underneath the piston is compressed.



The expansion of this compressed air, when the hydraulic pressure is relieved assists in the closing of the valve. The air is supplied with a small amount of oil for lubrication purposes. Air is also led down the exhaust valve guide. This keeps the guide cool and lubricated, and prevents the exhaust gas leaking up the guide. Excess oil which collects at the bottom of the air spring cylinder is drained to a collecting tank.

To prevent the possibility of an air lock, the hydraulic system has a small leak off at the top of the exhaust valve hydraulic cylinder. Oil is made up via a non return valve. A relief valve is also fitted. A damping arrangement on top of the piston in the exhaust valve prevents hammering of the valve seating.

The valve spindle is fitted with a winged valve rotator. The kinetic energy in the exhaust gas rotates the valve a small amount as it passes. This keeps the valve at an even temperature and helps reduce the build up of deposits on the valve seat.

The cage of the exhaust valve is of cast iron as is the guide. The renewable valve seat is a hardened molybdenum steel and the valve spindle can be a molybdenum chrome alloy with a layer of stellite welded onto the seating face, or alternatively a heat resistant nimonic alloy valve head, friction welded to an alloy steel shaft.

When the valves are overhauled, the valves and seats are not lapped together. Instead special grinding equipment is used to grind the seat and spindle to the correct angles.

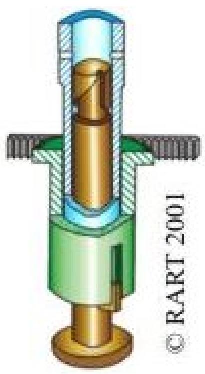
The Fuel Pump

Fuel has to be injected into the engine at a high pressure so that it atomizes correctly. Injection takes place over a short period of time and this period of time must be accurately controlled; late or early injection will lead to a lack of power and damage to the engine. Because the timing of injection is crucial, cams mounted on the camshaft, which is driven by the crankshaft are used to operate the fuel pumps, one of which is provided for each cylinder.

As the cam rotates it operates a spring loaded ram (the plunger) which moves up and down in a cylinder (the barrel). As the plunger moves up the barrel, the pressure of the fuel in the barrel above the plunger rises very quickly. The high pressure fuel then opens the fuel valve (injector) and is sprayed into the cylinder in tiny droplets known as atomization. It is important to note that the injection only takes place when the plunger is moving up the cam slope.

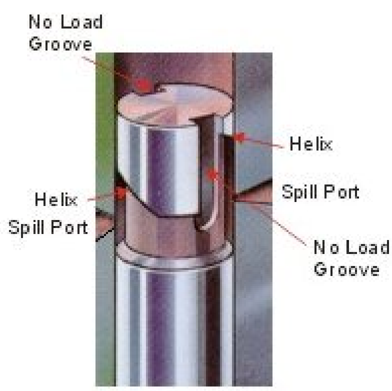
This is the principle behind the operation of the fuel pump. However, the pump illustrated opposite could not be used because it will always deliver the same amount of fuel. Once started, the engine would overspeed. A method which will infinitely vary the amount of fuel injected into the engine controlled by the governor must be utilised.

Two different methods are used. In the first, the plunger has a helix machined into it which also forms a vertical groove and an annular groove at the base of the helix. The plunger reciprocates in a barrel, located in the pump body which has spill ports, connected to the suction side of the pump, drilled so that they are above the top of the plunger when the cam is on the base circle. The plunger is keyed to a sleeve which has a gearwheel (pinion) machined into it. The pinion meshes with a rack which can rotate the plunger relative to the barrel. The rack is connected to the engine governor.



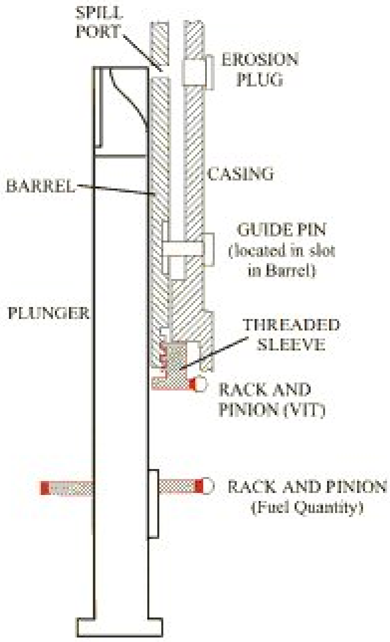
As the plunger moves upwards in the barrel, injection will commence once the plunger has closed off the spill ports and the pressure builds up. As soon as the helix or scroll passes the spill ports the pressure above the plunger will immediately drop, even though the plunger is still moving upwards. It should therefore be evident that the amount of fuel injected into the cylinder is dependent on the position of the helix relative to the spill port. When the vertical groove is lined up with the spill port, then no injection will take place and the engine will stop.

In the example shown the plunger has a single helix machined into it. More common are pumps with two helices (and thus two no load grooves) diametrically opposite each other. This gives a balanced plunger.



The plunger is machined to very fine tolerances, as is the matched barrel in which it reciprocates. Wear due to abrasive particles in the fuel will mean that the pump will take longer to build up the injection pressure required. Wear due to erosion also takes place on the top edge of the plunger and the edge of the helices and spill ports. This, together with the wear in the plunger and barrel, will lead to the injection timing becoming retarded, for which adjustment may have to be made.

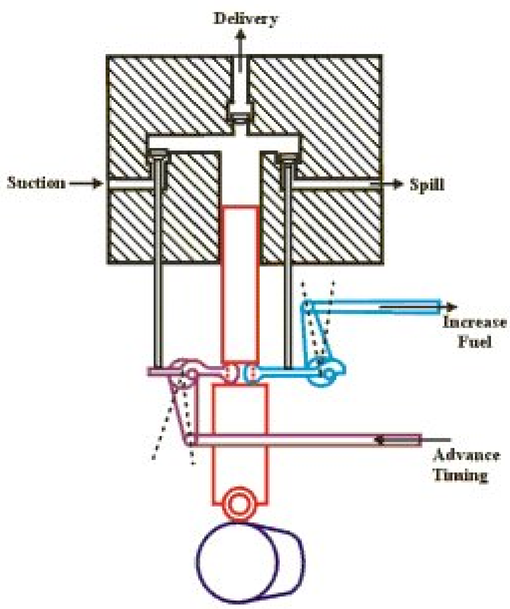
On the scroll or helical fuel pump previously described, although the end of injection can be varied, the start of injection (i.e. when the top of the plunger covers the spill ports) is fixed. Fuels of different qualities may require advancing or retarding the injection timing, in addition to which if the injection timing is advanced when the engine is running at loads below the maximum continuous rating, then a saving in fuel can be achieved.



This method of varying the injection timing (known as Variable Injection Timing) can be achieved by the method shown. The bottom of the barrel has a coarse screw thread cut into it. This is located in a threaded sleeve which is turned by a rack and pinion. The barrel is free to move up and down in the pump casing but cannot rotate. This means that as the threaded sleeve is rotated by the VIT rack the position of the spill ports relative to the barrel is changed, thus altering the start of injection.

The second method of controlling the quantity of fuel is by using suction and spill valves operated by push rods. The principle is illustrated opposite.

A plain plunger reciprocates in a barrel. As the plunger moves up and down, two pivoted levers operate push rods which open the suction and spill valves. When the cam follower is on the base circle of the cam, the suction valve is open and the spill valve is closed. As the plunger moves up the barrel, the suction push rod moves downwards and the suction valve closes. Injection then commences and fuel is delivered via a non return valve to the injectors. As the plunger continues upwards so the spill push rod will open the spill valve, the pressure above the plunger will fall and injection will cease.



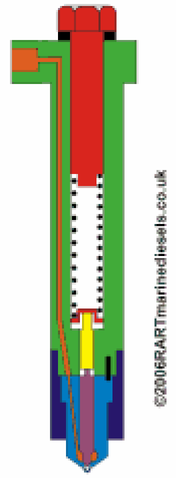
The quantity of fuel delivered can be controlled by altering the position of the eccentric pivot for the spill valve operating lever. This will cause the spill valve to open earlier or later.

By altering the position of the suction valve pivot, the start of injection can be similarly controlled, and therefore it can be seen that the pump utilises VIT.

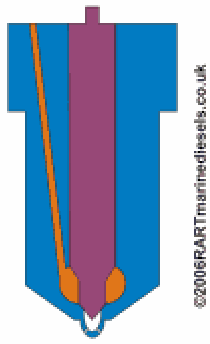
This pump will not suffer the erosion problems that affect the scroll type pump. However wear due to abrasive particles in the fuel will still affect performance. Regular maintenance will include overhaul of the valves and seats.

The Fuel Injector

The fuel is delivered by the fuel pumps to the fuel injectors or fuel valves. For the fuel to burn completely at the correct time it must be broken up into tiny droplets in a process known as atomisation. These tiny droplets should penetrate far enough into the combustion space so that they mix with the oxygen. The temperature of the droplets rise rapidly as they absorb the heat energy from the hot air in the cylinder, and they ignite and burn before they can hit the relatively cold surface of the liner and piston.



Fuel injectors achieve this by making use of a spring loaded needle valve. The fuel under pressure from the fuel pump is fed down the injector body to a chamber in the nozzle just above where the needle valve is held hard against its seat by a strong spring. As the fuel pump plunger rises in the barrel, pressure builds up in the chamber, acting on the underside of the needle as shown. When this force overcomes the downward force exerted by the spring, the needle valve starts to open. The fuel now acts on the seating area of the valve, and increases the lift.



As this happens fuel flows into the space under the needle and is forced through the small holes in the nozzle where it emerges as an "atomised spray".

At the end of delivery, the pressure drops sharply and the spring closes the needle valve smartly.

Older loop scavenged engines may have a single injector mounted centrally in the cylinder head. Because the exhaust valve is in the centre of the cylinder head on modern uniflow scavenged engines the fuel valves (2 or 3) are arranged around the periphery of the head.

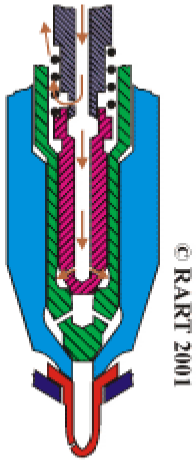
The pressure at which the injector operates can be adjusted by adjusting the loading on the spring. The pressure at which the injectors operate vary depending on the engine, but can be as high as 540bar.

Some injectors have internal cooling passages in them extending into the nozzle through which cooling water is circulated. This is to prevent overheating and burning of the nozzle tip.

Injectors on modern 2 stroke crosshead engines do not have internal water cooling passages. They are cooled by a combination of the intensive bore cooling in the cylinder head being close to the valve pockets and by the fuel which is recirculated through the injector when the follower is on the base of the cam or when the engine is stopped.

As well as cooling the injector, recirculating the fuel when the engine is stopped keeps the fuel at the correct viscosity for injection by preventing it from cooling down.

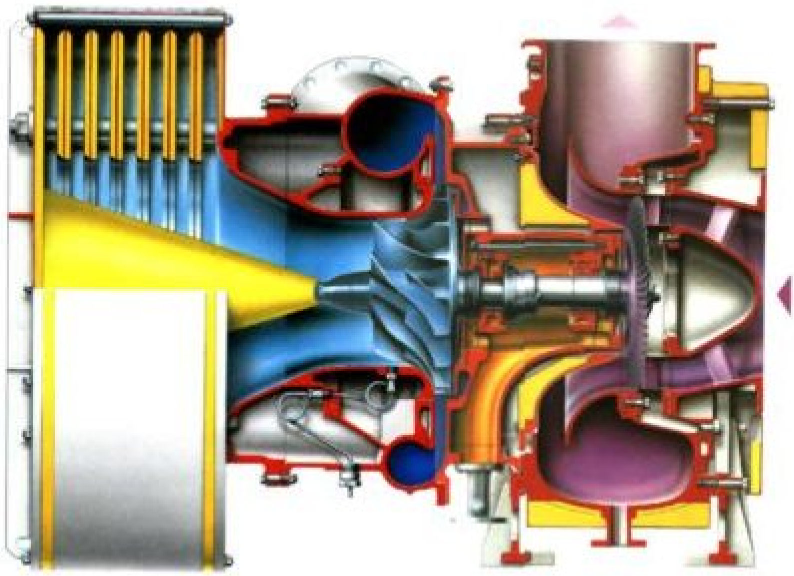
The picture opposite shows the principle on which one system operates.



Fuel injectors must be kept in good condition to maintain optimum efficiency, and to prevent conditions arising which could lead to damage within the cylinder. Injectors should be changed in line with manufacturers recommendations, overhauled and tested. Springs can weaken with repeated operation leading to the injector opening at a lower pressure than designed. The needle valve and seat can wear which together with worn nozzle holes will lead to incorrect atomisation and dribbling.

The Turbo Charger

A two stroke crosshead engine must be supplied with air above atmospheric pressure for it to work. Although the first turbochargers were developed for aero engines in the first world war, it was not until the 1950s that large two stroke engines were turbocharged.



Before then the pressurised air needed to "scavenge" the cylinders of the exhaust gases and supply the charge of air for the next combustion cycle was provided by mechanically driven compressors (Roots Blowers), or by using the space under the piston as a reciprocating compressor (Under Piston Scavenging). This of course meant that the engine was supplying the work to compress the air, which meant that the useful work obtained from the engine was decreased by this amount.

Engine powers have increased phenomenally in the past 20 years. In 1980 an engine delivering 15000kW was a powerful engine. Today's largest engines are capable of delivering over 4 times this amount. This is due not only to improved materials and manufacturing techniques, but also to the improvements and developments in the design of the turbochargers fitted to these engines.

The amount of useful energy that an engine can produce is dependant on two factors; The amount of fuel that can be burnt per cycle and the efficiency of the engine.

Fuel consists mainly of Carbon and Hydrogen. By burning the fuel in oxygen the energy in the fuel is released and converted into work and heat. The more fuel that can be burnt per cycle, the more energy released.

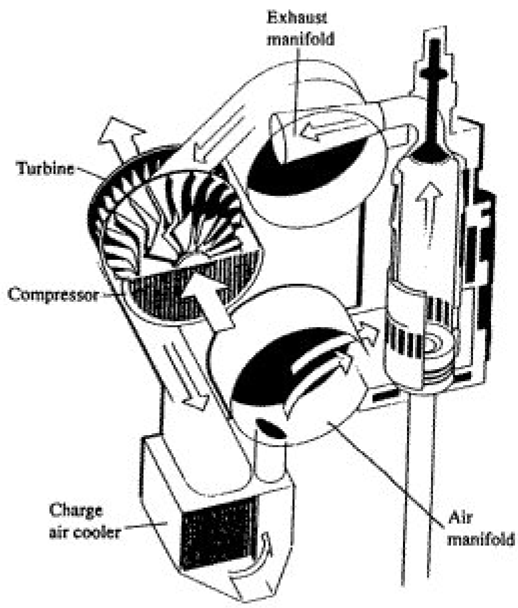
However, to burn more fuel, the amount of air supplied must also be increased. For example, a 10 cylinder engine with a bore of 850mm and a stroke of 2.35m must burn 1kg of fuel per revolution to deliver 38500kW when running at 105 RPM. (assuming 50% efficiency). This means that each cylinder burns 0.1 kg fuel per stroke. To ensure that the fuel is burnt completely it is supplied with 200% more air than theoretically required. Because it takes about 14kg of air to supply the theoretical oxygen to burn 1kg of fuel, 4.2kg of air must be supplied into each cylinder to burn the 0.1kg of fuel.

A lot of this air is used up scavenging (clearing out) exhaust gas from the cylinder. The air also helps cool down the liner and exhaust valve. As the piston moves up the cylinder on the compression stroke and the exhaust valve closes, the cylinder must contain more than the theoretical mass of air to to supply the oxygen to burn the fuel completely (about 100% or 2.8kg)

2.8kg of air at atmospheric pressure and 25ºC occupies a volume of 2.4m3. The volume of the cylinder of the engine in our example is about 0.74m3 after the exhaust valve closes and compression begins. Because the temperature of the air delivered into the engine is raised to about 50ºC, it can be calculated that to supply the oxygen required for combustion, the air must be supplied at 3.5 × atmospheric pressure or 2.5 bar gauge pressure.

NOTE: These figures are approximate and for illustration only. Manufacturers quote the specific fuel oil consumption of their engines in g/kWh. These figures are obtained from testbed readings under near perfect conditions. Quoted figures range between 165 and 175g /kWh. The actual specific fuel consumption obtained is going to depend on the efficiency of the engine and the calorific value of the fuel used.

About 35% of the total heat energy in the fuel is wasted to the exhaust gases. The Turbocharger uses some of this energy (about 7% of the total energy or 20% of the waste heat) to drive a single wheel turbine. The turbine is fixed to the same shaft as a rotary compressor wheel. Air is drawn in, compressed and, because compression raises the temperature of the air, it is cooled down to reduce its volume. It is then delivered to the engine cylinders via the air manifold or scavenge air receiver.



The speed of the turbocharger is variable depending on the engine load. At full power the turbocharger may be rotating at speeds of 10000RPM

Materials

Gas Casing: Cast Iron (may be water cooled)

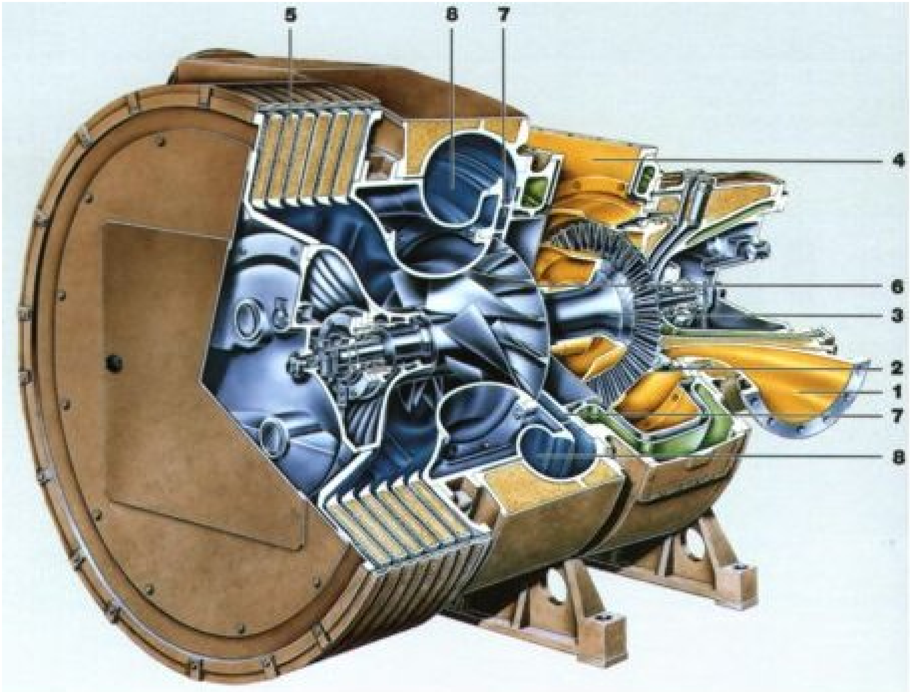
Nozzle ring and blades: Chromium nickel alloy or a nimonic alloy.

Compressor casing: Aluminium alloy

Compressor Wheel: Aluminium alloy, titanium or stainless steel

Starting the engine

Because the engine needs to be supplied with air when starting up and running at low speeds, an auxiliary blower powered by an electric motor is provided. This automatically cuts out when the charge air supplied by the turbocharger is sufficient to supply the engine on its own.

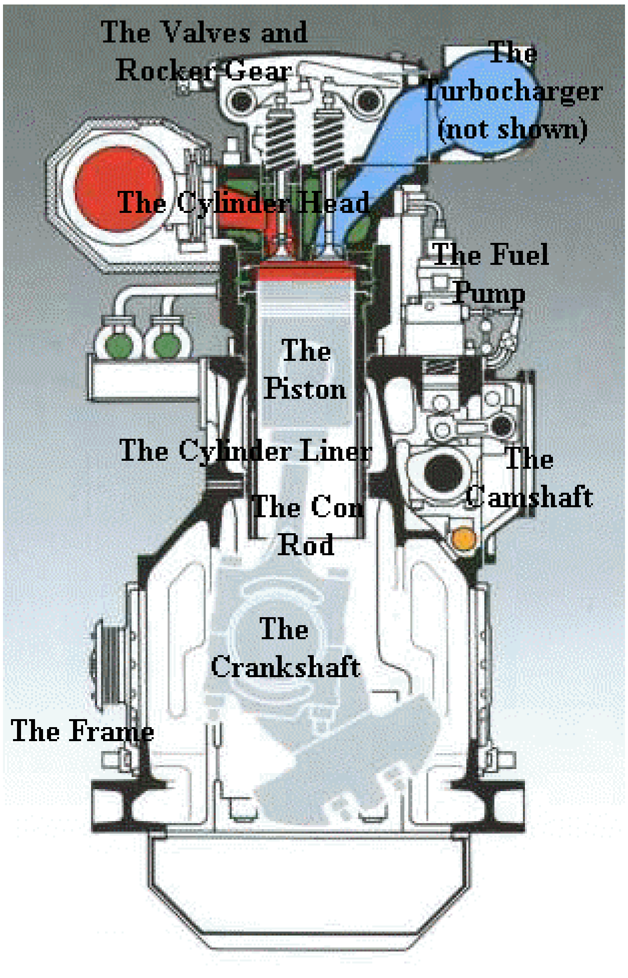


1. Gas Inlet Casing
2. Turbine Nozzles
3. Turbine Wheel
4. Gas Outlet Casing
5. Silencer Filter
6. Compressor
7. Diffuser
8. Volute Casing

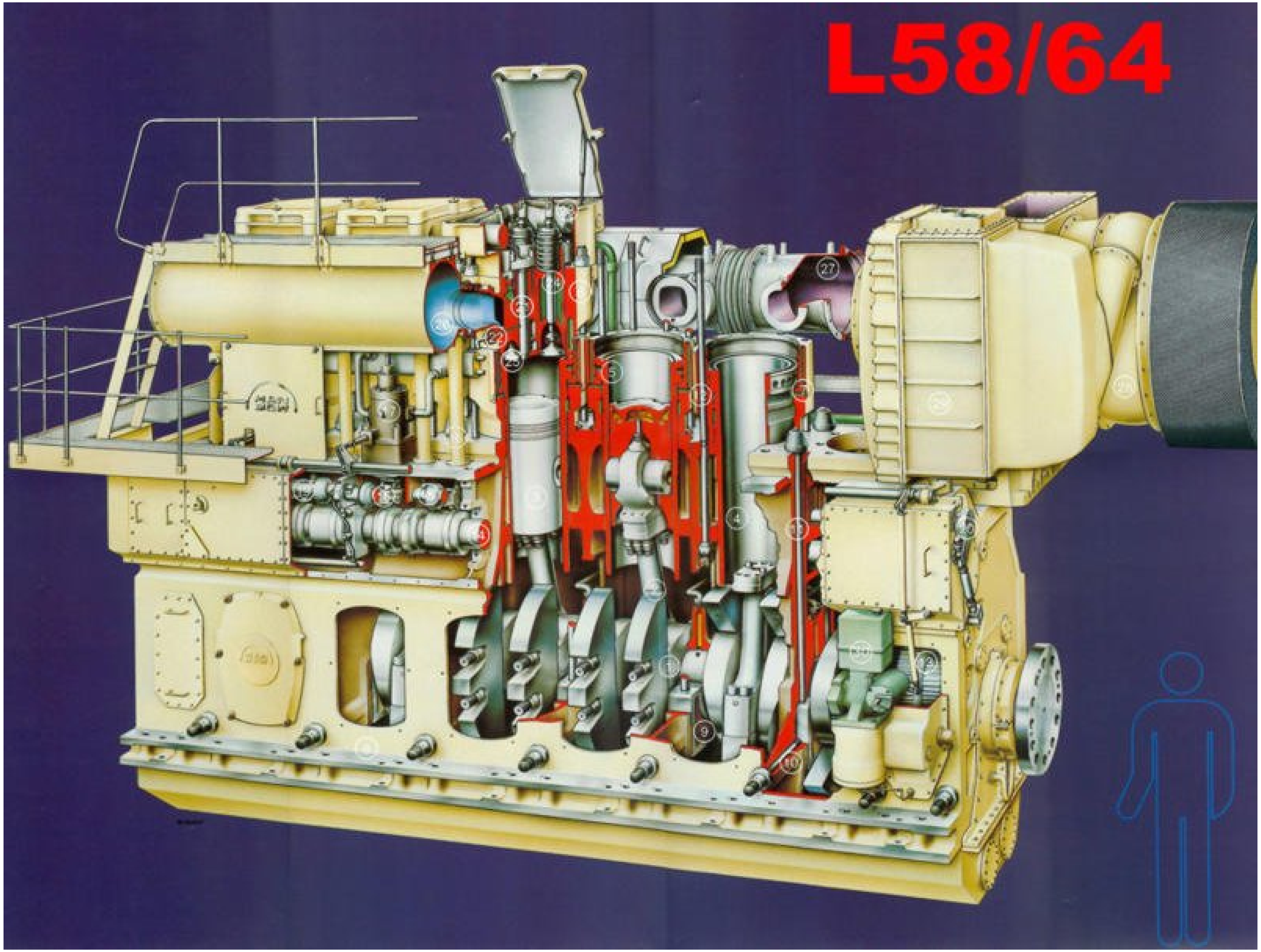
THE MEDIUM SPEED 4 - STROKE TRUNK PISTON ENGINE

The medium speed 4 stroke trunk piston engine can be found on most medium to large merchant vessels even if the main engine is either a steam turbine or a 2 stroke crosshead engine. In these cases it will often be found that the electrical power is supplied by alternators driven by medium speed 4 stroke engines.

