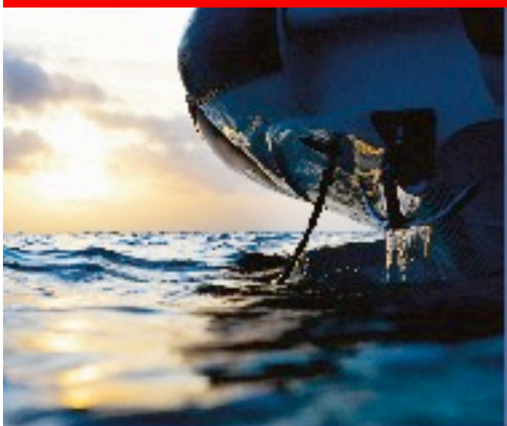
MARINE DIESELS ENGINEERING

ENGINEERING COURSE NOTES



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Second Engineer - Syllabus

Marine Diesel Engineering

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1. **Engine working principles**

   a) Basic working principles of compression ignition (diesel) and spark ignition(petrol) type engines
   b) Working principle of 4 stroke diesel engines:
      i. 4-stroke diesel engine cycle
      ii. 4-stroke diesel engine timing diagram
      iii. 4-stroke diesel engine PV diagram
      iv. Relationship between the 4-stroke timing diagram and PV diagram
      v. 4-stroke scavenging process
      vi. Explanation and reasons for valve overlap
      vii. 4-stroke air start timing (begin and end)
   c) Basic knowledge of power balancing an engine
   d) Combustion requirement (viscosity, atomization, penetration)
   e) Diesel engine combustion process
   f) Basic knowledge of importance of monitoring the combustion process
   g) Basic knowledge of peak pressures and indicator diagrams

2. **Turbochargers and superchargers**

   a) Principles and reasons for turbo-charging and supercharging
   b) Turbo - charger construction, components (turbine, blades, air intake filters, compressor, bearing types
   c) Pulsed turbocharger system
   d) Constant pressure turbocharger system
   e) Sequential (multistage) turbocharger system
   f) Reasons for charge air cooling
   g) Construction of charge air coolers
   h) Super charge system performance - assessment

3. **Engine construction**

   a) Constructional details of medium and high speed, diesel engines used for main propulsion, electrical power generation and other auxiliary purposes
   b) Engine bedplate, block / entablature and tie bolts
   c) Holding down arrangements; bolts; resin chocks, resilient (flexible) mountings

d) Crankshafts (solid forged, grain flow) and main bearings (bearing shells, materials, plain and thrust bearings, lubrication arrangements)

e) Axial vibration damping arrangements

f) Camshafts; camshaft drives, bearings, connecting rods (top and bottom end bearings, lubrication); cylinder liners; solid and composite pistons

g) 4-stroke pistons, construction, crown, skirt, materials, cooling, gudgeon pin

h) Piston rings (theory of working; types, compression, oil control, clearances, sealing)

i) Cylinder heads (cooling; push rods; inlet valves; exhaust valves; fuel injectors; safety valves; air start valves; indicator cocks)

j) Setting tappet clearance. Effects of too small and too large tappet clearances

k) Flywheel, turning gear, barring over arrangements

l) Materials and processes (casting, forging, fabrication etc.) commonly used in the manufacture of the engine constructional components

m) Engine formats used in construction, including in-line (straight), V-type

4. Basic principles of simple hydraulic and electronic governors

5. Engine safety and protection

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b) Air start system (direct) safeties (automatic non return valve), manifold drain cocks, flame arrestor manifold safety devices

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d) Oil mist detectors

e) Turning gear interlocks for starting system

6. Fuel oil supply arrangements.

a) Principles and operation of the following:

b) Basic distillate fuel oil system, layout and components (storage bunker tanks, settling tanks; centrifugal separator, day or service tank, transfer pumps, LP supply pumps, HP circulating or booster pumps, filters)

c) Engine fuel components (fuel rail, individual HP pump [Bosch or jerk type], multiple HP fuel pump blocks, HP fuel pipes [double sheathed], fuel injectors, spill return, spill return fuel coolers)

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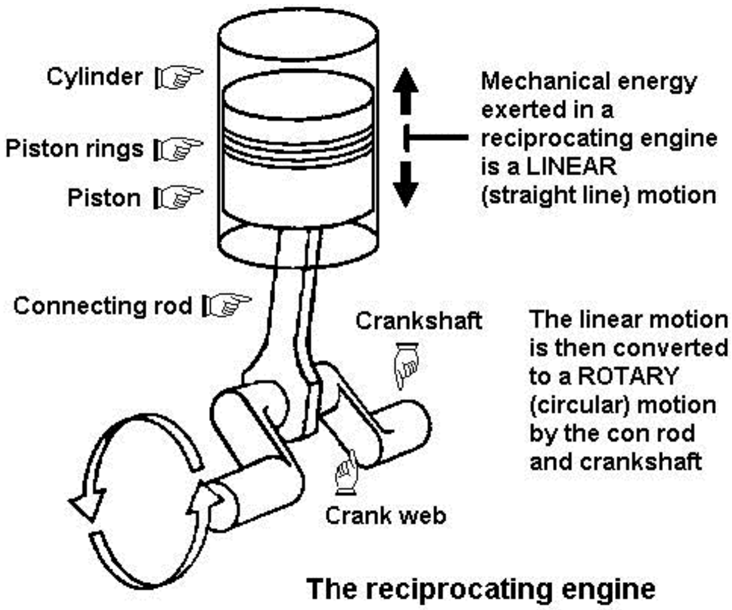
SECTION 1- Diesel Working Principles

The reciprocating engine

Engine classification

Engines may be classified in a variety of different ways.

Irrespective of the engine type a reciprocating engine commonly operates on a continually repeated cycle in which fuel and air are drawn into the combustion space, ignited, burnt and the waste discharged (exhausted).



The reciprocating engine

Classification by cycle

With either the petrol or diesel engine there are two types of engine cycle:

1 The two stroke cycle

2 The four stroke cycle

Classification by speed

There are no rules that govern engine speed, but as a 'rule of thumb' the following generally holds true:

- Slow speed engines, up to 250 revs/min
- Medium speed engines, 250 – 1000 revs/min
- High speed engines, over 1000 revs/min

Classification by piston format

The most common piston arrangements may be either:

1 In-line (or straight) piston

2 V-format piston

3 Opposed piston (rarely found as propulsion engines)

Classification by fuel used

The engine may commonly be powered by either:

1 Petrol

2 Diesel

The petrol engine

(Note that it is illegal to use petrol as a fuel on a ship (ref SOLAS) because of its low flash point (about 36°C). National Administrations (such as MCA) may give exemptions to this law.)

The petrol engine has to mix the air and fuel to form a combustible gas **before** it enters the engine. In order for the air and fuel to be mixed correctly the mixture must be atomised, that is broken up into fine particles, and this operation is achieved in the **carburetor or by fuel injection**.

The petrol engine is defined as a **spark ignition engine**, as it requires a spark (generated electrically) to ignite the fuel/air mixture.

This is achieved by the spark plug in which a high voltage electric current 'jumps' the gap between the electrodes. The resulting spark ignites the fuel mixture at precisely the correct moment on the compression stroke.

The diesel engine

The diesel engine is defined as a **compression ignition engine**, as the fuel is ignited by air compressed to a sufficiently high temperature.

In the diesel engine, air is drawn into the cylinder and compressed which causes it to become very hot at a high pressure. At the correct moment a metered quantity of fuel is injected under pressure into the cylinder. The fuel vaporises and mixes with the air. The resulting mixture then ignites in the hot compressed air. No electrical ignition is required for the fuel mixture to ignite in the diesel engine.

Valves and ports

The four stroke version diesel engine has air **inlet valves** and **exhaust valves** fitted in the cylinder head. The valves, which control the entry and discharge of the fuel mixture and the exhaust gases, are external components operating in the cylinder head.

The two stroke version engine does not have inlet valves but uses air inlet ports. These are radial openings in the cylinder liner that are covered and uncovered by the movement of the piston. This version of the engine may be fitted with **exhaust valves**, or with **exhaust ports**, which are openings in the cylinder liner, similar to the air inlet ports.

Important terminology

Force

Force is the influence that tends to change the motion or direction of a body at rest or in motion. A simple explanation is pushing or pulling.

Therefore, applying a force would either:

- Start moving a body from rest or bring a moving body to rest.
- Increase or decrease the speed of a moving body.

- Change the direction of motion of a moving body.

Force is measured in newtons (N).

Work

Work is the use of energy to overcome resistance. The amount of work done is moving an applied force through a distance. The unit of measurement of doing work is the joule.

With work force is measured in newtons (N) and distance is measured in metres (m). Therefore:

- Work = Force x Distance (joules)

Therefore work would be in newton metres (Nm).

To prevent confusion between 'work' and 'torque' (see next item), the unit given to the formula for work is the joule.

- 1 newton metre = 1 joule.

Torque

Torque is when a force tends to cause a movement about a point. Torque is also called a turning or twisting effort. Therefore:

- Torque = Force x Distance (Nm)

Torque is the force exerted and not moved over a distance, but a movement or twisting about a point.

With torque force is measured in newtons (N) and distance is measured in metres (m). Torque is therefore measured in newton metres (Nm).

As an example, the force on the piston of an engine exerts a turning moment, or torque, on the crankshaft.

Power

Power is the amount of work done or energy expanded in a given time.

Power is also expressed as the capacity to do work. The unit of measurement of power is the watt (W). A watt is the power used when energy is expended or work done at the rate of one joule per second.

- 1 watt = 1 joule/second

$$\textbf{Power} = \frac{\textbf{Force(N) x Distance (m)}}{\textbf{Time (second)}} \quad \textbf{(joules/second) or (watts)}$$

As force is in newtons (N), distance in metres (m), and time in seconds (s), the answer will be in newton metres per second or joules per second.

However, as one joule per second equals one watt, the units used for power is watts.

The power of an engine is commonly measured in kilowatts (kW) rather than watts (W).

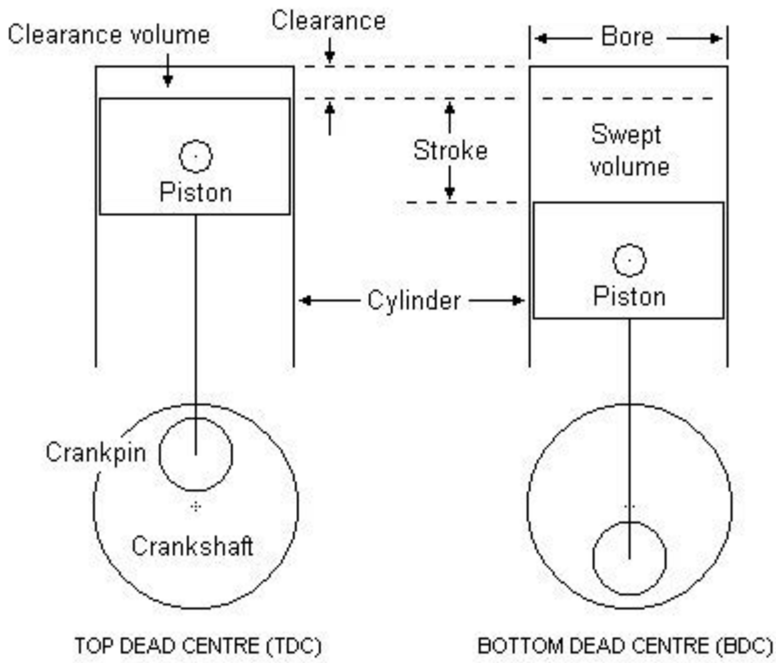
- 1000 W = 1 kW Note: For conversion 1 horsepower = 74.6 Watts

Top dead centre

When the piston is at the limit of its upward travel in the cylinder, it is said to be at the **top dead centre** (TDC).

Bottom dead centre

When the piston is at the limit of its downward travel in the cylinder, it is said to be at the **bottom dead centre** (BDC).



Terminology

Stroke

The vertical distance travelled by the piston between TDC and BDC is called the stroke.

Total volume (Vt)

The total volume is the volume of the cylinder above the top of the piston when the piston is at BDC.

Swept volume (Vs)

This is the volume swept or covered by the piston when moving in the cylinder through its stroke (or from BDC to TDC). Sometimes swept volume is referred to as displacement volume.

Swept volume (Vs) = the piston area x the stroke.

Clearance volume (Vc)

The clearance volume is the space left between the piston at TDC, and the cylinder head.

Clearance volume (Vc) = Total volume (Vt) – Swept volume (Vs)

Compression ratio (r)

The compression ratio is the ratio of the volume of the gas at the beginning of compression to the volume at the end of compression.

$$\text{Compression ratio (r)} = \frac{\text{Total volume (Vt)}}{\text{Clearance volume (Vc)}}$$

or

$$\text{Compression ratio (r)} = \frac{\text{Swept volume (Vs)} + \text{Clearance volume (Vc)}}{\text{Clearance volume (Vc)}}$$

Volumetric efficiency

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

Net specific energy (NSE)

Fuel contains a specific amount of heat energy that is released when the fuel is burnt. This energy may be converted into work energy.

The correct term, when using the SI system, for the amount of heat energy in a fuel that can be converted to work is the net specific energy (NSE).

Net specific energy may be measured in:

- joules / kilogram J / kg
- kilo-joules / kilogram kJ / kg
- mega-joules / kilogram MJ / kg

Note that this measured energy was known as the calorific value of the fuel. Calorific value is not an SI system term. As a consequence the term calorific value is obsolete and should not be used.

Thermal efficiency

Thermal efficiency is the ratio of work done at the flywheel to the amount of heat energy, (NSE), contained in the fuel. Thermal efficiency is expressed as a percentage.

Turbulence or swirl

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

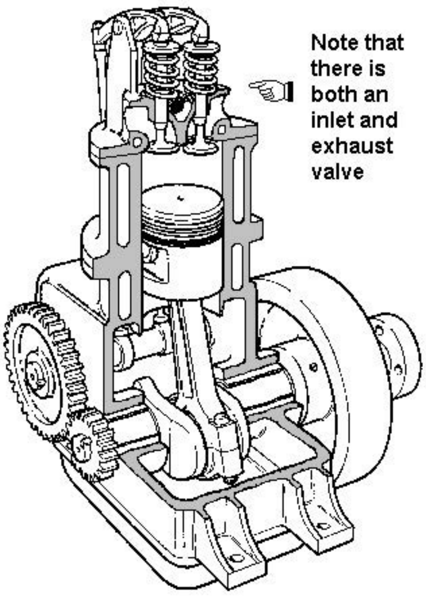
Engine working principles

Diesel engine cycles

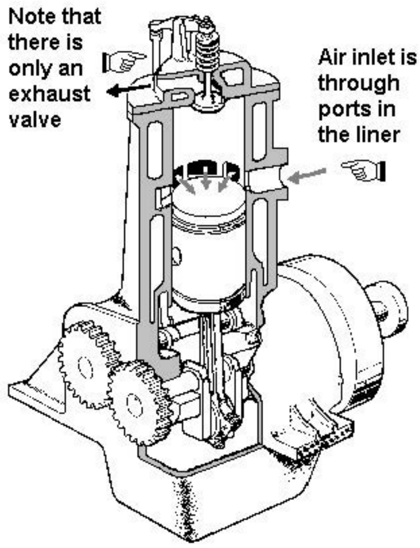
There are basically two types of diesel engines. Each engine type operates using its own cycle of operation, which are known as:

1 The two stroke cycle.

2 The four stroke cycle.



A basic 4-stroke diesel engine



A basic 2-stroke diesel engine

The revised (2016) Small Vessel Engineer Syllabus does not cover the 2 – stroke cycle

4 stroke diesel engine cycle

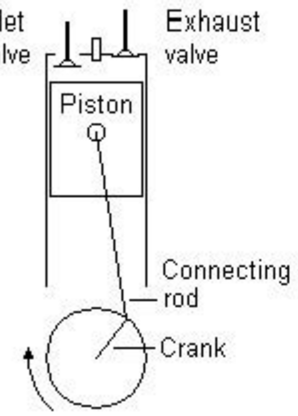
Engine strokes

In a 4 stroke cycle engine, for each cylinder:

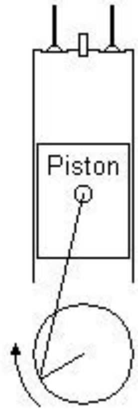
- Four strokes of the piston are required to complete one cycle.
- There is one power stroke for every two revolutions of the crankshaft.
- A cycle is completed in two revolutions.

In a 4 stroke cycle engine, four strokes of the piston are required to complete one cycle, the strokes being known as:

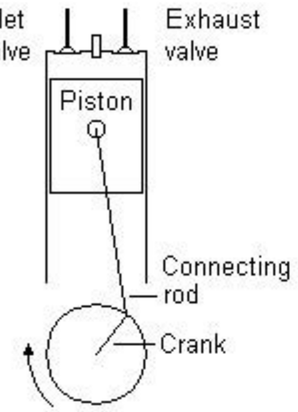
1. Suction (or induction)
2. Compression
3. Power (or expansion)
4. Exhaust



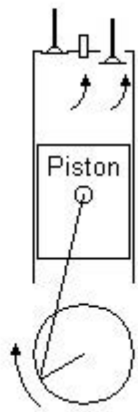
1 Suction



2 Compression



3 Expansion



4 Exhaust

Figure 1

Suction or induction stroke. Piston on down-stroke. Inlet valve open, air drawn into cylinder.

Figure 2

Compression stroke. Piston on up-stroke. Inlet and exhaust valves closed, air compressed to high temperature in cylinder.

Figure 3

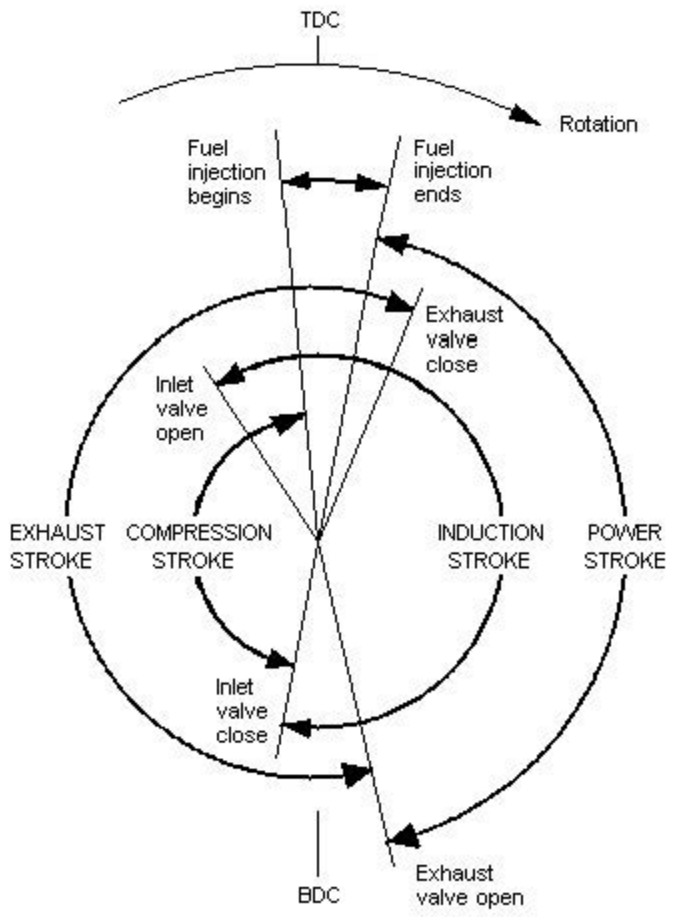
Power or expansion stroke. Piston on down-stroke. Fuel is injected before TDC and is ignited by the compressed gasses.

Inlet and exhaust valves closed, combustion, expanding gases force piston downwards.

Figure 4

Exhaust stroke. Piston on up-stroke. Exhaust valve open, waste gases exhaust from cylinder.

Basic 4 stroke timing diagram



The diagram illustrates the main processes, but does not specific include angles.

The actual opening and closing of the inlet and exhaust valves and the period of injection of the fuel can be taken from the timing diagram.

Timing diagrams will vary between engine models and manufacturers.

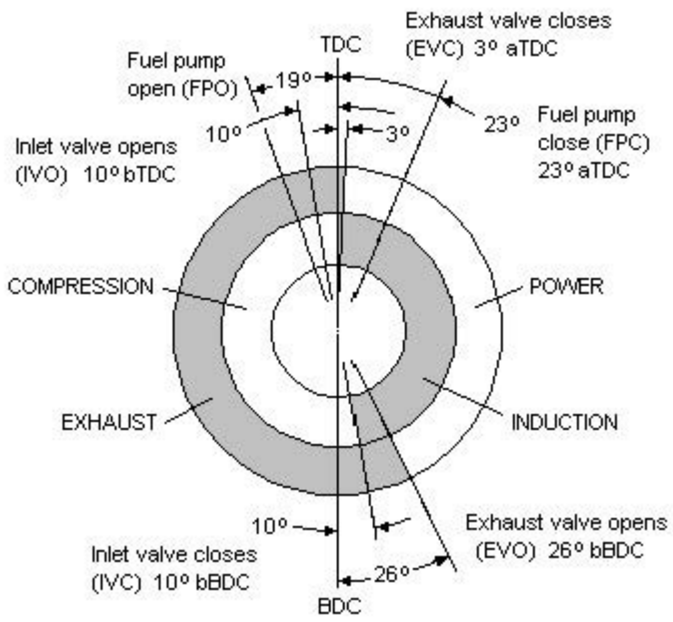
Turbocharged engines

Timing diagrams shown are for particular types of engines, and timing diagrams may vary from manufacturer to manufacturer, a lot depending on the various designs.

There is a distinct difference in timing diagrams between normally aspirated and turbocharged engines. In turbocharged engines the exhaust requires to be opened a lot earlier to drop exhaust pressure quickly before air entry and also requires to be open for a longer period to allow the discharge of the greater gas mass.

This longer open period will also improve the scavenging effect and provide a pronounced cooling effect which either reduces or maintains mean cycle temperature to within acceptable limits even if the loading maybe increased.

4 stroke timing diagram with angles



- The suction, or induction, stroke commences when the inlet valve opens 10° TDC and air is drawn into the cylinder as the piston moves down.
- The inlet valve closes 10° before BDC.
- The air is now trapped in the cylinder and as the piston rises on the compression stroke, the air is compressed.
- When the air is compressed, the temperature rises.
- When the piston reaches 19° before TDC, the injection of fuel commences and continues until 23° after TDC.
- The heat in the compressed air ignites the fuel and combustion takes place.
- The gases expand forcing the piston down on the power stroke.
- The exhaust valve opens at 26° before BDC and the exhaust gases are discharged as the piston rises on the exhaust stroke. Most of the exhaust gases have been discharged as the piston nears TDC.
- At 10° before TDC, the inlet valve opens and air enters the cylinder and helps discharge any remaining exhaust gases until the exhaust valve closes at 3° after TDC.
- The whole cycle is repeated.

Valve overlap

Valve overlap is the period that both the inlet valve and exhaust valve are **open at the same time.** The inlet valve opens before top dead centre (TDC), at around 10° and the exhaust valve closes after TDC, at around 35°. The opening of the inlet valve overlaps the closing of the exhaust valve. The valve overlap in this case would be 45°.

The purpose of valve overlap is to ensure that the exhaust gases are discharged from the cylinder and the cylinder receives a fresh charge of air to make it more efficient when combustion next takes place. Valve overlap also increases the cooling effect.

Scavenging

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

Introduction

There are basically two types of indictor diagram that may be taken:

1 **The pressure-volume diagram (PV diagram)**

2 **The fuel pressure diagram**

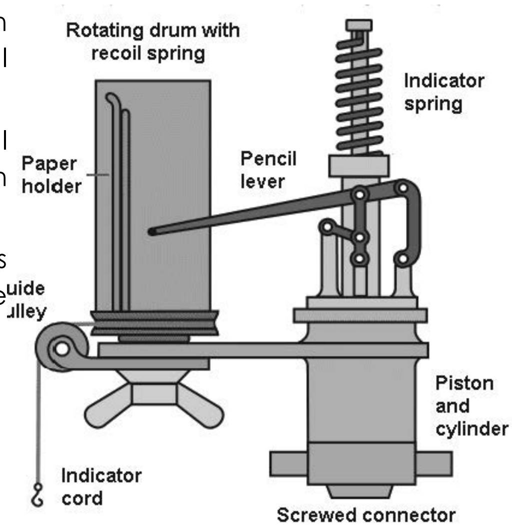
PV diagrams will be described first in this section, then fuel oil (FO) pressure diagrams.

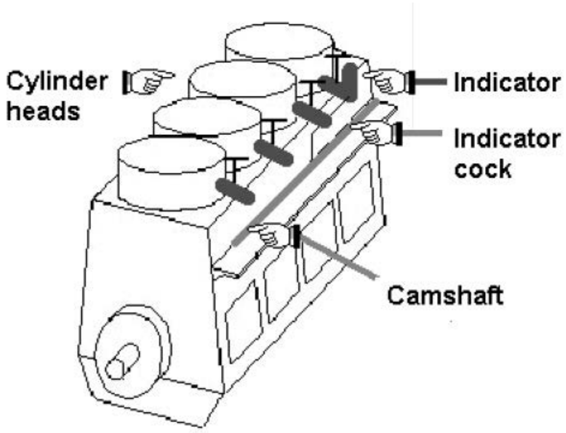
The mechanical indicator

Traditionally indicator diagrams have been taken manually using a mechanical instrument called an **indicator**.

The indicator is screwed onto a special valve, called the indicator cock, fitted on the cylinder head.

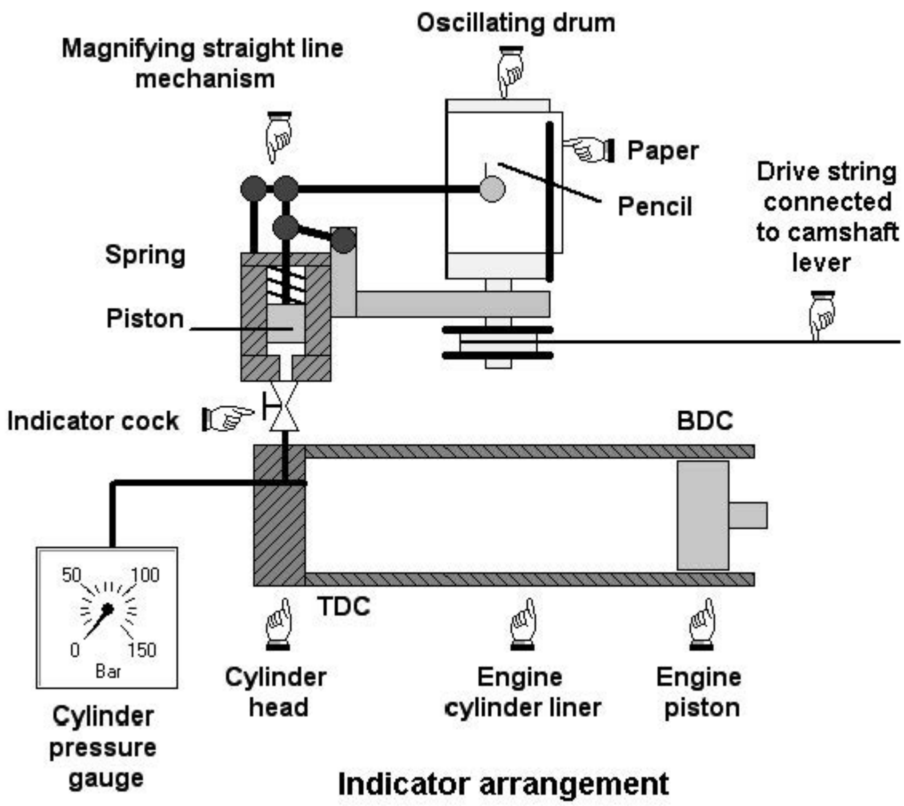
The cylinder combustion gas pressure is directed through the indicator cock to the indicator.





The oscillating drum is connected (by some mechanical device such as a cord) to a moving part of the engine, such as a lever on the camshaft.

This moves the indicator drum in time with the piston stroke.



Indicator arrangement

The mechanical indicator has become more or less obsolete and has been replaced by electronic devices because:

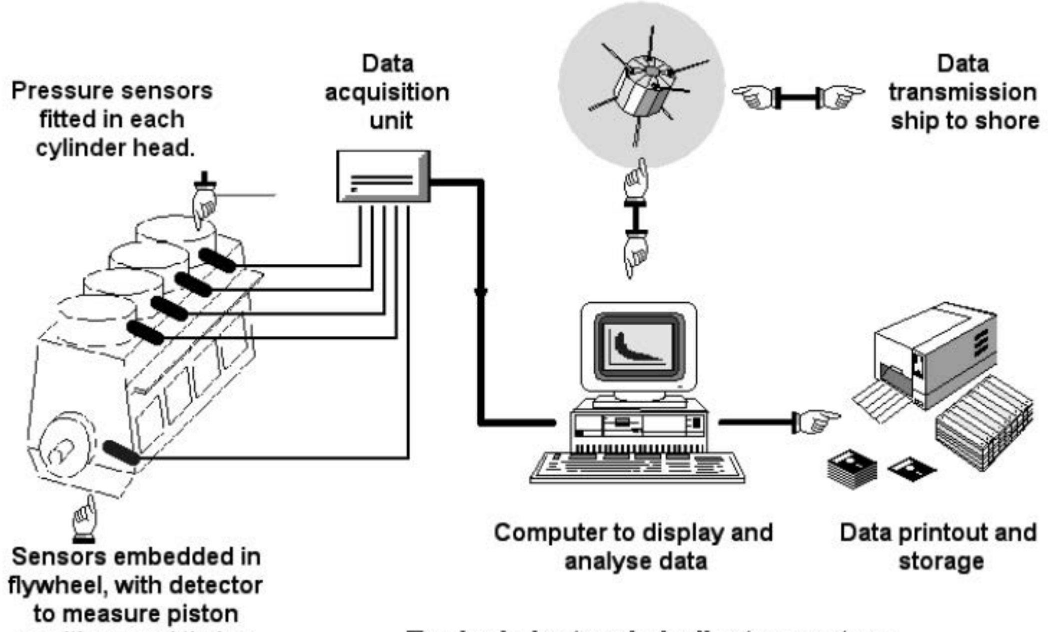
- The quality and accuracy of the diagrams is very dependent on the skill of the engineer taking the cards;
- It can take up to 2 to 3 hours to get a good set of diagrams;
- The mechanical indicator is difficult to use on engines with a speed greater than (about) 150 revs/min;
- With a computer and electronic technology the operation is more accurate, more reliable and quicker.