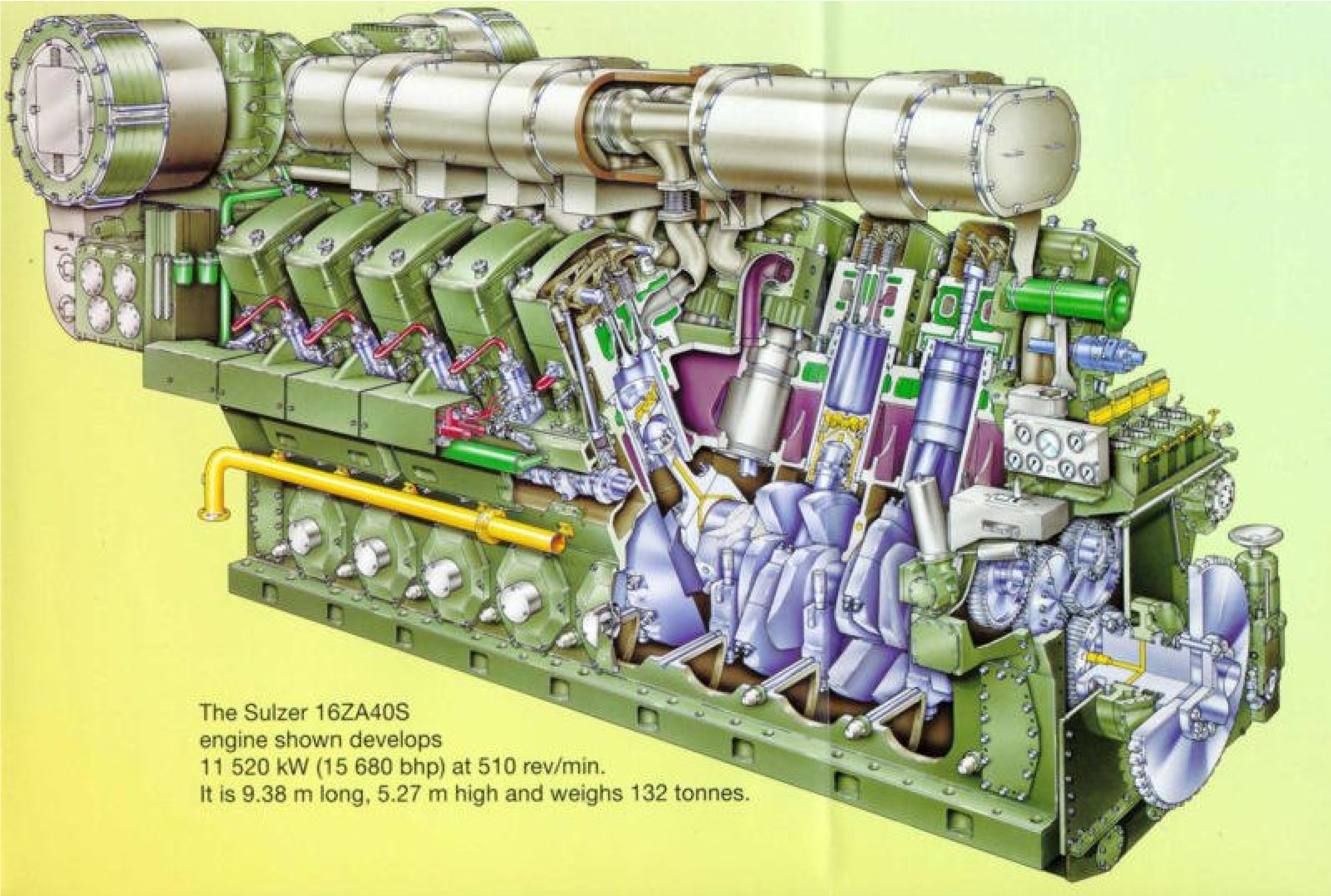
They are the favoured method of propulsion on ships where head room is a minimum, for instance, on ferries and passenger vessels, and where, as is the current trend for these ships, diesel electric propulsion is utilised. Diesel electric propulsion allows the engines to be placed wherever is most suitable, as they no longer have to be aligned with reduction gearing and shafting as is the case with conventional installations.



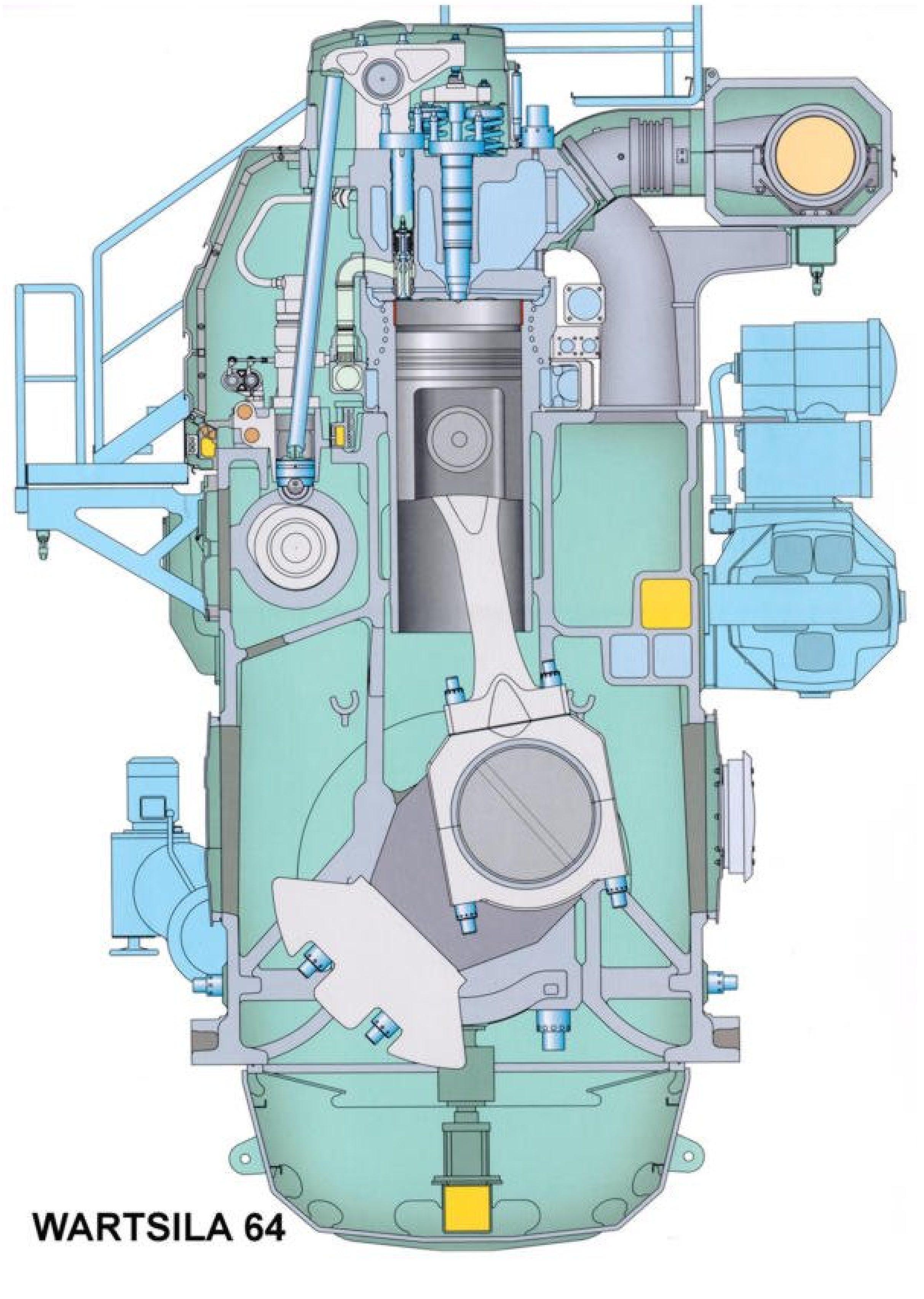
Generally, medium speed engines run at between 250 - 850 RPM. Above this range they are defined as high speed engines. Although not as powerful as their 2 stroke crosshead cousins, the largest 4 stroke engines are delivering just over 2000kW per cylinder. Advances in design and materials have led to an increase in efficiency, together with an increase in turbocharger pressure ratios which allow a greater quantity of fuel to be burnt per cycle. Medium speed engines have a higher power to weight ratio than the slow speed two strokes, but due to the higher speeds tend to have reduced maintenance intervals. The largest of these engines have a bore of 640mm and a stroke of 900mm (Wartsila 64), although engines which are nearly "square" are more the norm: For example, the Sulzer ZA40 has a bore of 400mm and a stroke of 560mm or the MAN-B&W 58/64 which has a bore of 580mm and a stroke of 640mm. A square engine is one where the bore is equal to the stroke.



The MAN B&W L58/64 engine Bore: 540mm Stroke: 640mm. Speed: 428rpm. Power output: 1390kW/cyl. Specific fuel consumption: 177g/kWh. Mass of 6 cyl engine: 151 tonnes, 9 cyl engine: 213 tonnes.



The Sulzer 16ZA40S
engine shown develops
11 520 kW (15 680 bhp) at 510 rev/min.
It is 9.38 m long, 5.27 m high and weighs 132 tonnes.



Bore: 640mm, Stroke: 900mm Speed: 330 RPM. Power output: 2010kW/cyl.
Specific fuel consumption: 169g/kWh. Mass of 6 cyl engine: 237 tonnes, 12 cyl engine: 437 tonnes.

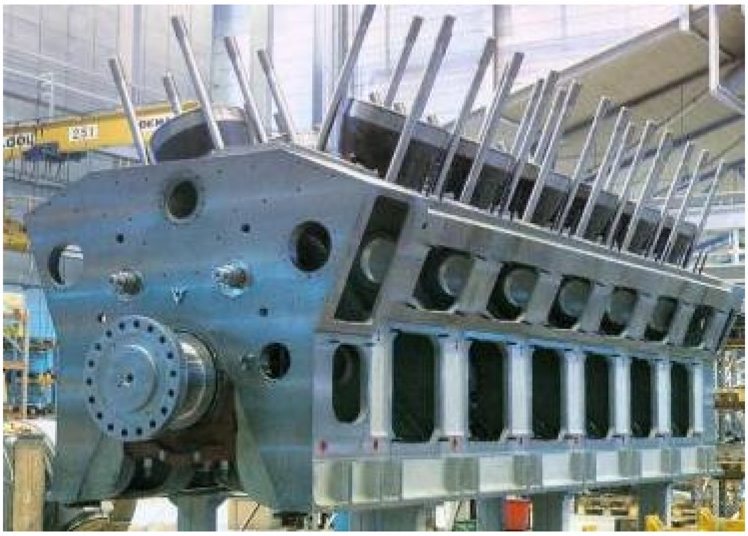
The name "Trunk Piston" refers to the piston skirt or trunk. The purpose of the skirt or trunk in four-stroke cycle engines is to act in a similar manner to a crosshead. It takes the thrust caused by connecting-rod angularity and transmits it to the side of the cylinder liner, in the same way as the crosshead slipper transmits the thrust to the crosshead guide. With such engines, which are termed trunk-piston engines, the engine height is considerably reduced compared with that of a crosshead engine of similar power and speed. The engine-manufacturing costs are also reduced. It means of course that there is no separation between the crankcase and the liner and piston. This has its disadvantages, especially when considering the choice of lubricating oils when burning high sulphur residual fuels.

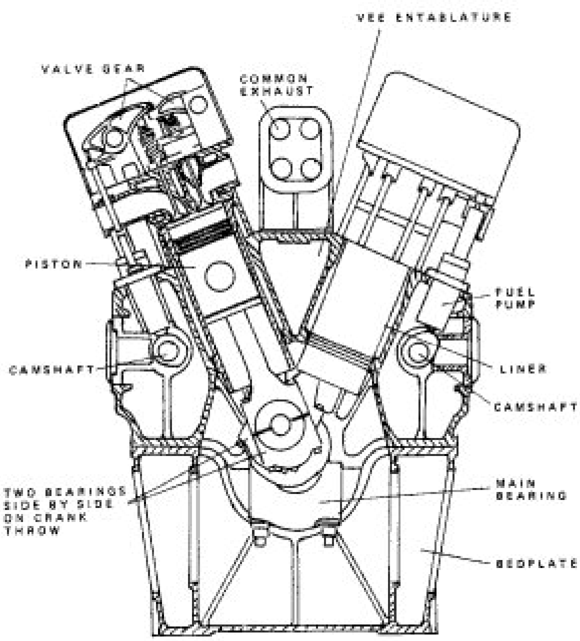
The Engine Frame

The engine frame of a modern 4 stroke medium speed diesel can be produced as a single casting or fabricated from cast steel sections and steel plates welded together.

With this design, there is no separate bedplate, frame and entablature as with a 2 stroke slow speed engine.

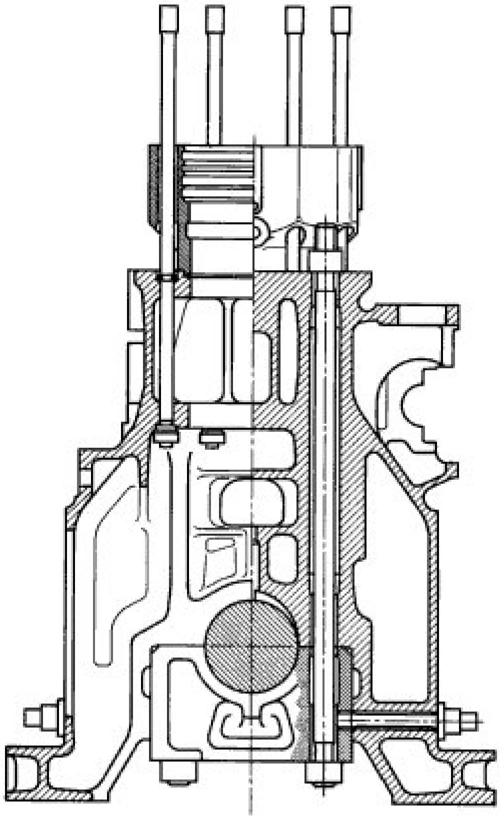
The photograph shows the frame of an engine with the liners and crankshaft in place.





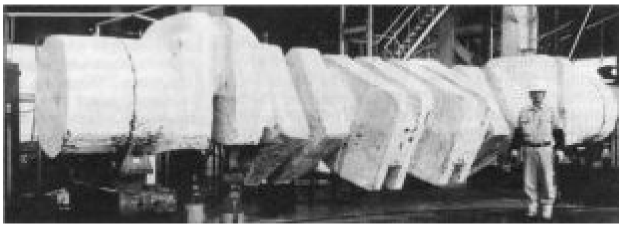
An alternative method of construction is shown opposite. A separate bedplate is bolted to an entablature which holds the underslung crankshaft.

Shown here is a partial cross section from a one piece medium speed engine frame. The Crankshaft is underslung, and it can be seen in this example that the load on the bearing caps is transferred back to the frame by the use of tie bolts. Note the use of the side tie bolts which locate the bearing cap, and prevent sideways movement.



The Crankshaft

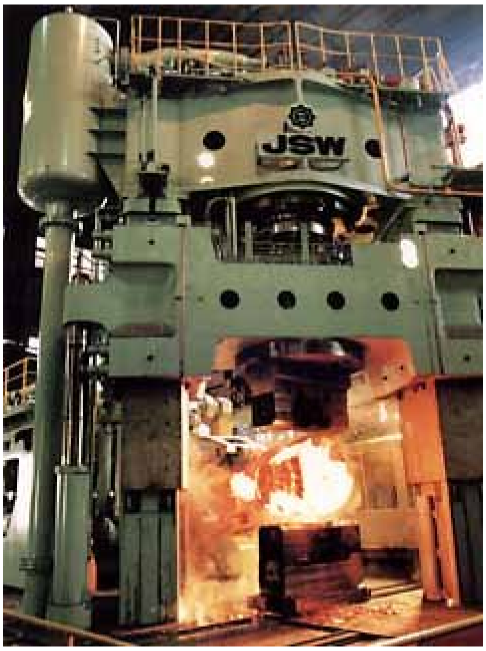
The Crankshaft for a medium speed 4 stroke diesel engine is made from a one piece forging.



First the billet of 0.4% carbon steel is heated in a furnace It is then moved to the forging presses.

Heating Furnace

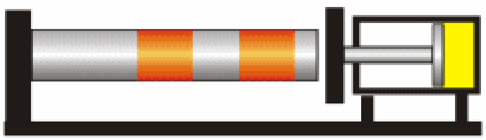
4,000 Ton
Forging Press



In the hydraulic forging press the crankshaft throws and flanges are formed.

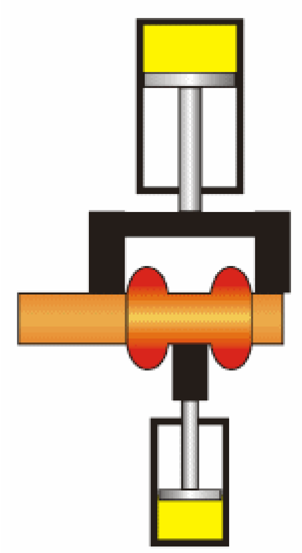
A Guide to how the Crankshaft Throws are Forged

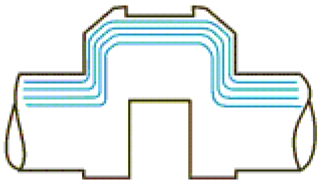
The crankshaft is locally heated to a white heat where the webs are desired to be formed. The crankshaft is then compressed axially to form the start of the webs



Sets of hydraulic presses are then used to form the crankpin journal and webs.

This method of forging gives the crankshaft continuous grain flow. This is where the grain structure follows a path parallel to and along the journal, bends round along the line of the web, round through the crankpin, and back down the second web before turning again to follow the journal. Continuous grain flow gives the crankshaft better fatigue resistance.





The forgings are then machined, stress relieved, and the radii at the change of section cold rolled.

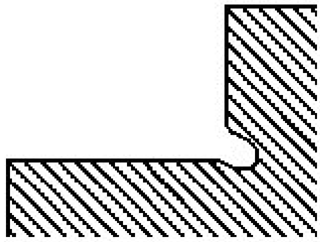
If the crankshafts are to be surface hardened they are made of a steel alloy known as nitralloy (a steel containing 1.5%Cr, 1% Al and 0.2% Mo)

The crankshaft is heated to 500ºC in ammonia gas for up to 4 days. The nitrogen dissociates from the ammonia gas and combines with the chromium and aluminium to form hard nitrates at the surface. The molybdenum refines the grain structure at the still tough core.

Fillet Radii

At the change of section between journal and web and web and crankpin, fillet radii are machined so there is not a sharp corner to act as a stress raiser. These radii are cold rolled to remove machining marks, harden the surface and to induce a residual compressive stress, again to increase fatigue resistance.

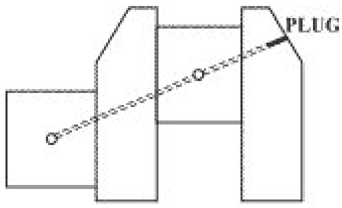
Re-entrant fillets are sometimes employed; This allows for a shorter crankshaft without compromising on bearing length.



Re-entrant fillet

Oil Holes in Crankshafts.

Unlike the crankshafts for slow speed 2 stroke crosshead engines, which lubricate the bottom ends by sending the oil DOWN the con rod from the crosshead, the crankshaft for the medium speed trunk piston engine must have holes drilled in it so that oil can travel from the main bearing journals to the crankpin and then UP the con rod to lubricate the piston pin and cool the piston. If the surface finish of the holes is not good, then cracks can start from the flaws.



At the exit points on the crankpin, the holes must be smoothly radiused. So that the crankshaft strength is not compromised the holes should be positioned horizontally when the crank is at TDC.

The Connecting Rod

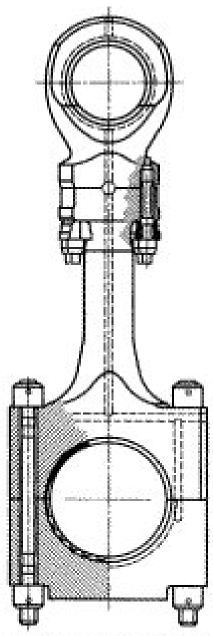
The connecting rod in a medium speed 4 stroke engine is subject to an inertia whip loading due to the mass of the con rod swinging about the piston pin. (Because of the lower speed of a 2 stroke engine, the whip loading is not large enough to influence the design of the con rod) Added to this, the inertia loads due to the mass of the reciprocating parts cause a stress reversal from high compressive stress (during power and compression stroke) to a low tensile stress between the exhaust and inlet strokes.

This loading of the rod influences its design, and to withstand the loading described above, connecting rods are often forged from a manganese molybdenum steel in an I or H section which reduces its mass from one made of round section steel (and thus reduces the whip loading) while maintaining strength. This is not always the case, as can be seen from the pictures shown, and often a round section rod is of sufficient strength.

Because of the large diameter of the crankpin to increase bearing area and decrease bearing load, the width of the bottom end of the con rod is greater than the diameter of the cylinder liner.

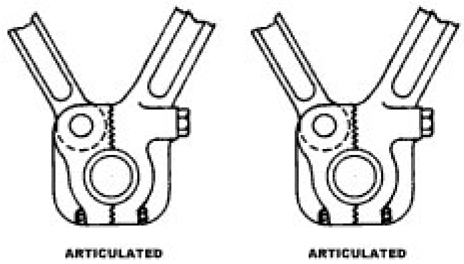
So that the piston can be withdrawn from the liner, 3 different designs are used:

- The con rod can be fitted with a marine palm as in the photo above.
- The con rod can be split in two parts as shown opposite.
- The bottom end can be split obliquely. Serrations are used to locate the two halves relative to one another.



MAN - B&W L58/64 CON ROD

The advantage of using a vee engine is that the overall length of the engine is reduced for a given power output.



If a normal bottom end arrangement is used then the con rods must be placed side by side which means the opposite cylinders are offset. The crankpins must be long enough to accommodate two bottom ends side by side, and of large enough diameter to resist bending. The increased length of the crankshaft means a longer engine.

Two alternative arrangements are pictured (right). Both allow the cylinders to be opposite one another. However, both arrangements restrict access to the crankcase, and because the design of the bottom ends are different, more spares have to be carried.

Bottom End Bolts

Because of the stress reversal mentioned above, bottom end bolts have a limited life. This varies from engine to engine, but is generally around 12-15000 hours. If a bottom end bolt was to fail in operation, then the results would be disastrous.

Bottom end bolts should be treated with care when removed from the engine during overhauls. They should be inspected for any damage to the surface from which a crack could start. This damage could be due to corrosion (water in LO) or because of incorrect handling.

The Cylinder Liner

The cylinder liner is cast separately from the main cylinder frame for the same reasons as given for the 2 stroke engine which are:

- The liner can be manufactured using a superior material to the cylinder block. While the cylinder block is made from a grey cast iron, the liner is manufactured from a nodular cast iron alloyed with chromium, vanadium and molybdenum. (cast iron contains graphite, a lubricant. The alloying elements help resist corrosion and improve the wear resistance at high temperatures.)

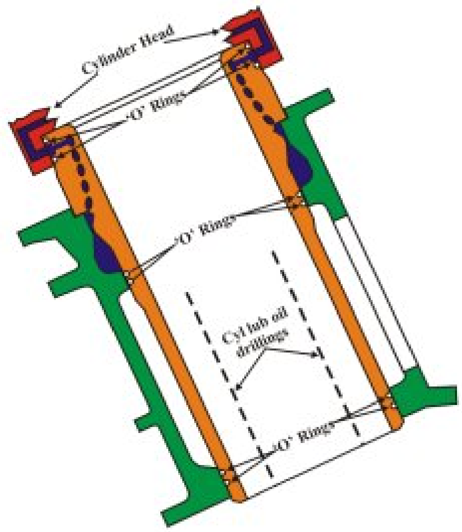
- The cylinder liner will wear with use, and therefore may have to be replaced. The cylinder jacket lasts the life of the engine.

- At working temperature, the liner is a lot hotter than the jacket. The liner will expand more and is free to expand diametrically and lengthwise. If they were cast as one piece, then unacceptable thermal stresses would be set up, causing fracture of the material.

- Less risk of defects. The more complex the casting, the more difficult to produce a homogenous casting with low residual stresses.

Modern liners employ bore cooling at the top of the liner where the pressure stress is high and therefore the liner wall thickness has to be increased. This brings the cooling water close to the liner surface to keep the liner wall temperature within acceptable limits so that there is not a breakdown in lubrication or excessive thermal stressing. Although the liner is splash lubricated from the revolving crankshaft, cylinder lubricators may be provided on the larger engines.

On the example shown opposite, the lubricator drillings are bored from the bottom of the liner circumferentially around the liner wall. Another set of holes are drilled to meet up with these vertically bored holes at the point where the oil is required at the liner surface.



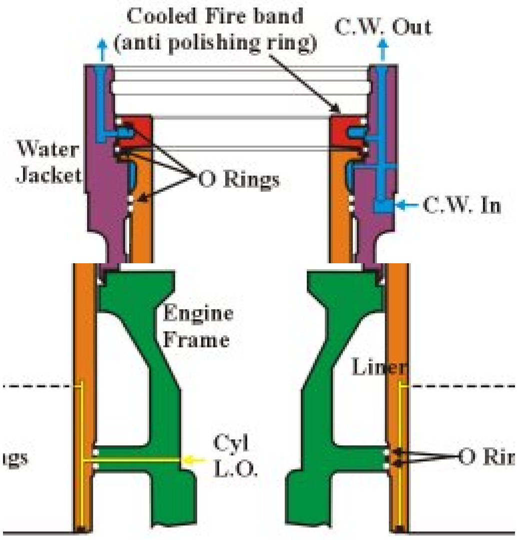
Sulzer ZA40 Liner (vee engine; The straight engine is similar)

Other engines may utilise axial drillings as in a two stroke engine.

Where the cooling water space is formed between the engine frame and the jacket, there is a danger that water could leak down and contaminate the crankcase if the sealing O rings were to fail. As a warning, "tell tale" holes are led from between the O rings to the outside of the engine.

Modern engines tend not to use this space for cooling water. Instead a separate water jacket is mounted above the cylinder frame. This stops any risk of leakage of water from the cooling space into the crankcase (or oil into the cooling water space), and provides the cooling at the hottest part of the cylinder liner.

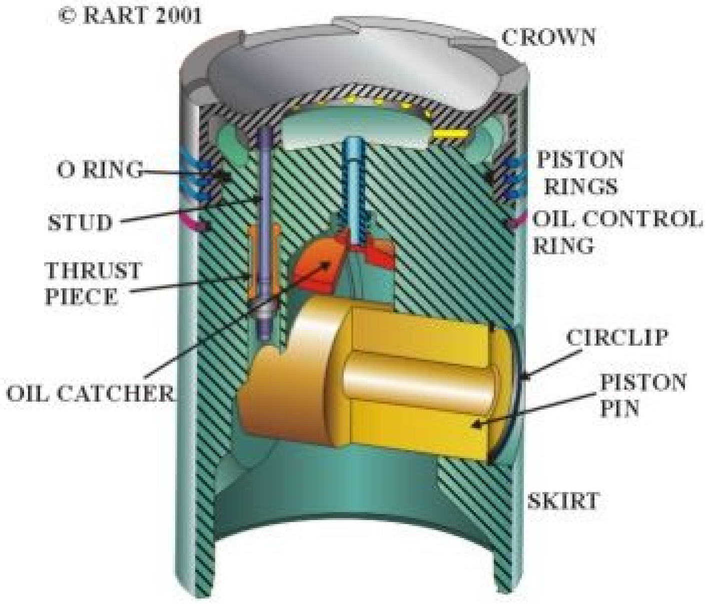
Note that the liner opposite is fitted with a fireband. This is sometimes known as an antipolishing ring. It is slightly smaller in diameter than the liner, and its purpose is to remove the carbon which builds up on the piston above the top ring. If this carbon is allowed to build up it will eventually rub against the liner wall, polishing it and destroying its oil retention properties.



The liner must be gauged regularly to establish the wear rate and check that it is within manufacturers tolerances. The wear rate for a medium speed liner should be below 0.015mm/1000hrs. Excessive wear is caused by lack of lubrication, impurities in fuel air or Lubricating oil, bad combustion and acid attack.

The Piston

Pistons for medium speed trunk piston engines which burn residual fuel are composite pistons; i.e the crown and the skirt are made of different materials.



MAN B&W L58/64 PISTON

The crown is a heat resisting steel forging which may be alloyed with chromium, molybdenum and nickel to maintain strength at high temperatures and resist corrosion. It is dished to form a combustion chamber with cutouts to allow for the valves opening. The topland (the space between the top ring and the top of the piston) may be tapered to allow for expansion being greater where the piston is hottest.

The skirt can either be a nodular cast iron or forged or cast silicon aluminium alloy. Aluminium has the advantage of being light, with low inertia, reducing bearing loading. However because aluminium has a higher coefficient of expansion than steel, increased clearances must be allowed for during manufacture. This means that the piston skirt clearance in the liner is greater than that for cast iron when running at low loads. The skirt transmits the side thrust, caused by the varying angularity of the con rod, to the liner. Too big a clearance will cause the piston to tilt.

The piston pin for the con rod small end bearing is located in the piston skirt. The piston pin floats in the piston skirt and is located in place by circlips. Depending on the material used for the skirt (esp. cast aluminium), a bushing may be used for the pin.

The piston rings may be located in the crown or in both crown and skirt. Normally, the rings are chrome plated or plasma coated to resist wear. Because the liner is splash lubricated, an oil scraper (oil control) ring is fitted to the piston skirt.

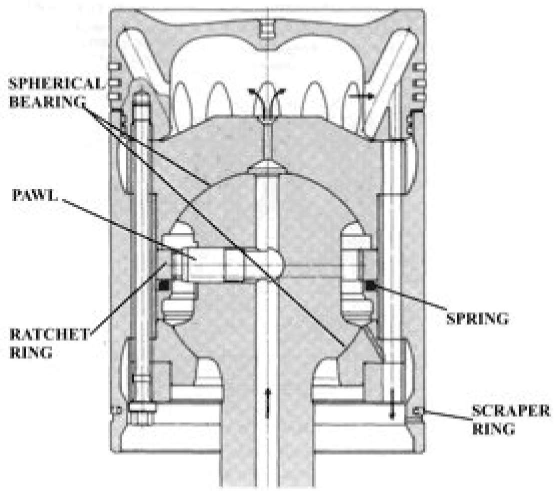
The piston is oil cooled. This is achieved by various means; The simplest is for a jet of oil to be directed upwards from a hole in the top of the con rod onto the underside of the crown. A more efficient method is to use an oil catcher as shown in the picture above. This directs oil into the cooling spaces on the underside of the crown where the cocktail shaker effect of the reciprocating piston ensures a positive cooling effect. It is unusual for the oil return temperature to be monitored (unlike the 2 stroke slow speed crosshead engine, where both temperature and quantity are monitored).

Some engines are fitted with one piece pistons manufactured from either cast iron or silicon alloy aluminium . These cannot be used with residual fuel, because the higher temperatures causes burning of the piston crown. Aluminium also suffers from carbon build up above 300º C. Ring grooves in aluminium pistons usually take the form of a chrome plated cast iron insert.

The Rotating Piston

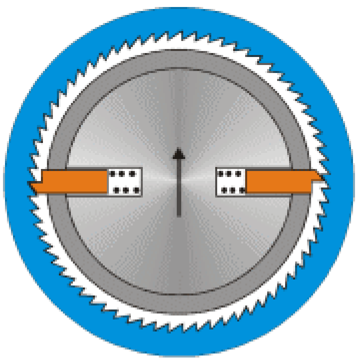
The Rotating piston is used on the Sulzer ZA40 engine. Instead of a conventional piston pin and bearing, the top end consists of a two part spherical bearing. Inside the spherical top end of the con rod are two spring loaded pawls. These pawls engage with a ratchet ring which is connected to the piston. The ratchet ring has an uneven number of teeth.

As the con rod swings, the pawls engage alternately with the ratchet ring, rotating the piston.



The advantages of this system are:

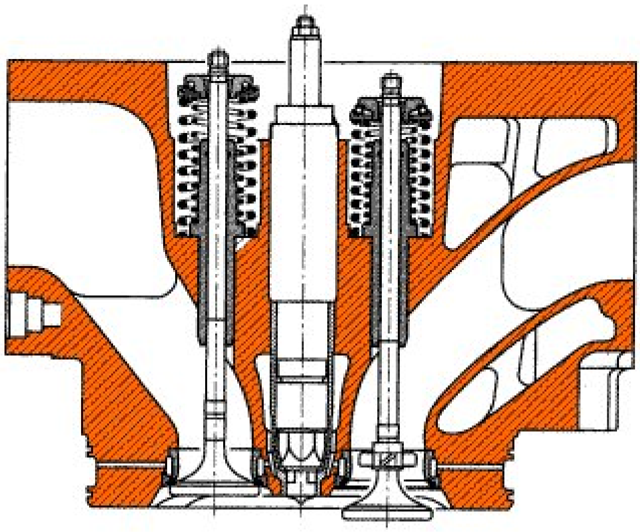
- At each stroke a different part of the freshly oiled skirt is in contact with the part of the liner wall absorbing the side thrust. This reduces wear and the risk of seizure.
- The rings rotate, so the ring gap is not always in the same position; this reduces local overheating due to blowby.
- Because the loading on the spherical bearing is symmetrical, and because the piston is symmetrical (no hole for piston pin), the piston can be made with smaller clearances which reduces piston rocking.



The operating principle of the ratchet is shown above. The arrow indicates the direction of the con rod swing.

The Cylinder Head

Cylinder heads for 4 stroke engines are of a complex design. They have to house the inlet and exhaust valves, the fuel injector, the air start valve, relief valve and indicator cock. The passages for the inlet air and exhaust gas are incorporated, as are the cooling water passages and spaces.

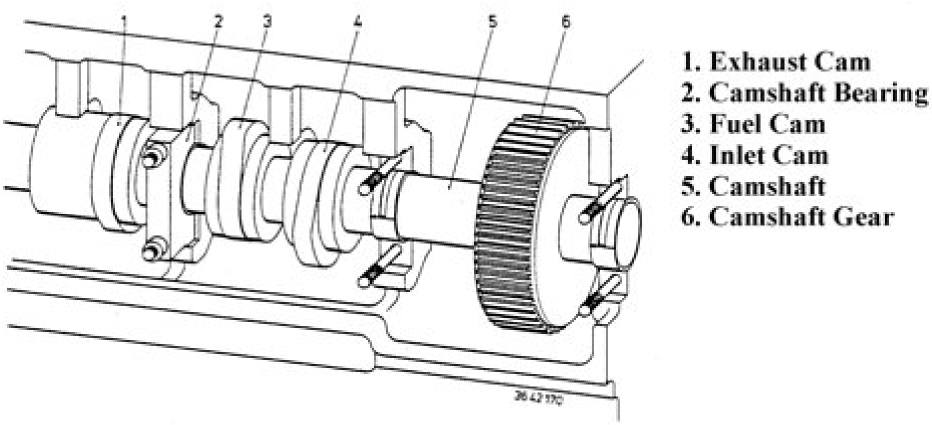


Normally manufactured from spheroidal graphite or nodular cast iron which is easy to cast. Although not as strong as cast steel, which is difficult to cast into complex shapes due to its poor fluidity, it maintains a reasonable strength under load. Adequate cooling is essential to prevent thermal fatigue due to uneven expansion throughout the casting, and bore cooling has been introduced along with cooling spaces to ensure effective cooling of the "flame plate" (the underside of the cylinder head which forms the top of the combustion chamber).

Cracking of cylinder heads can occur due to poor cooling causing thermal fatigue. Poor cooling can be the result of scale build up within the cooling spaces due to inadequate water treatment. Overloading of the unit causing high peak pressures is also a cause as is incorrect tightening down of the cylinder head. Cracking normally occurs between the valve pockets and/or cooling water spaces. Cracked cylinder heads can be repaired by specialised welding; but this must be done under the guidance and with authorisation from the classification societies.

The Camshaft

There are several different methods of manufacturing camshafts for medium speed 4 stroke marine diesel engines. On the smaller engines, the camshaft may be a single forging complete with cams.



Alternatively the camshaft can be built up in single cylinder elements, each element made up of the fuel, inlet, and exhaust cam on a section of the camshaft with a flange on each end. So that the element can be used on any unit in the engine, the number of holes for fitted bolts in the flanges must be sufficient to allow the cam to be timed for any unit on the engine. For example, on a six cylinder engine, the flanges must have 6 equi spaced holes or a multiple thereof. The cams must be hard enough to resist the wear and abrasion due to impurities in the lub. oil, yet they must be tough enough to resist shattering due to shock loading. The cams are therefore surface hardened using the nitriding process.

On the larger engines it is usual to manufacture the camshaft and cams separately. The nitrided alloy steel cams are then shrunk on to the steel shaft using heat or hydraulic means. Because the cams are fitted progressively onto the shaft, if the bores in the cams were all the same diameter, it would be very difficult, if not impossible, to fit the first cams all the way along the length of the shaft to the correct position. To overcome this problem the camshaft is stepped, with the largest diameters at the end which has the cams fitted first. The larger bored cams fit easily over the small diameter steps till they reach the correct position on the camshaft.

Keys are not generally used to locate the cams as they would act as stress raisers.

Most medium speed engines are unidirectional (i.e they only rotate one way). This is because they either are driving an alternator, or because if they are used as direct main propulsion they tend to be driving a controllable pitch propeller. In the case where the engine is reversing, then the camshaft has two sets of cams, one for ahead operation, and one for astern.

To reverse the direction of the engine, pressure oil is led to one side of a hydraulic piston which is coupled to the camshaft. The whole camshaft is moved axially and the cam followers slide up or down ramps which connect the ahead and astern cams.

The camshaft is either chain or gear driven from the crankshaft. Because the engine is a four stroke, the camshaft will rotate at half the speed of the crankshaft. (the valves and fuel pump will only operate once for every two revolutions of the crankshaft).

In a case where the cams are shrunk on the camshaft, if a cam becomes damaged and has to be replaced, then it can be cut off using a cutter grinder. Care must be exercised not to damage the camshaft or adjacent cams during the operation. The replacement cam is fitted in two halves which is then bolted on the camshaft in the correct position and the timing rechecked.

This is a damaged fuel cam from a ZA40 engine which has been cut off using a grinding wheel. Note the grooves which are used to distribute the hydraulic oil when expanding the cam on the camshaft.

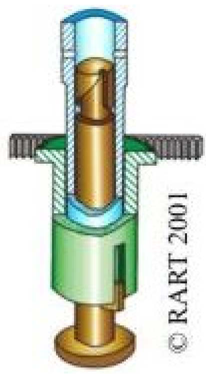
Fuel Cam for unidirectional medium speed engine.
The cam has fast lift for injection and a slow return to avoid shock loading

Inlet or exhaust valve cam for unidirectional medium speed engine. The cam has to open and close the valve smartly without shock loading

The Fuel Pump

Medium speed four stroke engines are equipped with jerk type fuel pumps, one for each cylinder. A plunger operated by a cam reciprocates in a barrel.

The plunger has a helix machined into it which also forms a vertical groove and an annular groove at the base of the helix. The barrel is located in the pump body which has spill ports, connected to the suction side of the pump, drilled so that they are above the top of the plunger when the cam is on the base circle. The plunger is keyed to a sleeve which has a gearwheel (pinion) machined into it. The pinion meshes with a rack which can rotate the plunger relative to the barrel. The rack is connected to the engine governor.



As the plunger moves upwards in the barrel, injection will commence once the plunger has closed off the spill ports and the pressure builds up. As soon as the helix or scroll passes the spill ports the pressure above the plunger will immediately drop, even though the plunger is still moving upwards. It should therefore be evident that the amount of fuel injected into the cylinder is dependent on the position of the helix relative to the spill port. When the vertical groove is lined up with the spill port, then no injection will take place and the engine will stop.

In the example shown above the plunger has a single helix machined into it. More common are pumps with two helices (and thus two no load grooves) diametrically opposite each other. This gives a balanced plunger. (shown left)

The plunger is machined to very fine tolerances, as is the matched barrel in which it reciprocates. Wear due to abrasive particles in the fuel will mean that the pump will take longer to build up the injection pressure required. Wear due to erosion also takes place on the top edge of the plunger and the edge of the helices and spill ports. This, together with the wear in the plunger and barrel, will lead to the injection timing becoming retarded, for which adjustment may have to be made.

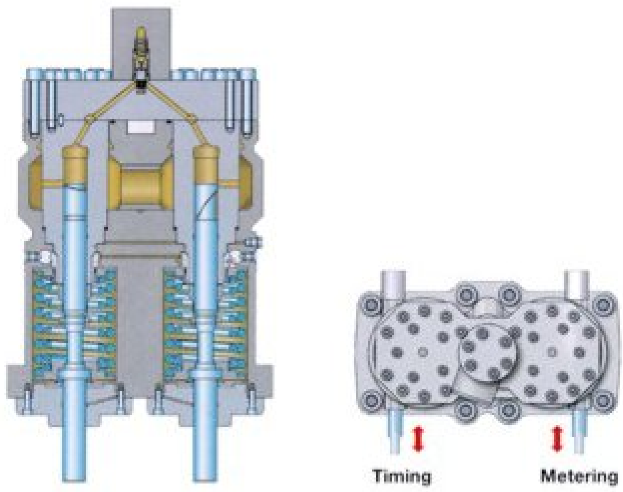
Plunger and barrel from a Sulzer ZA40

On the scroll or helical fuel pump, although the end of injection can be varied, the start of injection (i.e. when the top of the plunger covers the spill ports) is fixed. Fuels of different qualities may require advancing or retarding the start of injection, in addition to which if the injection timing is advanced when the engine is running at loads below the maximum continuous rating, then a saving in fuel can be achieved.

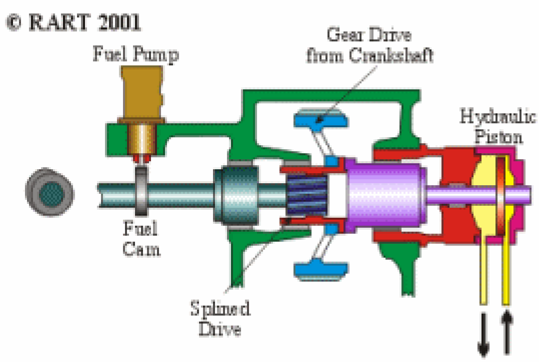
Different engine manufacturers achieve this Variable Injection Timing (VIT) using different methods.

The Wartsila 64 engine uses a fuel pump with two plungers and two barrels with common suction and discharge. The plunger for controlling the start of injection (timing) has a helix in the top of the plunger, while the plunger for controlling the end of injection (metering) is a conventional scroll type fuel pump plunger.

Both plungers are operated by the same cam. As they move upwards in their respective barrels injection will not start until the helix on the timing plunger has covered the spill port. This point is controlled by rotating the plunger in the barrel by means of a rack and pinion.



End of injection is controlled in the normal way, when the helix on the metering plunger uncovers the spill ports.



The MAN B&W 32/40 engine has a separate camshaft for the fuel pumps that can be advanced or retarded as the engine is running. The final drive gear on the timing gear train has an internal helically toothed sleeve bolted to it. The gear wheel and sleeve can be moved axially by means of a hydraulic piston. The toothed sleeve meshes with a matched helical gear fixed to the camshaft.

The camshaft is fixed so that it cannot move axially. Therefore as the sleeve moves up and down controlled by the hydraulic piston, so the fuel pump timing is advanced or retarded.

The camshaft for the inlet and exhaust valves utilises two different profiles for economy and full power operation. The camshaft can move axially from one set of cams to the other whilst the engine is running similar to the method used for reversing the engine direction as shown on the camshaft page.

The Rocker Gear and Valves

The 4 stroke marine diesels used for main or auxiliary power on board ship will have multiple inlet and exhaust valves fitted to the cylinder heads. On the medium speed engines this normally takes the form of two inlet and two exhaust valves per unit. The reasons for this are as follows:

- The area of the valve openings must be large enough to provide for an efficient gas exchange process. If the area is too small then not enough air will be pushed/drawn into the cylinder during the induction stroke, and on the exhaust stroke the engine will be doing work pushing the exhaust gas out of the cylinder.

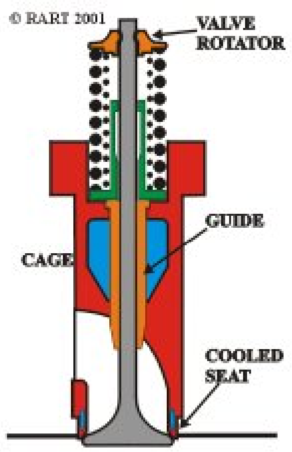
- The cylinder head must accommodate inlet and exhaust valves, so unlike a two stroke engine, one large central exhaust valve is not possible.

- If the valves are too large, then the strength of the cylinder head will be compromised.

- Keeping the exhaust valve temperature within acceptable limits is of paramount importance. It is easier to cool a smaller valve.

- The moving parts and springs are of smaller proportions reducing the inertia of the parts and the power demand on the engine.

- A symmetrically designed strong cylinder head is achieved.



Exhaust valves are subject to arduous conditions, and require regular overhaul. To aid this, exhaust valves are often fitted in separate cages. This allows the exhaust valve to be changed and overhauled without removing the cylinder head. The cages have water cooling passages connected to the cylinder head cooling water.

The cage is of cast steel. The cooled seats are made from a heat resistant molybdenum steel which may be stellite faced. The exhaust valve may be of a similar material or of a nimonic alloy.

Inlet valves are subject to much less arduous conditions and are not usually fitted in separate cages.

Two different sized springs are fitted to aid positive closing of the valves. The reason for fitting two springs are that if one fails, the other will prevent the valve dropping down into the cylinder. The two springs have different vibration characteristics, so the incidence of resonance is reduced. (resonance is where two items vibrate at the same frequency thus the amplitude of the vibration is amplified.)

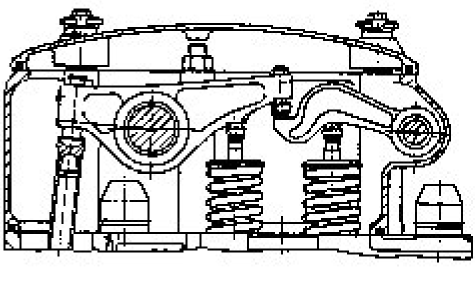
Exhaust valves are designed to rotate in service. The reasons for this are to prevent uneven temperatures so it does not distort and leak by, and to help dislodge any build up of deposits on the valve and seat which may prevent the valve closing properly and lead to "hammering" of the seating faces. A mechanical method is generally used, and this is either the "rotocap" or the "turnomat". Winged rotators or spinners as used on the 2 stroke engine exhaust valves can also be used, but this entails using a ball bearing race between the spring carrier and the cover.