The electronic indicator

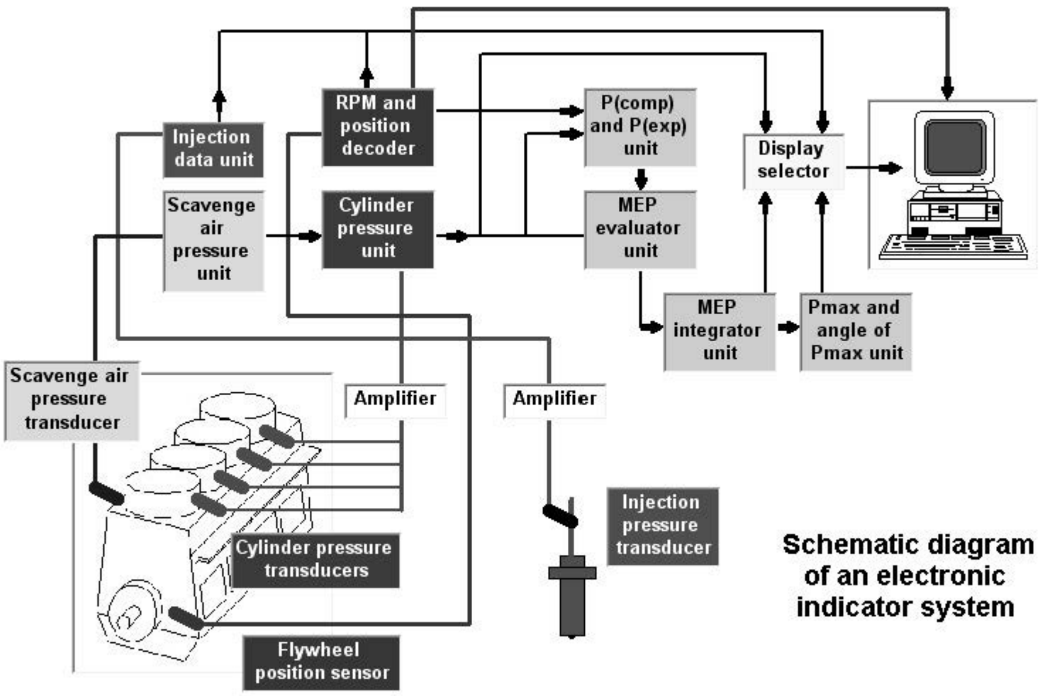
Indicator diagrams are now commonly taken using an electronic system. With the aid of a computer the data can be easily manipulated to analyse the combustion process.

The electronic indicator may be a portable unit, or a fixed installation. The system includes two other components:

- The pressure sensor (attached to the indicator cock);
- The timing device (commonly from the flywheel)



Typical electronic indicator system



Schematic diagram of an electronic indicator system

PV diagrams

Diagram functions

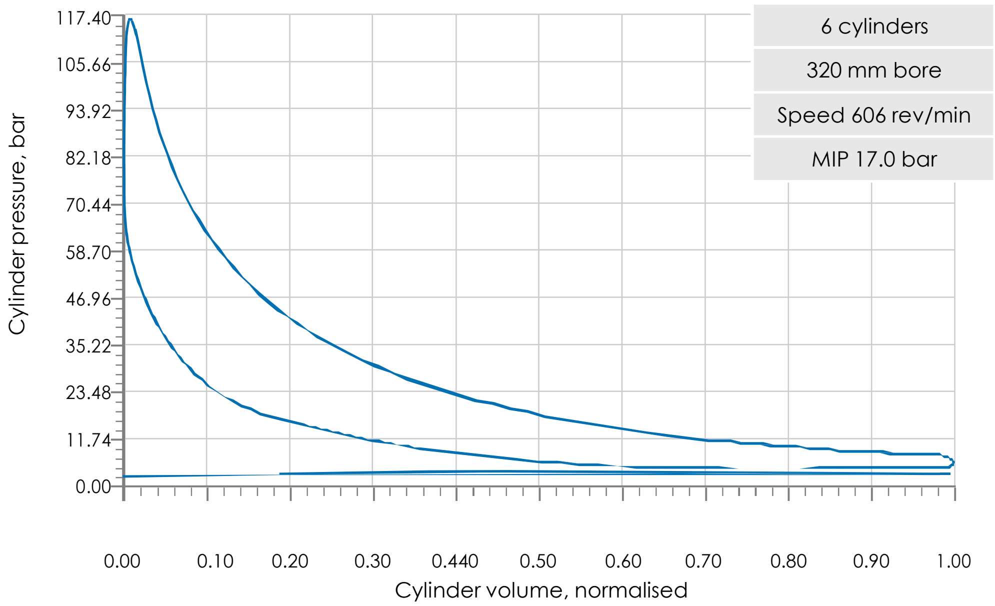
The **pressure-volume diagrams** have several functions, including:

- To monitor and analyse the condition of the engine;
- To monitor and analyse the combustion process of the engine;
- To monitor and analyse the timing of the engine;
- To measure the total power, the useful power, and non-useful power;
- To measure the peak pressure and angle of peak pressure;
- To measure the mean effective pressure (MEP);

Types of PV diagram

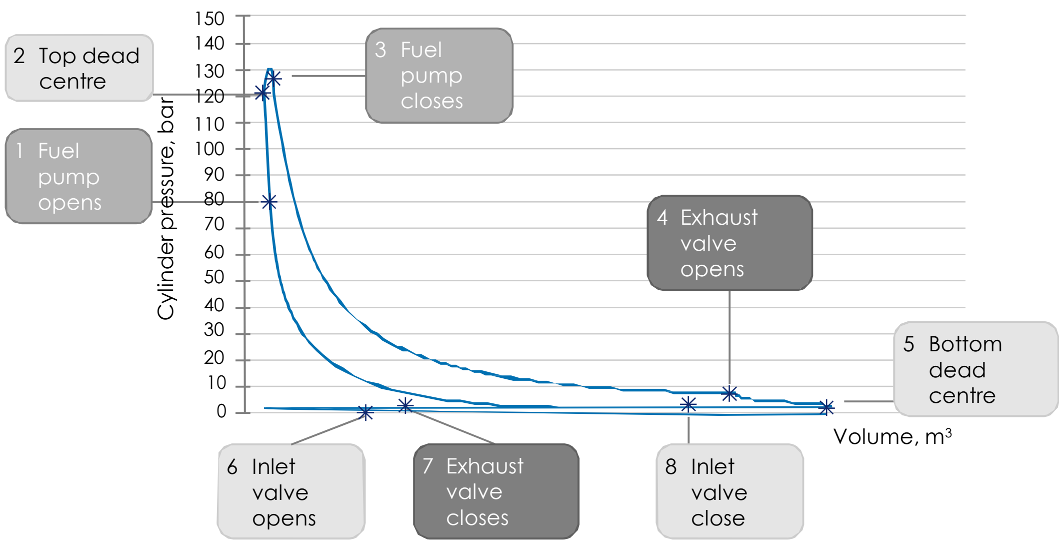
The pressure volume diagram.

The PV diagram is a plot of the engine cycle, the plot being **combustion pressure (P)** against the **cylinder volume (V).**



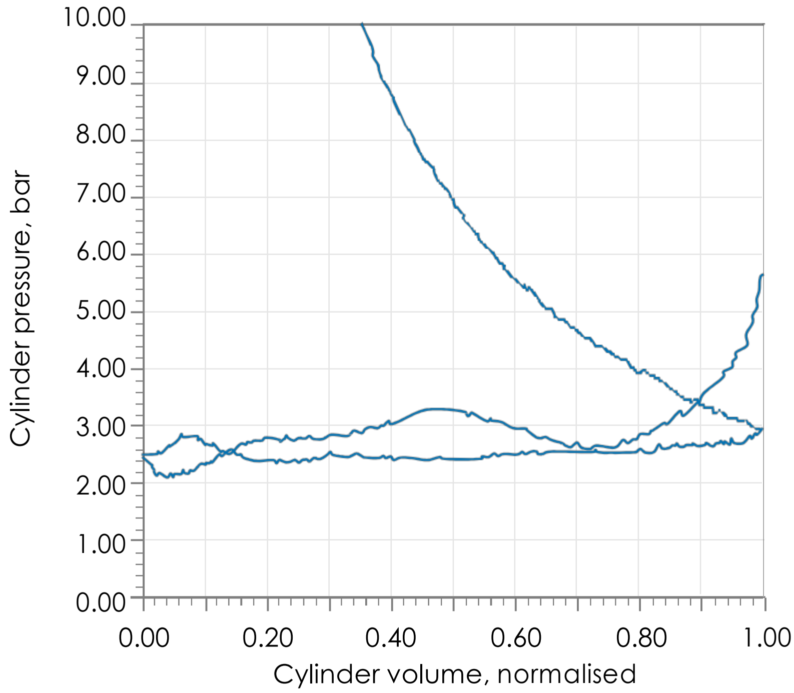
A 4 stroke engine PV diagram

Main events, 4 stroke engine



The light spring diagram.

The light spring diagram is an expanded view of the lower part of the pressure scale of the PV diagram, to show the **scavenging process** in greater detail.



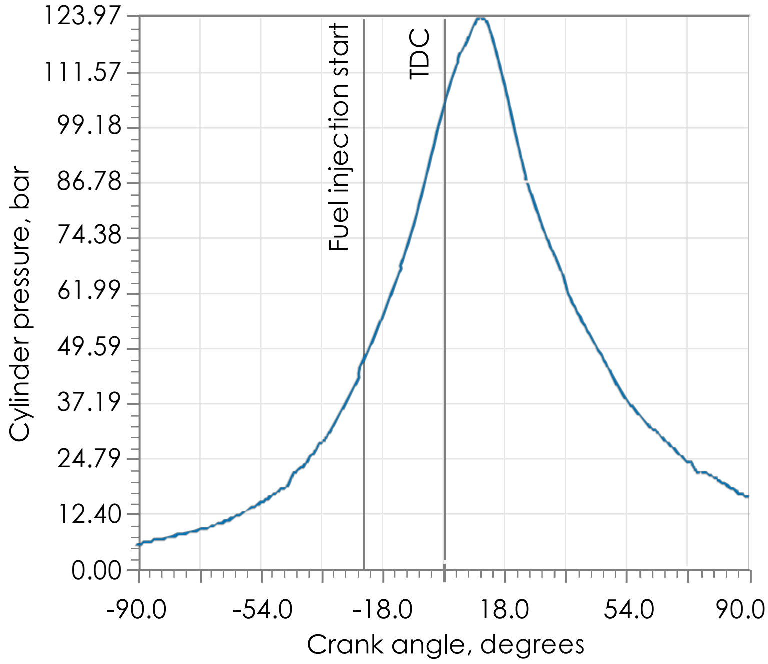
6 cylinders
320 mm bore
Speed 606 rev/min
MIP 17.0 bar

The resolution of the vertical pressure scale may vary, to give more detail. This plot shows the pressure from 0 to 10 bar, max pressure being 117 bar.

Light spring diagram for 4 stroke engine

The draw card.

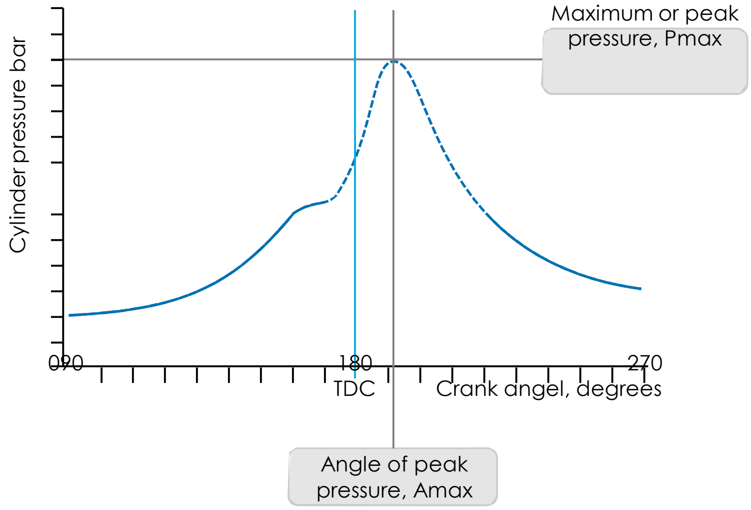
The draw card (sometimes known as the open card) is an expanded view of the combustion process, and is commonly a plot of **combustion pressure (P)** against the **crank angle (alpha)**.



6 cylinders
320 mm bore
Speed 606 rev/min
MIP 17.0 bar

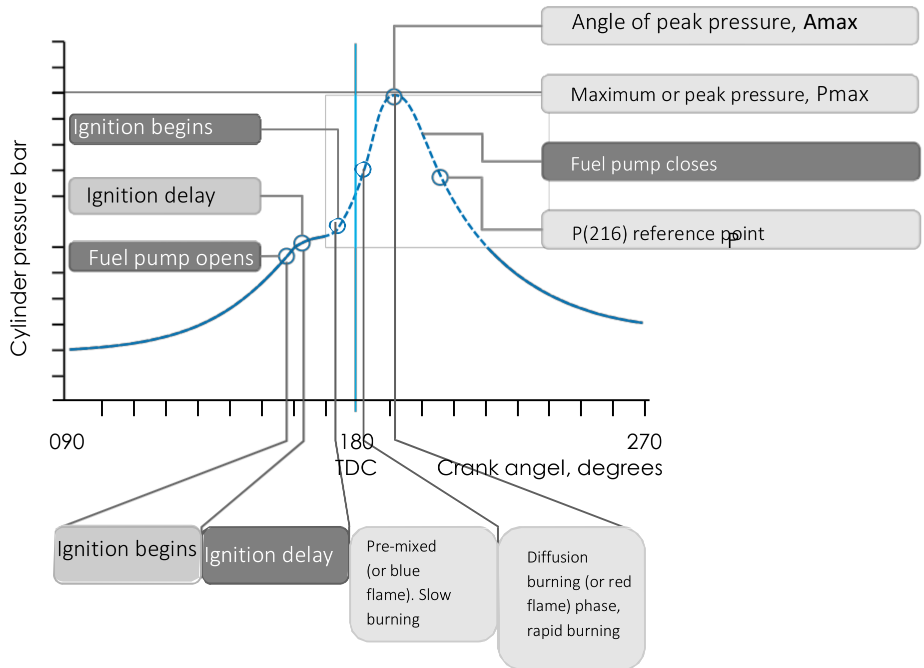
This plot shows an expanded plot of 180 degrees crank angle about TDC

Draw card,
4 stroke engine



Theoretical draw card

The draw card is probably the most useful for the analysis of the combustion process and its timing. Note that the horizontal scale of the diagram is crank angle, and not cylinder volume as with the PV diagram



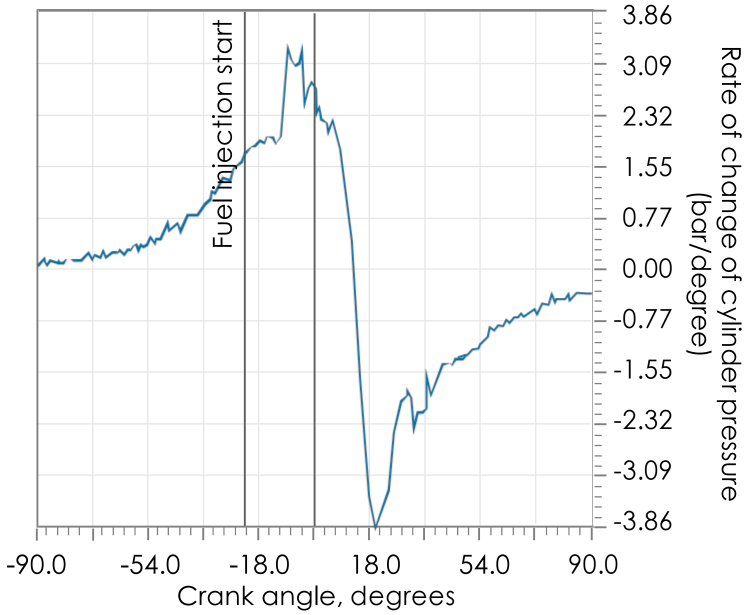
Events during combustion as shown on a draw card

The delta P diagram.

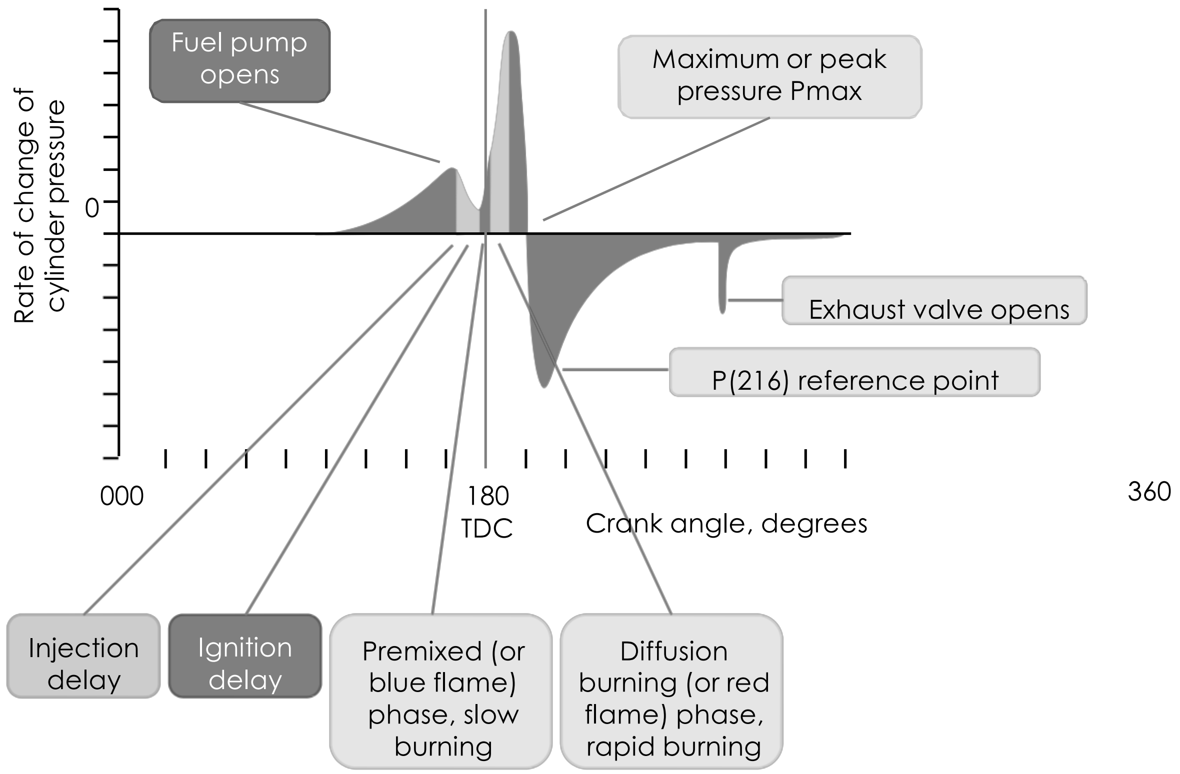
This is a plot of the engine cycle, the plot being the rate of change of **combustion pressure (P)** against the crank angle (alpha).

6 cylinders
320 mm bore
Speed 606 rev/min
MIP 17.0 bar

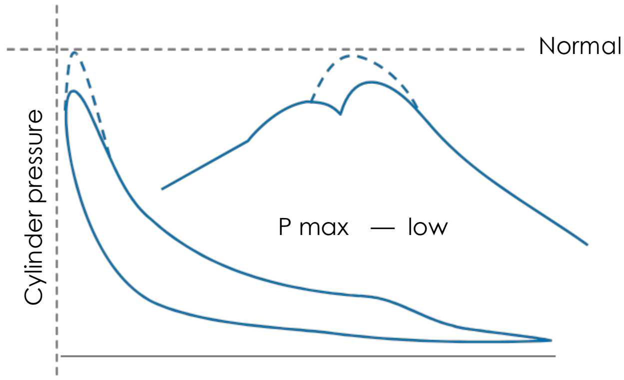
This plot shows an expanded plot of 180 degrees crank angle about TDC



Rate of change of pressure diagram, 4 stroke engine

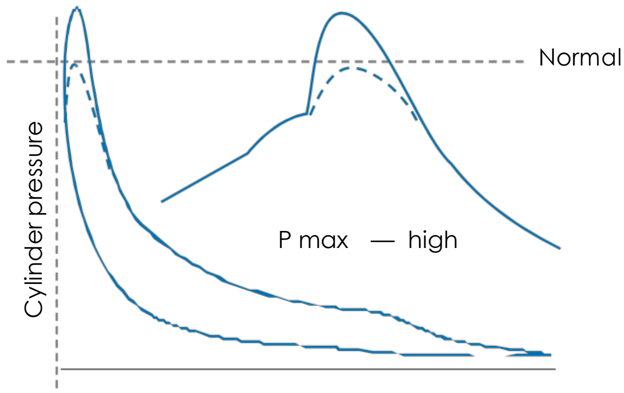

Fuel pump opens
Maximum or peak pressure Pmax
Rate of change of cylinder pressure
0
Exhaust valve opens
P(216) reference point
000
180
TDC
360
Crank angle, degrees
Injection delay
Ignition delay
Premixed (or blue flame) phase, slow burning
Diffusion burning (or red flame) phase, rapid burning

Fault detection

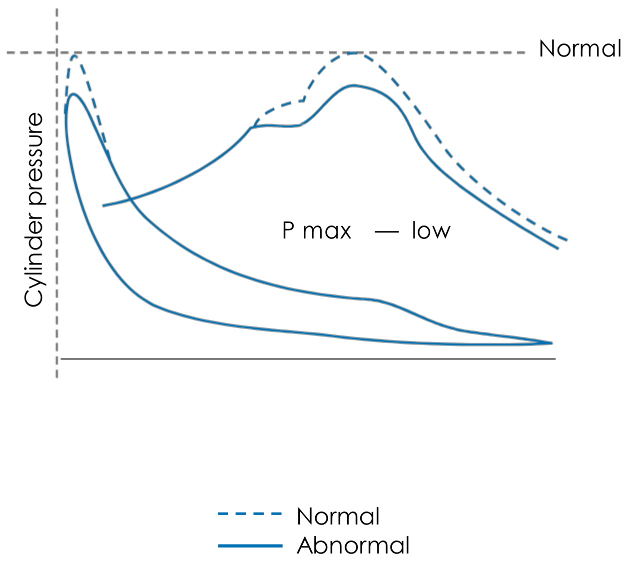


Low pressure Worn rings/ liners Burned/damaged valve seats

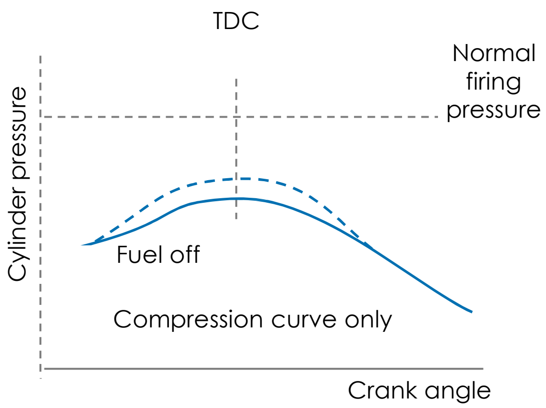
Failed valve spring



Early fuel injection knock may occur due to combustion commencing prior to T.D.C. trying to force piston downwards against inertia



Late fuel injection
After burning may occur High exhaust temperatures or scavenge fires

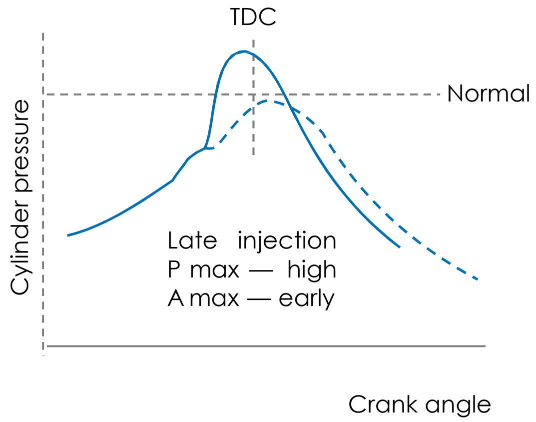


Compression diagram

The diagram is taken with the fuel shut off the cylinder, just giving the compression line.

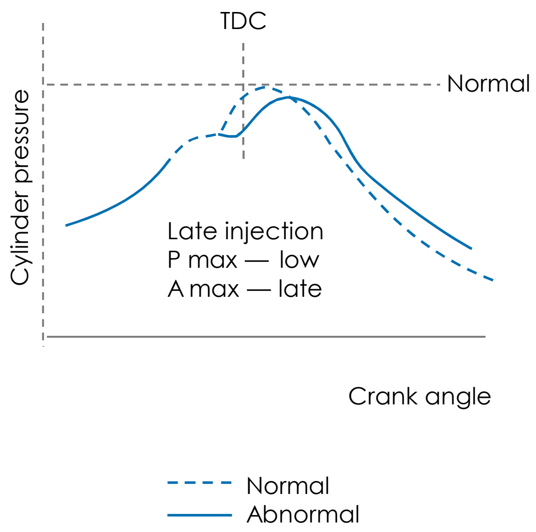
If the compression line is low it would possibly indicate:

- **Worn rings,**
- **Worn liner,**
- **Burnt or damaged inlet / exhaust valves**



Early fuel injection

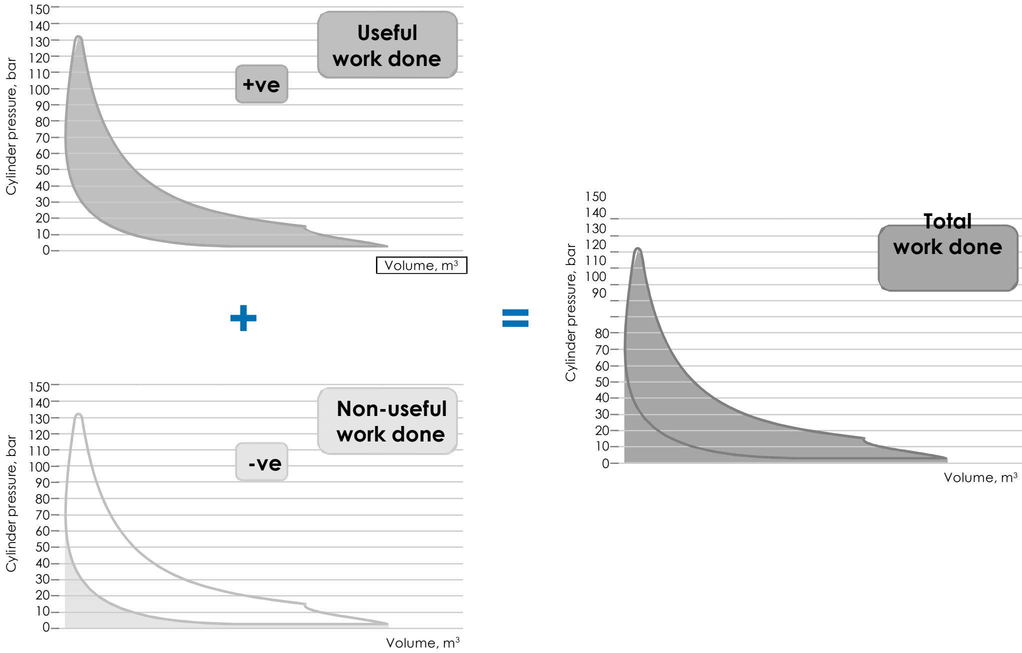
High Cylinder Pressure



Late fuel injection

High Exhaust Temperature

Work done



The PV indicator can be used to calculate the work done by each cylinder of the engine:

- The area enclosed by the diagram curve represents the useful work done by the cylinder.
- The area below the lower curve represents the non-useful work done by the cylinder, for example the work used to overcome friction.
- The total area below the upper curve represents the total work done by the cylinder.

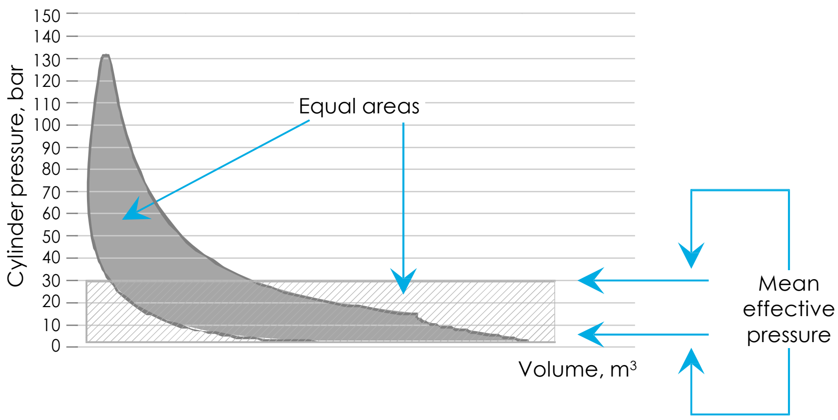
Mean effective pressure (MEP)

The mean effective pressure may be defined as:

The average net pressure which, acting on the piston area for one stroke, does the same work as that represented by the indicator diagram.

The mean effective pressure is commonly abbreviated to MEP.

Typical values for a medium speed engine are from 18 to 25 bar.



The mean effective pressure is the height of a rectangle of equivalent area and the same length as the indicator diagram, as shown in the diagram.

Power formula (PLAN)

The indicated (or brake power) per cylinder for any reciprocating engine may be calculated from the formula:

$$\textbf{Power per cylinder} = \frac{\textbf{Pm x L x A x N}}{\textbf{Constant}}$$

P = Indicated mean effective pressure [to calculate indicated power]
or Brake mean effective pressure [to calculate brake power]

L = Length of engine stroke

A = Net area of piston

N = Number of power strokes per cylinder per minute

For a 2 stroke engine, N = the engine revs/min

For a 4 stroke engine, N = $\dfrac{\text{the engine revs/min}}{2}$

Power Balance

This is important as load sharing between cylinders keeps stresses and wear to a minimum by keeping individual cylinders within design limits of pressure, temperature and force. Failure to maintain adequate power balance may result in excessive vibration, substantial damage or even sudden failure to occur in overloaded units.

If the power balance between cylinders is found to be incorrect, the problem cylinder has to be identified first. This could manifest itself as a high pressure or temperature in one unit or conversely low. The engine should be stopped and the cause investigated.

Normally in a logical fault finding algorithm for a diesel engine (assuming the readings are correct and not faulty instruments) a thorough inspection should be made to look for visible signs of a problem with fuel lines or linkages. If nothing untoward is observed an adjustment to the injector spring setting or an injector change is the least intrusive place to start.