Burning Out of Exhaust Valves

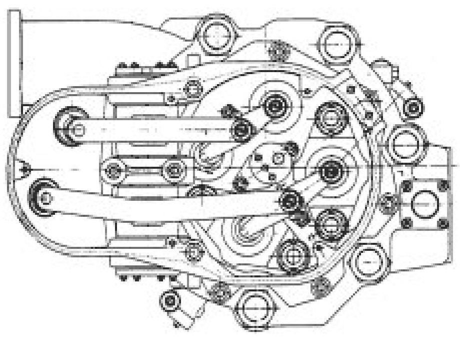
Once an exhaust valve does not seat correctly, the high pressure burning gas will pass across the faces of the valve and seat during the power stroke. This will cause the temperature of the valve and seat to rise in this area, weakening the material and distorting the surfaces. The velocity of the burning gas will erode the surface, allowing more gas to leak by. The temperature of the valve in this area will rise further, leading to further burning and greater distortion. The first indication of a valve burning out will be a rise in the exhaust temperature, which will rapidly increase together with a loss of power from the unit.

Vanadium slag deposits which occur at temperatures above 540º C cause corrosion of the valve surfaces which can lead to exhaust gas blow by. This is combated by effective cooling and the use of suitable materials (stellite and nimonic alloys).

Rocker Gear



Master and Slave



Yoke

Most medium speed four strokes use push rods and rocker gear to open and shut the valves at the correct time. Operated by cams, mechanically timed to the crankshaft, the pushrods transmit the motion to the rocker gear, which pushes the valves open at the correct time. Because there are two of each valve mounted in the cylinder head, the rocker gear must operate both valves simultaneously. Various methods are used including master and slave arrangements (Sulzer ZA40) and yoke (Fiat).

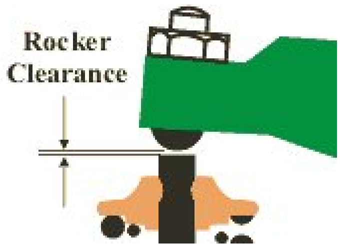
A hydraulic operating system was introduced in place of push rods and rocker gear on the Sulzer ZA50. This had the advantage of being able to adjust the timing of the closing of the valves to suit operating conditions.

Rocker or Tappet Clearances

Rocker or Tappet clearances refer to the clearance between the top of the valve spindle and the rocker arm. It is to ensure that the valve closes properly when it expands as it gets to operating temperature. Clearances are set according to manufacturers instructions, but usually done with the engine cold, and with the push rod follower on the base circle of the cam. (one way of ensuring this is to turn the unit being adjusted to TDC on the power stroke.)

If the clearance is too small, then not only is there a chance that the valve will not close properly when it comes up to temperature, but it effectively will open early and close late.

Conversely if the clearance is too large, then the valve will open late and close early.



Turbocharging - Principles and Construction

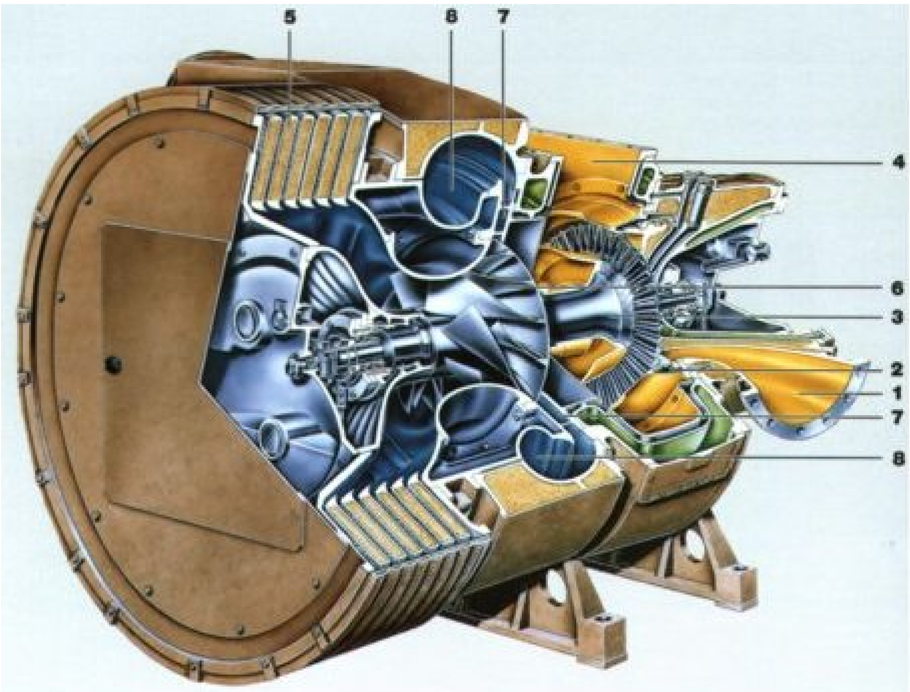
INTRODUCTION

By turbocharging an engine, the following advantages are obtained:

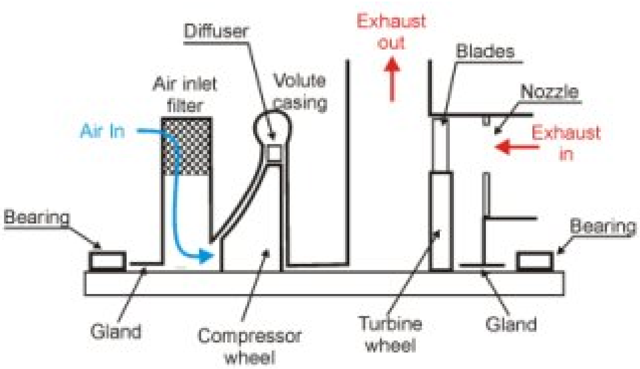
- Increased power for an engine of the same size OR reduction in size for an engine with the same power output.

- Reduced specific fuel oil consumption - mechanical, thermal and scavenge efficiencies are improved due to less cylinders, greater air supply and use of exhaust gasses.

- Thermal loading is reduced due to shorter more efficient burning period for the fuel leading to less exacting cylinder conditions.



1. Gas Inlet Casing	**5. Silencer Filter**
2. Turbine Nozzles	**6. Compressor**
3. Turbine Wheel	**7. Diffuser**
4. Gas Outlet Casing	**8. Volute Casing**



The turbocharger consists of a single stage impulse turbine connected to a centrifugal impeller via a shaft.

The turbine is driven by the engine exhaust gas, which enters via the gas inlet casing. The gas expands through a nozzle ring where the pressure energy of the gas is converted to kinetic energy. This high velocity gas is directed onto the turbine blades where it drives the turbine wheel, and thus the compressor at high speeds (10 -15000 rpm). The exhaust gas then passes through the outlet casing to the exhaust uptakes.

On the air side air is drawn in through filters, and enters the compressor wheel axially where it is accelerated to high velocity. The air exits the impeller radially and passes through a diffuser, where some of the kinetic energy gets converted to pressure energy. The air passes to the volute casing where a further energy conversion takes place. The air is cooled before passing to the engine inlet manifold or scavenge air receiver.

The nozzle ring is where the energy in the exhaust gas is converted into kinetic energy. It is fabricated from a creep resistant chromium nickel alloy, heat resisting moly-chrome nickel steel or a nimonic alloy which will withstand the high temperatures and be resistant to corrosion.

Turbine blades are usually a nickel chrome alloy or a nimonic material (a nickel alloy containing chrome, titanium, aluminium, molybdenum and tungsten) which has good resistance to creep, fatigue and corrosion. Manufactured using the investment casting process. Blade roots are of fir tree shape which give positive fixing and minimum stress concentration at the conjunction of root and blade. The root is usually a slack fit to allow for differential expansion of the rotor and blade and to assist damping vibration. On small turbochargers and the latest designs of modern turbochargers the blades are a tight fit in the wheel.

Lacing wire is used to dampen vibration, which can be a problem. The wire passes through holes in the blades and damps the vibration due to friction between the wire and blade. It is not fixed to each individual blade. The wire can pass through all the blades, crimped between individual blades to keep it located, or it can be fitted in shorter sections, fixed at one end, joining groups of about six blades.

A problem with lacing wire is that it can be damaged by foreign matter, it can be subject to corrosion, and can accelerate fouling by products of combustion when burning residual fuels. Failure of blading due to cracks emanating from lacing wire holes can also be a problem. All the above can cause imbalance of the rotor.

The turbine casing is of cast iron. Some casings are water cooled which complicates the casting. Water cooled casings are necessary for turbochargers with ball and roller bearings with their own integral LO supply (to keep the LO cool). Modern turbochargers with externally lubricated journal bearings have uncooled casings. This leads to greater overall efficiency as less heat energy is rejected to cooling water and is available for the exhaust gas boiler.

The compressor impeller is of aluminium alloy or the more expensive titanium. Manufactured from a single casting it is located on the rotor shaft by splines. Aluminium impellers have a limited life, due to creep, which is dictated by the final air temperature. Often the temperature of air leaving the impeller can be as high as 200°C. The life of the impeller under these circumstances may be limited to about 70000 hours. To extend the life, air temperatures must be reduced.

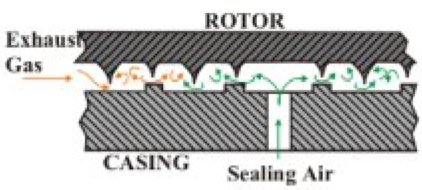
One way of achieving this is to draw the air from outside where the ambient air temperature is below that of the engine room. Efficient filtration and separation to remove water droplets is essential and the impeller will have to be coated to prevent corrosion accelerated by the possible presence of salt water.

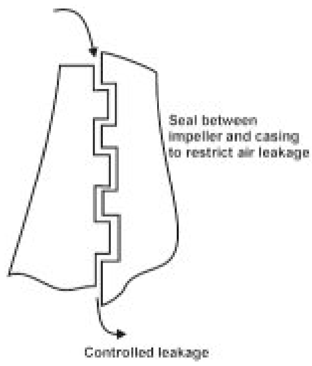
The air casing is also of aluminium alloy and is in two parts.

Bearings are either of the ball or roller type or plain white metal journals. The ball and roller bearings are mounted in resilient mountings incorporating spring damping to prevent damage due to vibration. These bearings have their own integral oil pumps and oil supply, and have a limited life (8000 hrs). Plain journal bearings are lubricated from the main engine oil supply or from a separate system incorporating drain tank, cooler and pumps. Oil is supplied in sufficient quantity to cool as well as lubricate. The system may incorporate a header tank arrangement to supply oil to the bearings whilst the turbocharger comes to rest should the oil supply fail. A thrust arrangement is required to locate and hold the rotor axially in the casing. In normal operation the thrust is towards the compressor end.

Labyrinth seals or glands are fitted to the shaft and casing to prevent the leakage of exhaust gas into the turbine end bearing, or to prevent oil being drawn into the compressor. To assist in the sealing effect, air from the compressor volute casing is led into a space within the gland. A vent to atmosphere at the end of the labyrinth gives a guide to the efficiency of the turbine end gland. Discoloring of the oil on a rotor fitted with a roller bearing will also indicate a failure in the turbine end gland.

A labyrinth arrangement is also fitted to the back of the compressor impeller to restrict the leakage of air to the gas side.





OPERATIONAL INFORMATIONS

Holding Down and Chocking

The engine is mounted on resin or cast iron chocks and bolted to the hull using holding down bolts.

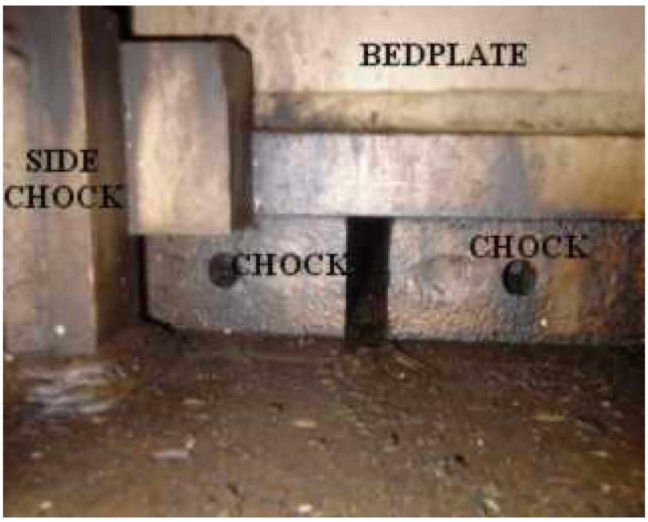
The engine must be securely fixed into the ship. As the engine turns the propeller, the propeller tries to push or thrust the propeller shaft and engine crankshaft forward into the ship. The thrust bearing which is situated at the aft end of the engine transmits this thrust from the crankshaft to the bedplate.

The bedplate is mounted on chocks and is securely bolted to the engine foundation plate on which it sits and which forms part of the structure of the hull.

The Engine must also be lined up with the propeller shaft. If the engine output driving flange was higher or lower, or to port or stbd of the propeller shaft, then it is easy to visualise that trying to connect them would cause bending stresses to be set up.

The engine must also be bolted to a flat surface. If the surface was uneven, then when the bolts were tightened the bedplate would be distorted, which in turn would distort the crankshaft, causing unacceptable stresses to be set up when the engine was running.

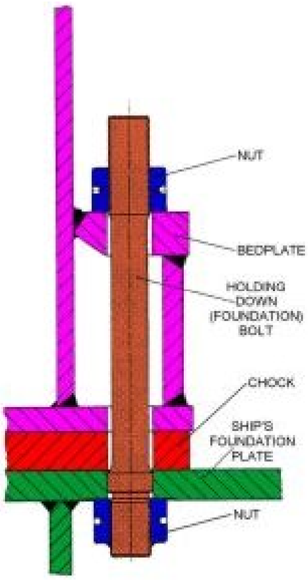
Before the engine is bolted down it is supported on jacks whilst it is aligned with the tailshaft bearing. This can be done by stretching a wire above the tailshaft and crankshsft, and measuring the distance from the wire to the crankshaft bearing centres. Modern methods use a laser.

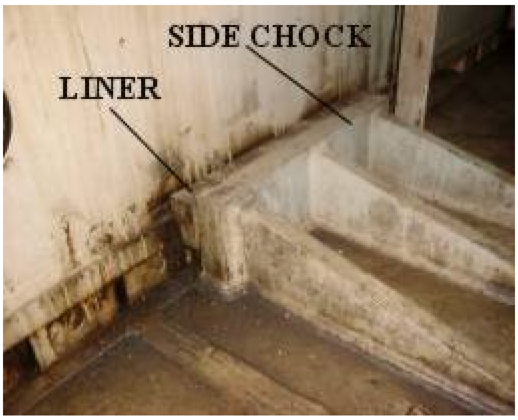


When the bedplate is in perfect alignment, cast iron chocks are hand fitted between the machined underside of the bedplate and machined spots on the foundation plate. This is a skilled task and 80% contact is the aim.

Once the engine is supported by the chocks the jacks are removed and the holding down bolts are tightened using a hydraulic jack to stretch the bolts.

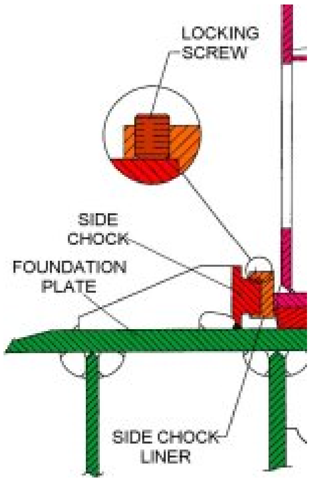
Holding down bolts should be checked regularly for tightness. If they are allowed to come loose, then the mating surfaces will rub against each other and wear away in a process known as fretting. If this continues and the bolts are subsequently tightened down, the bedplate (and main bearings) will be pulled out of alignment.





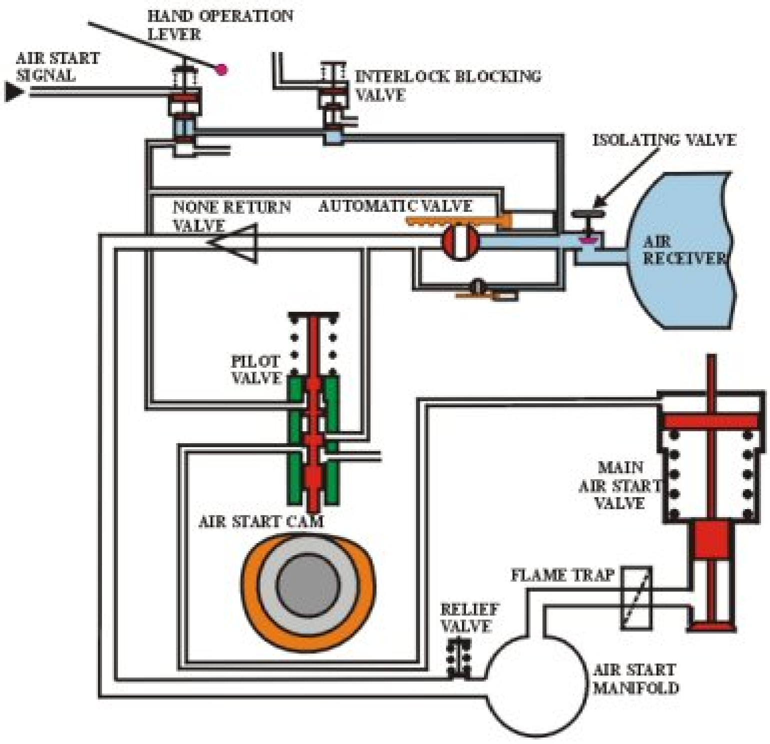
Side chocks are fitted to prevent the engine from moving sideways due to the movement of the vessel or because of the sideways component of thrust from the reciprocating and rotating parts. The chock is welded to the foundation plate as shown, a liner is hand fitted on a 100:1 taper and then driven home.

This is a side chocking arrangement, where after driving the liner home, locking screws are hardened down as shown.



The Air Start System: How An Engine Starts On Air?

Large Marine Diesel Engines are started using high pressure compressed air. The air is admitted into the cylinder when the piston is just past TDC and continued until just before the exhaust valve opens. There is always more than one air start valve open: - a situation known as overlap. This ensures that the engine will start in any position. The opening of the main air start valves is controlled by a set of pilot valves located in the air start distributor, which in turn are timed to operate by a drive linked to the main camshaft. In the example shown, a small camshaft is used to control the opening and closing of the air start pilot valves.



The drawing shows the principle of operation of an air start system. Large air receivers are used to store the compressed air. The diagram shows the isolating valve open so air is being allowed as far as the automatic valve and the air start control valve.

When the engine is required to start, a low pressure air signal is sent to the air start control valve (which can also be hand operated in an emergency). The air pushes a piston down which opens the valve and allows high pressure air to flow to the pilot valve and the automatic valve operating pistons. The pilot valve is forced down onto the cam profile and the automatic valve opens and high pressure air is led to the main air start valves and the pilot valve. When the pilot valve cam follower is on the lowest point on the cam, air flows to the operating piston of the main air start valve for that particular cylinder, opening the valve and allowing high pressure air to flow into the cylinder.

When the pilot valve is lifted by the cam, the pilot valve vents and the main air start valve closes. When the start air signal is taken off the air start control valve, the system vents and the automatic valve shuts.

An interlock blocking valve will operate, for instance if the turning gear is left in, and this will stop high pressure air from reaching the air start control valve and thus either the automatic valve or the pilot valve.

A slow turning valve is fitted. This will open instead of the main automatic valve if the engine has been stopped for more than 30 minutes during manoeuvering. It will only supply enough air to turn the engine over very slowly; This is a precaution in case a cylinder has had oil or water leak into it which would cause damage to the engine when starting. If the engine completes a full revolution on the slow turn, then the main automatic valve opens and the engine will start. (note: The operating system for the slow turning has been omitted for simplicity).

International Association of Classification Society rules state:

In order to protect starting air mains against explosion arising from improper functioning of starting valves, the following devices must be fitted:

(i) An isolation non-return valve or equivalent at the starting air supply connection to each engine.

(ii) A bursting disc or flame arrester in way of the starting valve of each cylinder for direct reversing engines having a main starting manifold. OR

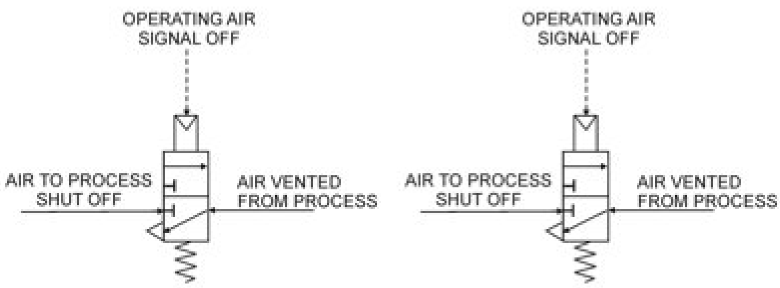
(iii) At the supply inlet to the starting air manifold for non-reversing engines.

Devices under *(ii)* above may be omitted for engines having a bore not exceeding 230 mm.

The system may also be provided with a relief valve.

Air Start System L58-64

To be able to understand the diagrams it is necessary to understand how the pneumatic symbols "work". For those students unfamiliar with them, the following explanation should help.



Condition 1: Valve not operated   Condition 1: Valve not operated

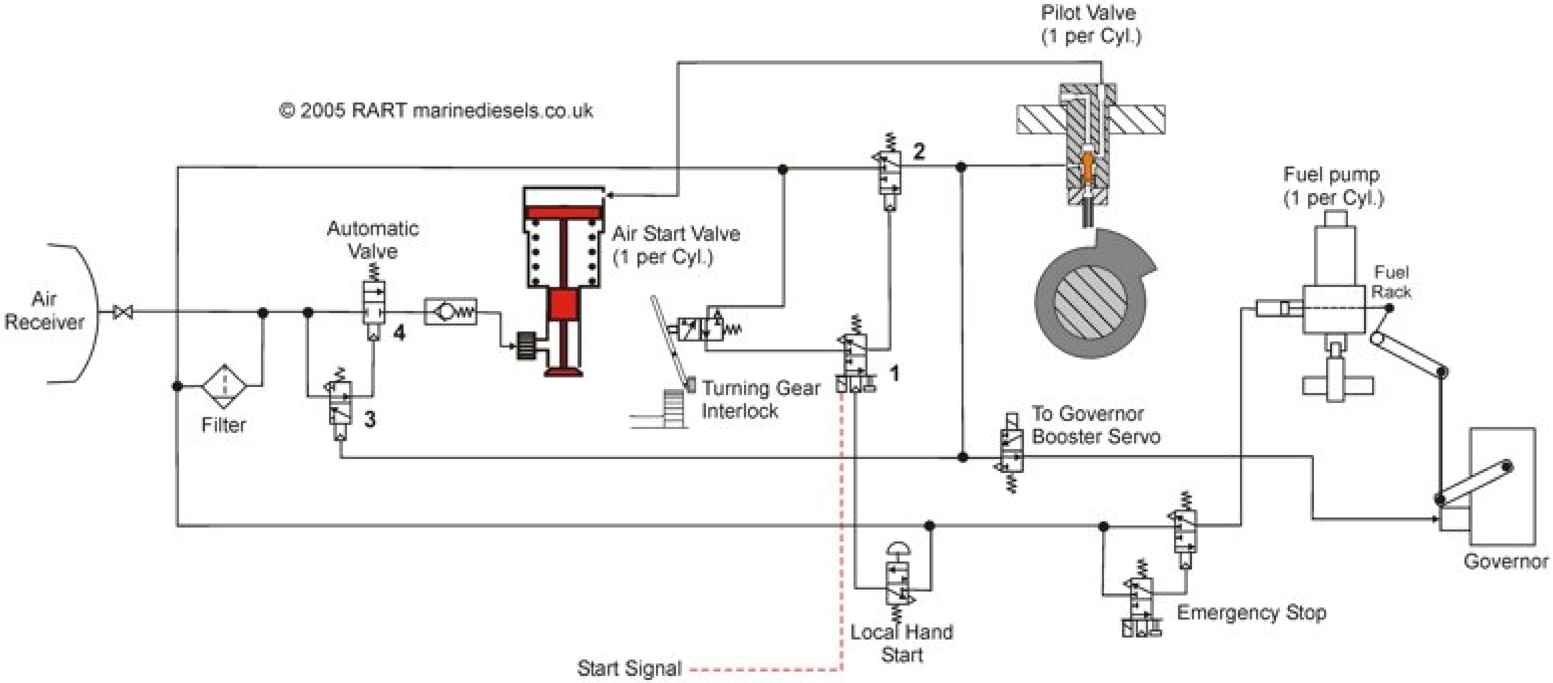
Shown opposite is a basic pneumatically operated, spring return 3/2 valve (3 ports, 2 positions). Its normal position is shown, which in this case, is with the air to the process shut and the process vented. When the operating air signal is applied, the whole valve is moved downwards and the air can flow through the ports to the process.