If the injector is not at fault having re-run the engine and the same problem exists then adjustments may have to be made to the fuel pump rack position, or timing mechanism. More intrusive problems can be initially investigated with the use of an endoscope could reveal damage or wear to rings, liners or valves, springs and valve stems and seat. The latter will almost certainly require some dismantling of the engine to observe.

The engine should be retested after each adjustment to avoid making the situation worse.

Thermal and Mechanical Losses

Heat from the combustion process is given up to the cooling system, out as exhaust gasses, and through conduction and convection to the engine room reducing thermal efficiency.

Mechanical losses are usually attributable to FRICTION between moving parts. Changes in direction such as linear piston to rotary crankshaft and any auxiliary drives belts and gear trains will use energy that is not seen at the flywheel. Further losses are seen in the gearbox, some clutches, intermediate bearings and stern tubes. Propellers will also have slip and efficiency is reduced by damage or fouling.

Section 2 – Turbochargers and Superchargers

Principles of pressure charging

Combustion

For combustion to occur in a diesel engine there are three basic requirements:

1 Air

2 Fuel

3 Source of heat.

The principle of the operation of pressure charging involves two of the above requirements, that is:

1 Air

2 Fuel

Complete combustion

For complete combustion to occur the air and the fuel must be mixed in the correct proportions, or in the correct ratio. The ratio of air and fuel can be quoted in one of two ways:

1 The air to fuel ratio

2 The fuel to air ratio

The fuel to air ratio is just the reverse of the air to fuel ratio!

Air-fuel ratio

The air fuel ratio is determined by measuring the air mass flow rate and the fuel mass flow rate.

$$\textbf{Air/fuel ratio, (A/F)} = \frac{\textbf{Mass flow of air}}{\textbf{Mass flow of fuel}}$$

$$\textbf{Air/fuel ratio, (A/F)} = \frac{\dot{m}_{air}}{\dot{m}_{fuel}}$$

(Note that the dot over the letter m, representing mass, is the mathematical representation of mass flow.)

Typically:

For a spark ignition engine using petrol, Air : Fuel = 14.7 : 1

For a compression ignition engine using diesel, Air : Fuel = >18 :1

As fuel oil is the excepted means of fuel for ships engines and generators, it will require a large amount of air to maintain correct combustion. It is therefore essential to maintain a correct air to fuel ratio to maintain efficient combustion. This will ensure the engine is running in its optimum condition and maintain the correct exhaust gas constituent balance.

To maintain the correct air to fuel ratio, ensure the following is carried out:

- Maintain the fuel in a clean condition. Monitor fuel filter condition and ensure no water is present.
- Fuel pump timing is correct.

- Engine load is within the design parameters.
- Air filters are clean.
- Ensure the turbocharger (if fitted) is running correctly.
- Engine exhaust gas temperature outlets are balanced and within their design temperature parameters. Any wide exhaust temperature discrepancy may possibly indicate a faulty fuel injector.
- Adequate engine room ventilation.

Excess air supply

Commonly, in practice, slightly more air is supplied than is necessary for combustion.

This extra air being known as the **excess air**.

When excess air is supplied to the engine this is sometimes known as a **fuel lean** or a **lean burn** mixture.

If too much air is supplied to the fuel mixture then this may tend to generate white smoke emissions from the exhaust.

Because the smoke is white it is not "clean", but is considered a pollutant.

Low air supply

When **low** air is supplied to the engine this is sometimes known as a **fuel rich** or a **rich burn** mixture.

If too little air is supplied to the fuel mixture then this may tend to generate blck smoke emissions from the exhaust.

Black smoke is considered a pollutant.

Normally aspirated engines

The term is derived from the verb aspirate that means to breathe, or draw in, by suction.

A normally aspirated engine is one that draws air into the combustion chamber at atmospheric pressure. This limits the amount of air that can be mixed with the fuel for combustion, and as a consequence limits the power of the engine.

Pressure charging

Getting more air into the combustion space is the basic function of pressure charging, or more commonly known as turbocharging. A turbo charged engine develops greater power than a naturally aspirated engine of similar size and speed because waste exhaust is used to drive a turbine that is connected to an air compressor raising the air pressure into the engine.

- **Thus if more air enters the combustion space, it can be mixed with more fuel. As a consequence more power can be developed at a greater efficiency.**

- **Also naturally aspirated engines suffer from air losses due to sucking in air on the induction stroke. (Volumetric efficiency)**

Methods of pressure charging

There are several methods used for pressure charging, the most common include:

- Turbochargers

  The most commonly used on both 2 and 4 stroke engines.
- Rootes blowers

  Not often used.
- Under-piston pressurising

  Used on 2 stroke engines.
- Scavenge reciprocating pumps

  Once very common on earlier engines, but now rarely used.
- Combinations of any of the above

  Some large 2 stroke engines use turbochargers and under-piston pressurising.

Function of pressure charging

The main function of any pressure charging device is too raise the air pressure above atmospheric pressure.

In doing so the density of the air is increased allowing more fuel to be mixed with the air.

This increases the engine power and efficiency with only a relatively small increase in size, weight and cost of the engine.

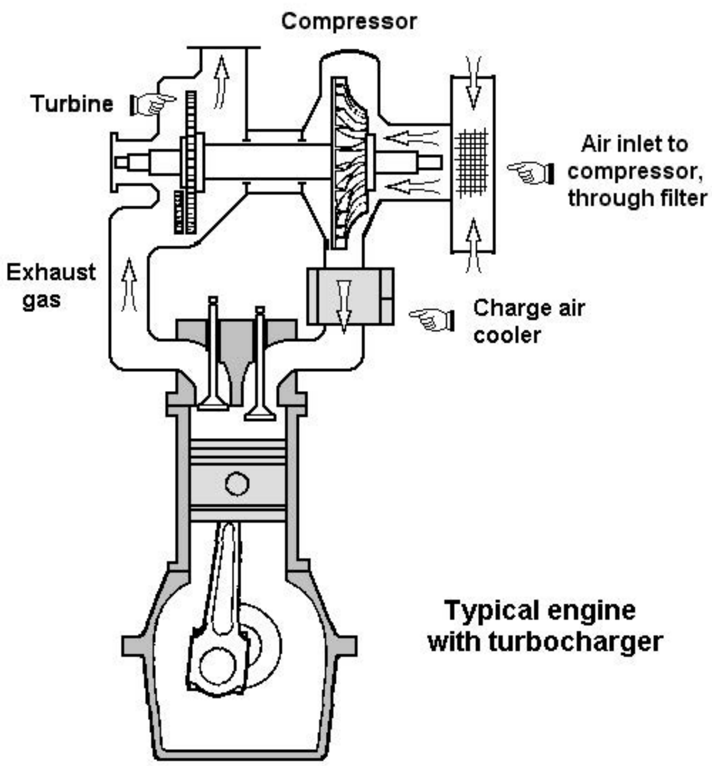
Terminology

The compressed air output from a pressure charger is usually referred to as:

- The charge air (on smaller engines)
- The scavenge air (on larger engines) There are no rules that say that either term is correct or incorrect.

Turbo charging

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



Advantages

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

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

The turbo charger causes a larger mass of air into the cylinder to that of a same cubic capacity normally aspirated engine.

This allows for a proportional increase in the amount of fuel that can be injected and burnt in the cylinder thereby providing an increase in the power output of the engine.

Main components

The main components of a turbocharger system include:

1 The turbocharger casing;

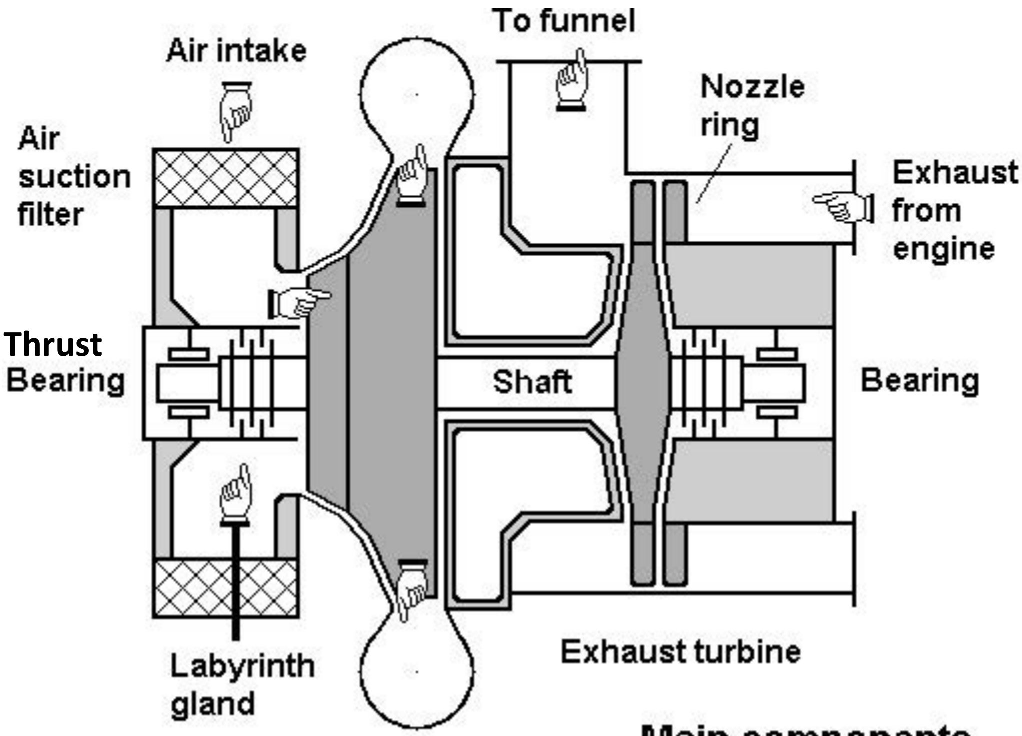
2 The rotor assembly;

  a The exhaust driven turbine;

  b The air compressor;

3 The air suction filters;

4 The charge air cooler



Main components of a turbocharger

Rotor assembly

The rotor shaft has exhaust gas turbine on one end and air compressor on the other end.

Casings

The exhaust gas turbine blades are housed in a casing that is attached to the exhaust manifold and to the exhaust pipe. Some casings are fresh water cooled to minimise the heat radiated out into the engine space. This allows for a cooler engine space, cooler air entering the engine air intake and therefore more power again. On some turbochargers a nozzle ring is fitted inside the casing to direct the flow of exhaust gases to the turbine blades.

The air compressor blades are also housed in a casing that has an air cleaner on the intake side and is connected to the intake manifold on the discharge side. Where an engine is after cooled, the discharge side is connected to the after cooler that is then connected to the intake manifold.

Both the above casings are attached to a centre casing that contains the bearings, seals and method of lubrication.

Air suction filter/silencer

An air filter/silencer is filled to the compressor inlet casing. The filter/silencer consists of wire mesh filter element.

The importance of maintaining adequate engine compartment ventilation is to ensure good engine performance and the durability of the engine and the auxiliary components (mechanical and electrical).

A lack of air or high inlet air temperature will lead to fuel richness that will promote cylinder bore washing, and will be indicated by black exhaust emission.

To ensure trouble free running of both the turbocharger and the engine, the air must be clean. The air intake may be located inside the engine room immediately at the turbocharger inlet or it may located external to the engine room and ducted to the turbocharger. In both cases, it is usual to provide a filter.

The filter will to some degree act as a silencer.

The design of the machinery room ventilation system is usually ducted to the bottom of the engine room to promote bottom up circulation of the fresh air and to clear fumes and moisture from the bilge. The exhaust vent should be located near the top of the engine room to carry away the hot air in the engine room.

Any build up of particles or dirt on the filters can well impair the efficiency of the engine combustion process.

Cooling system

There are various methods of cooling turbochargers:

- Smaller turbochargers are air cooled;
- Larger turbochargers circulate cooling water from the main engine through the jacket in the outlet casing surrounding the exhaust gas passage in which the turbine wheel and nozzle ring is situated.

Bearings and lubrication

The shaft may rotate in **white metal bearings** that can be lubricated from the engine driven oil pump. This method of lubrication also allows the oil to remove some of the heat in the turbo charger. One bearing locates the shaft and takes the small residual thrust, the other bearing allows the shaft to move longitudinally to accommodate the differential thermal expansion of casings and shafting. **Advantages**, long lasting, lubricated from engine, smaller turbo size, reduced vibration. Does not suffer from false brinelling. **Disadvantages,** higher friction coefficient, access for removal, cost.

Alternatively, the smaller turbo chargers usually incorporate a **ball bearing** for positioning at the compressor end and a roller bearing to accommodate axial expansion at the turbine end of the rotor shaft. The bearings may have their own reservoir which forms part of the turbo charger. These reservoirs usually have round oil level sight glasses with two horizontal lines marked to indicate the high and low levels. Seals are fitted to retain the oil.

Advantages of Roller Bearings, Lower friction, has own sump so specialist oil can be used, ease of access for maintenance. **Disadvantages**, may suffer from false brinelling, may require damping springs, and can be prone to sudden failure.

Labyrinth seal

To prevent oil loss past the compressor end, air is bled from the compressor casing via labyrinths on the rear face of the impeller. An air supply also feeds through tubular passages in the centre casing, which in turn pressurises the turbine end preventing exhaust gas and oil leakage, and also serves to cool the turbine disc.

Types of turbocharger

There are two main designs of turbocharger, that differ primarily by the type of exhaust turbine drive:

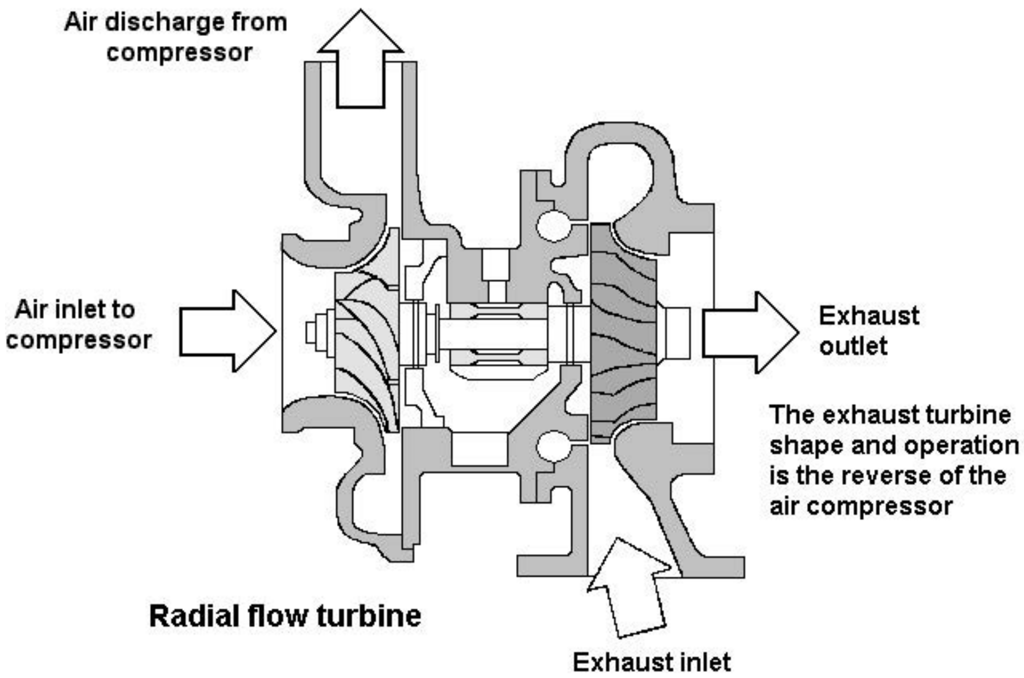
1 The **radial flow** exhaust gas turbine;

These tend to be found on smaller engines.

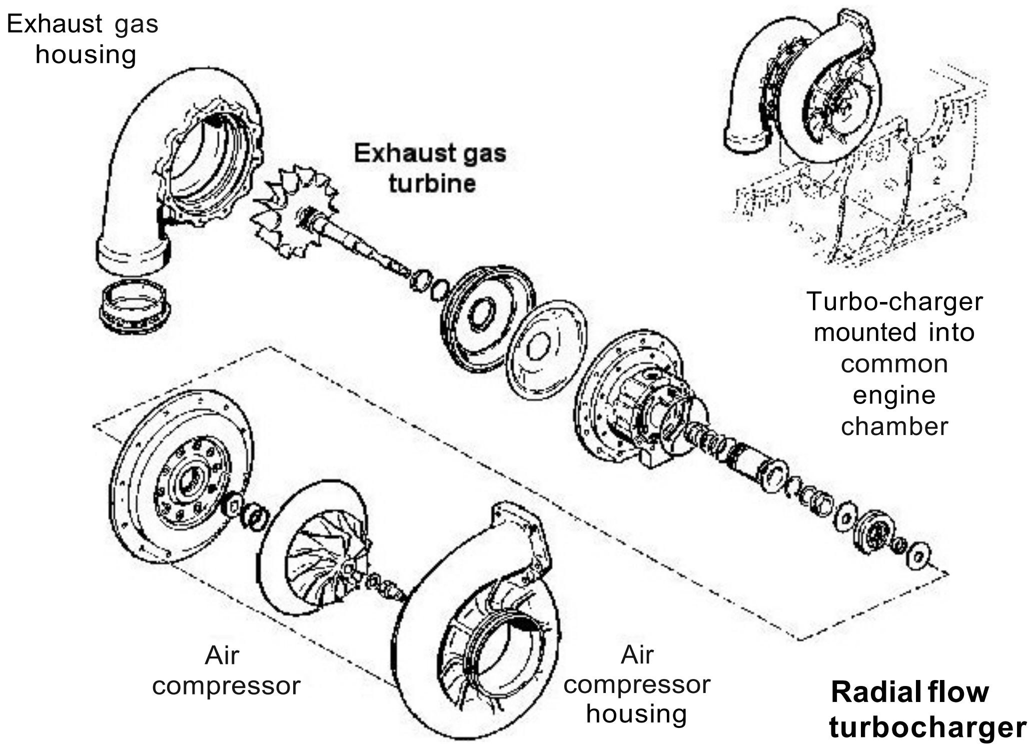
2 The **axial flow** exhaust gas turbine.

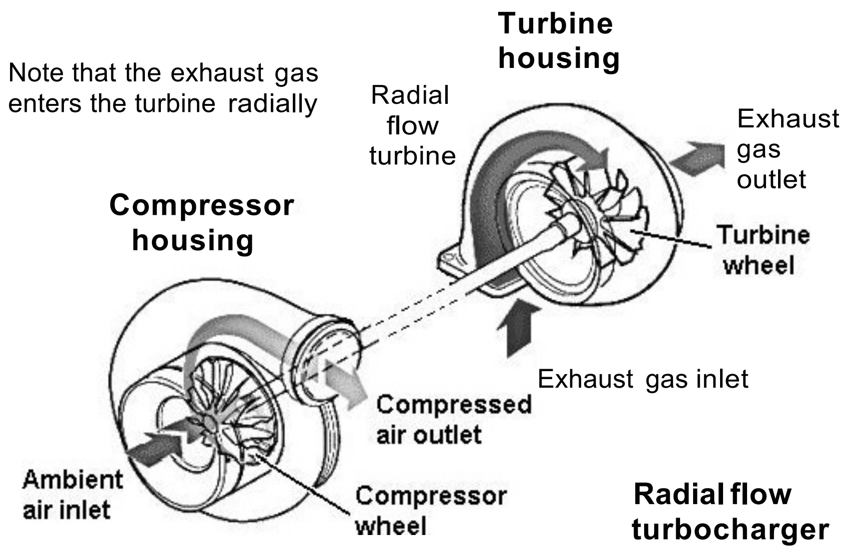
These tend to be found on larger engines.

Radial flow turbines

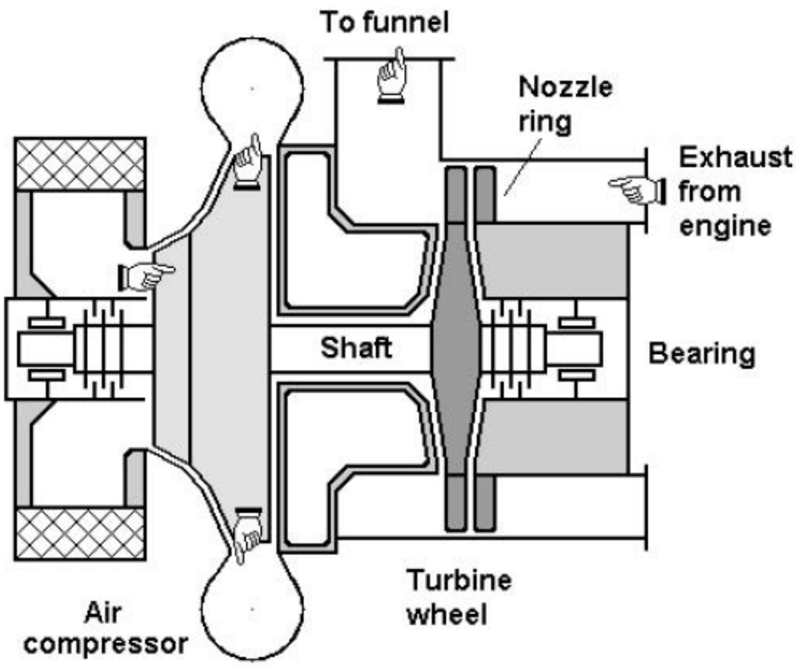


Radial flow turbine


Exhaust gas housing
Exhaust gas turbine
Turbo-charger mounted into common engine chamber
Air compressor
Air compressor housing
Radial flow turbocharger

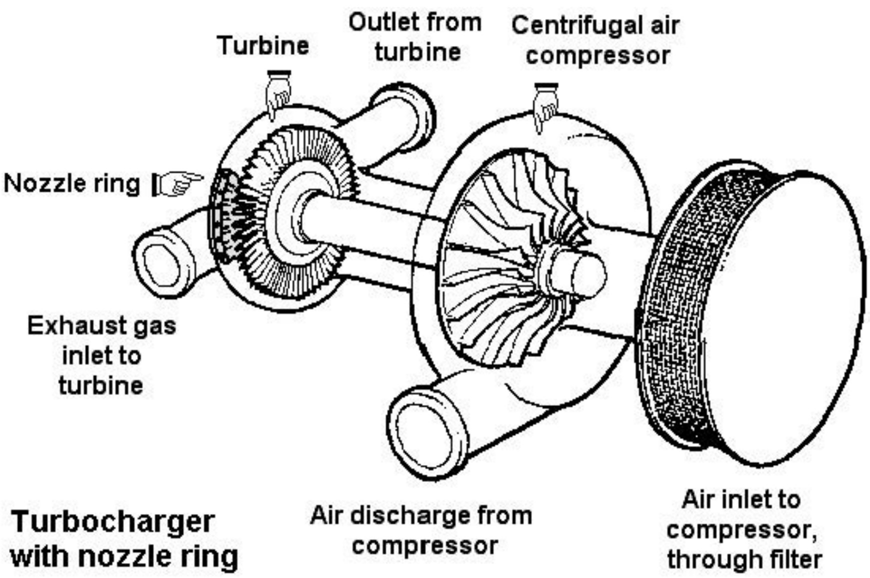

Turbine housing
Note that the exhaust gas enters the turbine radially
Radial flow turbine
Exhaust gas outlet
Compressor housing
Turbine wheel
Exhaust gas inlet
Compressed air outlet
Ambient air inlet
Compressor wheel
Radial flow turbocharger

Axial flow turbines

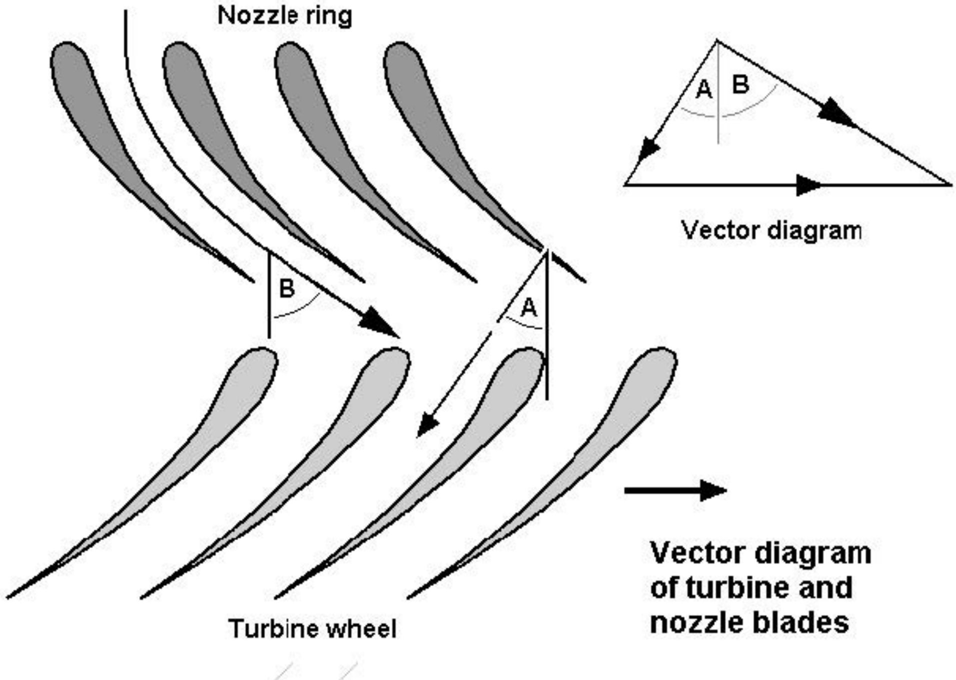


Axial flow turbine

The axial flow turbine is fitted with a nozzle ring in the exhaust inlet, that directs the exhaust gas axially into the turbine wheel.



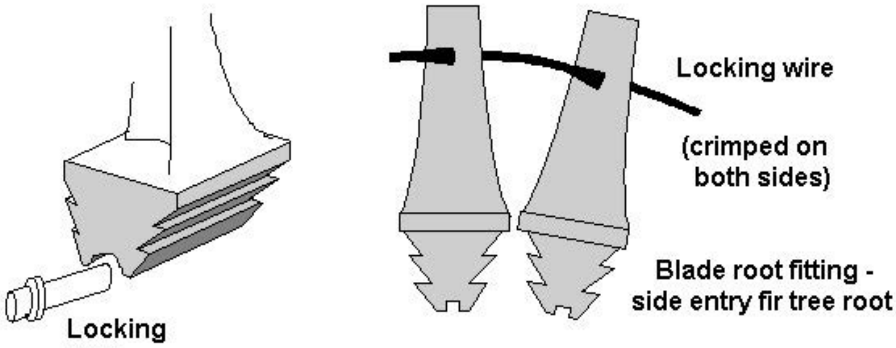
In AXIAL flow turbochargers a thrust bearing is normally fitted to absorb the axial thrust produced by the turbine. This axial thrust tends to push the rotor shaft towards the compressor end. In larger Turbos the bearing is of the roller type fitted at the compressor end or on smaller Turbos inside and of the plain bearing type.



Vector diagram of turbine and nozzle blades

Turbine blade root

Because of the high speed of rotation the turbine blades are subject to very high centrifugal force. To resist this force the blades have a special secure fitting known as a fir tree root. The locking wire is added security, and also dampens vibration.



Blade fir tree root fitting

Air compressor, principle of operation

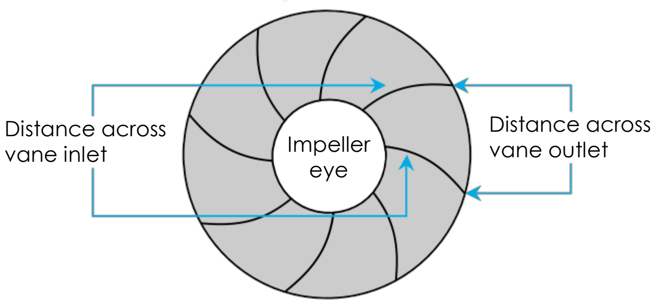
The operation of the centrifugal turbocharger air compressor depends primarily on:

1 The conversion of energies in the impeller (kinetic to pressure);

2 Centrifugal force (providing kinetic energy)

Centrifugal force

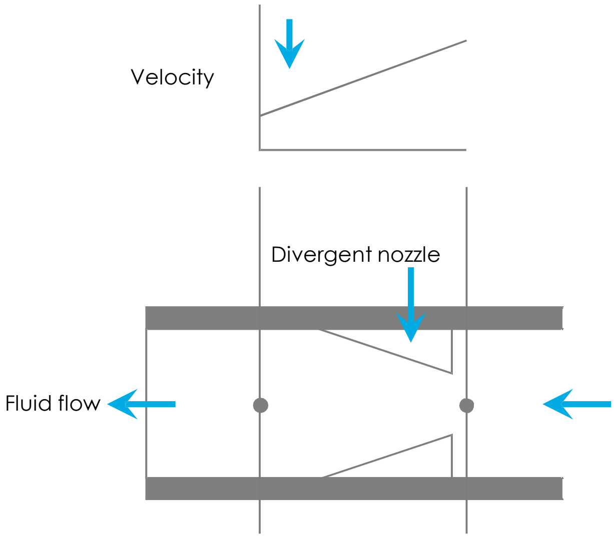
As the air compressor impeller spins at high speed a force is developed, known as centrifugal force. Centrifugal force gives **kinetic energy** to the air particles as they travel from the eye of the impeller to the outer edge.



Fluid is drawn into the impeller at the centre of the impeller, which is known as **the eye of the impeller.**
The impeller is divided up into segments by curved vanes. The curved shape of the vanes follows the same shape as the path of a particle of fluid (relative to the impeller surface) travelling from the eye of the impeller to the outer edge of the impeller.

The distance (and sectional area) at the inlet between the impeller vanes is smaller than that at the outlet between the vanes.
This shape forms what is known as a **divergent nozzle.**

Divergent nozzle

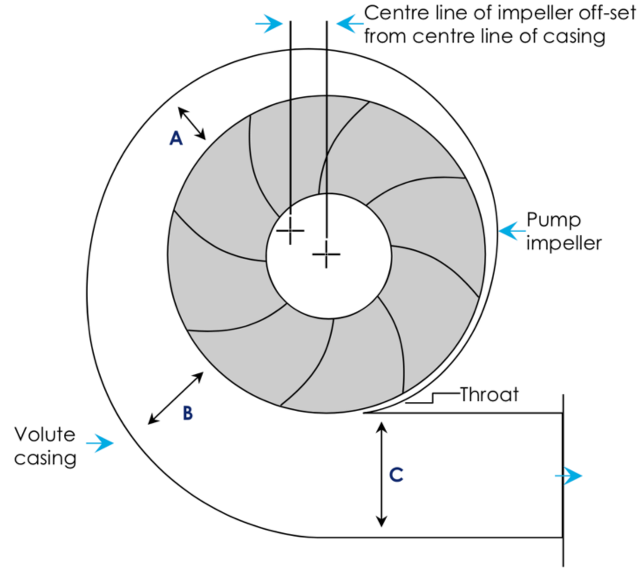


Energy can neither be created nor destroyed, but only converted from one form to another.
The kinetic energy from centrifugal force is converted to pressure energy through the divergent nozzle shape of the impeller vanes.
When the fluid flows through a divergent nozzle:

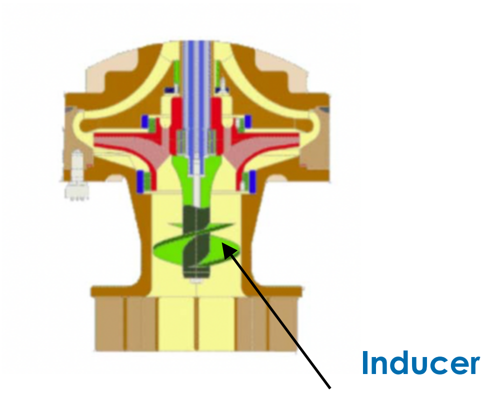
- The velocity decreases;
- The pressure increases;
- The temperature increase.

Turbo Volute Casing

The impeller rotates inside a casing whose sectional area increases as it nears the discharge outlet, known as a **volute casing**. This volute forms a diverging nozzle A-B-C that acts as already described, further raising the air pressure at the expense of kinetic energy.



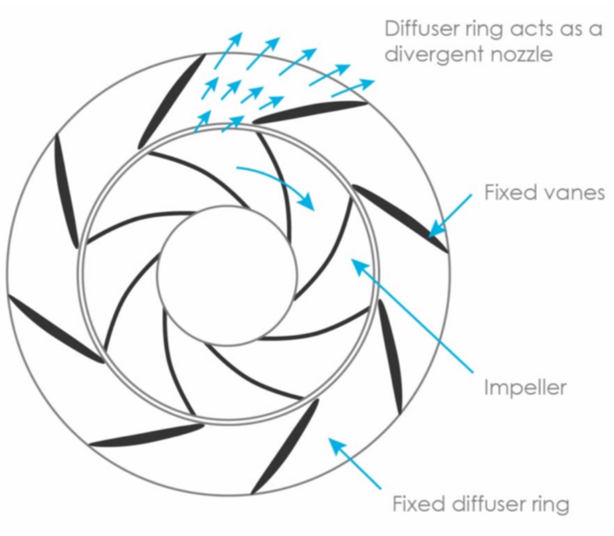
Inducers



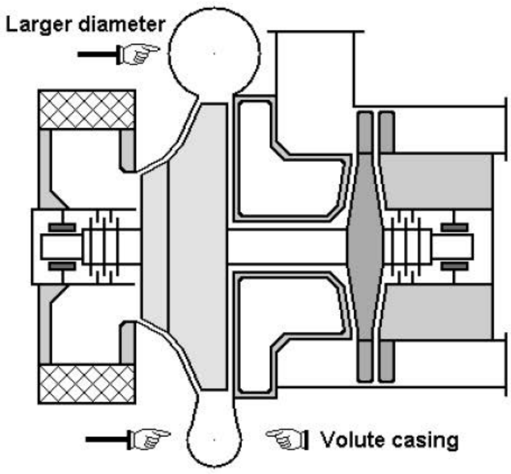
Inducers are usually small helix swirling devices that guide air smoothly into the eye of the impeller for greater efficiency.

Diffuser Ring

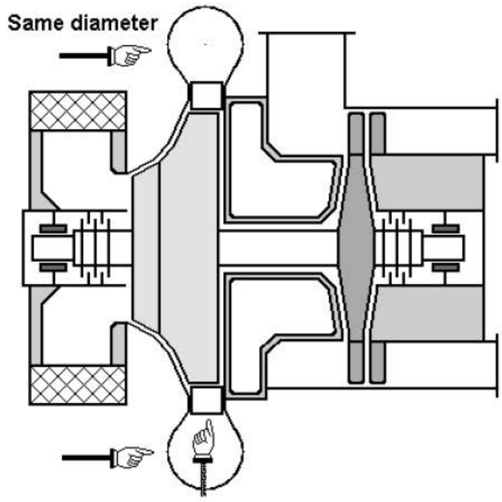
A diffuser ring may be fitted in the outer periphery of the casing which acts as a static set of divergent vanes formed into a ring which further convert the kinetic energy into pressure energy. In some Turbochargers this ring is adjustable to vary the boost pressure at low or high speeds in order to maintain an efficient air to fuel ratio throughout the power range.



Diffuser ring arrangement



Side section, volute casing turbocharger



Side section, diffuser ring turbocharger

Exhaust systems

The turbocharger is driven by waste energy of the exhaust gas from the diesel engine.

There are two basic exhaust system arrangements:

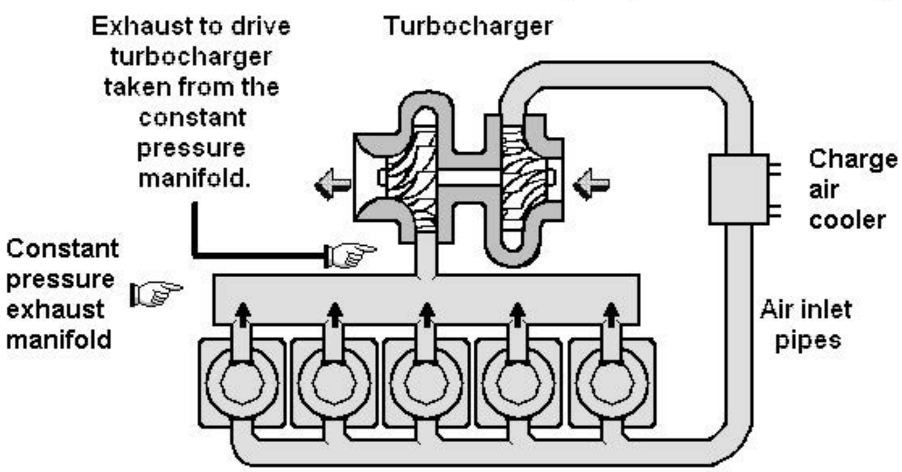
1 The **pulsed exhaust** system

The pulsed exhaust system is used on both 2 and 4 stroke engines.

2 The **constant pressure** exhaust system

The constant pressure exhaust system is normally only used on 2 stroke engines.

Constant pressure system



All cylinders exhaust into the constant pressure manifold

This air delivery system operates by allowing the exhaust gases to be received into a common manifold, which is large enough to convert pulses into a steady pressure. This system has one connection to the turbine, due to the common nozzle ring and steady pressure conditions, can be designed to operate at a high thermal efficiency.

High efficiency turbochargers can operate effectively down to about 25% of full engine power.

One of the disadvantages of the constant pressure system is the slow build-up of pressure when starting, and insufficient air is available to the two stroke engine during manoeuvring or the operating of the engine at low speeds and low power.

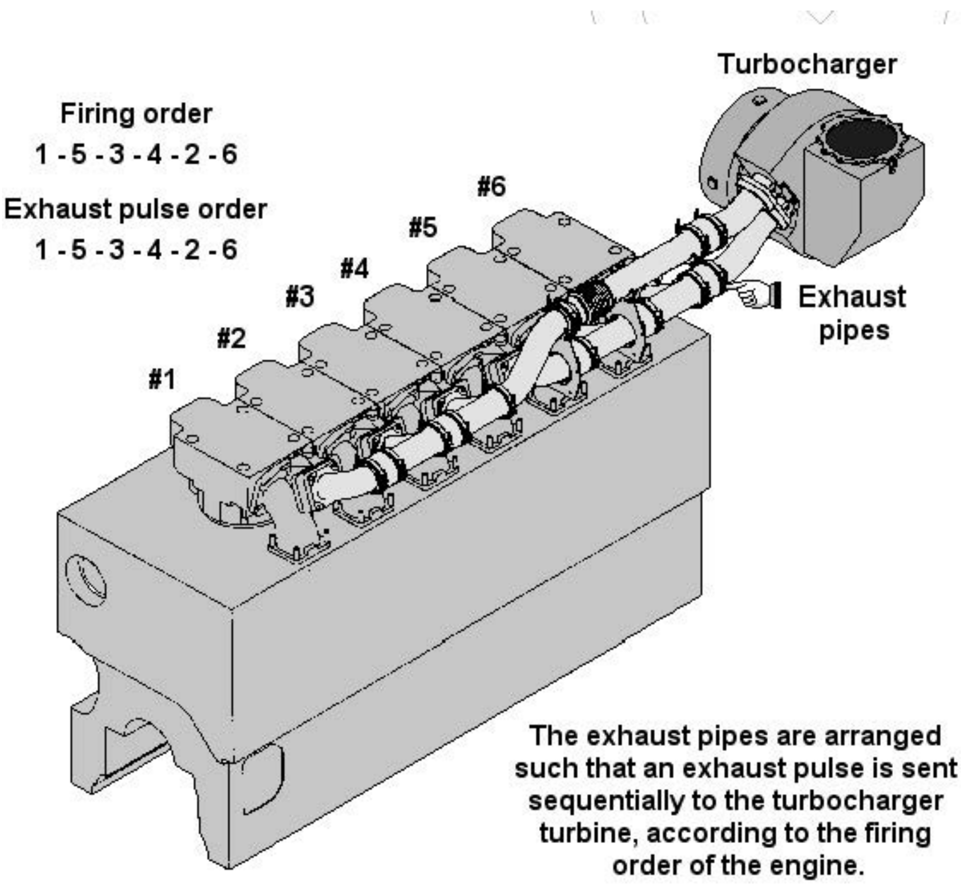
To overcome this difficulty engines are filled with an electric driven centrifugal compressor (auxiliary turbocharger) to compensate the reduced air pressure in the scavenge trunking when required. The electric driven compressors operate on a constant speed controlled automatically if the scavenge pressure drops to a pre-determined level.

Pulsed exhaust system

The main energy to power the turbine in the pulse system is derived from the pulse or impulse energy in the pressure wave formed during the blowdown from each cylinder. These waves travel through the manifold to the turbine nozzles where they are converted to kinetic energy at high velocity to rotate the turbine blades. This system gives a rapid build-up of turbine speed when an engine is started or manoeuvred.

To maintain the pulses, the following has to be adhered too:

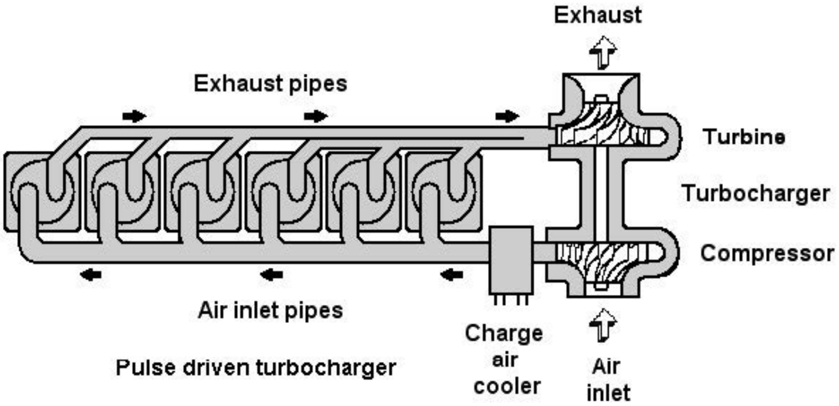
- Exhaust gas connections are of limited diameters.
- No sharp bends.
- The turbocharger is close to the engine.



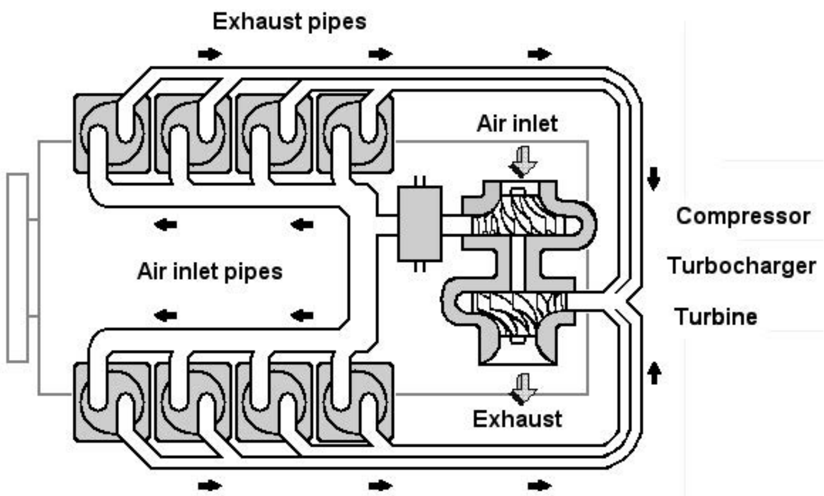
Advantage of the pulse system

The advantage of the pulse system is it allows individual cylinders to exhaust to a common manifold, giving higher turbine efficiency and a more compact system that allows rapid acceleration when manoeuvring.

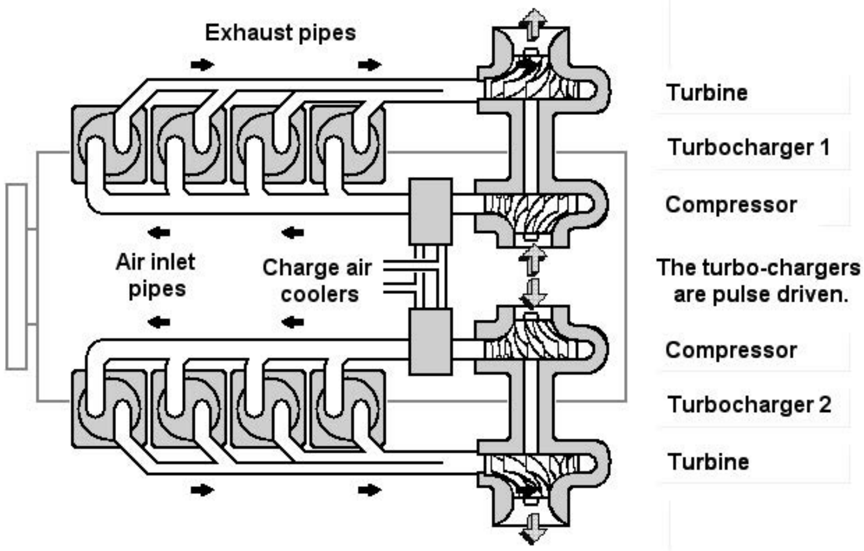
The peak pressure in pulse waves may be higher than the pressure in other cylinders whose exhaust valves are also open. To prevent a back flow of exhaust gases into these cylinders, it becomes necessary on multi-cylinder engines to sub-divide the exhaust between a number of manifolds, with each connected to a separate nozzle box at the turbine. Up to three cylinders can be used on each manifold without interference, dependant on the firing order. A divided exhaust system reduces turbine efficiency and may require more than one turbocharger per engine.



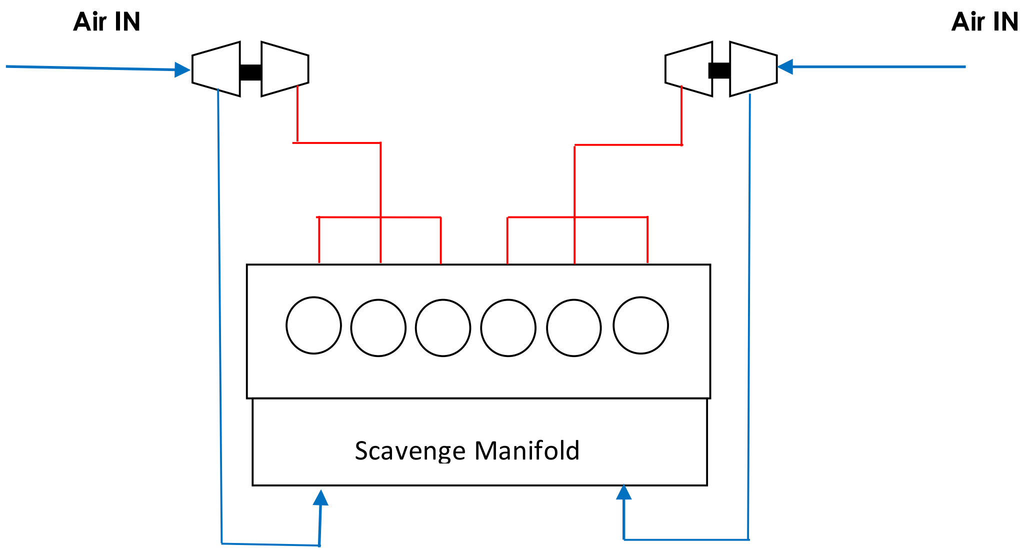
Pulse driven turbocharger



V-8 cylinder medium speed 4 stroke diesel engine with single turbo-charger



V-8 cylinder medium speed 4 stroke diesel engine, with twin turbo-chargers



Pulse type, twin turbocharger, six cylinder

2 stage turbocharger

The combustion air flows through the low-pressure stage with the "big" turbocharger for pre-compression and then through the high-pressure stage with the "small" turbocharger. After each of these two compression stages it is re-cooled in the intercoolers to boost the quantity of combustion air and to reduce the thermal load on the engine.

Up to medium speeds the low-pressure stage does about 1/3 of the compression work and the high-pressure stage about 2/3. At higher speeds and loads, a waste-gate valve in the bypass between the high and low pressure stages opens, depending on the boost pressure. Now the low pressure stage does about 2/3 of the compression work, the high pressure stage about 1/3.

The effect of this split in the turbocharging is that at low speeds and at partial load the "small" turbocharger in the high-pressure stage works at optimum boost pressure. It thus builds up a high boost pressure and in turn leads to a high torque. At high speeds and in the full-load range the engine's greater demand for combustion air is satisfied mainly by the "big" turbocharger.

The insulated exhaust manifold not only makes for more power output but also reduces emissions of pollutants and smoke. The lower heat loss between exhaust gas and coolant results in more energy for driving the turbocharger. This means a better build-up of boost pressure for a high torque at low and medium engine speeds, better manoeuvring of the vessel and faster acceleration.

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

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

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

Poor Turbocharger performance

Poor performance is usually observed by a lack of power, low engine speed, lower boost pressure, unusual noise, excessive fuel consumption, higher exhaust temperatures or black smoke in the exhaust.

Common causes of reduced output:

- Blocked Suction Filter
- Damaged, worn or seized bearings
- Fouling of the compressor blades
- Blocked Nozzle ring

Turbocharger Vibration

If the turbocharger is at steady speed the cause of the vibration may be caused by imbalance due to blade damage or by asymmetric fouling. Bearing failure may also be the cause or security of fastenings can set up unusual frequencies but only at certain speeds.

The likelihood of the onset of vibration can be reduced by regular, inspection, cleaning and maintenance. The use of Vibration Analysis equipment may reveal through trend analysis and any deterioration which should be investigated without delay due to the very high speeds of the internal components.

Charge air coolers

A charge air cooler is sometimes called an inter-cooler or an after-cooler. The cooler is fitted between the air compressor side of the turbo charger and the air intake manifold on the engine.

Temperature and density

During the passage of air through the turbocharger compressor the compression process will raise the air temperature. As a consequence the density of the air will decrease.

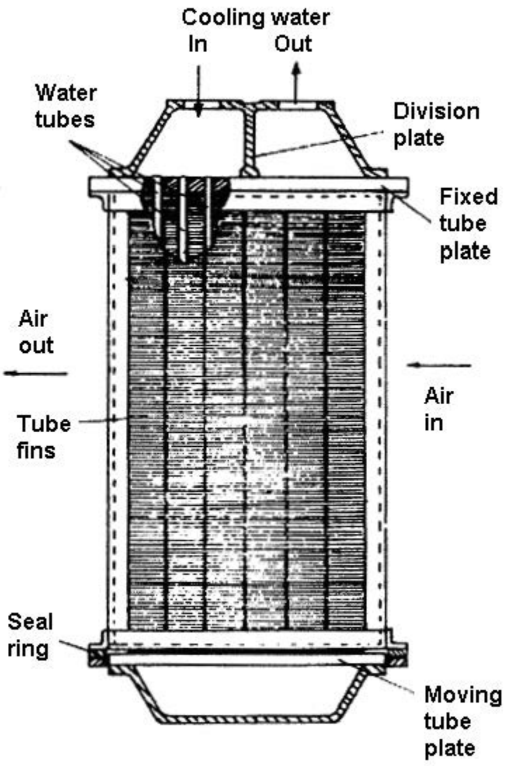
To correct this temperature increase a charge air cooler is fitted. The air cooler is installed to reduce the temperature of the air to the engine inlet manifold, thus increasing air density at a lower induction temperature.

The action of cooling the air has the effect of maintaining the engine components at a safe working temperature, and with the lowering of the compression temperature assists in reducing the stress on the piston rings, piston and liner.

Increased air density will raise scavenge efficiency and allow a greater mass of air to be compressed; more fuel may now be burned giving an increase in power.

Sub cooling below the dew point at the corresponding pressure may cause condensation which can cause corrosion or contamination of lubricating oil.

Construction



Charge air cooler element

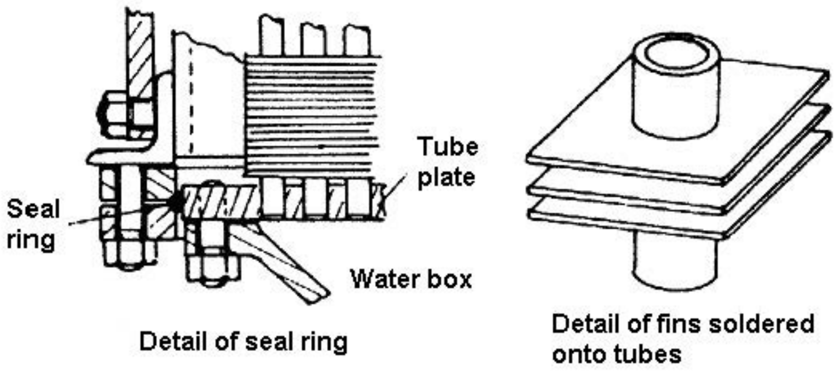
In the air cooler, air passes over the outside of the tubes while the engine cooling water or sea water passes through the tubes usually in the opposite direction (contra flow). Fin plates are attached to the outside of the tubes to increase the surface area for the air, thereby giving a better transfer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

The air makes a single pass through the cooler. For efficient cooling the air velocity should be low and the cooling area large. This is achieved by making the air inlet connection divergent; the outlet is convergent to restore air velocity after cooling.

The cooler consists of a tube stack of aluminium brass tubes rolled and solderbonded into two brass tube plates. Cast iron water boxes are attached to the tube plates and allow salt water circulation within the tubes to make two passes.

One tube plate is secured to the casing while the other is free to move axially as thermal expansion occurs. The air seal is maintained by means of a fitted rubber joint ring. An air vent is fitted to the top water box remove air that may have been released from the salt water system. Corrosion plugs may be fitted within the water space.

Condensation of moisture in the compressed air will occur during cooling and a drain is fitted to the outlet side air easing to allow this condensate to be removed. A moisture eliminator may also be fitted to remove entrained water droplets from the air stream. The drain should be kept open and its discharge noted; this will also indicate if a cooling water leak has occurred.



Thin copper fins are soldered to the outside of the cooler tubes. The air will pass between the plates, which greatly increase the area of heat transfer. There are two side plates of mild steel or aluminium alloy.

Temperatures and pressures are recorded at each inlet and discharge. Discharge air temperature should not exceed 55°C since engine temperatures, notably the exhaust temperatures, will increase, with loss in efficiency due to reduction in air density.

Some medium speed engines turbocharger systems may be adapted to improve low speed operation. A by-pass valve may automatically return some charge air to the compressor inlet to improve acceleration when running up to speed. Engines designed to operate with high power at reduced speed may have an excess of charge air at full speed and require a blow-off valve to open at 85% full speed.

Under-cooling of air

This occurs when the air is cooled to a temperature below the dew point at that pressure. To prevent under-cooling and excessive condensation, air temperature should not be taken below 20 – 25°C.

Air at very low temperatures will also cause thermal shock when in contact with hot liners and pistons.

Some measure of cooler efficiency can be ascertained from the difference between air discharge temperature and cooling water inlet temperature under normal running conditions: a rise in this indicates fouling of the cooler.

An increase in the air pressure drop indicates fouling of the air passages, while an increase in water pressure drop indicates fouling of the water side.

Air cooler maintenance

Sea water flowing through the tubes will tend to leave deposits in less time than if fresh water was used. The end covers can be removed and a wire brush pushed and pulled through the tubes. If the scale is not removed by the brush, the tube nest will have to be chemically cleaned.

On the air side, usually no maintenance is required if the air cleaner is doing its job and the filter is changed regularly.

A leaking tube will cause the cooling water to pass into the air side. Depending on the design, the air may enter at the bottom and leave at the top to prevent water carrying over with the air. A drain cock is fitted at the bottom.

As the air passes through the after cooler, its temperature may be reduced until it is below the saturation temperature. Heavy condensation of water vapour may then follow, this water being carried into the engine. If this is a problem, a water separator can be mounted between the after cooler and the air inlet manifold.

Zinc Anodes are often fitted to act as sacrificial anodes to protect the heat exchanger from Bi-Metallic corrosion.

A drain cock may be fitted to the air manifold which will give indication of leakage or build up of moisture from condensation due to **SUB COOLING**.

Differential temperature trend analysis will give indication of cooler performance. Similarly a pressure differential will give trend analysis to indicate a blockage through the cooler passages

Servicing of Turbo Chargers

Turbochargers are high speed machines requiring very careful handling in maintenance. Unless skilled contractors are available is advisable to fit replacement turbochargers and return the removed unit to the manufacturer for re-conditioning. The maintenance procedures should be undertaken in accordance with the manufacturer instruction.

When cleaning the turbine blades and the compressor impeller it is essential to ensure that all deposits are removed so as to maintain the rotor balance. Scale and sludge should be checked to see they are within the manufacturer's recommended limits.

All clearances and wear should be checked to see that they are within the manufacturer's recommended limits.

If the ball and roller bearings are used then these should be renewed.

If any parts of the rotating assembly such as a turbine blade or an impeller require replacement the whole assembly should be returned to the manufacturers for replacement of acceptable parts and re-balancing of the assembly.

When the turbocharger has been re-assembled, check that the rotor turns freely.

Water washing

If a turbocharger is not regularly water washed, do not suddenly start. This is because the washing may only clean off dirt on part of the blading, causing an imbalance of the rotor that will cause vibration. Only use water washing after a maintenance period and the turbocharger has been internally cleaned.

Turbochargers systems may become fouled causing reduced efficiency, loss in power that may be indicated by surging of the turbocharger. Compressor surfaces can be contaminated by oil and dust drawn from the engine atmosphere, passing through the intake filters and adhering to working surfaces. This gives loss in

compressor efficiency and chokes the charge air cooler. In the event of contamination the debris can be removed while the engine is running, by water washing. This method involves injecting (in a spray pattern) a small quantity of fresh water into the air stream at the compressor inlet. The water is drawn through the air side and scours the surfaces clean.

During the water washing process the water drains must be open to avoid the water with any contaminants from entering into the engines cylinders.

Caution

Additives to improve the cleaning effects of water washing must not be used in trunk piston engines, due to the possibility of passing through the cylinder to the crankcase oil.

Hydrocarbon based additives must not be used since they may add further combustibles to the cylinder and may create an explosion risk.

Water washing may also be used to clean the gas side of the system. A small water jet sprayed into the gas flow, upstream of the protection grids for the turbine, will dampen and soften the deposit reducing adhesion and enabling them to be blown clear by the gas stream.

The introduction of water to very hot surfaces can cause thermal shock, so before water washing the turbine, the engine power must be reduced so that the temperatures in the system are lower. Water drains must be open and great care exercised since removal of deposits may affect the balance of the turbine rotor.

Turbocharger surging

Surging is usually first detected by noises from the air compressor side. The noises may differ but may include howling, whining, knocking and banging. The turbocharger may race intermittently; air discharge pressure will drop and behave erratically.

Unless the surging becomes frequent or continuous it should not harm the turbocharger or engine, but loss of air will cause poor combustion with all its relative problems.

Turbochargers are designed to avoid surging under normal operating conditions and a surge will indicate abnormal change in either air or exhaust gas flow to or from the charger. Turbochargers may be prone to surging if an engine is operated with one or more units not producing power.

A sudden reduction in engine speed with the corresponding drop in demand for air may cause surging, but this is a temporary condition and stable conditions can soon be reestablished.

Provided no sudden change in engine power has taken place, surging in a normally stable system while running can usually be traced to:

- The engine is operating with one of turbochargers faulty.
- Fouling on the air side may include restrictions on the impeller and diffuser, intake filter or charge air cooler.
- The gas side fouling may be in the turbine, nozzle rings, exhaust grids or moving blades.

As a temporary remedy engine stability can be re-instated by reducing the engine speed and power. Measures must be taken as soon as convenient to remove the fouling.

Should a turbocharger vibrate and slow down, it should be stopped and examined for bearing damage or loss in balance.

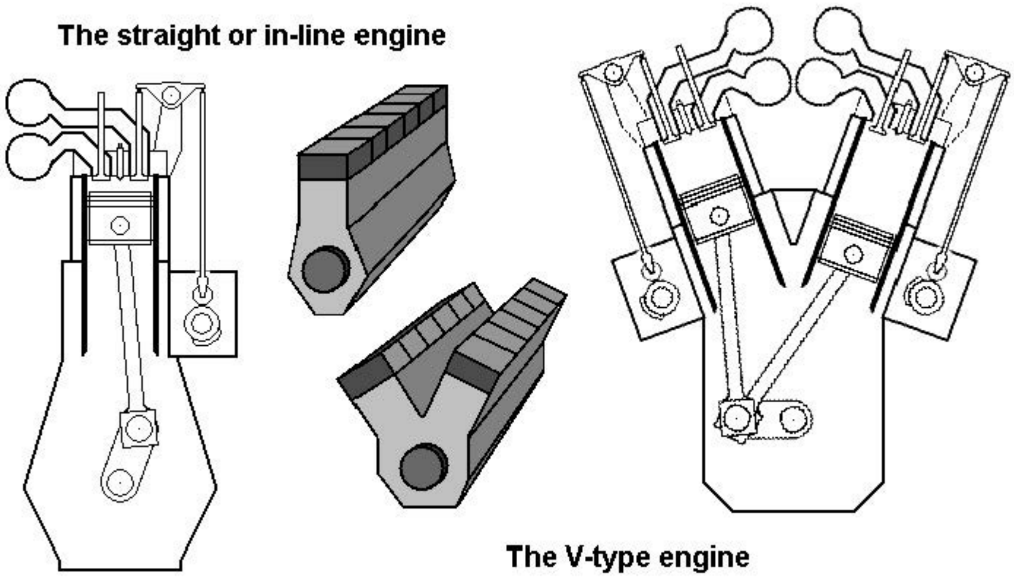
Section 3 – Diesel Engine Construction

Engine format

The diesel engine commonly has two main piston arrangements:

1 The straight or in-line format

2 The V-engine format



The advantages of the straight type engine include:

Maintenance is easier, e.g. pistons can be lifted vertically.