With reference to the diagram on the next page.

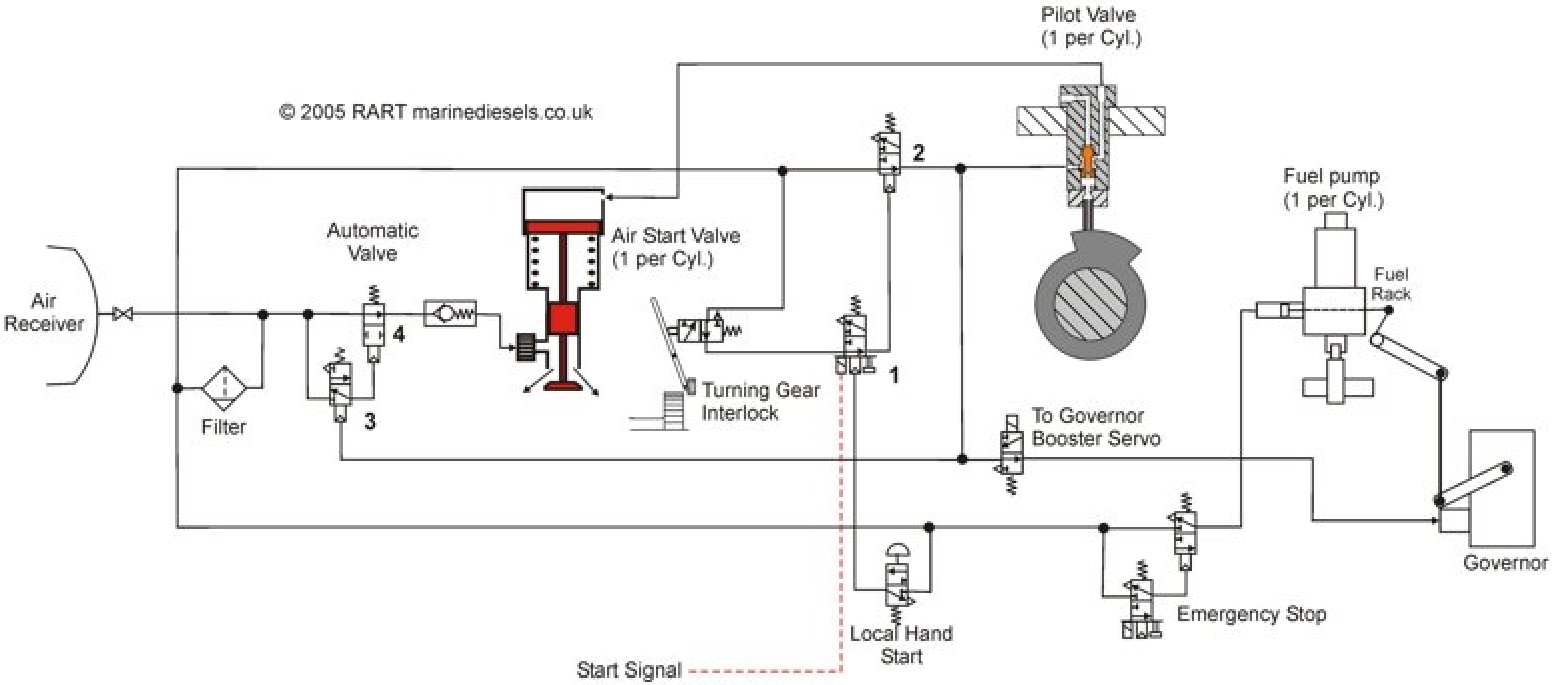
The isolating valve from the air receiver is open. Air at 30 bar flows to the automatic valve (4) which is closed. Air also flows to control valve (2) which is also closed. As long as the turning gear is out, air can also flow to the start control valve (1).

When a start signal is applied to the control valve (1) an air signal operates control valve (2). The air can now flow to the pilot valves, to control valve (3) which vents the automatic valve (4) which now opens allowing air to flow to the air start valves mounted in the cylinder head. Air will also flow to the governor booster servo, pulling the fuel pump control linkage to the zero position so that no fuel is injected whilst start air is admitted to the cylinders. When the pilot valve cam is in the correct position (i.e. as the piston comes over TDC on the power stroke), air flows through the pilot valve to the operating piston of the air start valve opening the valve and allowing the compressed air into the cylinder forcing the piston down and turning the crankshaft. Just before the exhaust valve opens, the pilot valve will vent, and the air start valve will close. By this time another air start valve will be open, allowing the engine to accelerate to firing speed, at which valve (1) will vent, control valve (2) will vent, the automatic valve (4) will shut and the governor will operate the fuel racks to allow fuel to be injected into the cylinders.

The emergency stop shown is independent of the governor stop signal. It can be operated by hand or from the engine shut down system (overspeed etc). If operated, an air signal opens a valve allowing compressed air to servo cylinders at the back of the fuel pumps which zero the fuel racks.



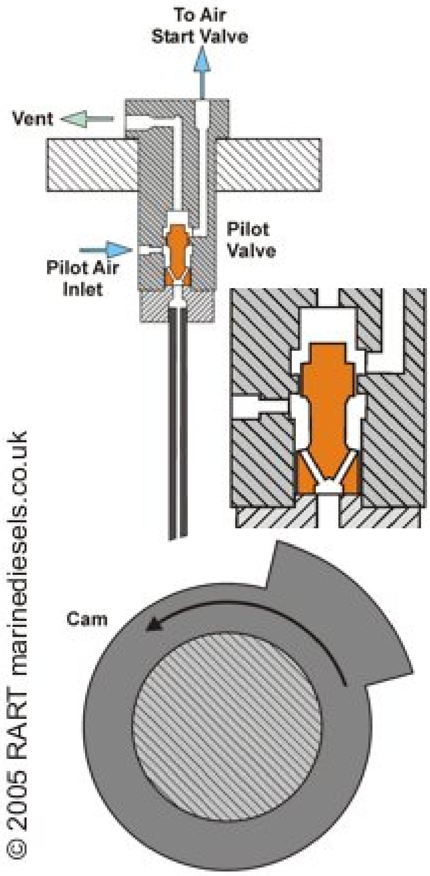
MAN B&W L58/64 (L48/60) Start Air System (Simplified)
Condition: Air On But Starting Signal Not Applied

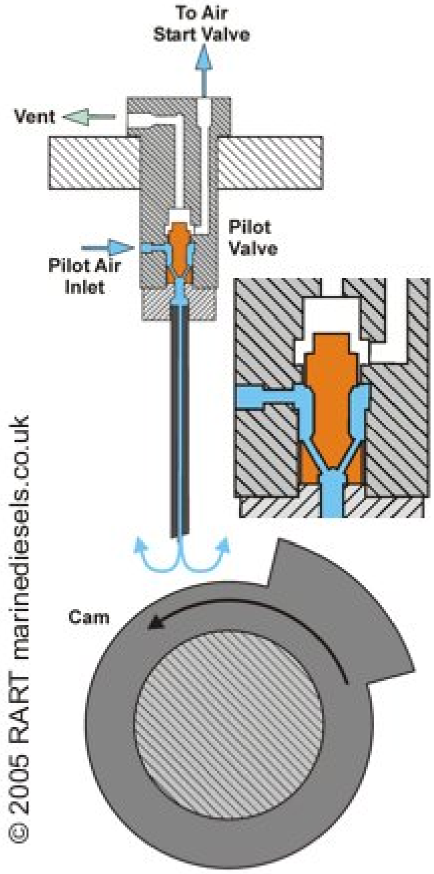


MAN B&W L58/64 (L48/60) Start Air System (Simplified)
Condition: Air On, Starting Signal Applied

The Air Start Pilot Valve

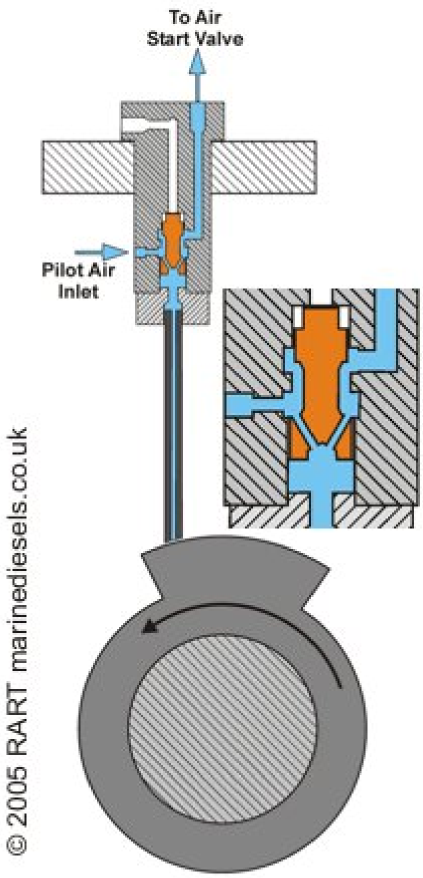
The L58/64 (L48/60, L40/54) and the V versions of the engines do not have an air start distributor to open the air start valves in sequence. Instead each cylinder has a pilot valve and an operating cam mounted on the main camshaft (see photo).



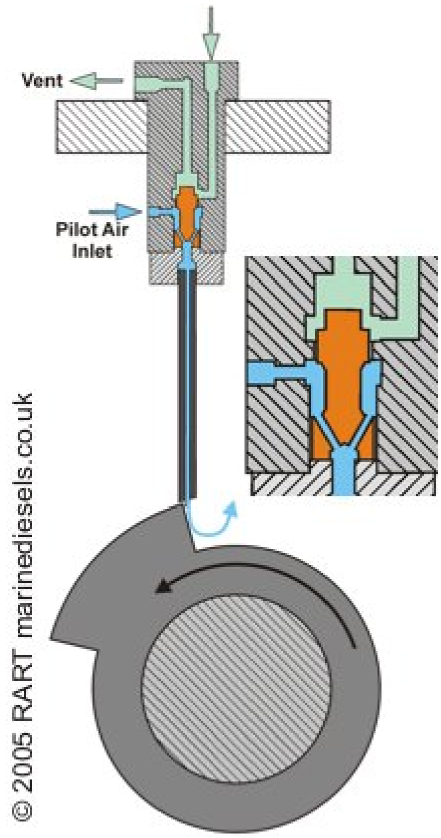


The start sequence is underway. Pilot air flows through bores in the shuttle valve plunger and escapes through the pulse pipe. Due to the difference in air pressure the shuttle valve plunger is in the lower position and the air start valve operating cylinder is vented.

As the cam turns the exit from the pulse pipe is restricted by the cam profile. The pressure under the shuttle valve plunger increases and due to the difference in areas the plunger now lifts allowing pilot air to operate the air start valve.



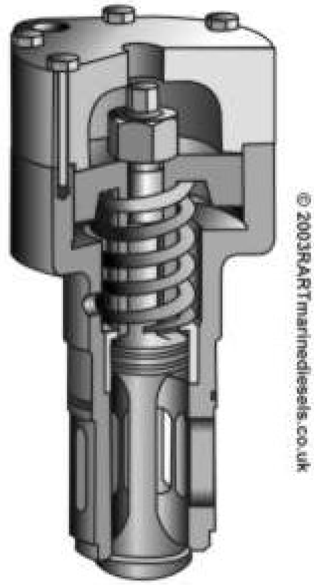
At the end of the opening angle for the air start valve, the underside of the shuttle valve plunger is vented through the pulse pipe and the valve closes allowing the air start valve pilot air to vent.



The Air Start Valve

The valve is fitted into the cylinder head. It is opened by control air from the starting air distributor.

The valve shown is from a slow speed MAN-B&W two stroke engine but a lot of modern engines have valves working on similar principles and design.



MAN B&W Air Start Valve

Materials

The body of the valve could be of mild steel, the spindle of high tensile or stainless steel, and the valve and seat could have the contact faces stellited or hardened.

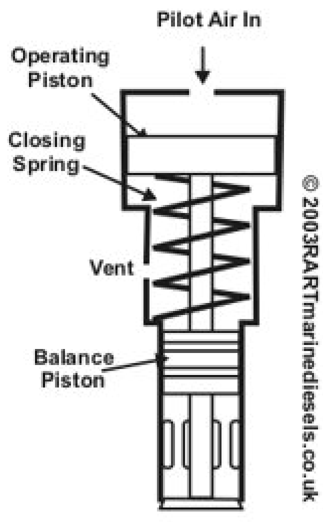
How it works?

Main starting air at about 30 bar from the manifold enters the chamber above the valve via the circumferential ports in the valve body.

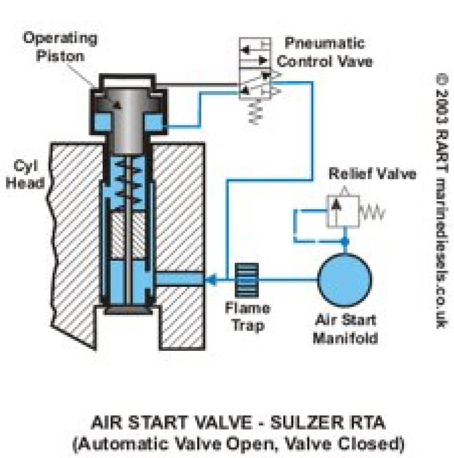
The air pressure will not open the valve because a spring is holding the valve shut, an the area of the balance piston is the same as that of the valve lid so the valve is pneumatically balanced.

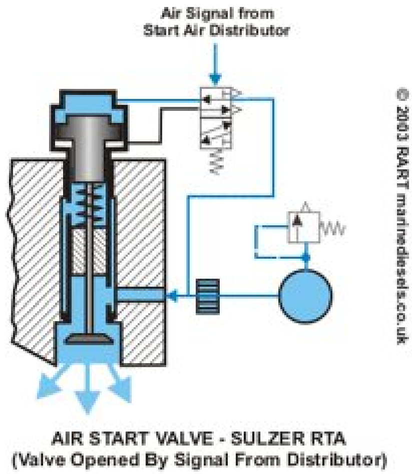
When the valve is required to open, air at 30 bar from the air start distributor enters the the top of the valve body and acts on a piston. This force overcomes the spring force holding the valve shut, and the valve opens. When the air signal from the air start distributor is vented, the spring closes the valve

When the start sequence is finished the main air start pressure is vented through holes in the main start air manifold.



Air Start Valve





The Sulzer RTA Air Start Valve operating principle.

The Sulzer air start valve uses air on both sides of the operating piston to maintain positive closing. The piston is stepped. The reason for this is so the starting air valve will not open when the gas pressure in the cylinder is higher than the starting air pressure; i.e. when the cylinder is firing. Once the valve starts to open then the opening is accelerated when the larger diameter piston has the opening air acting on it.

The stepped piston also means that closing of the valve is damped as air gets trapped in the annular space formed when the smaller diameter piston enters the upper part of the cylinder.

The air to operate the valve comes from the main air start supply. The distributor pilot air operates the pneumatic change over valve.

Maintenance

After certain periods of service starting air valves are changed and overhauled. If piston rings are fitted, care must be taken to ensure that they are free in their grooves. Should it be necessary to fit new rings, the butt clearances of the rings must be carefully checked by placing the ring into the operating cylinder and measuring the clearance. This is especially important if they are usually made of brass which has a larger coefficient of expansion than the other parts of the valve. The valve and valve seat are ground with grinding paste and finished to a fine surface with lapping paste. It is essential to ensure that all parts of the valve are scrupulously clean before reassembly. Lubricate all sliding surfaces sparingly with a molybdenum disulphide grease.

How does the starting air brake the engine when changing direction?

If the engine is required to reverse whilst there is still way on the ship, the engine will be driven by the propeller, and it may be a while before it comes to a halt, and is thus able to start in the reverse direction.. To speed up the process, starting air is admitted whilst the engine is still running ahead although the start air distributor will have been retimed to admit air for reverse running.

Because of this, starting air flows into the cylinder half way up the compression stroke. Towards the end of the compression stroke (no ignition, fuel injection cut off by the running direction cut-out), compressed air, (at a pressure which has increased above that of the starting air), then flows through the starting air valve, which is still being held open, into the starting air distribution pipe. If the starting air valve is then closed, there will be less air within the cylinder than at the beginning. In this way, considerably less expansion work is done than for compression, i.e. the engine is braked. The engine will come to a standstill and then start to turn in the opposite direction, since the control elements are set for this.

What causes an air start valve to stick?

Leakage of a starting air valve is usually caused by sluggish valve action preventing fast closure of the valve, or by dirt or foreign particles from the starting air supply lodging on the valve seat and so preventing the valve from closing fully. Sluggish valve action may be caused by dirty pistons or valve spindle guides and the like. In newly overhauled valves sluggish valve action may be caused by parts fitted with inadequate clearances.

How can I tell if an air start valve is leaking or has jammed open?

When an engine is in operation leakage of starting air valves is shown by overheating of the branch pipe connecting the starting air valve to the starting air rail. The heating occurs due to the leakage of hot gases from the engine cylinder into the starting air line connected to the starting air rail. During periods of manoeuvring the temperature of each supply pipe from the air rail to the starting air valve should be checked by feeling the pipe as close to the valve as possible.

What should I do if an air start valve jams open whilst manoeuvring?

The fuel pump should be lifted (fuel rack zeroed, puncture valve operated or whatever) on the affected unit and the bridge informed. The load should be kept at a minimum, as one unit is now out of operation. As soon as safe to do so, the engine should be stopped and the air start valve replaced.

Air Start Explosions

Air Start explosions occur during a start sequence, when oil, which can accumulate in the air start receivers or on the surface of the start air lines, becomes entrained with high pressure air in the air start manifold and is ignited. The most infamous incident happened onboard the Capetown Castle in 1960 which killed 7 men.

In 1999, a large container ship, built in 1981 and fitted with a large bore two-stroke engine, suffered damage when the starting air manifold was blown apart by an internal explosion. This occurred during manoeuvring when berthing. Fortunately there were no casualties.

Reference to Lloyds Register database has shown that this was not an isolated incident – between 1987 and 1999, 11 incidents of explosions in air start systems have been reported and most have been attributable to unsatisfactory shipboard practices by ships staff, resulting in the presence of oil or explosive vapour in the manifold.

The source of ignition for these explosions can be attributed to one of the following:

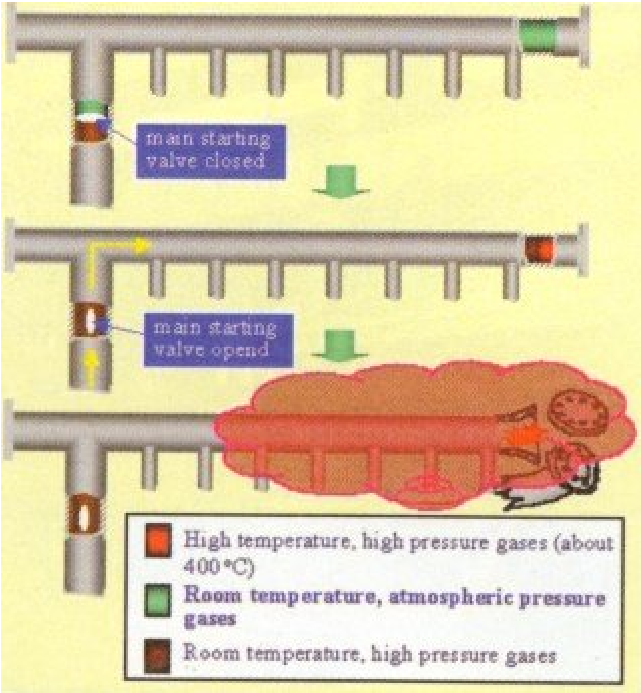
- A leaking air start valve. Whilst the engine is running, the hot gases produced as the fuel burns in the cylinder (at above 1200°C) leak past a valve which has not re-seated correctly. The branch pipe to the air start manifold heats up to red heat. If the engine is stopped and restarted before the pipe has time to cool, any oil vapour in the air can be ignited and an explosion can result if the mixture of oil/air is correct.

- Fuel leaking into the cylinder whilst the engine is stopped. When the engine then undergoes a start sequence, and builds up speed, the fuel which has leaked into the cylinder vaporises and the heat from the compression of the air in the cylinder, as the piston rises, ignites the fuel. When the air start valve opens as the piston comes over TDC, the pressure in the cylinder is higher than the air start pressure, and the burning combustion gases pass to the air start manifold, igniting the oil entrained in the air.

- A recent theory by ClassNK has concluded that the principal cause of explosions in starting air manifolds of marine engines is probably the auto ignition of oil deposited on the inner surface of the manifold, not backfire from cylinders as previously thought. Auto-ignition conditions occur because of the high temperature generated by the rapid inflow of high-pressure air, says the research. This incoming air compresses air downstream of the main starting valve, causing its temperature to reach as high as 400°C which in some cases causes oil deposits in the manifold to self-ignite leading to an explosion. ClassNK has adapted its safety requirements for a starting system to account for the findings. It now requires the fitting of rupture discs to the manifold on engines with a flame arrester in each branch pipe leading to the cylinders. This is beyond IACS unified requirements, which account for cylinder backfire as the cause of starting air manifold explosions.

To minimise the risk of explosions, the oil carry over from the compressor should be reduced to a minimum. Class regulations require that the air compressor's air intakes are located in an oil-free atmosphere, and a drain/filter for intercepting oil/water mist is fitted between compressor discharge and air receiver. There must be complete separation of compressor discharge and starting air supply to engines at the receiver which is fitted with a drain and a relief valve.

The air start system must be protected with a non return valve at the starting air supply to each engine. This is normally part of the automatic valve which opens when an air start is initiated.



In addition to this IACS require that:

For direct reversing main engines >230 mm bore flame arresters or bursting discs are required for each cylinder fitted between the cylinder start air valve and the manifold.

For non-reversing and auxiliary engines >230 mm bore a single flame arrester or bursting disc is acceptable fitted at the supply inlet to the starting air manifold.

Although not part of IACS regulations, a relief valve may be fitted to the manifold where flame arrestors are used instead of bursting discs.

Unsatisfactory practices which have led to explosions in the air start system include:

- 'Tell tales/drains' at each end of the starting air manifold found to have been blanked off with screwed plugs.

- Failure to drain starting air receivers and starting air pipes at regular intervals or before manoeuvring.

- Failure to check for leaking air start valves.

- Failure to maintain starting air valves and systems strictly in accordance with manufacturers recommended practices.

- Failure to maintain fuel valves correctly.

SAFETY DEVICES

Flame Arrestors

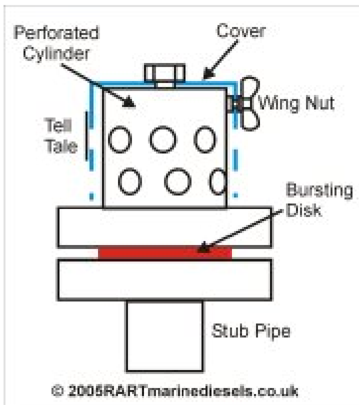
The flame trap is manufactured from brass or aluminium alloy which both have a high specific heat capacity. A number of holes are bored through the thick circular form to allow the air to pass through. They are fitted in the main air line immediately before the air start valve to restrict the risk of a flame in the cylinder propagating back to the main air start manifold, by dissipating the heat energy in the flame.

Flame Arrestor MAN B&W L58/64

Flame Arrestor Sulzer RTA

Bursting Disks

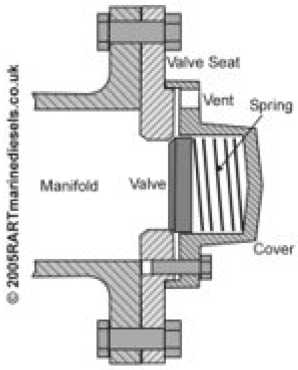
The safety cap consists of a bursting disk enclosed by a perforated cylinder and a perforated cover in order to protect any bystanders, in the event of a burst. The cover is fitted with a tell tale, which shows if the bursting disc has been damaged. If the bursting disc of the safety cap is damaged due to excessive pressure in the starting air line, overhaul or replace the starting valve which caused the burst, and mount a new disk.



If a new disk is not available, or cannot be fitted immediately, then the cover can be turned in relation to the perforated cylinder, in order to reduce the leakage of starting air.