The advantages of the V-type engine include:

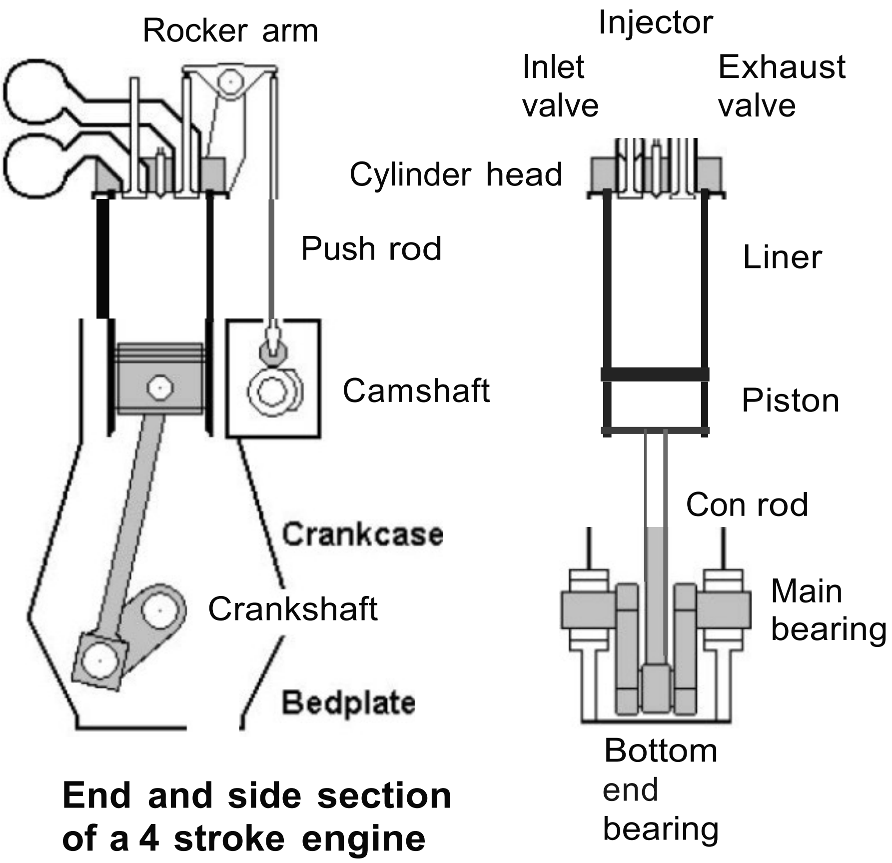
With straight engines of similar power the V-type engine is shorter in length.

The disadvantages of the V-type engine include:

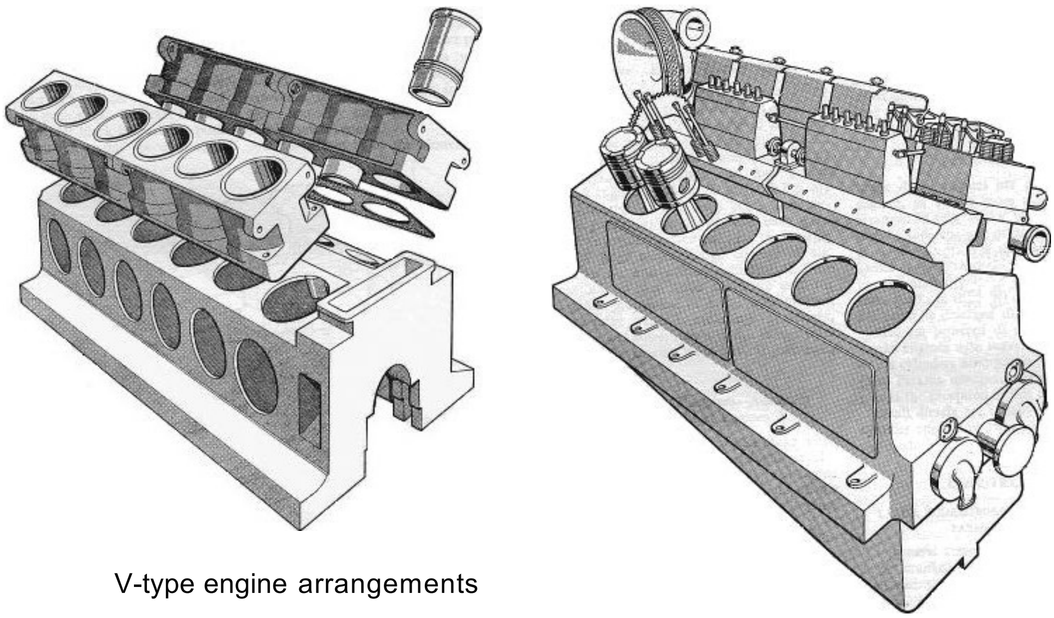
Maintenance is more difficult.

Liners can wear more quickly.

4 stroke trunk piston engine section diagrams



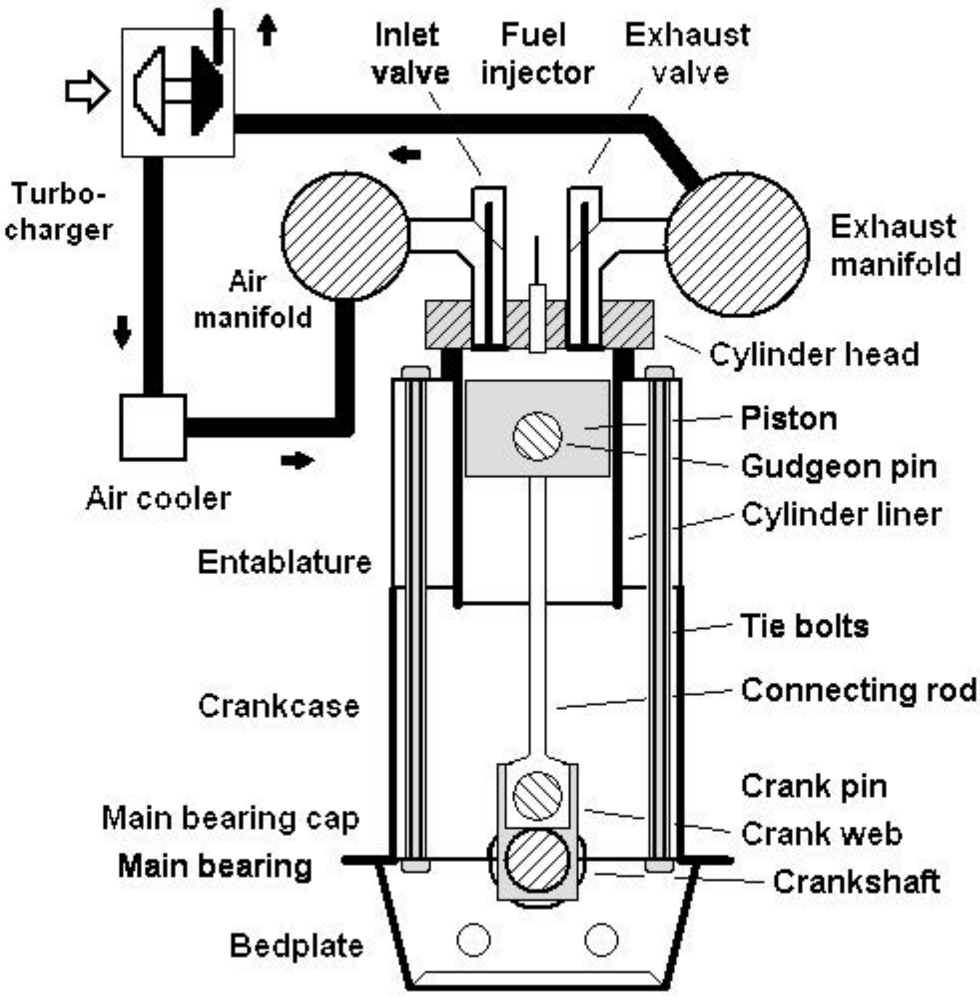
End and side section of a 4 stroke engine



V-type engine arrangements

Engine components

The main components of a single cylinder of a typical 4 stroke in-line engine are shown below.



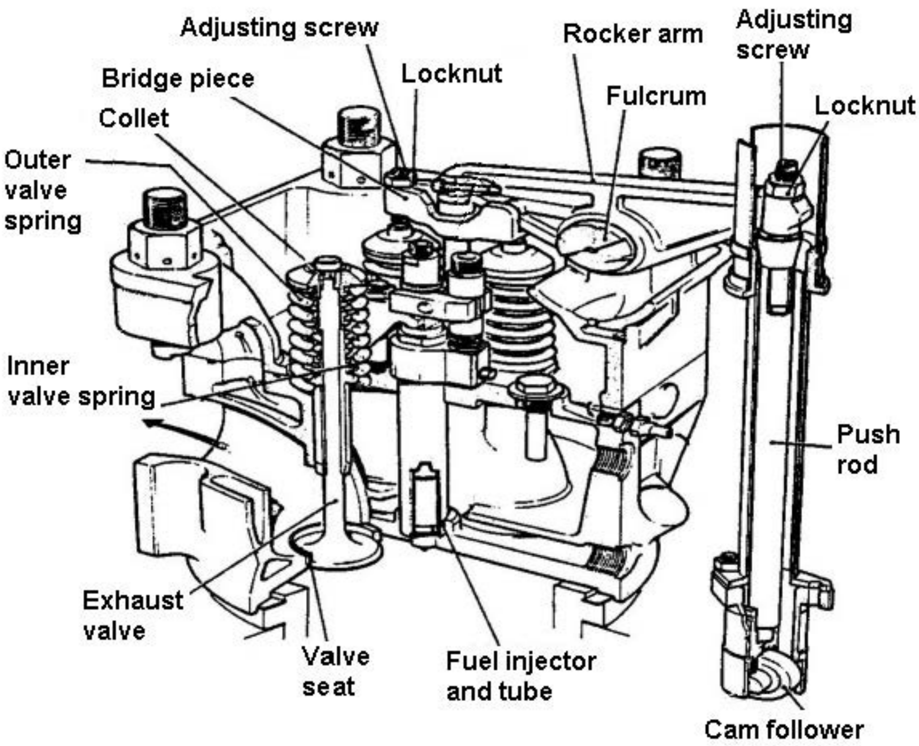
The components can be divided into two groups:

1 The **static components** (which do not move)
(The cylinder head; the liner; the bedplate etc.)

2 The **running gear** (the components that move)
(The piston; the connecting rod; the crankshaft etc.)

Cylinder head

Cylinder heads (sometimes known as a cylinder cover) are usually manufactured from special grey cast iron or aluminium. They are constructed as individual units or as combined multiple units. This is dependent on the size and capacity of the engine in blocks ranging from a unit containing two or more cylinder heads.



Typical 4 stroke engine cylinder head

The cylinder head is fitted with the following main components:

- Exhaust valve(s);
- Inlet valve(s);
- Fuel injector;
- Air start valve;
  (Only fitted on larger engines using compressed air admitted into the cylinder to start the rotation of the engine).
- Safety valve;
  (To relieve any excessive pressures that can build up inside the cylinder).
- Indicator cock.
  (Only fitted to larger engines to prevent compression when manually turning the engine; to blow through the engine before starting; and to record the pressure inside the cylinder using a special device called an indicator).

Cylinder head studs

The cylinder heads whether single or multiple units are all fixed to the cylinder block by studs each with the ability of securing the head and cylinder liner in tension. The cylinder head forms the top of the combustion chamber.

The cylinder head studs should be robust enough to resist the firing loads, and at the same time hold together the seal between the head and the liner. To ensure that a gas seal is maintained between the cylinder head and liner a metallic joint, copper or soft iron ring is located at the top of the cylinder head and liner.

The studs securing the head to the liner number from four to ten per cylinder, dependant on the size of the engine. To maintain an even tension and prevent fatigue the studs are secured evenly and at a torque recommended by the engine manufacturer.

Damaged studs

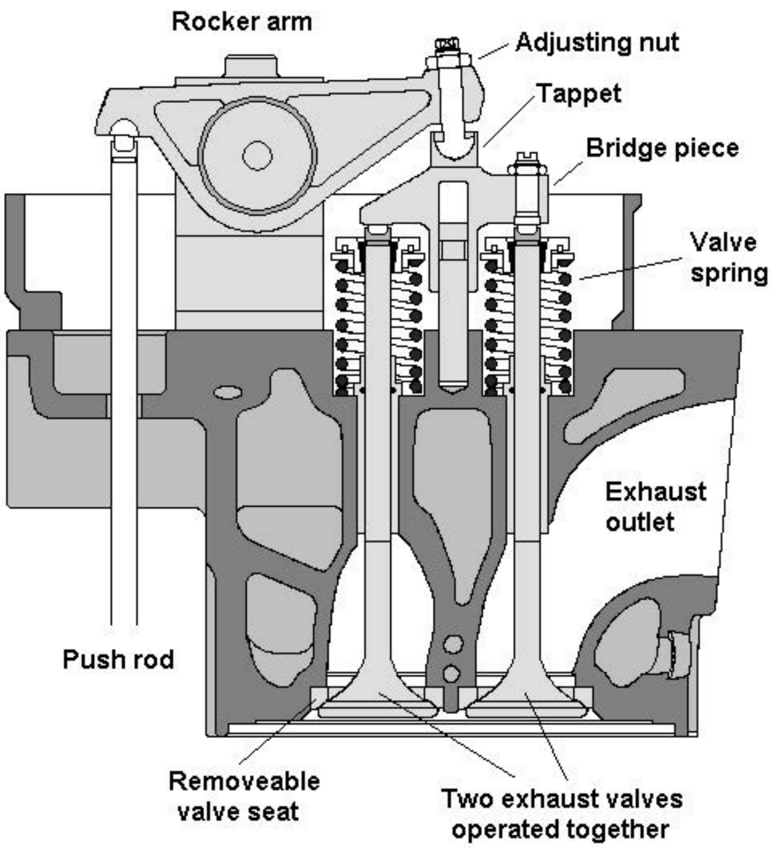
If the cylinder head stud threads are damaged, before using a die nut to re-cut the thread, check with the manufacturer's manual if this is allowed. On many engines the stud threads are not cut, but formed using a process called **rolling**. The threads are rolled into shape using special form pressing tools. This makes the grain structure finer, and the thread is stronger to withstand the high stresses of combustion.

Damaged rolled threads should only be dressed using a thread file.

Cooling water

The design of the cylinder head(s) allows for the free flow of cooling water to pass from the jacket cooling to the cylinder head. The coolant passes through cooling spaces within the cylinder head with the ability to cool the fuel injector, exhaust and inlet valve spaces before exiting from the top of the cylinder head. Cooling water leaving the top of the head assists in expelling any entrapped air that may accumulate in the cooling system.

Inlet and exhaust valve gear



Valves are machined from heat resisting materials.

They have ground faces on the under side of the heads so that they make a gas tight seal with the valve seats. They are held in the closed position by the valve springs and forced open against the pressure from the springs, by a force exerted on the stem of by the rocker arm.

The rocker arm pivots on the rocker shaft, being activated by the push rods that, through cam followers, are lifted by the cams on the camshaft. This mechanical linkage, between the cam and valve, has a small gap somewhere so that the valve can seat fully. This gap is known as the tappet clearance and is usually set or adjusted between the valve stem and the rocker arm.

Exhaust valves

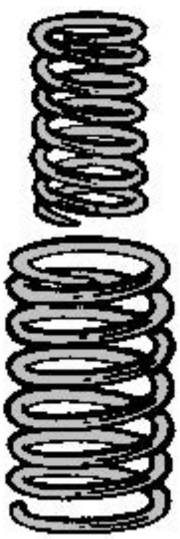
The exhaust valves open against the pressure within the cylinder at the end of the working stroke. This pressure is considerably higher than that against which the inlet valve has to open. Furthermore, the pressure of the exhaust gases assists, once the valve is open, in expelling the gases through the open valve. Due to this consideration, it is not unusual to find that the exhaust valves are designed to be of a smaller diameter than the inlet valves.

The exhaust being a smaller valve and is designed to be maintained (as much as possible) in a cool condition during operation. This is important considering the thermal problems the valves encounter. Due to these thermal problems and the carbonaceous particles that flow through, frequent maintenance is required especially for the exhaust valve. Maintenance is carried out by grinding the valve and seat to remove any pitting that may occur.

To assist in reducing valve deterioration some manufacturers install cooling water passages through the valve cage, and install special valve rotators.

Valve springs

Inner spring



Outer spring

The inlet and exhaust valve assemblies on many engines are fitted with double springs, an inner and outer spring.

All metallic objects have a natural frequency of vibration and resonance. This applies to springs, which can suffer from a phenomena known as **spring bounce**.

By using two springs, each with its own different frequency of vibration, the points of vibration and resonance cancel each other out, preventing bounce.

There are additional advantages:

- In the event of one spring fracturing, the other spring will prevent the valve dropping into the combustion chamber.
- The springs can be smaller, taking less space.

Valve rotators

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

Valve timing

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

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

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

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

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

Tappet clearance

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

When the valve and its operating gear heats up in service, the clearance between the rocker arm and the valve stem decreases, as the parts heat up and expand.

The correct tappet clearance and setting procedure will be specified by the engine manufacturer. Some manufacturers state clearances for when the engine is at its normal operating temperature, others when the engine is cold, while some give both.

Clearances can vary as much as 0.128mm between a cold and the normal operating temperature of an engine. Usually, an exhaust valve will have a greater clearance than an inlet valve because of their different operating temperatures.

If the tappet clearances are adjusted when the engine is cold, but only a hot tappet clearance is given, the tappet clearance must be checked again and if required, further adjusted when the engine is at its normal operating temperature.

The most common form of adjustment for tappet clearance is by means of a screw and lock nut located in one end of the rocker arm. The clearance is measured by means of a feeler gauge between the valve stem and the rocker arm when the valve is in the fully closed position. This is usually carried out when the relevant piston is on top dead centre before the power stroke.

Incorrect tappet clearance

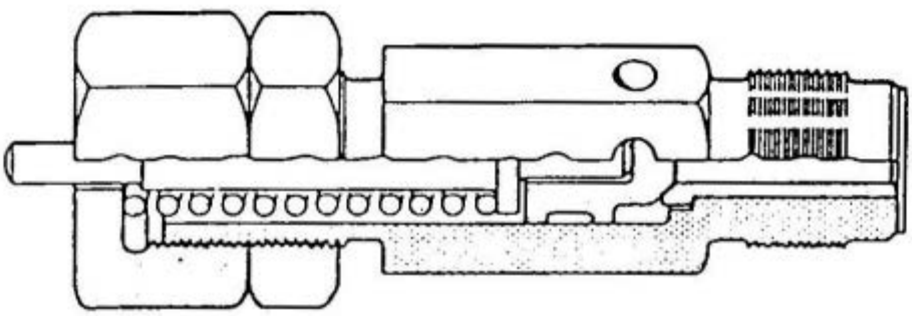
Excessive tappet clearance will cause:

- Noisy operation;
- Excessive wear;
- Altered valve timing that would result in late valve opening and early valve closing.

Insufficient tappet clearance will cause:

- The valve will be prevented from seating, this will result in:
  - loss of compression through valve leakage;
  - loss of engine power;
  - incomplete combustion;
  - burning and eroding of the valve and seat;
  - general overheating.
- In the extreme, it is possible that the piston could strike the valve resulting in a bent valve stem, damaged piston or worse.

Relief valve



Cylinder pressure relief safety valve

Cylinder heads are fitted with a relief valve, whose principle is that a spring loaded non-return valve is set to lift at a pressure above the normal combustion firing pressure. On some engines the relief valve is fitted with an indicator valve whose function is measure the respective cylinder pressures.

The valve is of stainless steel with a mitre seat and is loaded by compressing a helical spring. The lower end of the spindle has a radius to allow the valve to align with its seat; valve lift is limited by a shoulder at the top of the spindle; The spring keep cap nut is locked in position to regulate the correct spring compression and the valve is set to lift at not more than 20% above the designed engine combustion pressure.

Maintenance consists of cleaning and inspection at the same intervals as cylinder overhaul. The valve and seat should be examined and reground if necessary, the spring checked for its free length with no distortion. After assembly the valve should be set and pressure tested.

Lifting of a safety valve relieves the dangerous pressure in the cylinder and also warns of incorrect conditions. The reasons for this must be ascertained and corrective action taken. The high temperature gas and flame expelled may damage the safety valve seat.

Valves may lift during manoeuvring or slow running for a number of reasons:

- Ignition may be violent if engine speed is too slow;
- If a fuel injector has leaked during priming;
- A fuel pump setting is too high or incorrectly timed;
- Should starting air be used as a brake when stopping an engine for reversal or during a 'crash stop', high compression pressures at about top dead centre may cause safety valves to lift momentarily

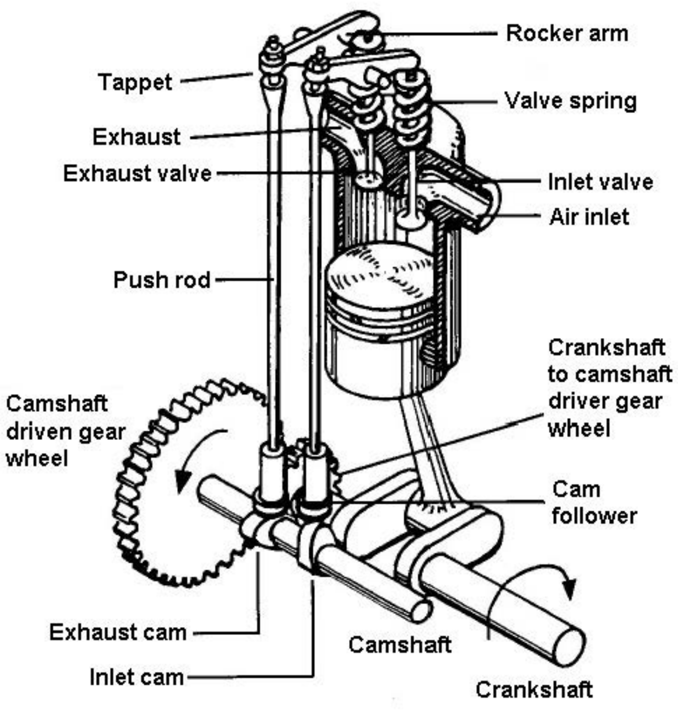
- Valves lifting during running may indicate an overload or timing faults including the camshaft drive.

Safety valve area is only designed to relieve excess gas pressure and may be insufficient to prevent damage in the event of cooling water or oil leaking into the cylinder (hydraulic compression). Before starting an engine for the first time, it should always be turned slowly with indicator cocks open to expel any leakage.

Air start valve

Some engine manufacturers design the engine to start on air by introducing an air start valve on each cylinder head. The air start valve functions as a non-return valve allowing compressed air into the cylinder at a specified position relative to the crank journals angle, forcing the pistons down and thus causing the crankshaft to rotate. This is an alternative means to starting an engine rather than using a rotary starting motor.

Camshaft



Camshaft drive arrangement

In the push rod 4 stroke engine, the camshaft is located inside the crankcase in such a way that the push rods are parallel to the pistons. It is driven from the crankshaft by sprocket wheels and chain or gears at half the engine speed.

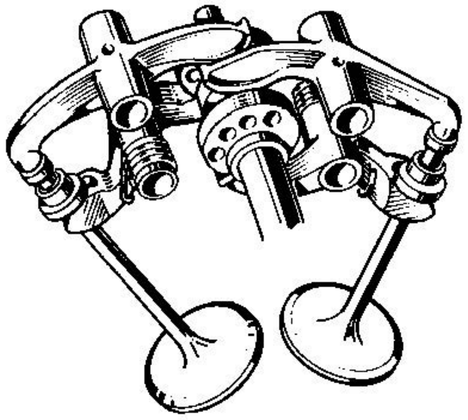
A camshaft is necessary to operate the valves and fuel pumps that control the engine cycle.

Each valve or pump is actuated by a cam follower that rises or falls, as the cam rotates beneath it.

High fluctuating forces are set up and cams are made of steel with case hardened surface to the profile.

On large engines they are an interference fit on the camshaft and it is possible to adjust or renew them hydraulically. Camshafts may consist of a number of part lengths joined at flanges with fitted bolts. The whole shaft must be rigidly supported with substantial bearings and adequate lubrication. Some engines have a separate camshaft lubrication system to prevent any possibility of fuel leakage from pumps passing into the crankcase oil.

Camshaft rotation must be accurately synchronized with the crankshaft and this timing must be checked periodically and after any adjustments or repairs have been carried out.



Overhead cam arrangement

Alternatively the camshaft(s) can be located above the cylinder head, in which case the unit is known as an overhead camshaft engine (OHC).

The drive is by sprockets and chain or becoming more frequent by toothed pulleys and matching toothed belts. In this arrangement push rods are eliminated and the cams actuate the valves direct. Tappet clearance is controlled/adjusted by the insertion of shims or by single rocker arms in which case the gap is set in the same way as in the push rod engine.

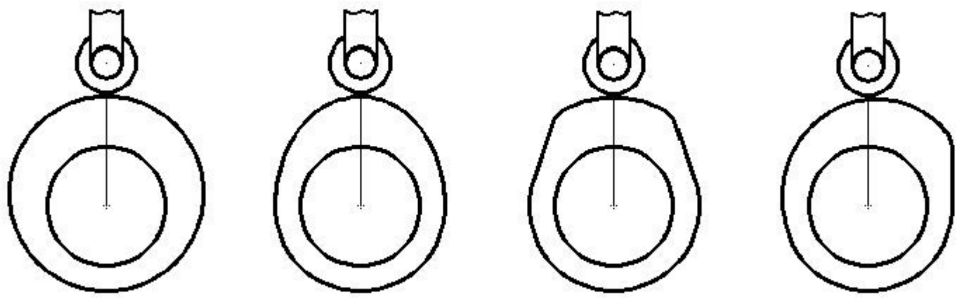
The way the cams are set out on the camshaft in relation to the position of the pistons on their various strokes, and the cam profiles, have a fundamental bearing on the performance, power output and fuel consumption of the engine.

V-type engines will require a separate camshaft for each bank of cylinders.

Reversible engines may have servomotors fitted to their camshaft to readjust the timing of the cams when the engine is to run astern.

A camshaft may be a single piece or (on larger engines) assembled from a number of similar part lengths; each will have a set of cams for one unit. Part lengths are connected at flanges. Each part length may be dismantled separately to simplify overhaul, repair or adjustment.

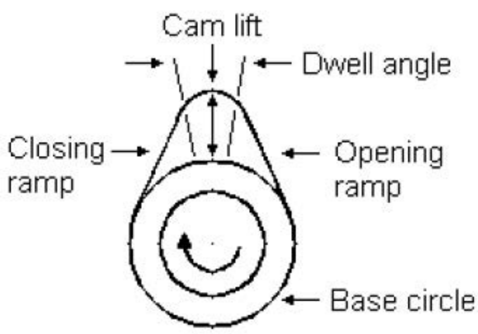
Cam profiles



The eccentric cam **The pear shaped cam** **The inlet valve cam** **The fuel pump cam**

The four cam profiles shown above are probably the most common to be found. The profile or shape of each cam is designed to give the correct timing, speed and height of lift to its corresponding follower.

Cam lift and dwell

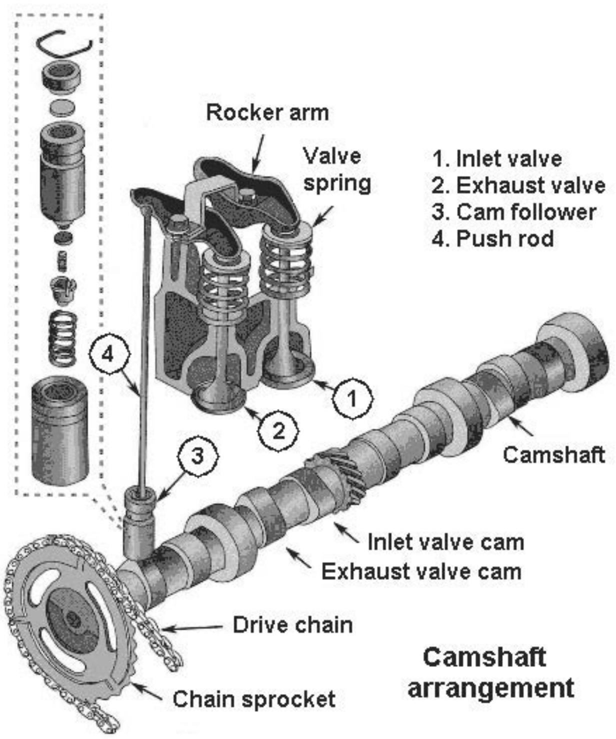


Cam lift is the distance from the peak of the lobe of a cam to its axis minus the distance from the back of the cam to its axis. Another description would be the distance the valve opens plus the tappet clearance, or valve lash, measurement.

Dwell is the angle that the valve remains in the fully open position. The profile of the lobe of the cam causes the valve to open until the lobe flattens out.

The valve stays in this fully open position, which is the angle of dwell, until the other side of the cam lobe is reached when the valve starts to close.

Camshaft drives



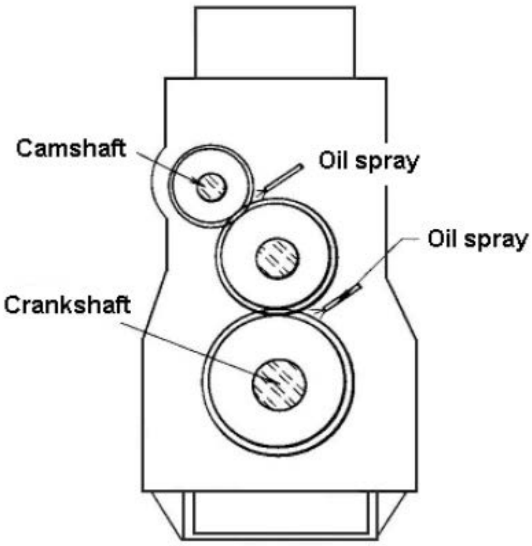
So that they remain in phase with engine timing, camshafts are driven from the crankshaft. Camshaft bearings are supported from the engine structure in a position convenient to the operating mechanisms that the shaft is to control. Choice of this position together with engine size and type will influence the camshaft drive system to be used.

Further engine systems may, in turn, take their drive from the camshaft mechanism. These may include starting air distributor, engine speed governor and cylinder lubricator pumps .Smaller engines may have power take off wheels to driving cooling and lubricating pumps, air compressors etc.

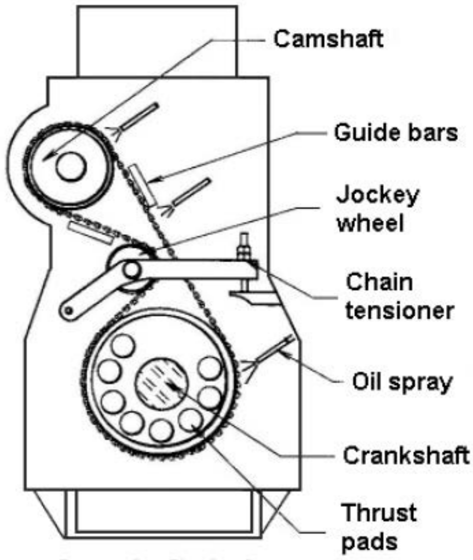
Two forms of camshaft drive are in current use:

- A train of gear wheels is arranged in positions and sizes to give appropriate speeds and directions required: these are used in most medium speed engines and those in which the distance between shafts is limited.
- A series of sprocket wheels connected by a roller chain may be used. This gives a reduction in weight, particularly where the distance between shafts is large.

Both methods have proved efficient and reliable.



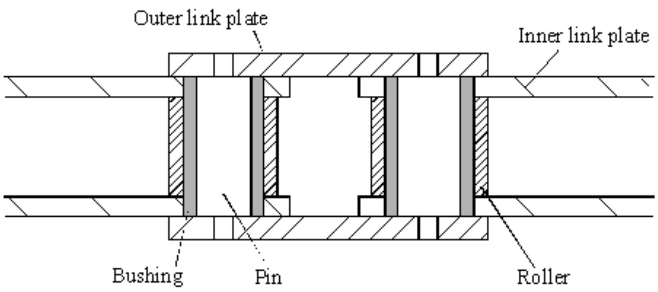
Camshaft gearwheel drive system



Camshaft chain drive system

Camshaft chain

A roller chain forms a flexible drive, robust but light in weight with very small friction loss; it is small in width, which adds little extra length to the engine. It can accommodate a number of additional driven wheels rotating at different speeds or even in opposite directions, and can be used to operate engine driven pumps, etc.



Camshaft drive roller chain

A roller chain consists of alternate pin links and roller links.

Each pin link consists of two pins riveted between two side plates.

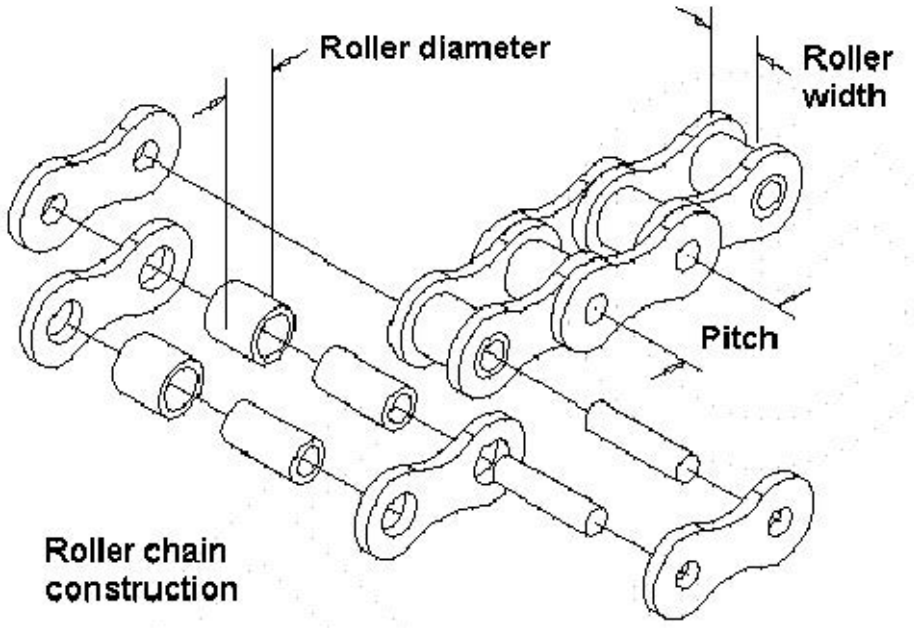
A roller link consists of two rollers free to rotate on two bushings that are a press fit into two side plates.

The pins fit within the bushings of two adjacent roller links.

Alternate links are all riveted together to form an endless chain of the correct predetermined length.

Chains have a very high factor of safety to prevent stretching. Any loss in tension in the chain will be due to wear while in use. Wear takes place between pins and bushings, between bushings and rollers and between rollers and sprocket wheel teeth.

Wear in wheel teeth flanks can be checked by a profile gauge while wear in the chain is measured by its extension.



Periodic inspections are made to check the chains tension. While in place, the extension and loss in tension is indicated by the transverse play in the chain span between wheels on the slack side of the drive. The chain is adjusted to allow a limited transverse movement approximately equal to one link pitch.

Chain Driven Camshafts

Regular inspections should be undertaken of the camshaft drives to avoid hot spots, excessive loading, shock loading, noise and vibration. The inspection should concentrate on:

- Stretch between pins (pitch)
- Wear of sprocket teeth
- Damage or cracks on link plates
- Scuffing of inside surfaces
- Lub oil sprayer damage
- Wear on bushes and rollers

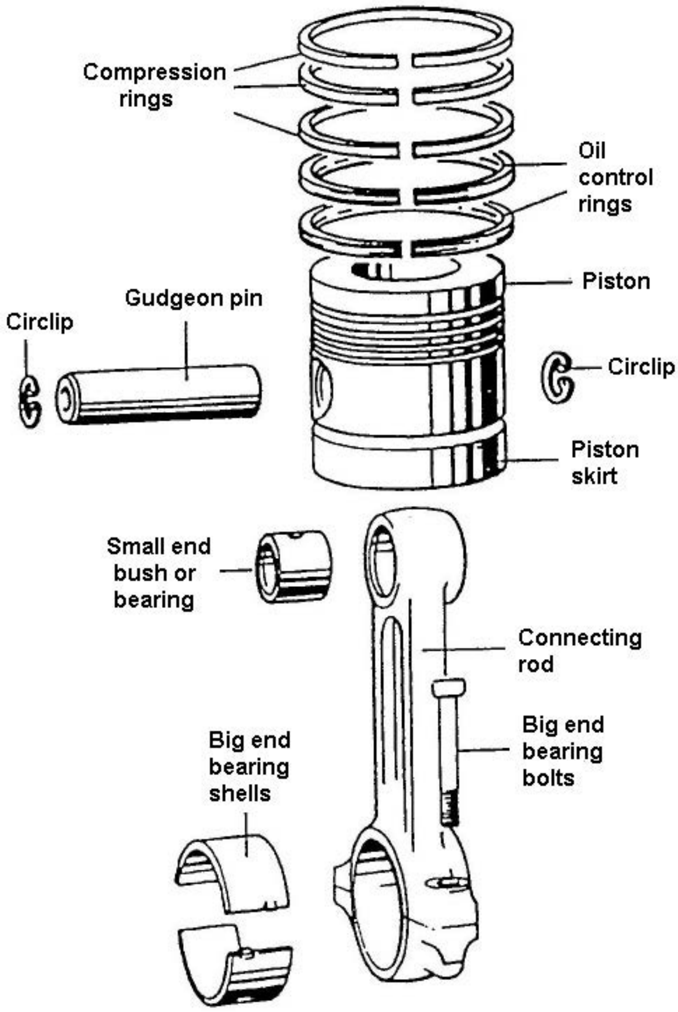
Camshaft speed

4 stroke engines require inlet valve, exhaust valve and fuel pump cams for each cylinder, and since this cycle is completed in two engine revolutions the camshaft rotates at half engine speed.

The running gear

The running gear comprises the parts of the engine that move and include:

- The piston
- The piston rings
- The gudgeon pin
- The connecting rod (including the top and bottom end bearings)



The piston is connected to one end (**the small end, or top end**) of the connecting rod using a gudgeon pin, which allows the connecting rod to swing from side to side.

This enables the reciprocating motion of the piston to be converted to rotational motion, which is achieved by connecting the other end (**the big end, or bottom end**) of the connecting rod to the crankshaft.

When combustion takes place in the cylinder the piston is forced down. The reciprocating motion of the piston has to be converted to a rotary motion to enable the engine to drive the load such as propellers and generators. This is achieved by a crank mechanism.

Pistons are fitted with piston rings to help form a seal against the cylinder liner.

Pistons

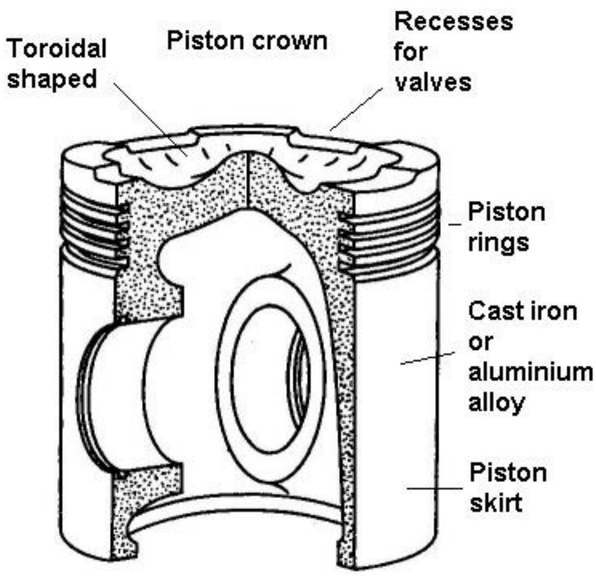
The piston has to withstand the pressure and heat of the burning fuel and transmit the resulting energy to the connecting rod. It must not allow the burning or burnt gases to escape past it, blowpast, and keep the cylinder walls free from excess lubricating oil.

The piston must be strong but light in weight and have a minimal expansion when heated. The material normally used is an aluminium alloy, which conducts the heat away quicker than cast iron that used to be the favoured material.

When heated aluminium expands more than cast iron, and so considerable design skill is required to accommodate this higher expansion.

Two methods construction used are:

- Split skirts where slots are cut at various angles in the portion of the piston below the rings.
- Pistons are ground elliptical, so that they take up a circular shape when heated.

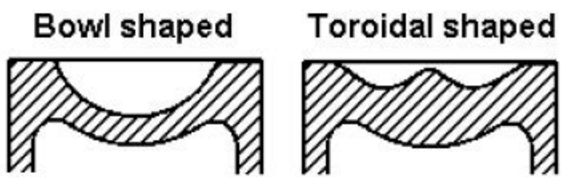


4 stroke engine piston

The construction of the piston is usually made from aluminium alloy in order to keep the weight down and allow for effective balancing at high speeds.

Some engines where weight is not a factor the piston is constructed of cast iron. In high output engines the piston is constructed from a two piece section, where the crown material is a heat resistant steel bolted to the skirt section of the piston.

The design of the piston includes the facility to carry the gudgeon pin, which is supported by a strong ribbed structure sufficient to ensure that the load of the piston is carried.



Piston crown shapes

There are variations in piston designs especially with regards to piston cooling arrangements.

Generally, the piston is pot shaped. The piston crown is usually either a bowl shape or a toroidal shape. This design assists in combustion efficiency by agitating the air and fuel mix. The crown design also may contain cut out portions to accommodate the valves when they open.

The cooling of the piston underside is usually carried out by a simple splash cooling process. Other cooling processes include a cocktail shaker cooling process, spray, coil (ported channels within the underside of the piston).

Note that 2 stroke pistons are usually longer than the pistons for 4 stroke engines. This is due to the requirement in a 2 stroke engine for a longer piston skirt to allow for the covering of the inlet ports (and exhaust ports when fitted) when the piston is at the top of its stroke.

Piston rings

The function of piston rings is to seal the gases within the top of the cylinder and prevent any excessive leakage down the sides of the piston. Leakage past piston rings is known as **blowpast**.

The requirements of the piston ring are as follows:

- The piston ring must be able to float freely within the whole depth of the piston groove.
- The piston ring must be free to follow the liner surface irrespective of transverse movement, and be designed to ensure a wedge of oil is maintained during its travel along the piston surface (reducing wear and spreading lubrication).

There are three main types of piston ring:

1 Firing (or combustion) ring

This is the top ring on the piston and withstands the pressures and high temperature of combustion forces.

2 Compression ring

These rings form the gas tight seal between the combustion space and the crankcase.

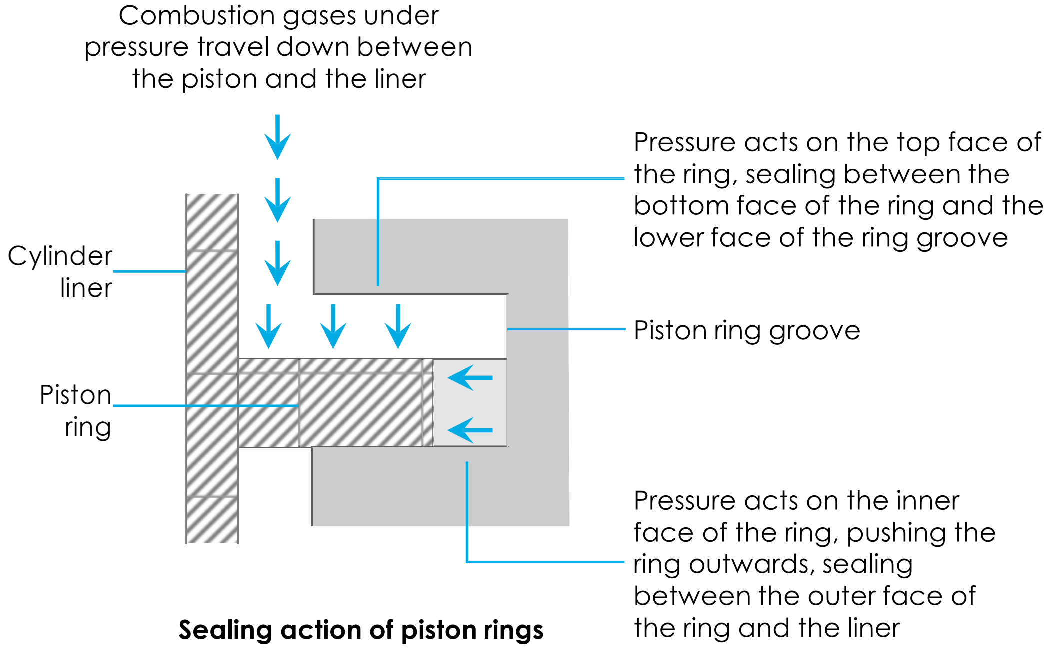
3 Oil control or scraper ring.

These are fitted to distribute lubricating oil for lubrication, then to remove excess lubricating oil not used or splashed from the crankcase.

Sealing action of piston rings

The piston rings are situated in grooves machined into the piston crown. The gas pressure acting on top of the rings and behind the rings carries out the sealing of the piston ring to the cylinder liner bore. This produces a gas tight seal and prevents the loss of compression from the combustion space.

There are usually three or four compression piston rings on each piston, this configuration allows for a continuous pressure drop from the pressurised gases passing each ring.



Sealing action of piston rings

Materials

Materials used for diesel engine piston rings must have good strength, elasticity and wear resistance with low friction. They must maintain these properties at high working temperatures.

The choice of material is to ensure the following:

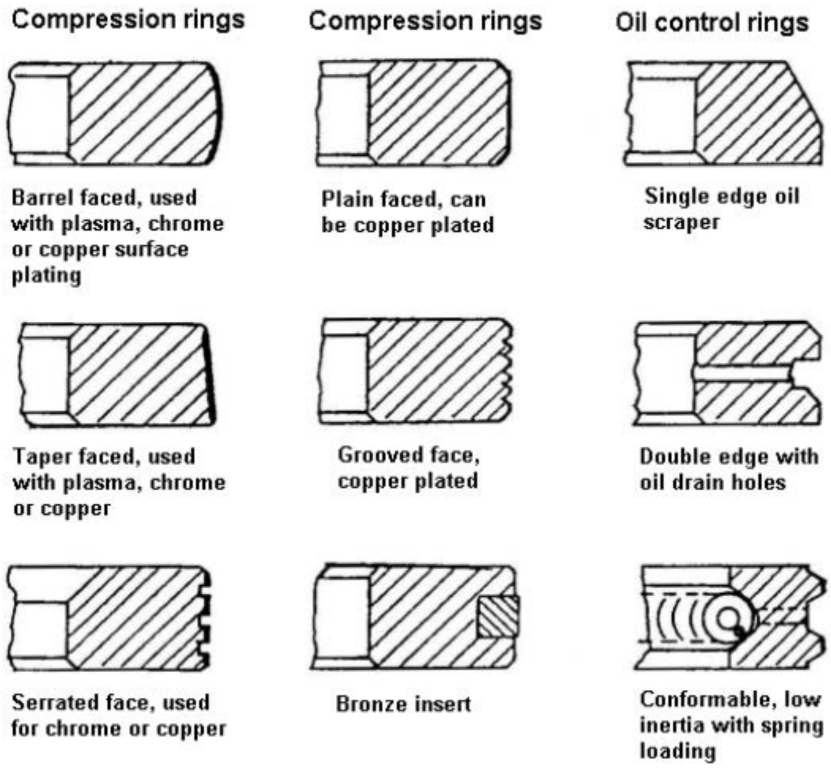
- The rings have good strength, elasticity and wear resistance with low friction.
- Ability to maintain these properties at high working temperatures.
- They must resist corrosion.

- Able to readily transfer heat and have thermal expansion compatible with the piston in order to maintain ring groove clearance.

Piston rings are usually manufactured of highly resilient cast iron (flake graphite cast iron alloyed to manganese and chromium) and located in grooves machined into the upper part of the piston. Piston rings have a limited degree of plasticity and can be expanded to fit on the piston, but they are brittle and can shatter very easily.

Because of the expansion factor, pistons cannot be a tight fit in the cylinder otherwise the pistons would seize up when they expand, due to the heat from combustion. Therefore some clearance is given and the piston rings are used to seal or maintain the compression.

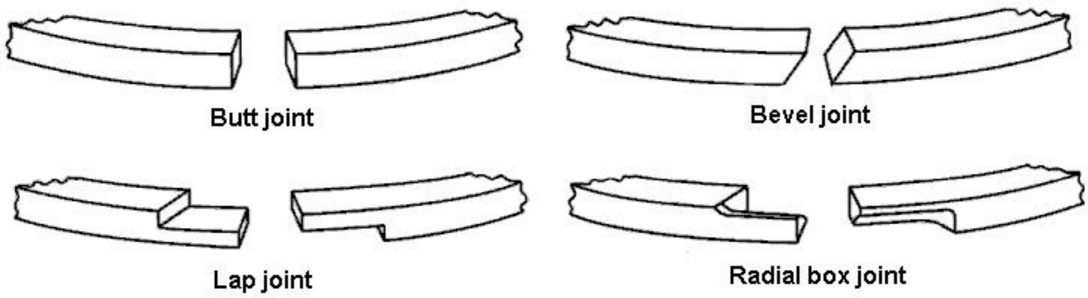
Piston ring profiles



Example piston ring profiles

The cross-section of piston rings is rectangular with small radii on all edges. This allows an oil wedge to build up on the outer surface and prevents sticking at the back of the ring groove. The section may vary adjacent to the ring butts. Rings are machined either circular or to a cam shape from which they expand to form a circle at working temperatures and avoid port chipping.

Ring circumferential joints



Piston ring circumferential joints

A radial or circumferential cut is made and the shape of ring joint ends may be:

- A butt joint (or vertical joint)

  Gives a good joint for top rings;
- A bevel joint (or scarfed or diagonal joint)

  Gives a better gas seal but less robust;
- A lap, radial box or bayonet joint

  Gives a good gas seal but is more vulnerable to breakage and is only used in some lower rings.

To allow for expansion there must be a clearance at the circumferential join. This clearance is known as the **ring gap clearance**, or ring butt clearance.

Firing ring

This is the top compression ring on the piston and withstands the pressures and high temperature of combustion forces.

The top ring, which is subjected to the greatest load and temperatures, may be chrome plated or plasma coated. Plasma coating consists of a layer of very hard powdered metals such as molybdenum and chromium, fused to the rubbing surface of the rings. Plasma coating is carried out with finely powdered metal in a stream of gas so hot that all metal molecules become electrically charged causing fusion with the ring surface layer to form a very hard rubbing surface.

Chromium or plasma coated rings must not be used in chromium plated liners.

To assist build-up of oil wedge lubrication and accelerate bedding-in and conformity, these rings may have their surfaces barrelled or grooved. Their cross-section may be bevelled to balance working pressures.

Compression rings

Piston compression rings are fitted in corresponding ring grooves machined in the piston. They will bear heavily on the lower surface or land of the piston groove during the power stroke and these groove landings must remain true or the rings will distort. To reduce wear and fretting, the grooves are either chromium plated, heat-treated or have hard wear rings inserted. Sufficient thickness of treatment should allow regrinding of surfaces to fit oversized rings if necessary as wear occurs.

Compression rings convey heat from the piston to the cylinder liner and act as a gas seal between this and the piston. They must be free to follow the liner surface irrespective of transverse movement and will build up an oil wedge on the liner, reducing wear and spreading the cylinder lubrication. The outward pressure is initially due to elasticity in the compressed ring but is increased by gas pressure that acts on the back of the ring. This pressure is greatest in the top rings. The temperature is higher here and the compression rings will have higher wear rates than others lower on the piston.

Lower compression rings may have bronze inserts or copper plating to ensure rapid bedding-in.

Oil control rings

Oil control rings are also referred to as scraper rings.

The piston has to be well lubricated for it to move effectively in the cylinder liner while carrying the side loads imposed on it. The lubrication of the piston and subsequently the liner should be sufficient to effectively lubricate but not excessive enough to flood the compression rings. Any excessive lubrication would result in an increase in carbonaceous deposits in the piston ring grooves, allowing the rings to become burnt, and oxidise. An oil control ring controls the flow of oil.

They may be fitted below the compression rings on the piston, or alternatively to the skirt.

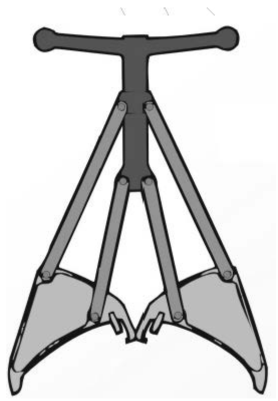
To control the cylinder oil film the oil control ring has a single narrow edge, which is in contact with the cylinder wall. When moving up the cylinder the oil control ring functions by riding over the film of oil on the cylinder wall. During the downward stroke the wedge of oil that is formed is scraped down the bore.

Unlike the compression rings they are not subject to a high gas load to force them onto the cylinder wall. They have to rely on their own strength to force them to maintain the wall pressure necessary to keep the oil film to the required thickness.

Bevelled relief of the back surface of the ring may be applied to reduce the ring pressure. They are light in section to conform readily to the liner contour.

Low-inertia oil rings are of reduced section supported by an outward loading spring. For improved life the scraping edges may be chromium plated. Scraper rings may have drain holes that allow rapid removal of oil to the back of the ring groove from where it can pass through holes to the inside of the skirt and return to the sump by gravity.

Fitting and removing piston rings



Piston ring expander tool

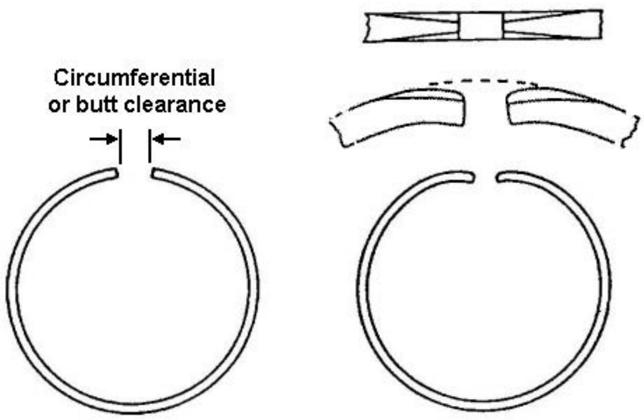
Piston rings are expanded outwards using a special expander tool, to pass the rings over the piston and released into the grooves that have been oiled.

The rings should then float freely within the whole depth of the grooves.

The special expander tool should be used to give even bending without twisting the ring section. Excessive bending should be avoided.

Piston ring clearances

Ring clearances are necessary to allow movement and thermal expansion. Axial clearance in the groove must be gauged to allow gas pressure to pass to and from the back of the rings. The clearance will increase with wear and the landings must not be allowed to taper. Clearances vary with engine size and rating but for a large engine may be 0.4 mm for the top ring to 0.2 mm for lower rings. Piston ring and groove wear will inevitably be uneven and rings must not be moved from one groove to another during overhaul. If wear is excessive the used rings must be discarded and new ones fitted.



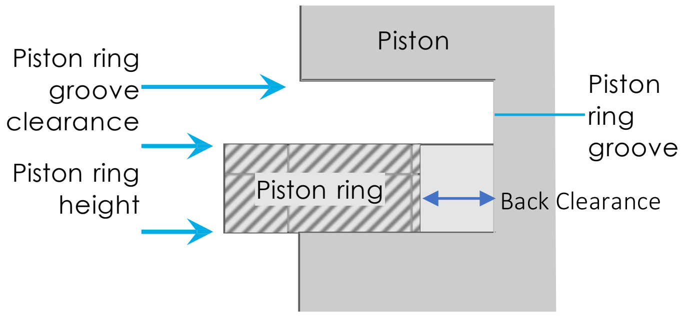
Circular ring   Cam turned ring

Cam turned rings have a special profile at the circumferential joint when cold, such that when they are at running temperature they will expand to become round.

The following calibrations should be taken and recorded during engine maintenance:

- Ring gap (or butt or circumferential) clearance
- Ring groove clearance
- Ring height or thickness
- Ring width
- Piston ring groove height
- Piston ring groove depth

The piston diameter may need to be measured as well to check for any piston wear or burning.



Piston ring groove clearance

Groove (or axial) clearance is measured with a feeler gauge after inserting the rings into the relevant grooves.

Groove clearance maybe worked out by the difference in the piston ring groove height and the ring height.

It is important to maintain the proper groove clearance as the gas load acts on the top of the piston ring for proper sealing of the ring against the liner.

Butt clearance is measured with the ring inserted into an unworn area of the liner or by inserting it into a new spare liner. The butt clearance is commonly measured with a feeler gauge.

Butt clearance at the ring joint is necessary to allow for thermal expansion, but should not be excessive, to prevent blowpast of gas. It is measured before fitting on the piston by inserting the ring into the least worn (lower) part of the liner bore. This clearance will vary with the shape of joint used, engine make, size and rating.

Circumferential wear of rings can be measured by reduction in the width of the ring section and by increase in butt clearance at the corresponding liner bore.

Excessive wear will reduce engine efficiency and may cause hot gas to blow past the rings, removing lubrication, causing ring distortion and breakage.

Gudgeon pins

The piston is attached to the little or top end of the connecting rod by a short spindle known as the gudgeon pin. The pins are manufactured from high tensile steel forging or a specially forged aluminium alloy such as Duralumin. Gudgeon pins are either filled tightly in the top end bush by pressing or clamping, or they are of the fully floating type, which have freedom of movement being constrained at the outer ends by circlips.

Combustion chambers

Combustion chamber design, which includes the shape of the cylinder head, the shape of the top of the piston and the air flow through the inlet ports, is one of the most important factors in efficient operation of the diesel engine.

Because of the very short space of time available in a diesel engine in which the fuel and air can mix, various methods have been devised in an attempt to give improved mixing and combustion.

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

Generally, combustion systems can be classified as follows:

1 Direct injection.

2 Indirect injection, the two most common types being:

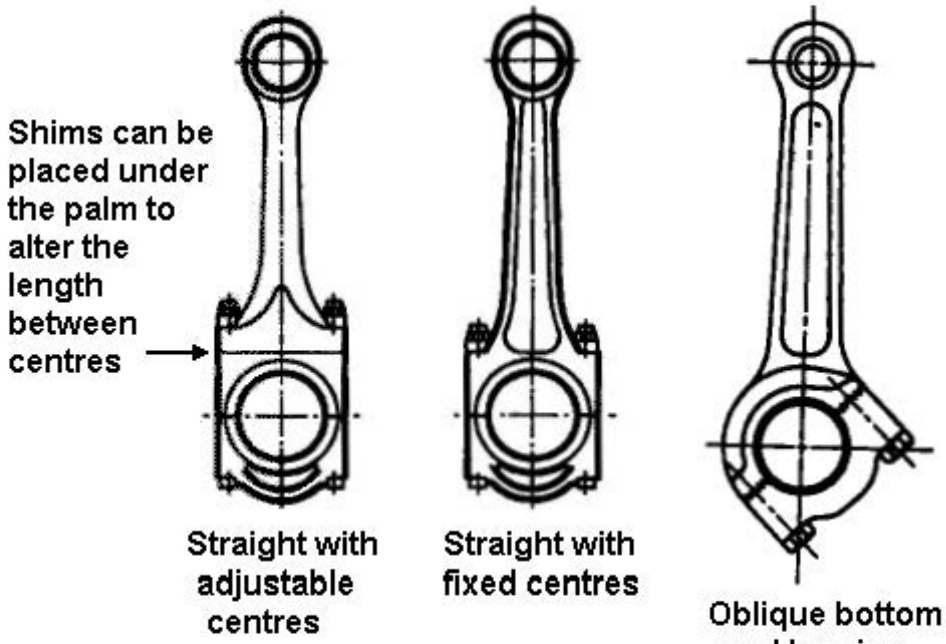
   a Turbulence chamber;

   b Pre-combustion chamber.