Relief Valve

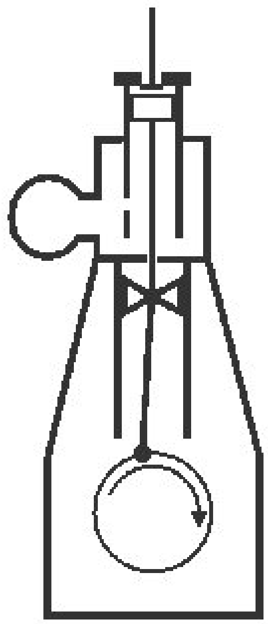
The sketch shows a relief valve as fitted to the air start manifold of Sulzer RTA 2 stroke engines. Its purpose is to relieve excess pressure in the air start manifold. It consists of a spring loaded valve disk which locates on a mating seat which is bolted to the end of the air start manifold. When the force exerted on the disk due to excessive pressure is greater than the spring force holding the valve closed, the valve will open.

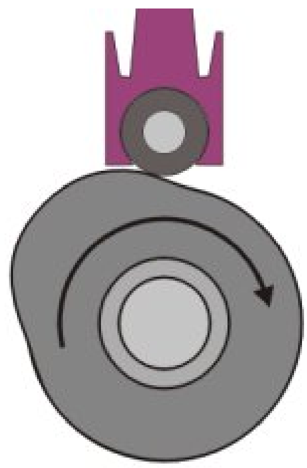


AIR START MANIFOLD RELIEF VALVE

Lost Motion

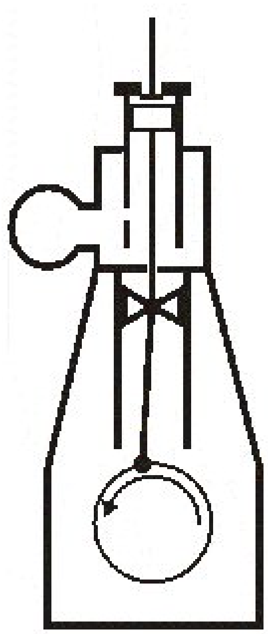
On a two stroke engine, the fuel pumps must be retimed when the engine is required to reverse direction (i.e. run astern). This is done by moving the fuel pump cams or fuel pump cam follower positions relative to the crankshaft.

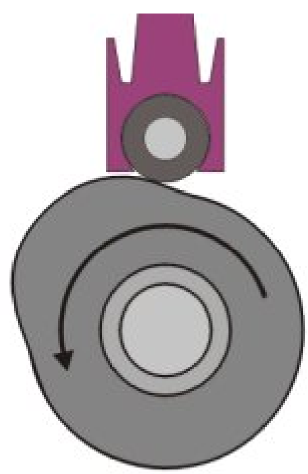




The fuel pump cam follower is moving up the rise of the cam on the delivery stroke. The cam is correctly in time with the engine.

If one cylinder of the engine is considered (left), the piston is just before TDC with the engine running ahead and the crankshaft rotating clockwise. The piston is moving up towards TDC. The picture on the right shows the fuel cam at this point; where the cam follower is rising up the lift of the cam as it rotates clockwise. This point can be considered as the start of injection.



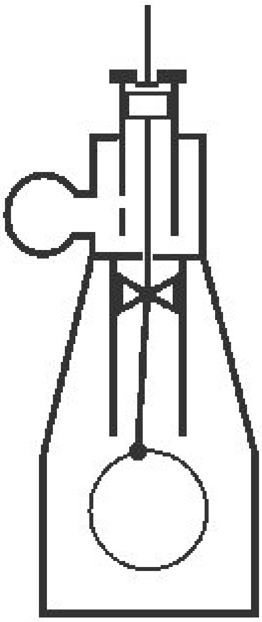


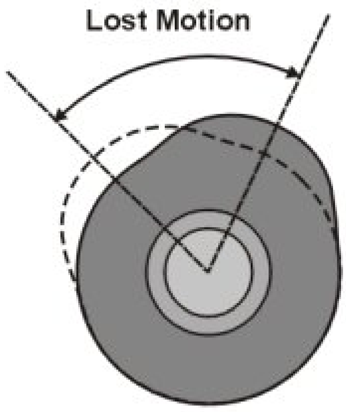
Here the fuel pump cam is in the wrong position. When the piston is just after TDC, fuel delivery should have finished and the follower should be approaching the peak of the cam.

If, at this point the engine is stopped, and is started in the reverse direction (astern), the crankshaft now moves in an anticlockwise direction. Then the piston in this particular unit is now moving down the cylinder and is just after TDC. At this point fuel injection should have just finished. However, by studying the picture of the cam (right) it can be seen that the camshaft has reversed direction (because it is directly driven from the crankshaft), and is also rotating anticlockwise.

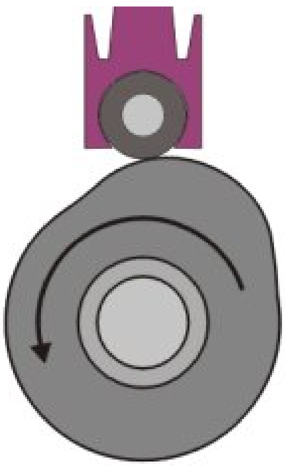
In the picture the follower is moving down the cam which means the fuel pump plunger is just finishing the suction stroke; i.e completely out of time with the engine.

So that the Fuel Pump cam is timed correctly with the crankshaft when the engine is reversed, the fuel pump cams are rotated by a hydraulic servomotor which changes the position of the cams relative to the crankshaft. The angle through which the cams are turned is known as the Lost Motion angle.





Although this can be made to happen when the engine is still rotating, it is probably easier to think of the engine stopped as shown left and the camshaft moving as shown on the animation below. Once the fuel cams have moved, the engine can then start running in the reverse direction (anticlockwise).



The angle that the cams move through is the lost motion angle.

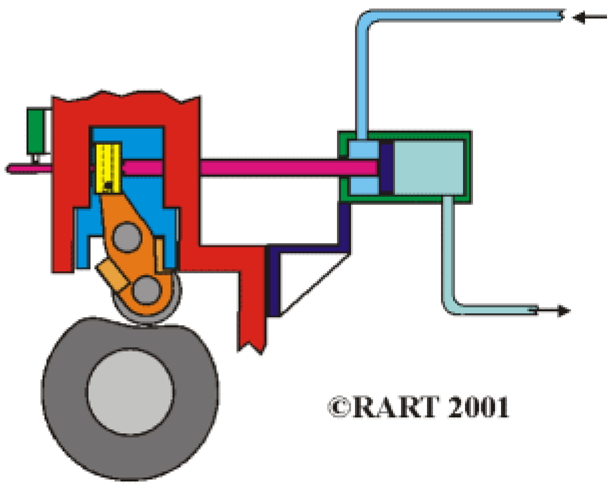
Because the engine is started using compressed air admitted through the air start valves, the operating mechanism for these must also be retimed.

This is not the only method of reversing a two stroke engine. Other methods include moving the whole camshaft axially so that a different set of cams are used, and a rather clever method used by MAN-B&W which alters the position of the cam followers.

The fuel pump cam on the MAN B&W MC series engine is designed to raise the plunger on the injection stroke and then keep the plunger at the top of its stroke while the follower stays on the peak of the cam until just before the next delivery stroke when the follower returns to the base circle of the cam, and the fuel pump plunger moves down on its suction stroke.

The animation on the left shows the cam follower just beginning to move up the slope of the cam with the camshaft rotating in anticlockwise direction. (i.e. start of injection)

If the engine direction is reversed at this point, then air will enter the pneumatic cylinder as shown and will move the piston to the right. The cam follower will be moved across and would finish in the position shown which would be at the correct fuel pump timing for running astern.



It should be noted that the reversal of the follower only takes place while the engine is rotating. If the engine had been stopped from running ahead, and then started astern, the fuel pump followers would move across as the engine starts to rotate, and before the fuel is admitted by venting the fuel pump puncture valves.

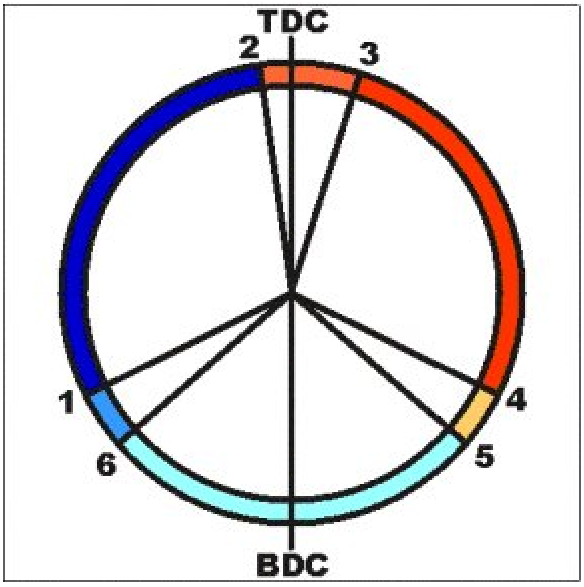
A micro switch shown on the LHS detects whether the follower has moved across. If not, an indicator light is lit in the control room, However the engine will still start if a follower fails to move, perhaps due to corrosion in the servo cylinder. A high exhaust temperature deviation alarm would operate within a short time. Allowing the engine to start in this situation could be useful during manoeuvring in confined waters.

Two Stroke Exhaust Valve Timing

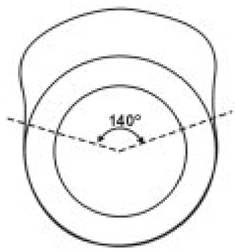
If a timing diagram for a two stroke engine is examined, it can be seen that the exhaust valve starts to open at about 110º after TDC (position 4 on the diagram). After the initial blowdown of the exhaust gas from the cylinder, the scavenge ports are opened at about 140º after TDC (position 5), as the piston moves down the cylinder.

The position of the scavenge ports is fixed in the cylinder liner, and so it should be obvious that their opening and closing must be symmetrical about BDC, and therefore they close at 140º before TDC as the piston moves up the cylinder on the compression stroke. When the engine is operating in the reverse direction, the timing of the opening and closing of the scavenge ports remains the same.

The exhaust valve can be timed to open and close symmetrically about BDC, and so again it means that when the engine is reversed, the exhaust valve will open and close at the same time as when the engine is running ahead. This means that there is no need to alter the position of the exhaust cams for astern running.



Engine builders may not time the exhaust valve symmetrically about BDC; instead, to achieve more economical and efficient operation when running ahead may retard the opening of the exhaust valve by up to 15°. For instance the exhaust valve may be timed to open at 125° after TDC and close at 95° before TDC. This of course will mean when the engine is running astern, the exhaust valve will open and close early.

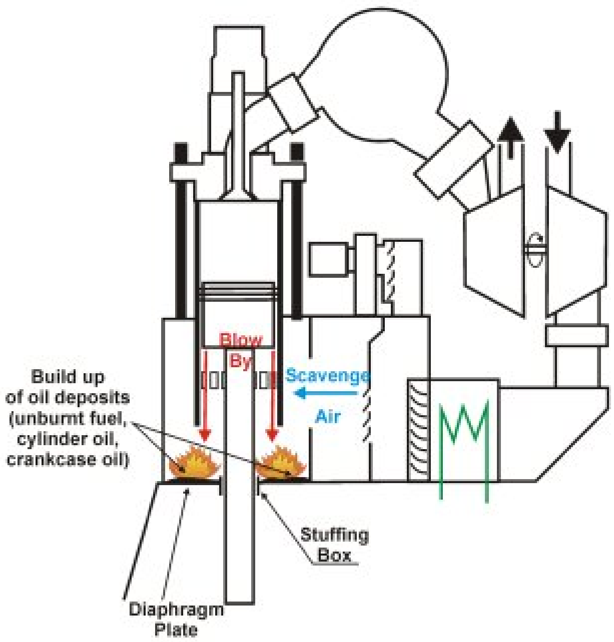


However, because the engine runs astern for only a very small percentage of it's operating life, the advantages gained when running ahead far outweigh the disadvantages when running astern.

Scavenge Fires

Introduction

For a scavenge fire to begin there must be present a combustible material, oxygen or air to support combustion, and a source of heat at a temperature high enough to start combustion. In the case of scavenge fires the combustible material is oil. The oil can be cylinder oil which has drained down from the cylinder spaces, or crankcase oil carried upwards on the piston rod because of a faulty stuffing box. In some cases the cylinder oil residues may also contain fuel oil. The fuel may come from defective injectors, injectors with incorrect pressure setting, fuel particles striking the cylinders and other similar causes. The oxygen necessary for combustion comes from the scavenge air which is in plentiful supply for the operation of the engines. The source of heat for ignition comes from piston blowby, slow ignition and afterburning, or excessive exhaust back pressure, which causes a blowback through the scavenge ports.



Indications

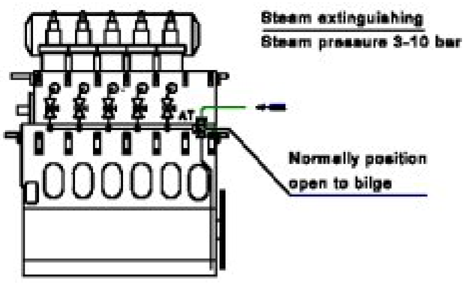
Indications of a scavenge fire are loss in power and irregular running of the engine, high exhaust temperatures of corresponding units, high local temperature in scavenge trunk, surging of turbocharger, and sparks and smoke emitted from scavenge drains. External indications will be given by a smoky exhaust and the discharge of sooty smuts or carbon particles. If the scavenge trunk is oily the fire may spread back-from the space around or adjacent to the cylinders where the fire started and will show itself as very hot spots or areas of the scavenge trunk surfaces. In ships where the engine room is designed as UMS, temperature sensors are fitted at critical points within the scavenge spaces. activation would cause automatic slow down of the engine.

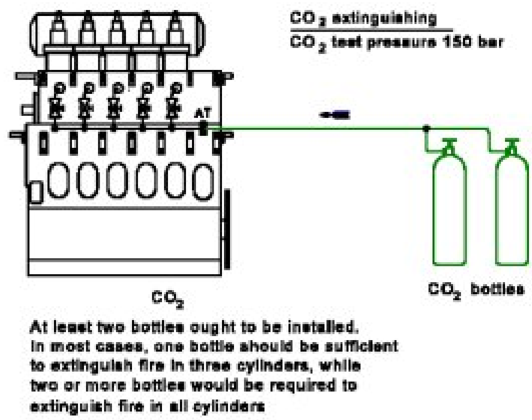
Action

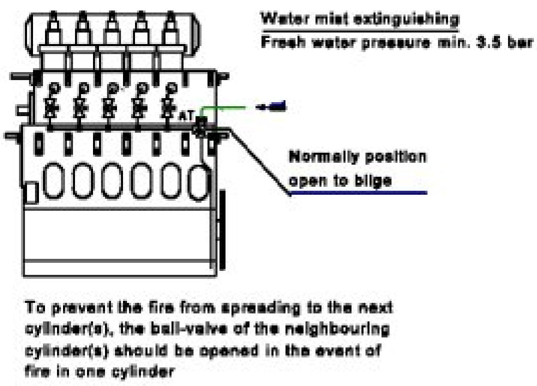
If a scavenge fire starts two immediate objectives arise- they are to contain the fire within the scavenge space of the engine and to prevent or minimize damage to the engine. The engine must be put to dead slow ahead and the fuel must be taken off the cylinders affected by the fire. The lubrication to these cylinders must be increased to prevent seizure and all scavenge drains must be shut to prevent the discharge of sparks and burning oil from the drains into the engine room. A minor fire may shortly burn out without damage, and conditions will gradually return to normal. The affected units should be run on reduced power until inspection of the scavenge trunking and overhaul of the cylinder and piston can be carried out at the earliest safe opportunity. Once navigational circumstances allow it, the engine should be stopped and the whole of the scavenge trunk examined and any oil residues found round other cylinders removed. The actual cause of the initiation of the fire should be investigated.

CO2 Scavenge Fire
Extinguishing Installation

If the scavenge fire is of a more major nature, if there is a risk of the fire extending or if the scavenge trunk is adjacent to the crankcase with risk of a hot spot developing it sometimes becomes necessary to stop the engine. Normal cooling is maintained, and the turning gear engaged and operated. Fire extinguishing medium should be applied through fittings in the scavenge trunk: these may inject carbon dioxide, dry powder or smothering steam. The fire is then extinguished before it can spread to surfaces of the scavenge trunk where it may cause the paint to start burning if special non inflammable paint has not been used. Boundary cooling of the scavenge trunk may be necessary. Keep clear of scavenge relief valves, and do not open up for inspection until the engine has cooled down.







After extinguishing the fire and cooling down, the scavenge trunking and scavenge ports should be cleaned and the trunking together with cylinder liner and water seals, piston, piston rings, piston skirt, piston rod and gland must be inspected. Heat causes distortion and therefore checks for binding of piston rod in stuffing box and piston in liner must be carried out. Tightness of tie bolts should be checked before restarting the engine. Inspect reed valves if fitted, and scavenge relief valve springs. Fire extinguishers should be recharged at the first opportunity and faults diagnosed as having caused the fire must be rectified.

Prevention

To prevent scavenge fires good maintenance and correct adjustment must be carried out. Scavenge trunking must be periodically inspected and cleaned and any buildup of contamination noted and remedied. The drain pockets should also be cleaned regularly to remove the thicker carbonized oil sludges which do not drain down so easily and which are a common cause of choked drain pipes. Scavenge drains should be blown regularly and any passage of oil from them noted. The piston rings must be properly maintained and lubricated adequately so that ring blow-by is prevented. At the same time one must guard against excess cylinder oil usage. With timed cylinder oil injection the timing should be periodically checked. Scavenge ports must be kept cleared

The piston-rod packing rings and scraper rings should also be regularly adjusted so that oil is prevented from entering the scavenge space because of butted ring segments. This may and does occur irrespective of the positive pressure difference between the scavenge trunk and the crankcase space.

Fuel injection equipment must be kept in good condition, timed correctly, and the mean indicated pressure in each cylinder must also be carefully balanced so that individual cylinders are not overloaded.

If cylinder liner wear is up to maximum limits the possibility of scavenge fires will not be materially reduced until the liners are renewed.

Crankcase Explosions

Introduction

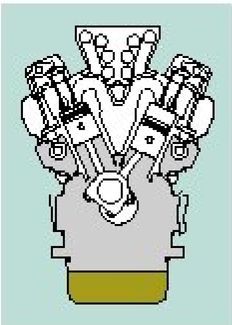
September 11th or 9/11 stands out in our minds for obvious reasons. However there was another 9/11, 11th September 1947, when a crankcase explosion on the Reina del Pacifico killed 28 men and injured 23 and led to the development of crankcase relief valves and oil mist detectors. Of course there had been crankcase explosions before this, but none which had such devastating consequences.

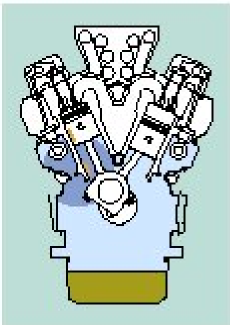
Between 1990 and 2001 143 crankcase explosions were reported to Lloyds Register which have about 20% of the worlds shipping in its class, so if we use that as a factor, we can estimate the total reported incidents were 715 in 11 years or about 65 a year. Don't forget that these are reportable incidents, i.e. those where the damage sustained has warranted a major repair or has resulted in injury. Minor explosions may have gone unreported, and it is possible that the actual number of incidents is more than double those reported. - maybe 3 a week!!

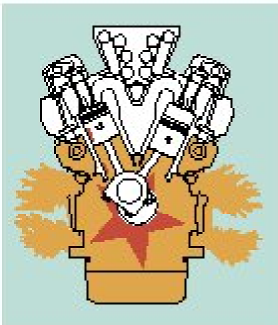
Of those incidents reported to Lloyds, 21 explosions happened in two stroke marine diesel engines and 122 in four stroke marine diesel engines. But this doesn't mean that four stroke engines are more likely to have an explosion; there are 7 times as many four stroke engines at risk than two stroke engines.

Sequence of events leading up to a crankcase explosion

For an explosion to occur there must be a source of air (oxygen), fuel and ignition. Oxygen is present in the crankcase, but the lubricating oil splashing around in the crankcase is in too large droplets to start burning at the speed needed to cause an explosion, and the oil/air concentration is too weak.


An unprotected engine – no Oil Mist Detector


Build-up of oil mist due to 'hotspot' being undetected


The possible result – ignition of oil mist causing a crankcase explosion

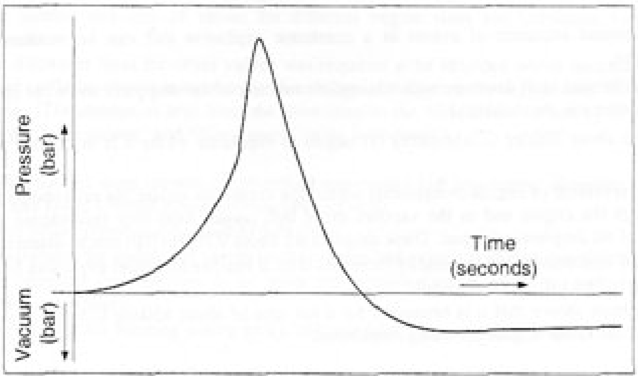
If, however a mechanical fault develops with the consequent rubbing of moving parts, then a hot spot will occur. This could happen in the crankcase, chaincase, or camcase. When the temperature of the hot spot reaches 200°C the lubricating oil splashing on to this hot spot vapourises. The vapour then circulates to a cooler part of the crankcase where it condenses into a white oil mist. The oil droplets in this oil mist are very small - 5 to 10 microns in diameter. When the concentration of oil mist reaches 50mg/l (about 13% oil mist - air ratio), it is at its lower explosive limit. If this oil mist is now ignited by the hot spot - and tests have shown that it is necessary for a temperature of about 850°C to ignite oil mist in a crankcase under operating conditions - then an explosion will occur.

Although the most common cause of of a localised hotspot is due to friction, it is not the only cause of a crankcase explosion. A cracked piston crown, blowby or an external fire have caused crankcase explosions in the past.

Primary and secondary crankcase explosions

Severity of explosions vary between a puff which may lift a relief valve to a violent explosions which causes major damage and may injure personnel and cause a fire. Evidence indicates that the longer the combustion path, the more violent the explosion. This has become an area of concern with the large two strokes of today which may have a crankcase volume of 500m3 +.

When an explosion occurs a flame front travels down the crankcase with a pressure wave in front of it. The turbulence caused by moving engine components causing churning and mixing of vapours increase the speed of the flame front and its area, which contribute to the increase in pressure. Turbulence caused by venting of the pressure through relief valves can also influence the explosion.



Explosion Pressure/Time Variation

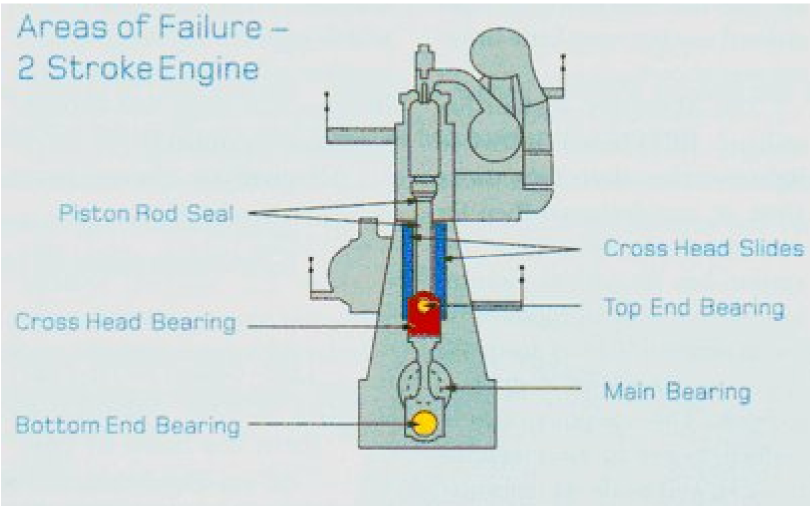
Following the venting of the explosion through the relief valves, there is a drop in crankcase pressure to below atmospheric pressure. This can cause air to enter the crankcase resulting in another flammable mixture to be developed resulting in a secondary explosion to occur. The secondary explosion is more violent and can result in crankcase doors being blown off the engine, and fires starting in the engine room. If the relief valves do not reseal after lifting, or if they do not lift at all in the primary explosion (due to lack of maintenance etc), then door(s) may be blown off in the primary explosion, giving a ready path for the ingress of air, which will make a secondary explosion more likely. Air can also be sucked in via the crankcase vent, although rules state that this must be as small as practicable and new installations must have a non return valve fitted.