Connecting rods

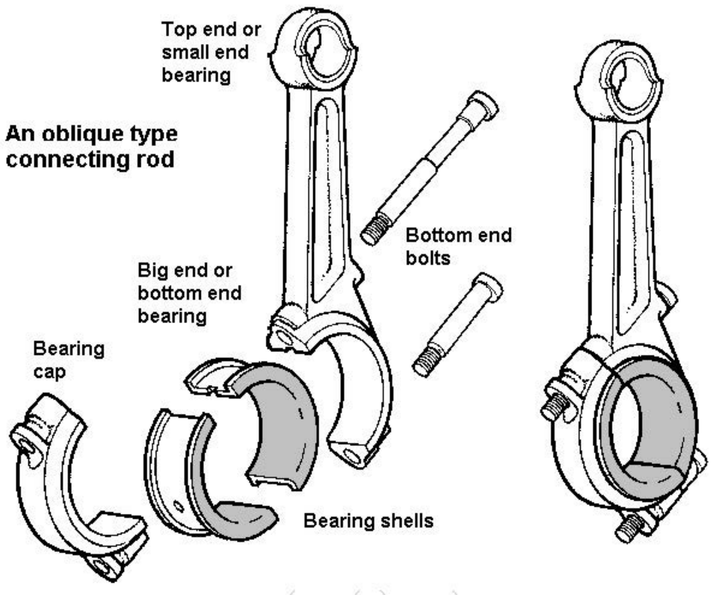
The connecting rod is often simply just called the con rod.

The connecting rod is manufactured from high tensile steel with the lower end containing the big end bearing which forms the connection between the rod and the crankpin of the crankshaft. The big end is split to enable it to be assembled with the bearing, on the crankpin, by bring the two halves together and clamping together with high tensile steel fitted bolts.



Types of connecting rod

The straight type con rod with adjustable centres (see left diagram above) allows the con rod to be lengthened or shortened, which will allow the compression ratio to be altered. The change in length is accomplished by placing or removing shims from under the con rod palm.



Great care must be taken to check the **bump clearance** between the top of the piston and the bottom of the cylinder head after any adjustment to check that they do not contact each other. Also clearance between the top of the piston and the exhaust and inlet valves (when fully open) should be checked.

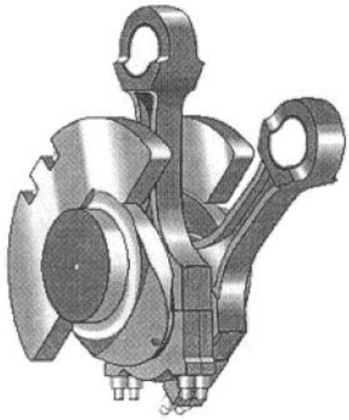
An important factor when deciding the type of con rod to use is the width of the bottom end bearing housing. The width determines whether the con rod can be withdrawn upwards through the liner or downwards through the crankcase during removal for maintenance.

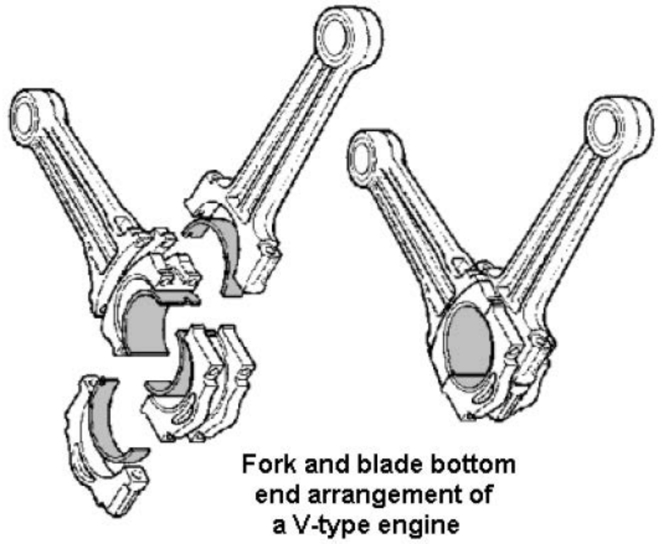
The use of oblique bottom end bearings makes the width narrower to allow for withdrawal upwards through the liner. Some larger diesel engines have a three piece bottom end bearing housing, again to allow the con rod to be withdrawn through the liner.

Connecting rod main bearings are similar in design to the main bearing. They are relatively thin walled sectioned bearings, having a lining of bearing metal, copper lead or tin aluminium, and a thin flashing of lead or indium to provide an anti-corrosion layer. The shells depend upon the accuracy of the bore to hold them in the correct circular shape.

The bearing shell has oil grooves set in the section of the shell. This design allows oil to flow from the oil port in the journal up to the connecting rod to lubricate the small end of the rod, and splash cool the underside of the piston.

The connecting rod large end bolts are very important component and are carefully designed to carry the high fatigue loads required. It is essential to treat them carefully and avoid any damage to their finely machined surfaces. Correct tightening of the bolts is again essential, and manufacturers recommendations on torque or stretch must be followed.


Side-by-side bottom end arrangement of a V-type engine


Fork and blade bottom end arrangement of a V-type engine

On V-type engines, the connecting rods for corresponding cylinders in each bank operate on the same crankpin journal.

There are two common types of connection:

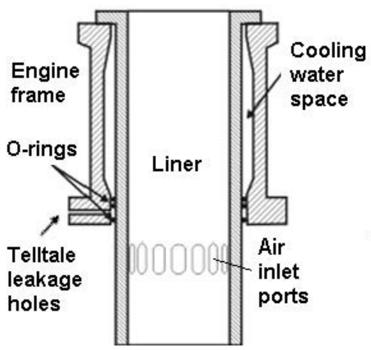
1 The side-by-side type;

This is probably the common arrangement.

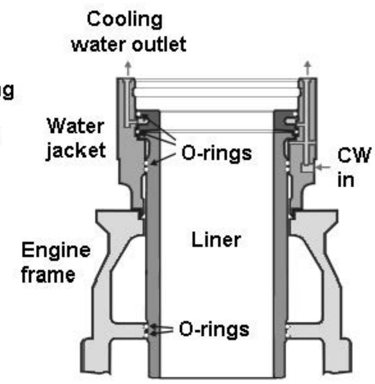
2 The fork and blade type.

The fork and blade type is more complex, but allows for a shorter engine.

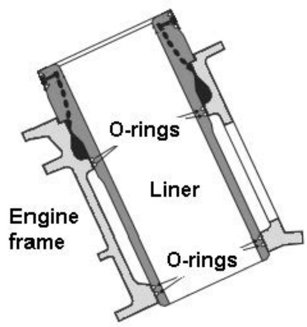
Cylinder liners



2 stroke in-line cylinder liner

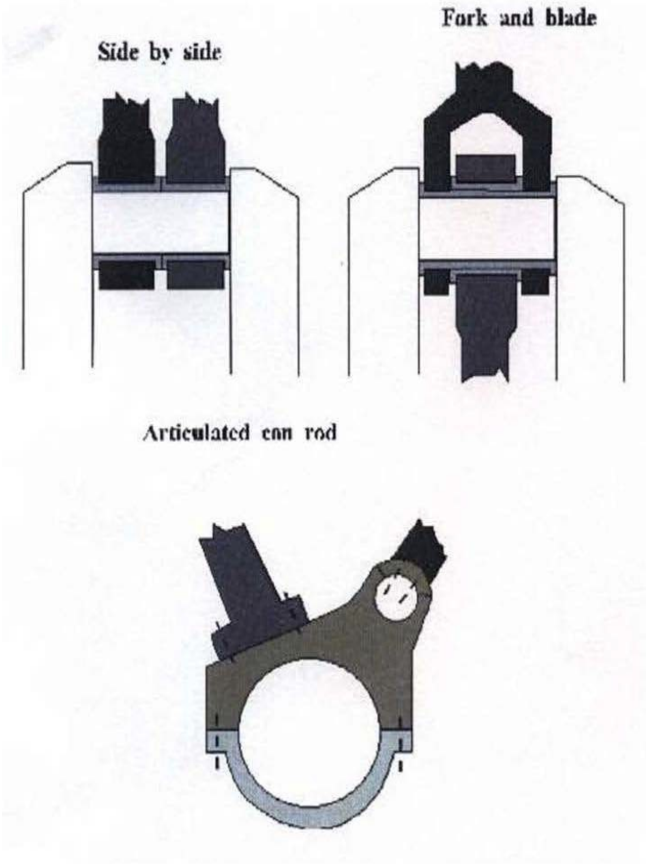


4 stroke in-line cylinder liner



4 stroke V-type cylinder liner

3 types of connecting rod application



Cylinder liners are made from close grain cast iron or pearlitic grey cast iron. For 4 stroke engines, they are simple cylindrical shaped top flange to provide location and a means of securing them in the cylinder block or to a water jacket. Below the flange, there is often a joint ring usually of heat resistant rubber or copper. The lower end of the liner is fitted with rubber rings to create a seal for the bottom of the water space. As well as stopping water leaks, they also have the facility to prevent oil from the crankcase entering the water jackets. A 'tell tale' leak off hole is fitted between the two lower rings.

Cylinder liners are designed and manufactured to ensure that oil can readily adhere to the liner surfaces during operation, therefore allowing a lubrication barrier to form and thus reduce wear on the liner surface and the piston rings. The greatest wear area of the cylinder liner is the upper section where the motion of the piston direction is reversed and therefore an oil film is not distributed. The area also suffers high gas pressures, heat and the build up of carbonaceous material which may be abrasive, therefore over a period of time these conditions may promotes an increase of wear.

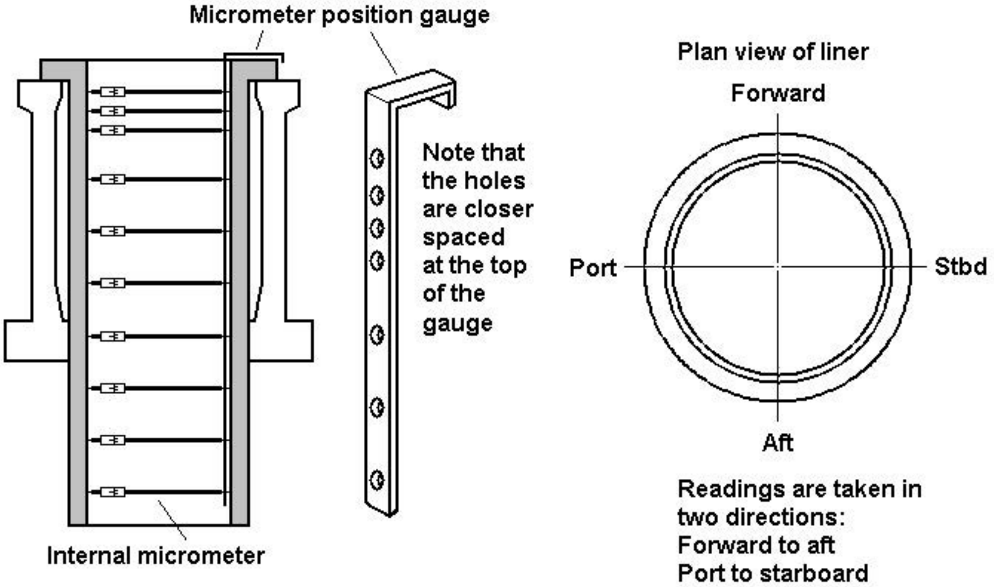
To minimise wear at the top end of the liner, the liner has small bore cooling passages to carry coolant as close to the cylinder bore as practical.

Liners can be replaced when the bore becomes worn out.

This type of liner configuration is called a **wet liner.**

The cylinder liners for 2 stroke engines have air admission ports about midway along their length. The water jacket does not usually extend below these ports. The sealing rings are situated just above these ports and are designed to prevent scavenge air entering the water spaces as well as water escaping from the jackets. An additional sealing ring of similar material is located below the ports to prevent the pressurised air blowing through to the crankcase.

Liner calibrations



Liner calibration and gauge

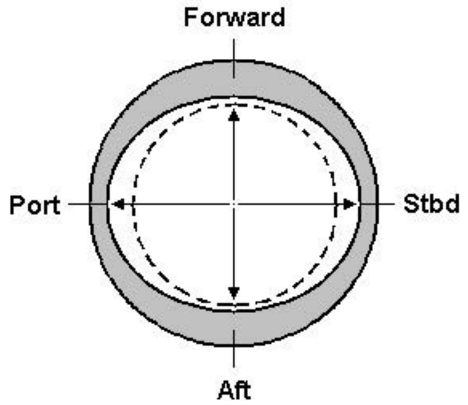
Liner clearances should be calibrated when unit maintenance is being carried out. Excessive liner wear would lead to problems such as low compression, blow past, piston ring breakage, insufficient lubrication on the cylinder walls etc. Therefore if liner clearances are excessive the liner will have to be replaced with a spare.

Liner calibration is carried out at different points along the length of the liner, with the use of an inside micrometer, as specified by the engine manufacturer. The micrometer is positioned in the same vertical position each time using a special liner gauge.

Commonly two readings are taken at each point, forward to aft and port to starboard.

The readings are recorded for comparison and future reference, and to produce a liner wear profile drawing.

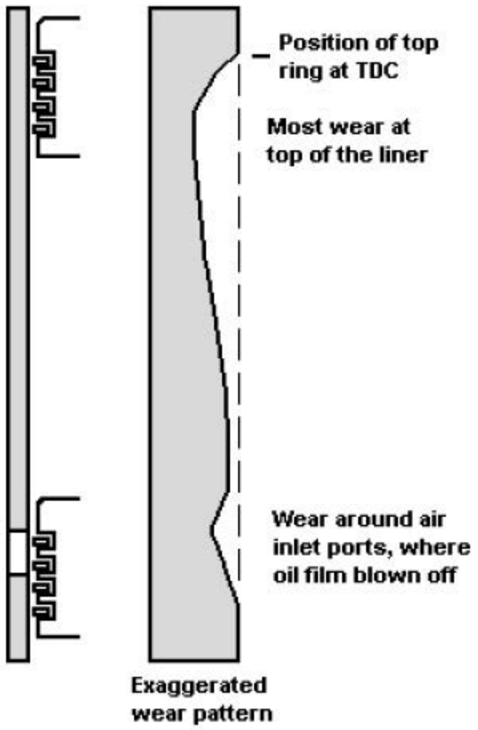
Plan view of liner

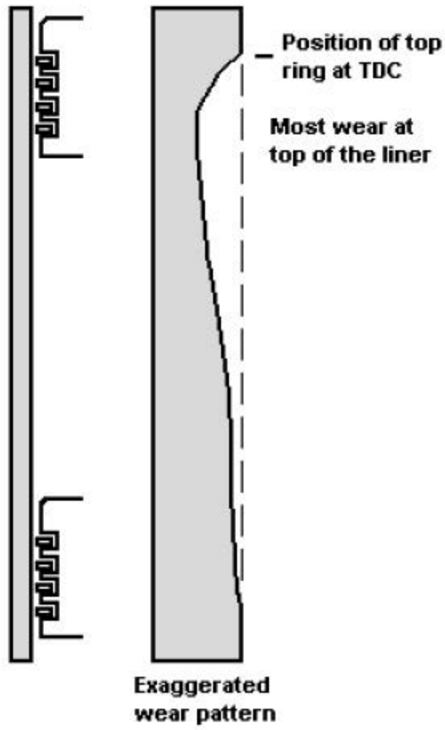


Wear is greater port to starboard than the wear forward to aft

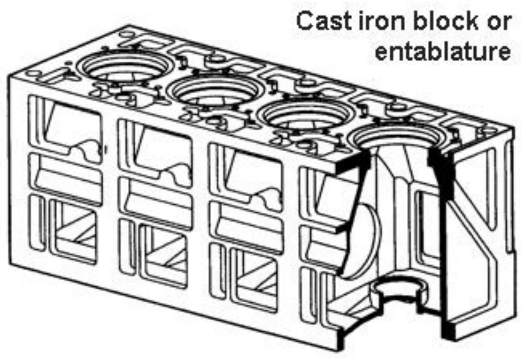
The liner wear pattern with a trunk piston engine tends not to be even circumferentially.

There will be greater wear on the port to starboard plane because of the additional side thrust from the action of the connecting rod on the piston during the power and compression strokes.





Engine cylinder block and crankcase



The main external component of an engine is the block and crankcase.

They are normally manufactured from castings of cast iron or sometimes of light alloys.

The blocks are machined for the cylinder liners in which the pistons operate.

Machined passages and holes in the

block provide for coolant circulation, valve operating components and the attachment of various items such as water and fuel pumps.

The crankcase provides housing for the main crankshaft, camshaft and thrust bearings. It also provides location and means of attachment for the sump, that acts as a reservoir for the lubricating oil.

The cylinders of medium speed diesels are water-cooled. To ensure that the temperature of each liner is correctly maintained, the cooling water is in direct contact with the outer surface of the liner.

The usual arrangement is for a number of cylinder liners to be enclosed in one (monobloc) ductile cast iron casing to form a single cylinder block. The cooling water jacket of each cylinder is common, but segregated to ensure that each cylinder receives the correct amount of cooling water to their individual spaces.

The top of each cylinder block, which supports the cylinder liner, is enclosed by a cylinder head. The cylinder head is attached to the engine frame (crankcase) by studs that ensure that the cylinder head forms a gas tight seal between the head and liner.

To ensure that the cylinder head temperature is maintained, the flow of jacket cooling water flows from the cylinder liner spaces to each individual head. This ensures that the spaces surrounding the exhaust and inlet valves as well as fuel injectors remain cool.

The forces produced by the reaction of the cylinder heads to the gas pressure in the cylinders are transmitted from the top of the cylinder block directly to the crankshaft main bearings through tie bolts. The tie bolts pass through all the separate components of the structure, therefore maintaining the components in compression and ensuring that these steel members carry all the tensile loads.

Bedplates

The bedplate of an engine acts as the foundation, providing rigid support for the main bearings and crankshaft. It is also a platform on which other structural components such as frames and blocks may be accurately mounted to support the engine cylinders and ensure the alignment of all working parts.

There are three common methods of constructing bedplates:

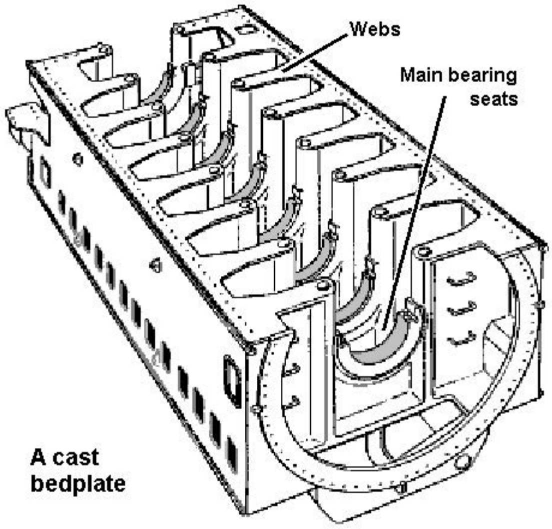
1 Fabricated from steel plate;

2 Casting

3 A combination of fabrication and castings

The bedplate also may hold the lubricating oil for the engine, if it is what is known as a **wet sump engine**. Very large engines are known as **dry sump engines**, the lubricating oil is not held in the bedplate sump, but stored in a drain tank underneath the engine.

Any welding in the bedplate must be to a very high standard, carefully controlled and inspected. It must be stress-relieved, shot blasted and tested for flaws. All plate edges must be correctly prepared, with double bull welds and complete penetration where possible. Plates of different thickness should not be butt welded together.



In high-powered engines the bedplate must withstand heavy, fluctuating stresses from working parts.

It must transmit engine loads to the ship's structure, distributing these over the necessary area, and may complement the ship's strength and propeller shaft alignment.

Engine mountings

There are two methods of securing a bedplate to its seating:

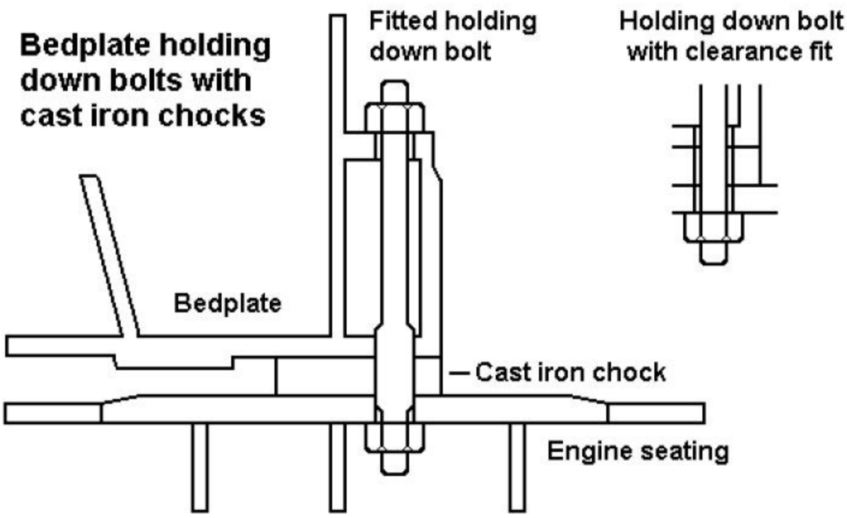
4 With holding down bolts, with either:

  a Cast iron chocks;

  b Resin chocks.

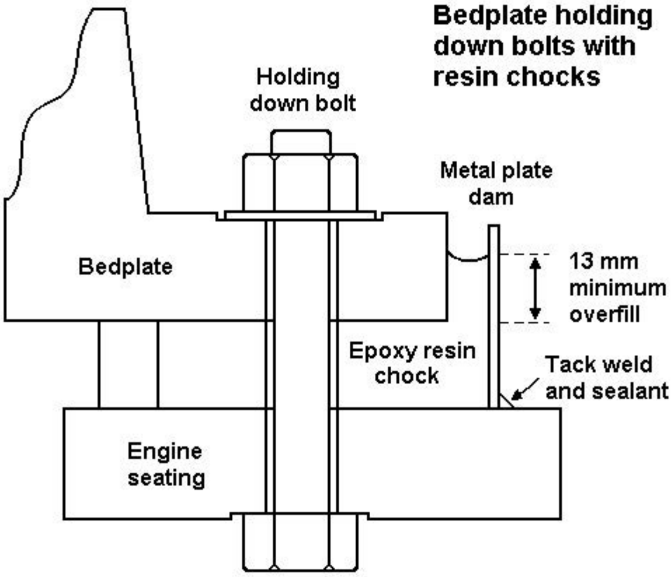
5 With flexible engine mountings.

Holding down bolts with chocks



Holdings down bolts or studs are screwed into the tank top and a nut fitted and locked underneath. Seals must be used to ensure the integrity of the watertight tank tops. Studs will normally have clearance in the bedplate to allow for thermal expansion of the engine. In some cases some fitted bolts may be used to transmit thrust at the drive end of the engine.

To improve the resilience of holding down studs, their unthreaded section may be of reduced diameter and the overall length increased. The top nuts are hydraulically tightened in sequence to reach the correct tension in the studs and compression in the chocks. Nuts must be hydraulically tested and chocks hammer tested at regular intervals, and additionally after heavy weather or damage.



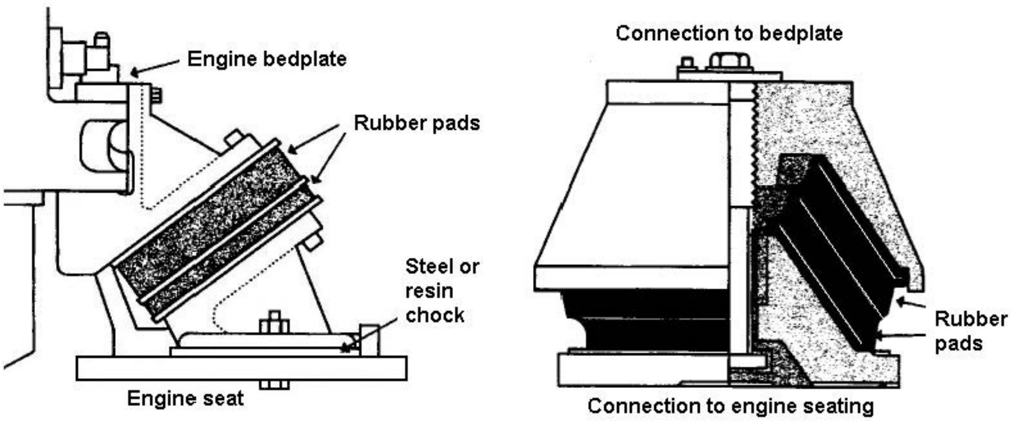
Side and end thrust (transverse and longitudinal) is transmitted through brackets welded to the tank tops at the sides and ends of the bedplate. Vertical chocks or packing pieces are filled and locked between each bracket and the engine. Side brackets are situated at the ends of each transverse member. End thrust is taken in a similar manner.

Although the main forces are transmitted at the bedplate, further transverse struts to secure large engines to the ship's structure are filled at upper platform levels.

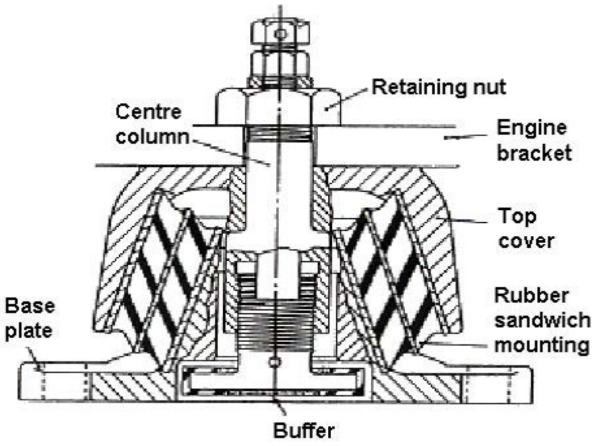
Flexible or resilient mountings

The use of flexible engine mounts has the following advantages:

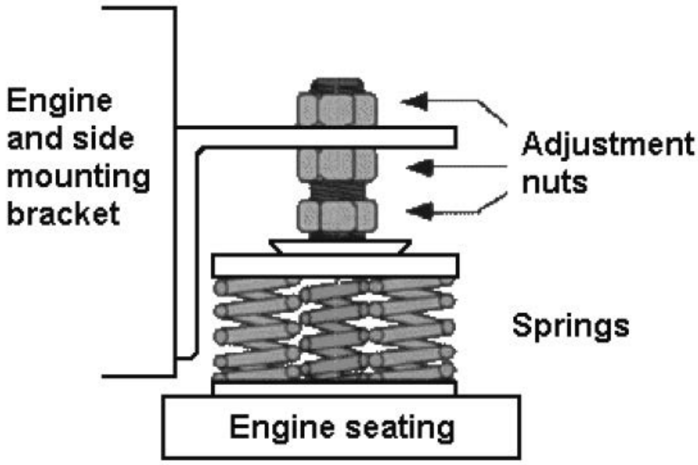
- Slight mis-alignment of the engine can be tolerated, with the use of a suitable flexible coupling to the drive shaft;
- Noise and vibration are reduced.



Flexible or resilient engine mounting

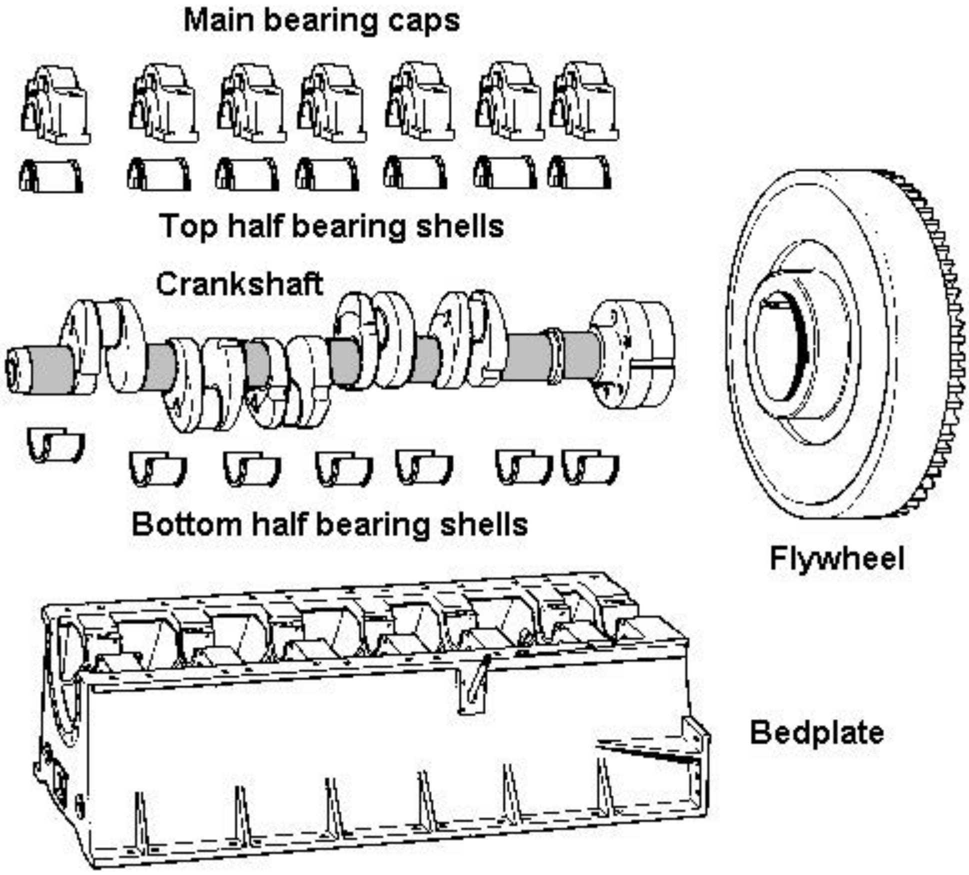


Flexible or resilient engine mounting



Methods of crankshaft support

There are two forms of the bedplate with respect to mounting the crankshaft:

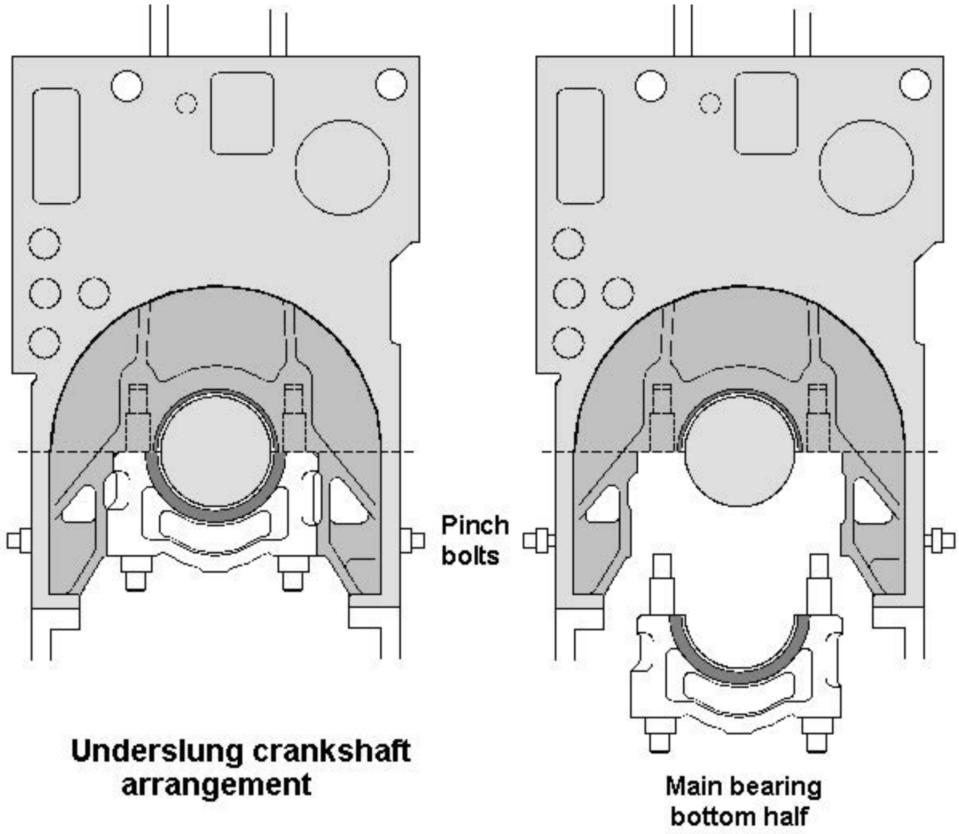


The bedplate supporting the crankshaft from underneath;

The crankshaft lies on the bedplate resting on its main journals. The cylinder liners are housed in a cylinder block (or entablature) that is fitted above the bedplate to form the crankcase.