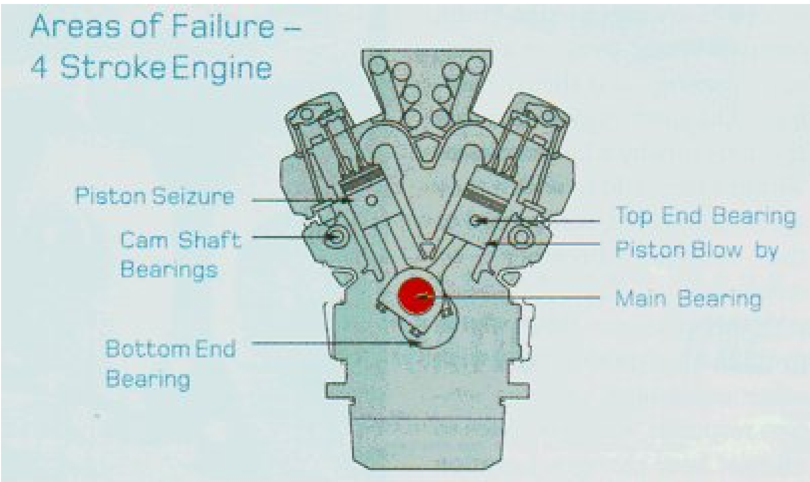
If a primary explosion occurs, the pressure wave may send a large amount of oil mist out into the engine room. Although the flame arrestors on the relief valves should prevent ignition of this oil mist by the flame front, the mist will be sucked up towards the turbocharger where it may be ignited by an unlagged hot exhaust manifold. This ignition of oil mist can cause severe damage to plant and personnel.

Causes of crankcase explosions

The table below (on the next page) gives details of a number of accidents which have occurred since 1995 to large slow speed 2 stroke engines where the cause is known. In a number of cases death or serious injury to members of the crew occured.

Year	Cause of Explosion	Cause of Failure
1995	Bearing in PTO gearbox	
1996	Inlet pipe for piston cooling oil falling off	Incorrect tightening
1997	Incorrect spring mounted in piston rod stuffing box	Unauthorised spare part
1997	Piston rod interference with cylinder frame	
1999	Weight on chain tightener falling off	Incorrect tightening
1999	Fire outside the engine	
2000	Main bearing	
2000	Camshaft bearing	
2000	Incorrect shaft in camshaft drive	Unauthorised spare part
2001	Crankshaft failure	
2001	Piston crown failure	
2001	Main bearing	
2001	Crankpin bearing	
2001	Inlet pipe for piston cooling oil falling off	Incorrect tightening





Fatigue

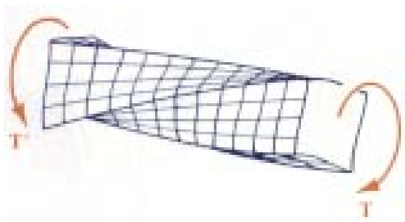
A metal subjected to a repetitive or fluctuating stress will fail at a stress much lower than that required to cause fracture on a single application of load. Failures occurring under conditions of dynamic loading are called fatigue failures, presumably because it is generally observed that these failures occur only after a considerable period of service. Fatigue accounts for at least 90 percent of all service failures due to mechanical causes.

Fatigue occurs when a material is subject to alternating or cyclic stresses, over a long period of time. Examples of where fatigue may occur in a marine diesel engine are: crankshafts, valve springs, turbocharger blades, piston crowns, bottom end bolts, piston skirts at the gudgeon pin boss and tie bolts.

Stresses can be applied in three ways, torsionally, axially and by bending.

The symbol for stress is the Greek letter sigma s and the units are force/ unit area i.e N/m2 or psi (imperial).

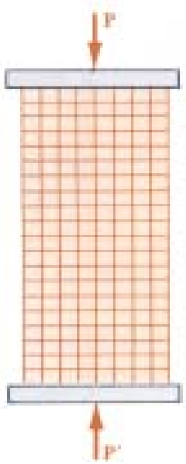
Torsional



This is where the material is twisted and untwisted along its axis. Any rotating shaft driving a load will be subject to torsional vibration at the natural frequency of the shaft. However torsional vibration is most easily visualised in an engine crankshaft where the compression and firing forces are applied to the crankpin through the piston and con rod. These forces vary according to angle of thrust applied by the conrod and the cylinder firing pressure but are greatest at about 10° either side of TDC.

The crank also has to absorb the inertia loading due to the conrods and pistons, which easily amounts to several tons on each cylinder.

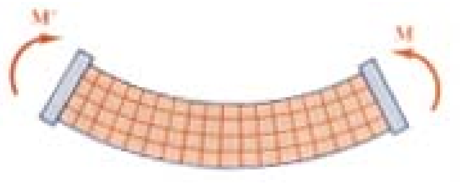
Axial



This is where the material is subject to tension or compression along its axis. An example of this are the bottom end bolts on a four stroke engine.

The bolts and their nuts are subject to tensile stress when tightened and additional varying tensile stress during operation. The total stress level is high and varies with time, giving rise to the risk of fatigue. The connecting rod is in compression during the compression and power strokes, but due to the inertia forces in the running gear when the piston changes direction between the exhaust and inlet strokes, the connecting rod is put into tension. This increases the tension in the bottom end bolts, leading to cyclic stressing.

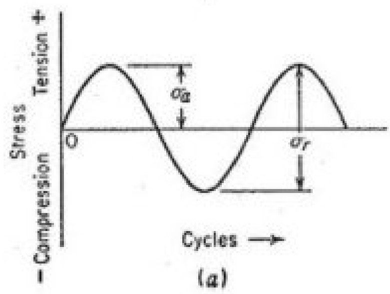
Bending



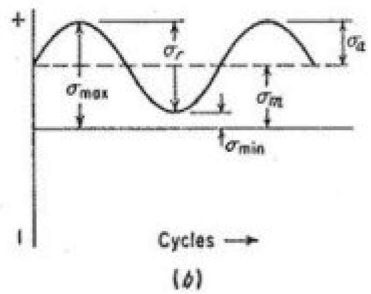
When material is bent, the inside of the bend will be in compression and the outside of the bend will be in tension. This type of stress can be easily visualised in a piston crown under the gas load and is compounded by the stresses induced by the difference in temperature on the top surface and the underside of the crown (thermal stressing).

It also occurs in crankshafts where the gas load on the piston is bending the crankshaft. If the main bearings are of different heights (i.e out of vertical alignment), then the bending is increased.

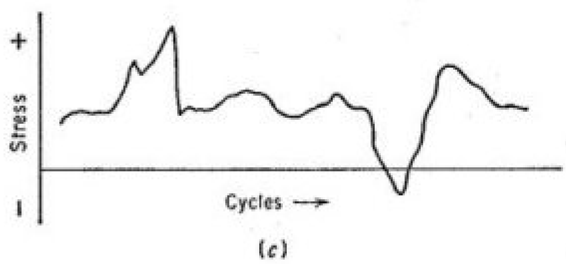
Stress Cycles



Reversed



Repeated

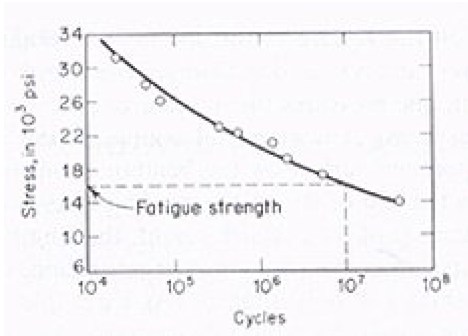


Random

There are three stress cycles with which loads may be applied to the component under consideration. The simplest being the reversed stress cycle . This is merely a sine wave where the maximum stress and minimum stress differ by a negative sign. An example of this type of stress cycle would be in an axle, where every half turn or half period as in the case of the sine wave, the stress on a point would be reversed. The most common type of cycle found in engineering applications is where the maximum stress (smax)and minimum stress (smin) are asymmetric (the curve is a sine wave) not equal and opposite. This type of stress cycle is called repeated stress cycle. A final type of cycle mode is where stress and frequency vary randomly. An example of this would be hull shocks, where the frequency magnitude of the waves will produce varying minimum and maximum stresses.

The S-N Curve

The S-N curve is just a graph plotted of stress, S against the number of cycles N.



N is a logarithmic scale i.e 105 cycles, 106 cycles 107 cycles etc.

The line plotted for the particular material will indicate how many stress reversals it can go through before it fails.

If the material is loaded below the fatigue limit, which in the example shown is 14×103 psi (95×103 kN/m2) then it will not fail regardless of the number of stress cycles.

Material such as aluminum, copper and magnesium do not show a fatigue limit, therefore they will fail at any stress and number of cycles. Other important terms are fatigue strength and fatigue life. The stress at which failure occurs for a given number of cycles is the fatigue strength. The number of cycles required for a material to fail at a certain stress is the fatigue life.

Crank Initiation, propagation and failure

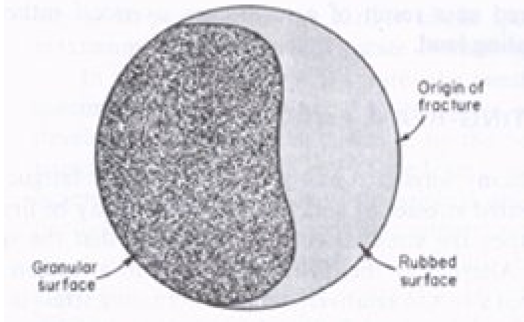
Failure of a material due to fatigue may be viewed on a microscopic level in three steps:

- *Crack Initiation*: The initial crack occurs in this stage. The crack may be caused by surface scratches caused by handling, or tooling of the material; threads (as in a screw or bolt), flaws in the material, slip bands or dislocations intersecting the surface as a result of previous cyclic loading or work hardening.

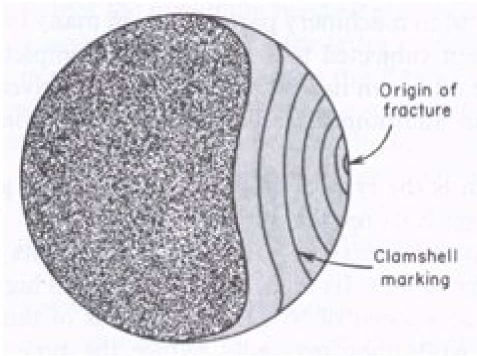
- *Crack Propagation:* The crack continues to grow during this stage as a result of continuously applied stresses

- *Failure:* Failure occurs when the material that has not been affected by the crack cannot withstand the applied stress. This stage happens very quickly.

Fatigue failure can be identified by examining the fracture. A fatigue fracture will have two distinct regions; One is smooth or burnished as a result of the rubbing of the bottom and top of the crack as it is growing. The second is granular, due to the rapid failure of the material.



Other features of a fatigue fracture are Beachmarks and Striations. Beachmarks, or clamshell marks, may be seen in fatigue failures of materials that are used for a period of time, allowed to rest for an equivalent time period and the loaded again as in factory usage. Striations which can be seen through a microscope, are thought to be steps in crack propagation, were the distance depends on the stress range. Beachmarks may contain thousands of striations.



Visible beachmarks on a tiebolt failure

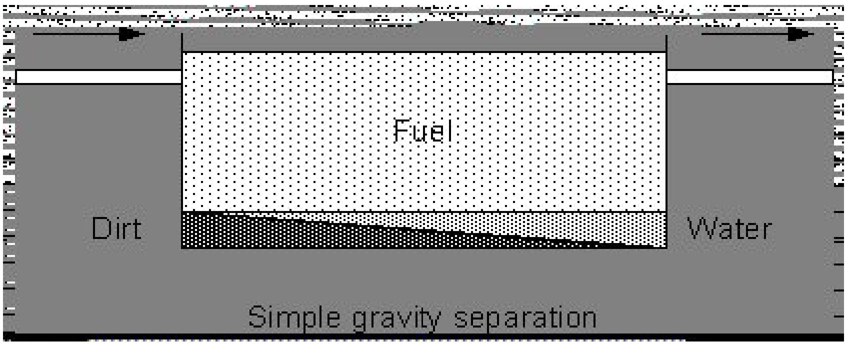
Magnification of fatigue failure
showing striations

Purifiers and Clarifiers

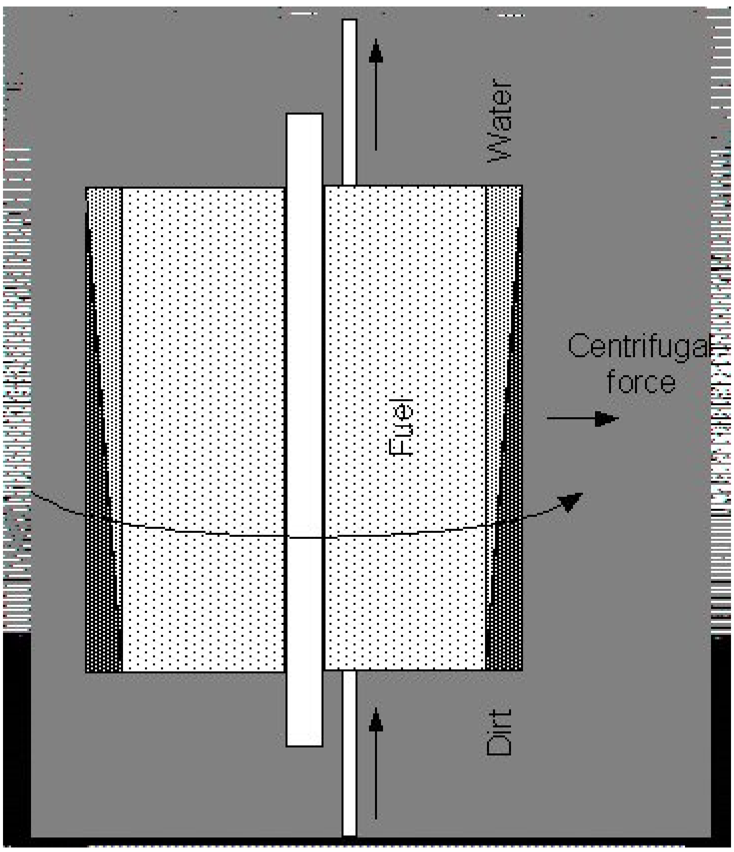
Separation

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

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



Centrifuging



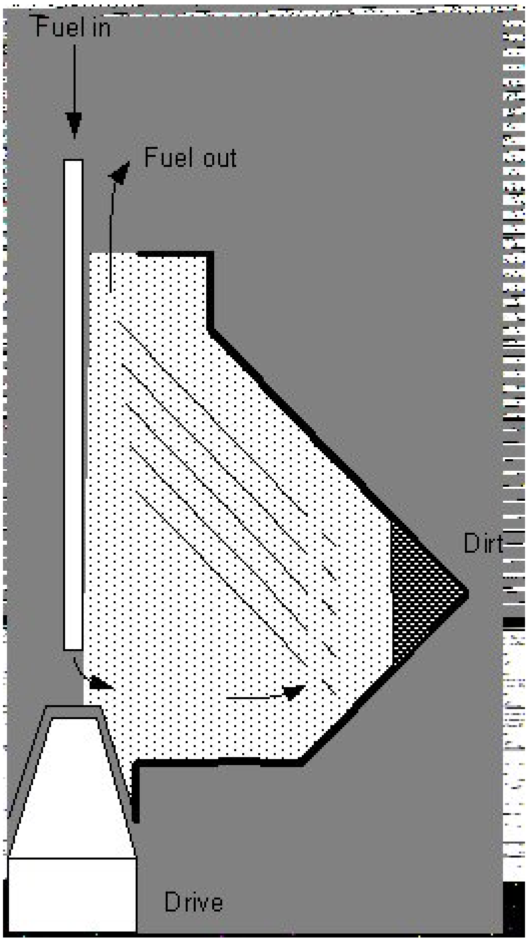
Centrifuging is the process by which the effects of gravity can be amplified by the use of centrifugal force to the extent that the separation process becomes rapid and continuous. Centrifuges work by rapidly spinning a bowl containing the liquid, thus producing the required centrifugal force to produce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

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

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

Clarifier

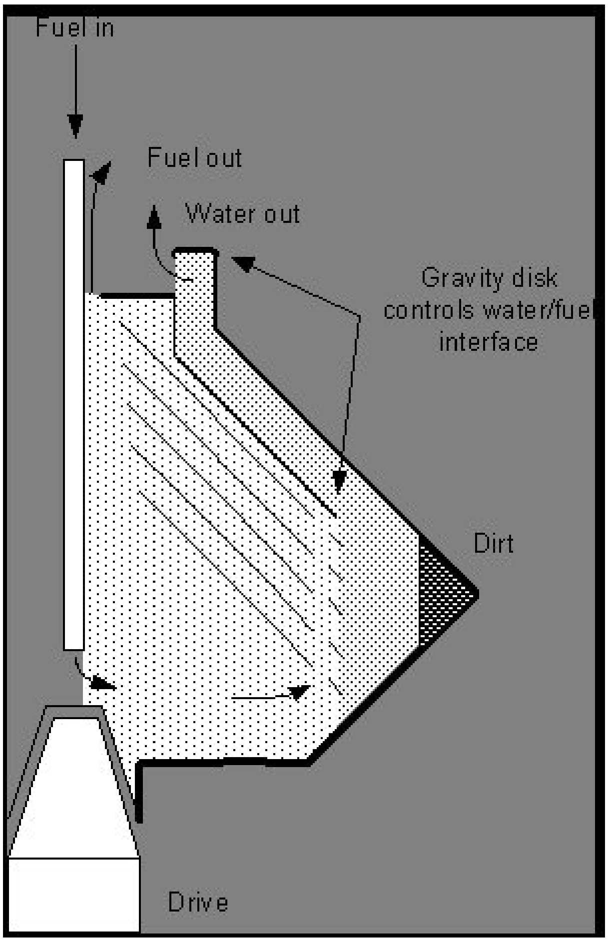
The addition of an inlet and an outlet connection forms a simple clarifier. Rotational speeds vary according to designs and are of the order of 7,000 to 9,000 rpm. Efficiency is increased by the inclusion of a number of discs (up to 150) that increase the surface area and thus help separation. Discs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



Purifier

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

A set of gravity discs is supplied with each machine and the optimum size to be fitted depends on the density of the untreated oil. When the fuel centrifuge is operating, particulate matter will accumulate on the walls of the bowl. If the centrifuge is set as a clarifier, the particulate matter will be a combination of water and solid material. If it is set as a purifier, the free water is continuously discharged, therefore, the particulate matter will consist of solid material. In older machines it is necessary to stop the centrifuge to manually clean the bowl and disc stack, however, the majority of machines today can discharge the bowl contents while the centrifuge is running.



Bearing Materials

Babbitt Metal

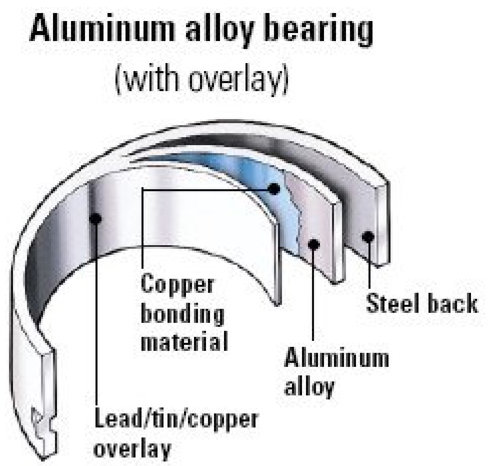
Babbitt metal, is an antifriction metal alloy first produced by Isaac Babbitt in 1839. In present-day usage the term is applied to a whole class of silver-white bearing metals, or "white metals." These alloys usually consist of relatively hard crystals embedded in a softer matrix, a structure important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

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

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

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

Tin Aluminium



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

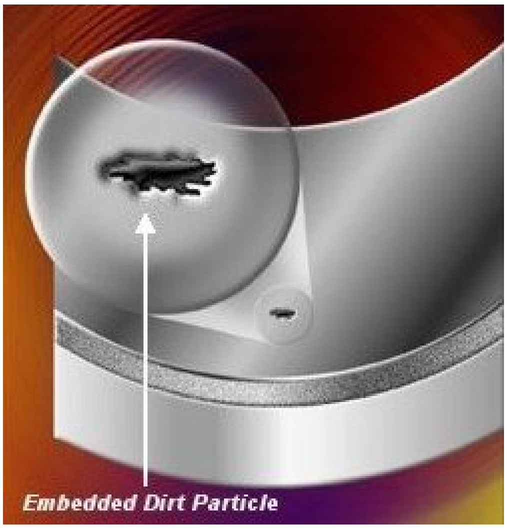
Alloys containing 20 to 40% tin, remainder aluminium, show excellent resistance to corrosion by products of oil breakdown and good embeddability. The sliding properties of this composition are very similar to those of tin based white metal but the loading capacity of this material is higher than tin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

Lead Bronzes

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

Overlay

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

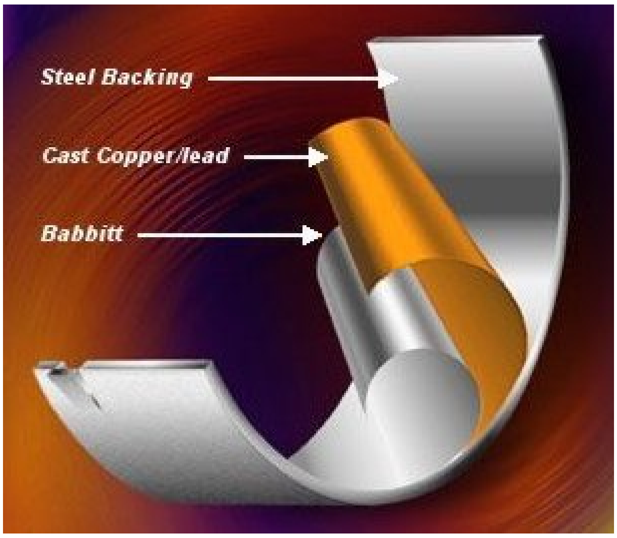


Flash layer

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

Tri-Metal Bearings

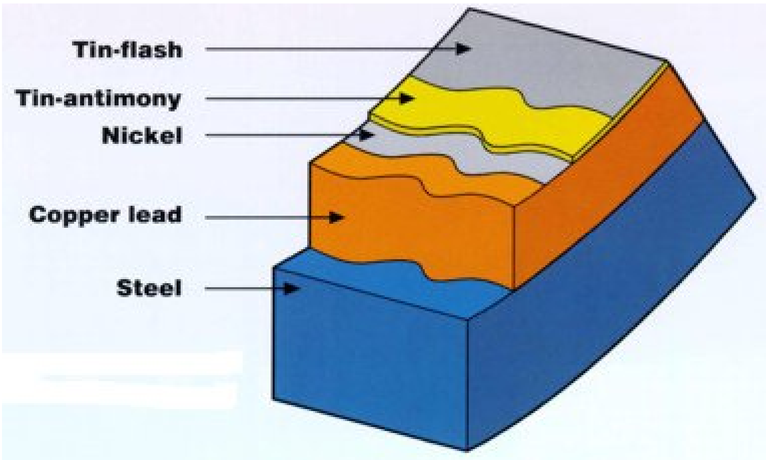
Multi layer thinwall bearings are used in modern diesel engines.



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

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

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



Hydrodynamic Lubrication

Boundary Lubrication

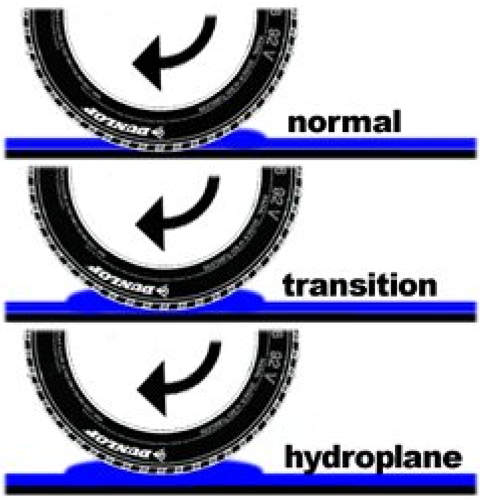
Boundary lubrication in marine diesel engine bearings occurs during start up and stopping, relatively slow speeds, high contact pressures, and with less than perfectly smooth surfaces. As running conditions become more severe such as with rough surfaces, and high contact pressures, wear becomes a severe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

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

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

Hydrodynamic Lubrication

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

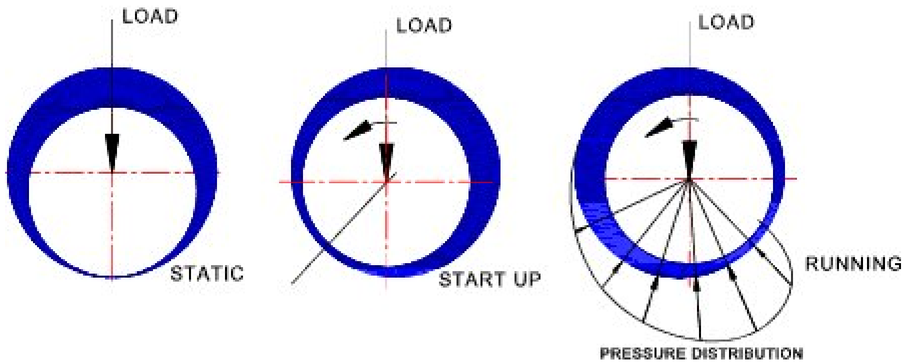


The principle which allows large loads to be supported by this film of oil is similar to that which causes a car to aquaplane on a wet road surface. Aquaplaning occurs when water on the road accumulates in front of your vehicle's tyres faster that the weight of your vehicle and the pumping action of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

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

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

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



Viscosity of the lubricant is an important feature. The higher the viscosity, the higher the friction between oil and shaft, but the thicker the hydrodynamic film. However friction generates heat, which will reduce the viscosity, the thickness of the film and may result in metal to metal contact. Using an oil with a low initial viscosity will also result in a reduced oil film thickness. We have to be very careful that the distance between the two surfaces is greater than the largest surface defect. The distance between the two surfaces decreases with higher loads on the bearing, less viscous fluids, and lower speeds. Hydrodynamic lubrication is an excellent method of lubrication since it is possible to achieve coefficients of friction as low as 0.001 (m=0.001), and there is no wear between the moving parts. However because the lubricant is heated by the frictional force and since viscosity is temperature dependent, additives to decrease the viscosity's temperature dependence are used. The oil of course is cooled before it is pumped back through the engine.

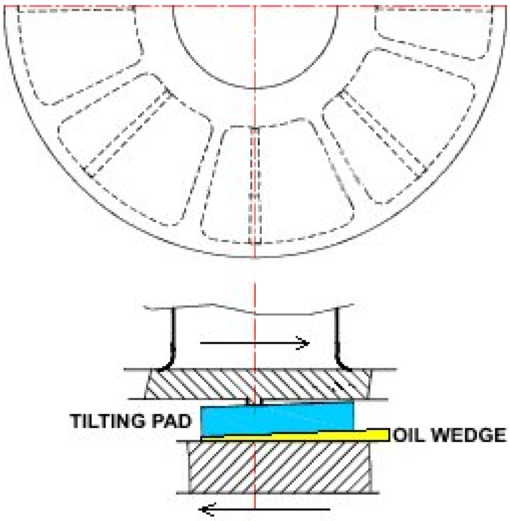
Thrust Bearing

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

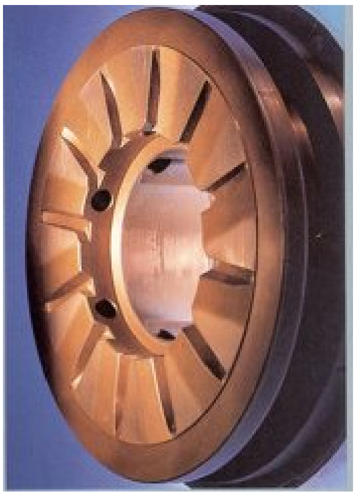
This is obtained in a number of ways, a common design is the tilted pad bearing, where a tilted pad skims over a sheet of fluid. This was developed by Australian engineer George Michell in 1905. Albert Kingsbury, an American, simultaneously and independently invented a bearing operating on the same principle.

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

This principle is the one used on main propulsion thrust bearings.



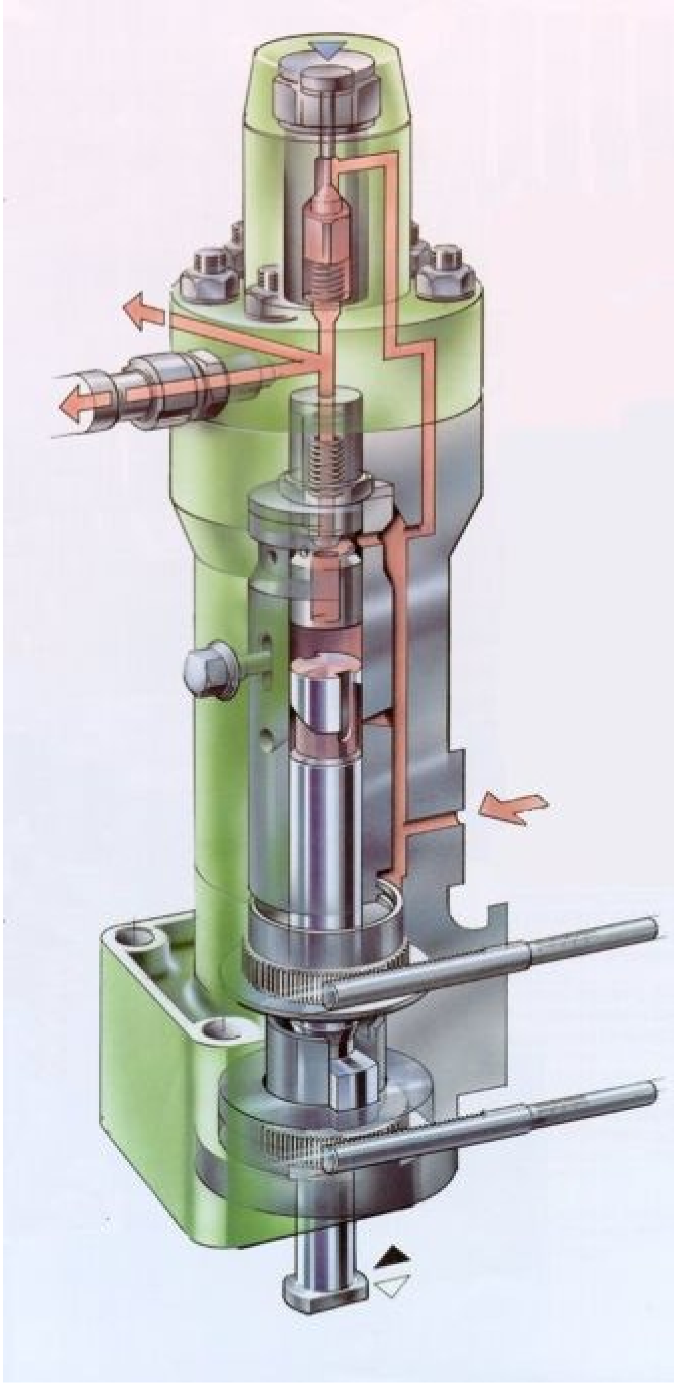
For some smaller thrust bearings, the wedges are machined into the bearing as shown. This photo illustrates the thrust bearing from a MAN B&W turbocharger.



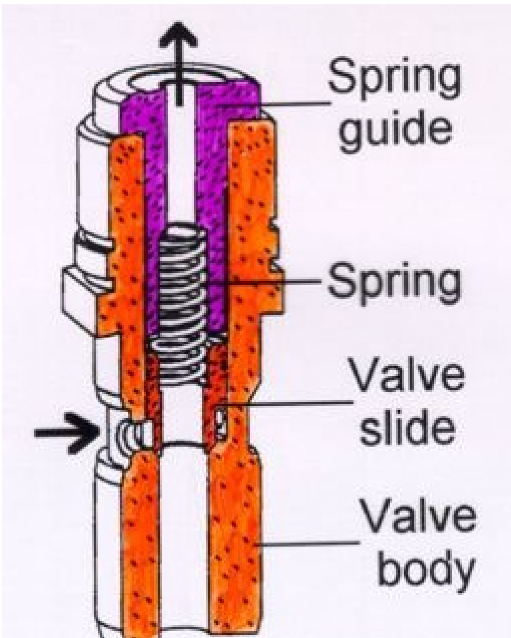
The MAN B&W MC Engine VIT Fuel Pump

The pump is basically a jerk type with a plunger moving in a matched barrel, using two helical grooves machined in the plunger to control the end of injection by uncovering spill ports and causing the discharge pressure to drop rapidly, thus causing the needle valve in the injector to close.

Oil is supplied to the barrel via the spill ports and a suction valve. The suction valve, situated at the top of the barrel opens when the pressure in the barrel falls below the supply pump pressure; i.e. during downward stroke of plunger, while spill ports are covered by plunger.



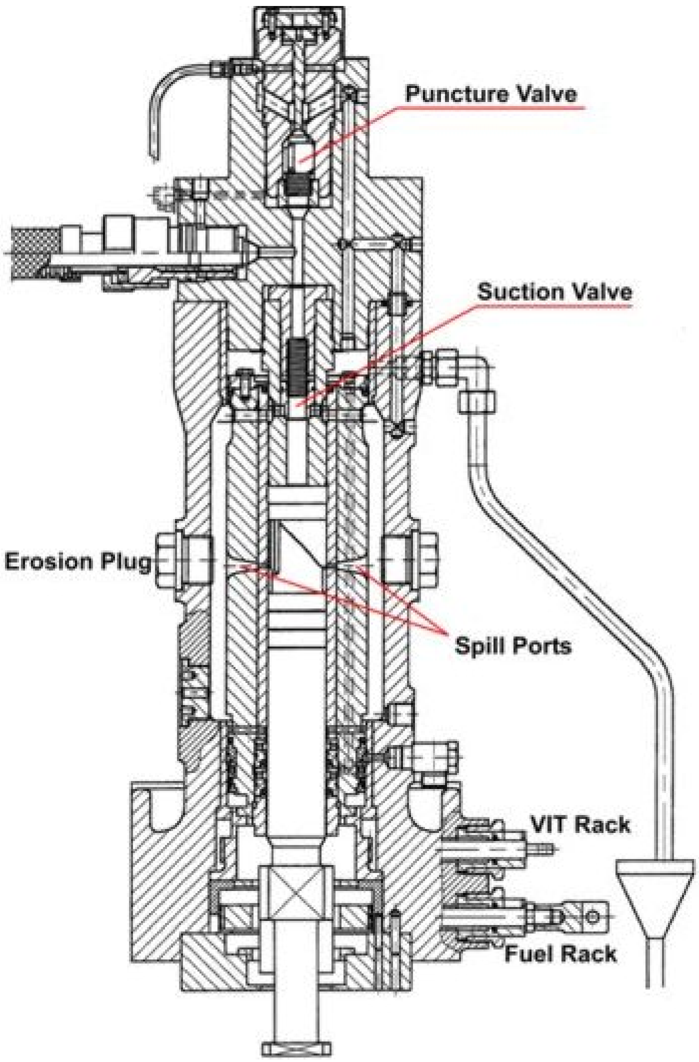
Replaceable erosion plugs are fitted in the pump housing opposite the spill ports. The high pressure oil, spilling back, as the edge of the helix uncovers the spill ports at the end of injection, hit the plugs, which prevent damage to the pump casing.

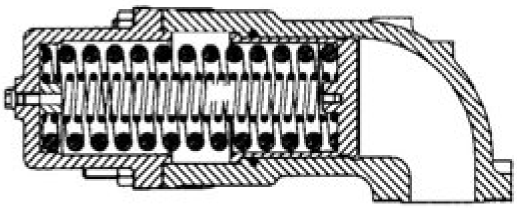


Suction Valve Detail

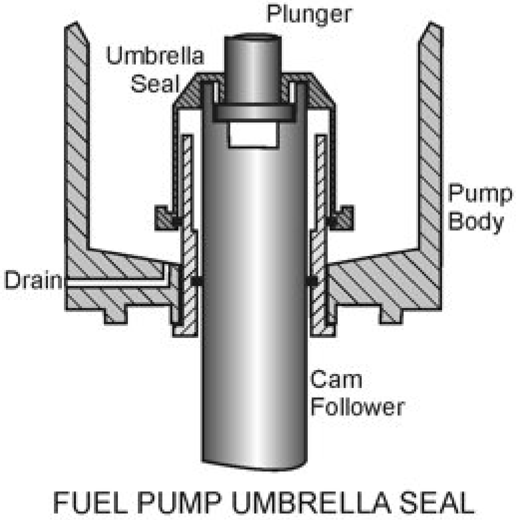
A puncture valve is fitted in the top cover of the pump. It is opened when compressed air from the control air system acts on top of a piston fitted in the top cover. Fuel oil from the discharge side is then returned to the suction side of the pump and no injection takes place. The puncture valve is operated in the event of actuation of the shut down system (all units), during the air start sequence or when excessive leakage is detected from the double skinned fuel pipes.

Fuel oil leakage past the plunger to the cam case is prevented by the use of an "umbrella" seal.





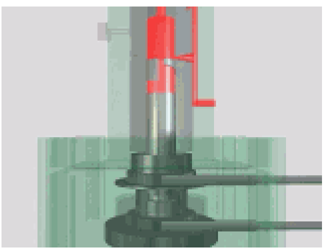
A spring loaded damper is fitted to the side of the pump connected through to the suction side of the pump. This smoothes out the pressure fluctuations as the high pressure fuel spills back at end of injection.



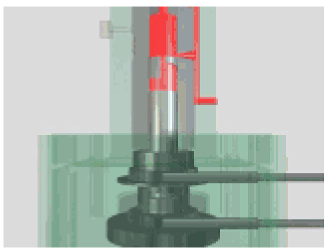
Variable injection timing (VIT)

The pump is capable of Variable Injection Timing (VIT). This overcomes the disadvantage of the basic jerk pump, where although the end of injection is infinitely variable, the start of injection is fixed by the position of the spill ports, injection commencing shortly after the ports are covered by the top edge of the plunger.

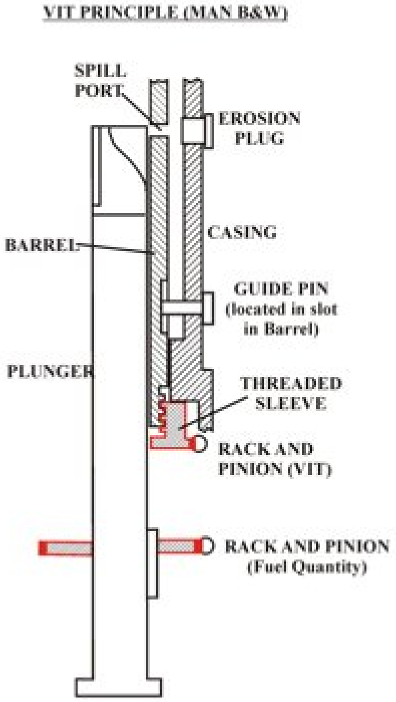
As well as having the normal fuel quantity control (i.e a rack which rotates the plunger in the barrel), the fuel pump is fitted with an adjustable barrel which has a large pitch thread machined on the bottom. The threaded barrel is located in a threaded sleeve which is rotated by a second rack. As the sleeve cannot move axially, and the barrel is prevented from rotating, then as the sleeve rotates, the barrel moves up and down, thus altering the position of the spill ports relative to the plunger, and varying the start of injection.



Quantity Control Using Fuel Rack



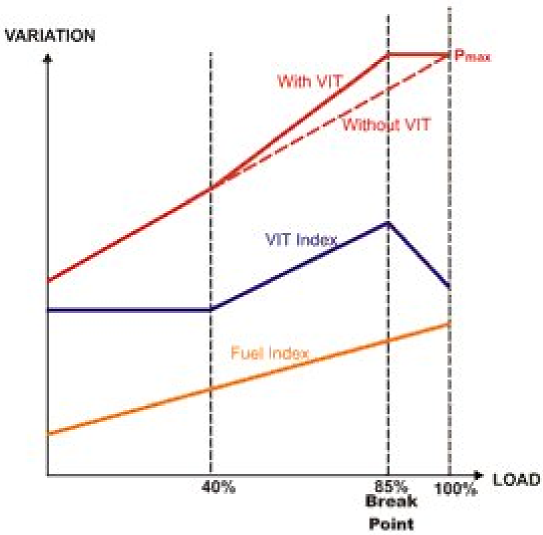
Timing Control Using VIT Rack



Fuel Quantity and VIT Linkages on Engine

Reason for using variable injection timing

The reason for using VIT is to achieve greater fuel economy. This is achieved by advancing the injection timing so that maximum combustion pressure (pmax) is achieved at about 85% MCR (maximum continuous rating).



Graph Showing Effect of VIT on Max Cylinder Pressure

The system is set up so that there is no change in injection timing at low loads (40%MCR). This is to avoid frequent changes of pump lead during manoeuvring.

As the engine load is increased above 40%, the start of injection advances. When the engine has reached approximately 85% MCR at which the engine is designed to have reached pmax, the servos retard the injection timing so that the maximum combustion pressure is kept constant between 85% and 100%MCR.

At 90% MCR a fuel saving of 4-5g/h.p.hour is claimed to be achieved.

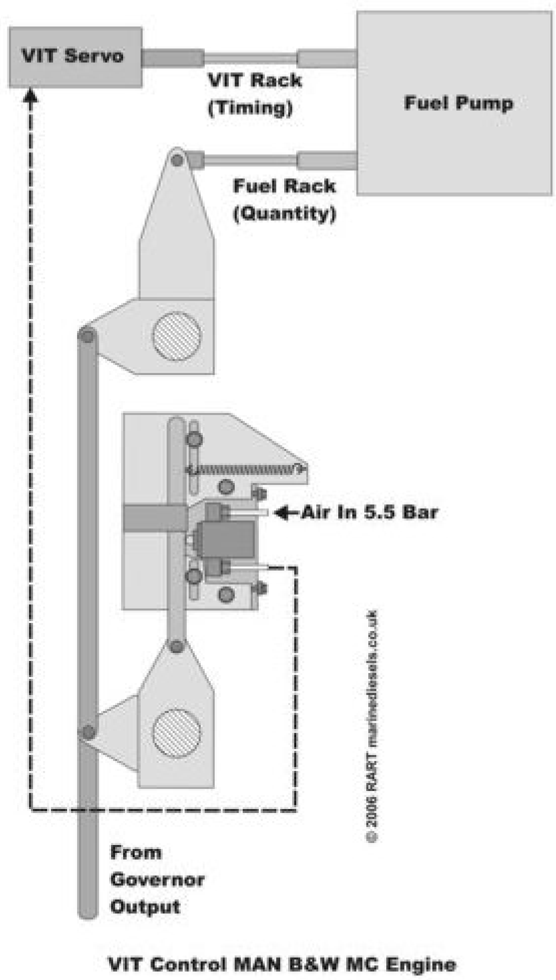
Variable Injection timing also allows for small adjustments to the fuel pump timing to be made to allow for fuels of varying ignition qualities. Wear on the fuel pumps can also be compensated for as can changes in the camshaft timing due to chain elongation (up to 2 degrees).

How variable injection timing is achieved?

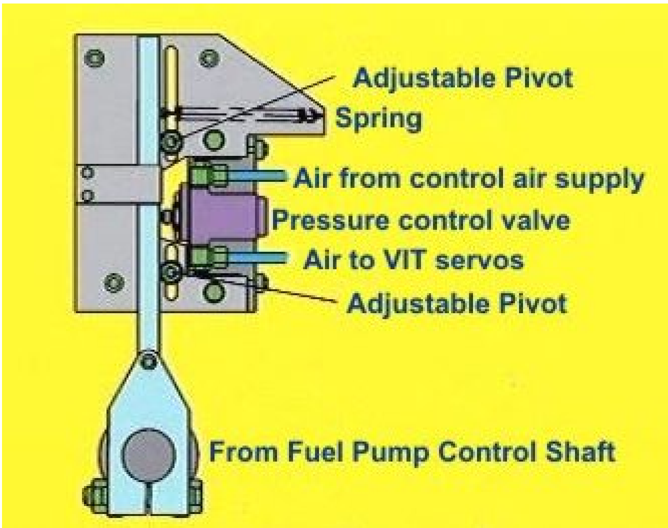
Low pressure air is fed to the pressure control valve, the output of which is fed to the VIT servos on the fuel pump. A link from the governor output (or fuel pump control handwheel) moves a pivoted bar, the position of which determines the output of the pressure control valve.

The position of the control valve is adjustable which can be used to allow for fuels of varying ignition qualities and changes in the camshaft timing due to chain elongation.

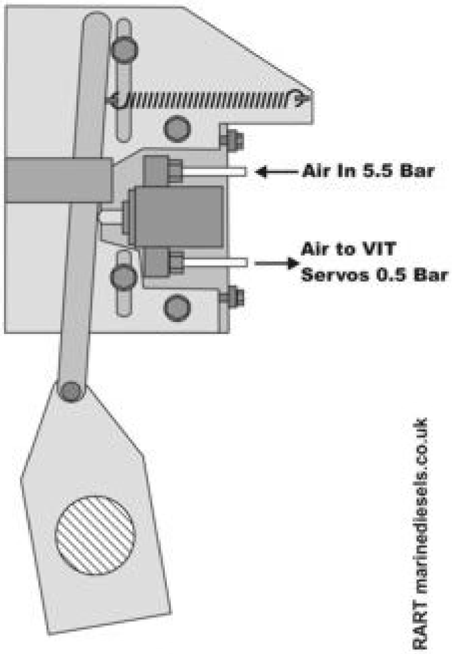
The pivots are also adjustable for initial setting up of the VIT and adjustment of breakpoint position.



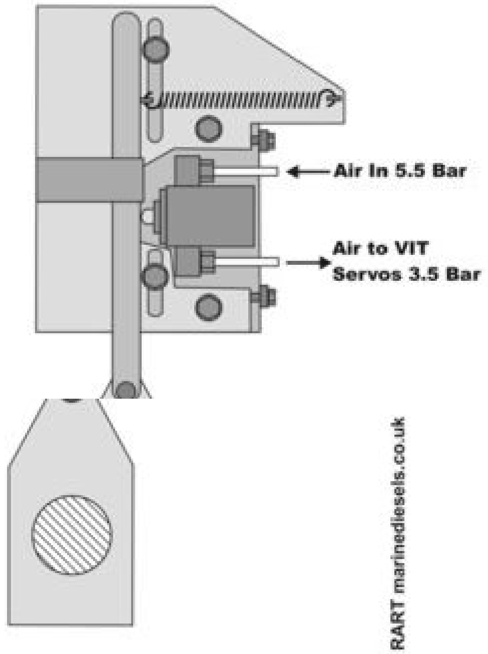
Linkage Between Fuel Quantity and VIT


Adjustable Pivot
Spring
Air from control air supply
Pressure control valve
Air to VIT servos
Adjustable Pivot
From Fuel Pump Control Shaft

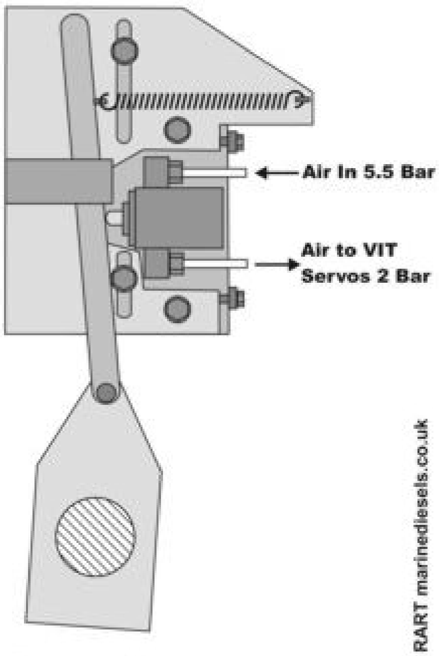
Position of VIT controller at various engine loads



Low Load Position
VIT Rack Setting
At Zero



Break Point Position
Approx 85% MCR
VIT Rack Setting
at about 9



Full Load Position
100% MCR
VIT Rack Setting
At about 5

Fuel pumps mounted on the smaller MC engines are not fitted with Variable Injection Timing.