Bedplate Cracking

Bedplates may suffer from cracking through poor manufacturing processes, over tightening of chocks and or holding down bolts. Excess loading may also result from grounding, power imbalance or fouling of the propeller.



The bedplate with an underslung crankshaft

The crankshaft is slung under the bedplate. The bedplate in this case may also form the engine block, which is commonly a single casting. The cylinders liners are housed in a cylinder block (or entablature).

Crankshaft

The crankshaft receives and transmits the full working power of the engine and is subjected to fluctuating bending, torsion and shear stresses. The material used must have high strength, a long fatigue life and form good bearing surfaces.

The crankshaft is designed and machined to give a multi-throw arrangement, with the angle of each throw determining the firing order for the engine.

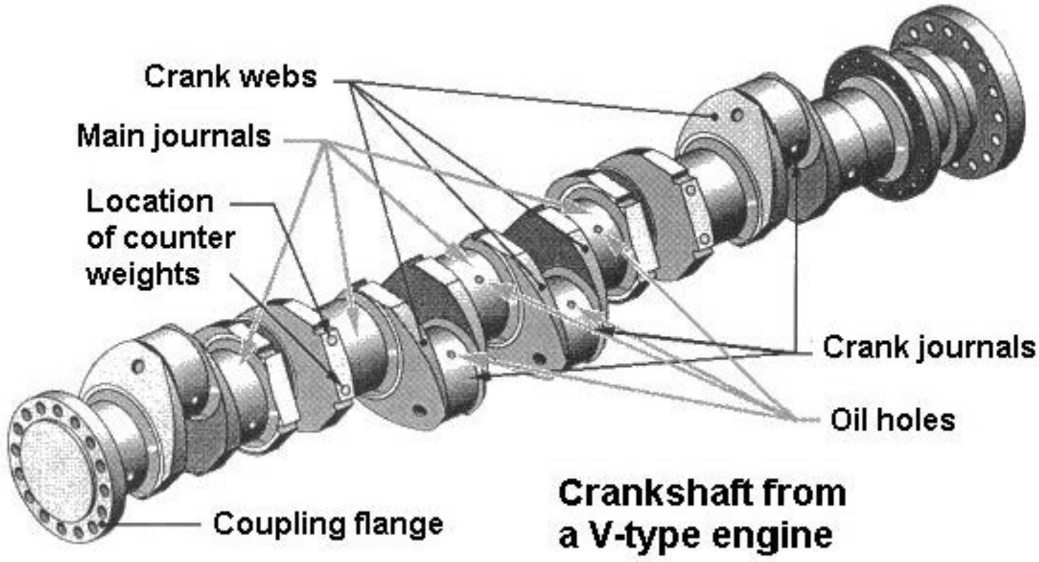
The firing order is designed to establish a mechanical balance, and a smooth torque. Consideration is also given to bearing loads, exhaust arrangement and torsional vibration. These considerations may result in the installation of balance weights to crankshaft throws.

Crankshafts are manufactured from high-grade steel forgings or a special high- grade cast iron. Carbon or low-alloy steels are used, depending on size.

There is a crank pin for each cylinder, journals on which it turns in the main bearing, and webs or cranks that act as balance weights.

At one end of the crankshaft there is an attachment for the flywheel, while the drive for the camshaft is usually taken from the other end.

A crankshaft consists of a number of cranks or throws, which are rotated by piston forces, transmitted through the connecting rods and bottom end bearings. In-line engines have one crank for each cylinder. Every crank is made up of two crank webs joined by a common crankpin to which the bottom end bearing is fitted. Each web is also connected to a journal to form part of a continuous shaft. A main bearing will support the shaft at each journal.



One end of the shaft will be flanged to transmit the engine power and the other end is termed free. Gear or chain drive wheels are added to drive camshafts and other mechanisms if they need to be synchronized with the crankshaft movement.

Medium speed and smaller engine shafts are usually manufactured as a solid forging and may be made by the continuous grain process. In this a single billet of steel is forged with its principal crystal grain in the longitudinal direction. Each crank throw is forged from this so that the grain is maintained continuously along journals, webs and pins for the whole length of the crankshaft. This process gives improved resistance to fatigue.

The crankshaft is used to drive engine peripherals including:

- The camshaft.
- Mechanical governor.

The crankshaft may also be used to drive engine peripherals including:

- Fuel boost pump.
- Seawater circulating pump.
- Fresh water circulating pump.
- LO circulating pump.

Manufacture of crankshafts

The manufacture of crankshafts falls into three categories:

Solid forged

The shaft is rough forged from a single ingot with blocks forged at correct angles to avoid torsional stress during manufacture. The web pins and journals are finished machined, hardened and polished (especially in smaller engines).

With short stroke engines, solid forged crankshafts are very rigid. They have overlap between crankpins and journals, which gives added strength. Oil holes are drilled between journals and pins to transmit lubricating oil from the main bearings to the adjacent bottom ends.

The continuous grain flow process

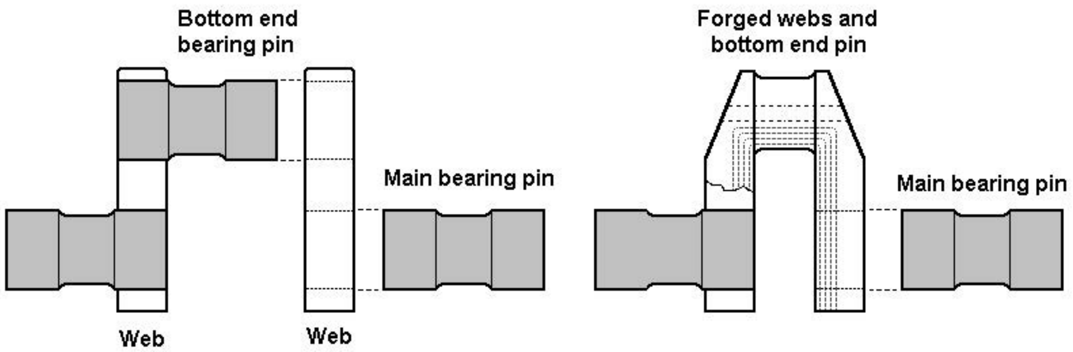
A plain rolled forging or formed bar (preferred for the larger engine) is brought to forging temperature and then gripped in three places to form the webs and crank pins. This process is limited to 20cm diameter pins. The advantage is that a continuous grain flow is obtained throughout the forging.

Semi-built crankshaft

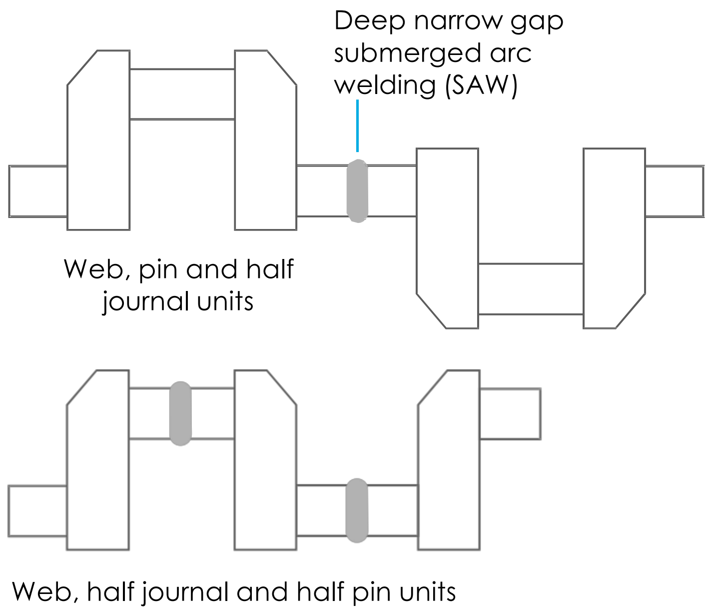
Crank pins and webs may be solid forged from a single ingot, or cast with the journal shrunk in as for the fully built crankshaft.

Fully built crankshaft

Crank pins and journals are forgings the webs are cast. Crankshafts are built with the webs being heated once only and the pin and journal entered simultaneously. Before assembly the webs are fully annealed, rough machined and stress relieved at 625°C.



Welded crankshafts



Welded crankshafts

Development in the manufacture of large crankshafts by welding together forged or cast components is relatively new.

Approval by classification societies for this type of construction has been given for some time.

The form of the various components being joined together by a welding process is dictated by the final construction cost of The crankshaft.

The form of a crankshaft could then consist of a web and one half of a crankpin and one half of a journal. For smaller crankshafts the component could consist of a pair of webs joined by the crankpin with one half of a journal being formed on the outer surface of the web.

Narrow-gap welding could be used to join the parts together. This is not a welding process but adaptations of established welding processes such as metal inert gas (MIG) or submerged arc welding (SAW).

Most Crankshafts are made of Spheroidal graphite cast iron, or FORGED CHROME STEEL

Crankshaft alignment

The importance of the alignment cannot be over stressed. The good alignment of the crankshaft and corresponding output shaft to the gearbox/propulsion ensures that stresses are minimised. Frequent crankshaft alignment checks are carried out in line with manufacturer's instructions, and should be carried out when the engine is warm, and the vessel in its **usual floating condition**.

Alignments should be carried out:

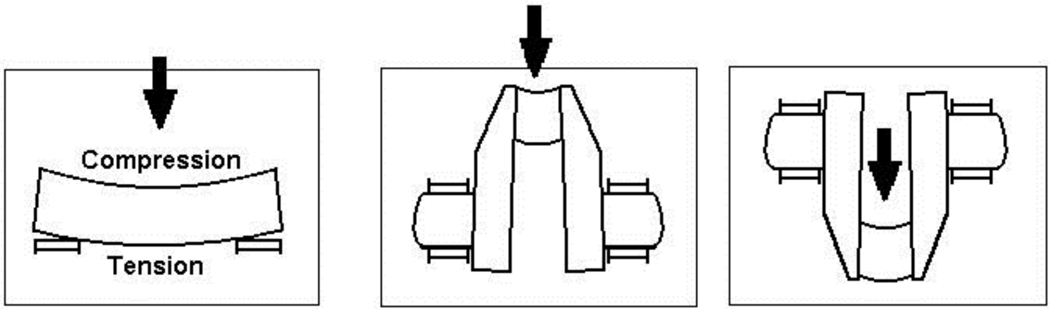
- Whenever a major component has been changed, e.g. .tie-bolt etc.
- Under the same conditions every time, i.e. the same draught and trim, and preferably in the light loaded condition (a loaded ship causes the crankshaft to bend by either hogging or sagging).
- Try to avoid extreme sea temperatures since the hull under these conditions can deflect.
- **Never take readings in drydock.**

Crankshaft deflections

There are two main reasons for taking crankshaft deflections:

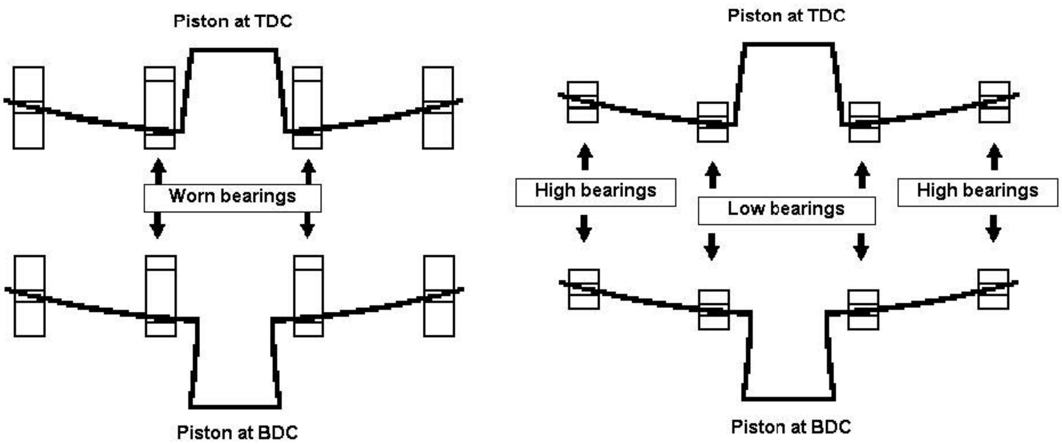
1 To check the alignment of the crankshaft;

2 To check for worn main bearings.



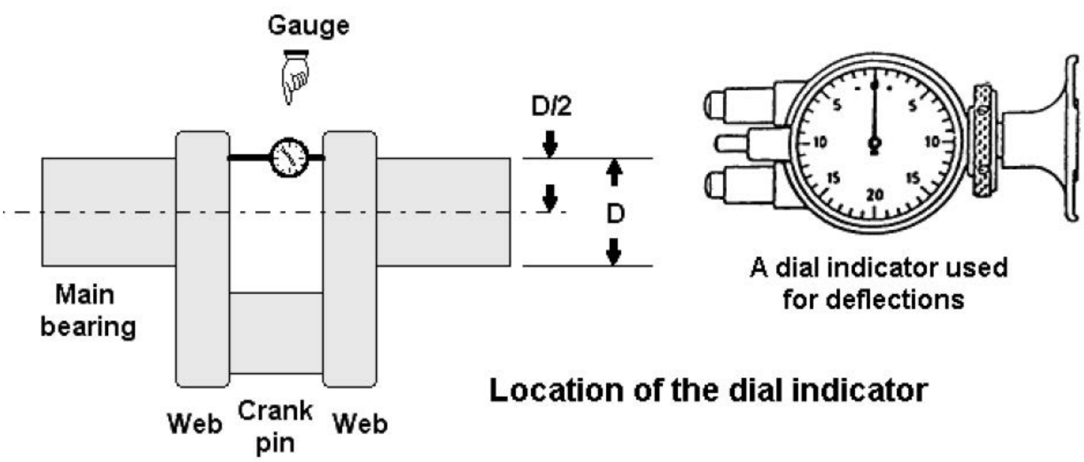
If a shaft, supported in two bearings, is loaded as shown in the left diagram above, then the shaft will bend. The inside of the bend will be in compression (get shorter), the outside of the bend will be in tension (get longer).

In a similar way the masses of the engine reciprocating parts, the con rod, the piston etc., act downwards loading the crankshaft, causing the crankshaft to bend.

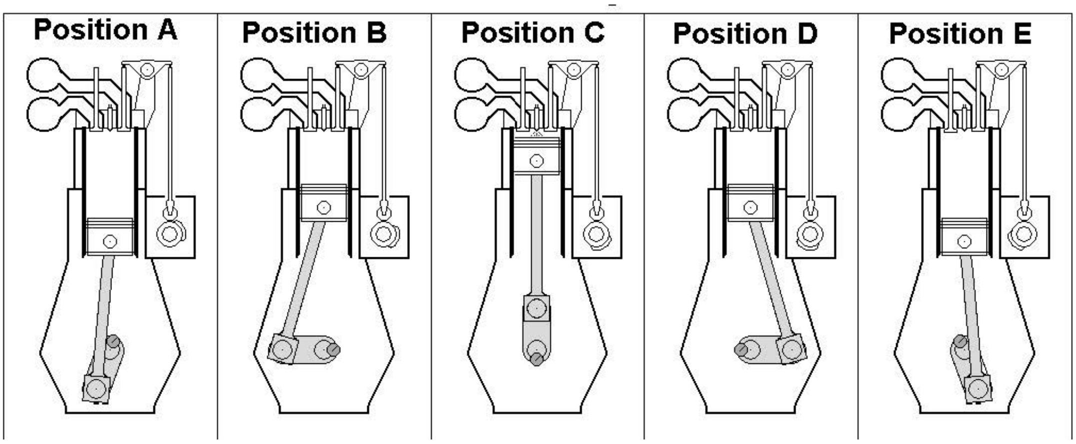


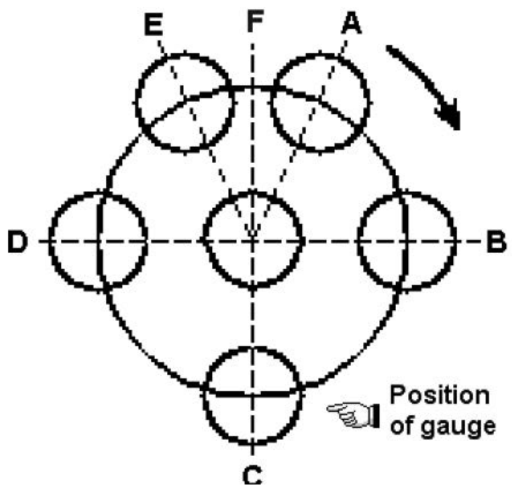
Both worn bearings and mis-aligned bearings will cause the crankshaft to deflect.

Crankshaft deflections are taken using a dial indicator. The condition of the crankshaft alignment can be assessed by the readings obtained from a set of deflections. The engine manufacturer would specify the maximum acceptable deflection reading. If any deflection reading is above the recommended maximum, repairs will have to be effected to correct the problem, usually by replacing the relevant main bearing shells.



The dial gauge is positioned between the crank webs, typically as shown in the diagram above. To locate the correct position reference the engine manufacturers manual.

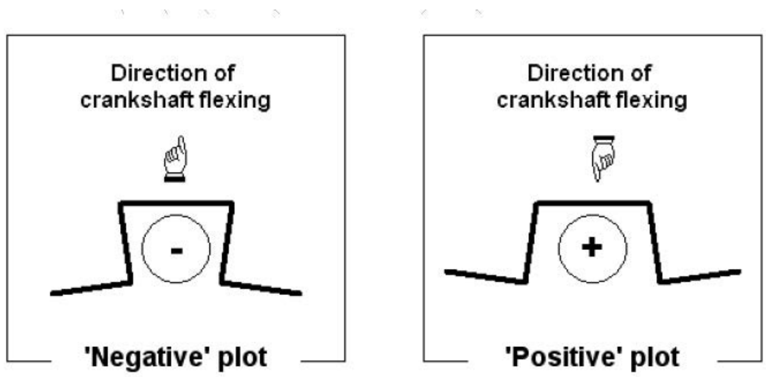




Readings corresponding to five crank angles are taken for each engine unit or set of crank webs.

The dial gauge is set to zero at position A and the crankshaft is rotated. During this rotation the readings of crank position B, C, D and E are recorded.

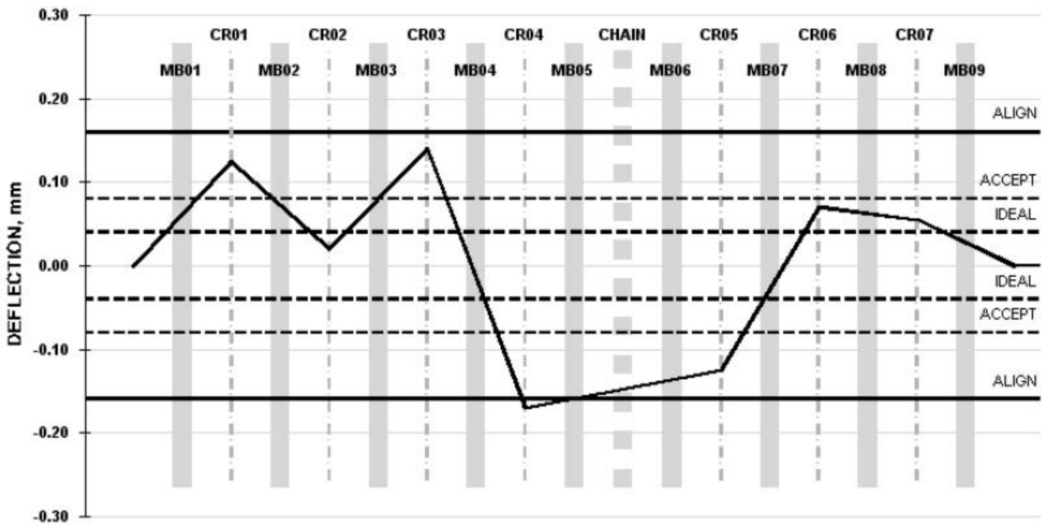
Position F (BDC) is calculated from the average of positions A and E.



There are various measurement conventions used when taking crankshaft deflections, an example is shown to the left.

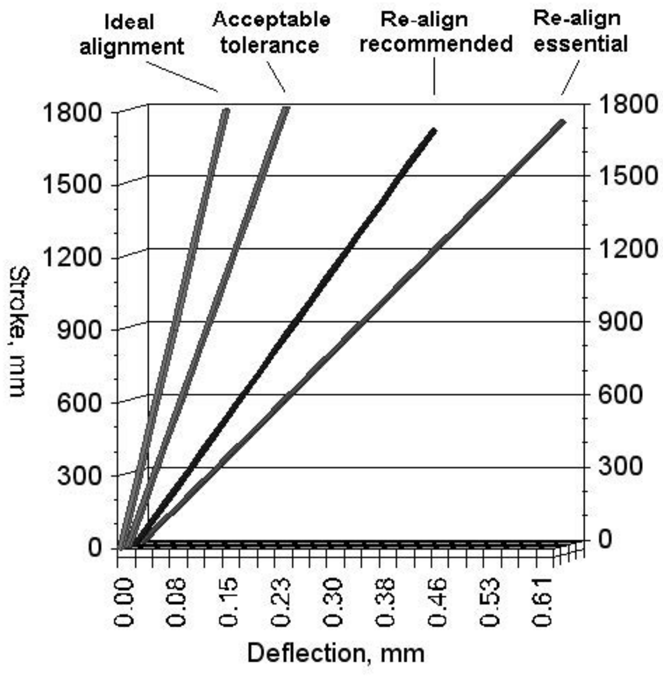
Check the convention used by the vessel and the engine manufacturer.

The readings obtained are recorded in tabular form a chart and compared with the recommended values, and the readings recorded in the past, to observe the trend. The deflections in both the vertical and horizontal planes can be calculated and plotted graphically, to get a visual view of the condition of the crankshaft.



Typical crankshaft deflection plot

As a guide a typical deflection would be -0.005 mm to +0.005 mm between throws; however, this is dependent on the engine size and manufactures recommendations.



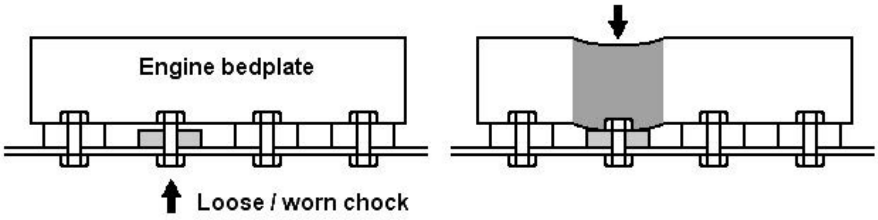
The graph illustrates typical deflection limits, their severity level, and recommended maintenance.

The limits are dependent upon the actual type and make of engine.

Causes of excessive deflections include:

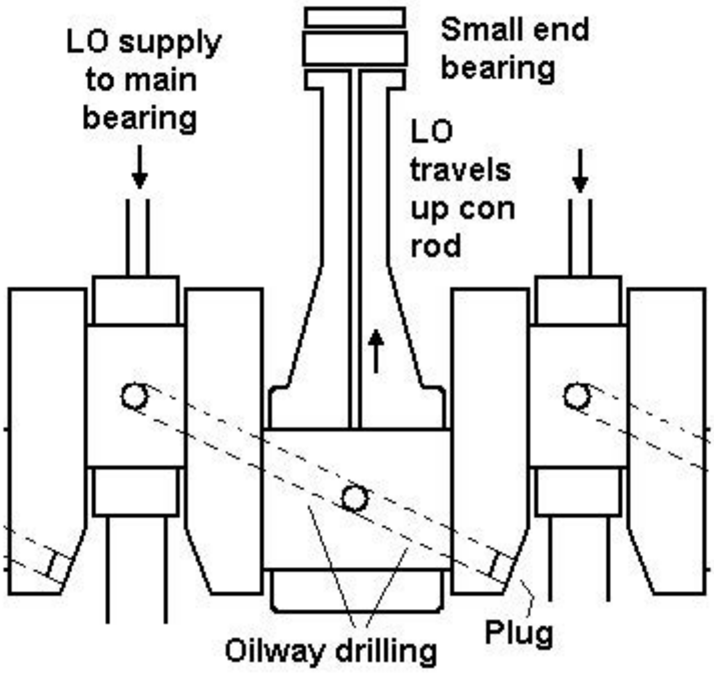
- Human error taking the readings;
- A bearing journal worn eccentric;
- A bearing journal not seating correctly (known as floating);
- Hot day, cold sea (deck expands, keel contracts;
- Hogging and sagging of the vessel due to badly loaded cargo;
- Worn main bearings;
- Mis-aligned main bearings;

- Clutch engaged, lifting crankshaft;
- Turning gear not backed off, lifting crankshaft;
- Distortion from incorrect tightening of holding down bolts.



When the loose holding down bolt is tightened, it may induce local distortion in the bedplate affecting the crankshaft alignment

LO distribution in engine



LO passage ways through crankshaft

The diagram illustrates a crank web with connecting rod, showing the path of the oil as the engine is lubricated.

Usually there is a supply line from the main lube oil supply header to each main bearing.

The crankshaft is drilled so the oil will flow from the main bearing to the connecting rod bearing.

The end of this drilling is plugged. These plugs are known as **core plugs**.

The oil then passes up through the con rod under pressure, through a drilled hole, to the gudgeon pin bearing.

Excess oil from the gudgeon pin may spray under the piston crown for additional cooling of the piston, or if there is a separate cooling system for the piston, it will drain back to the crankcase.

The lube oil level in the crankcase should be below that of the crankshaft, so the crankshaft itself does not dip into the oil reservoir.

Oil leaking from the main and connecting rod bearings is thrown up onto the cylinder wails by rotary motion of the crankshaft, thus lubricates the cylinder wails. This is not splash lubrication in the true sense; that occurs when the crankshaft itself dips into the oil reservoir and oil is thrown onto the cylinder liner walls by the crank webs.

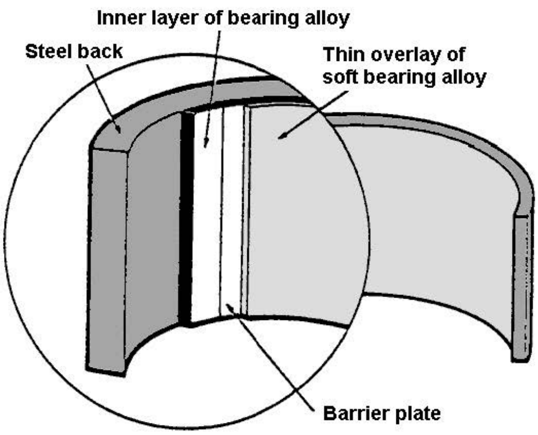
There are also branch lines from the main lube oil header to the camshaft bearings, to the gear trains, to the rocker arm assembly, and to other moving parts, as the header supplies more than just the main bearing lubricating oil.

LO alarms

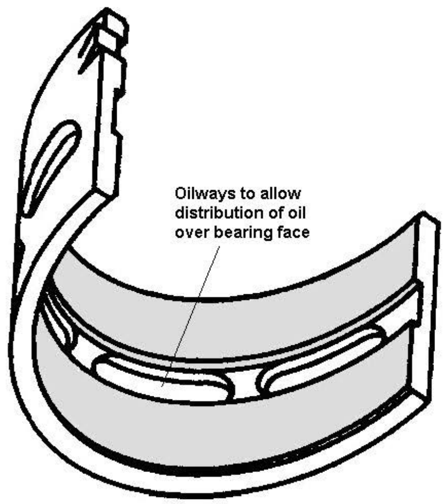
There are several alarms located on the pressure lube oil system, to warn of high oil temperature and low oil pressure. The alarms are audible and visual and may have the ability to shut down the engine.

Bearings

Bearings are fitted between components rotating at different speeds. The bearings on diesel engines are usually plain bearings as opposed to ball or roller bearings. They are usually split into two halves with soft white metal applied on to their inner surfaces. Lube oil is supplied under pressure between the shaft and the bearing to lubricate and reduce friction.



Construction of a tri-metal bearing shell



Plain bearings found in diesel engines include:

- The main bearing;
- The big end bearing;
- The small end or gudgeon pin bearing.

Main bearings

Main bearings are required to support the crankshaft at each journal. They support the weight of all working parts and are also subjected to heavy loads, fluctuating in magnitude and direction. They must be secure, accurately bored and aligned to prevent bending in the shaft. Each bearing is loaded by its adjacent units and wear rates may not be equal. This must be checked and recorded regularly. Weardown can be measured by bridge gauge and by crank deflections.

Medium speed engines with high maximum cylinder pressures use steel backed thin-wall bearings of harder materials such as aluminium-tin. Main bearings are underslung from the main frame or block with bolts or studs securing the lower half. Horizontal side bolts are fitted to give added transverse rigidity.

The main bearing shells are made of steel with a lining of bearing metal, which may be **white metal, copper lead or aluminium tin alloy**. In addition, they usually have a thin lead or indium to provide a layer giving protection against corrosion. They are held in position by the bearing housing.

The external circumference of the bearing shells is slightly larger than the bearing housing that receives them. This ensures that an interference fit is maintained between both the shells and the top and bottom bearing housings.

Causes of High Bearing Temperatures:

- Abraisive particles
- Contaminated oil
- Wrong oil
- Insufficient oil
- Overload
- Misalignment
- Incorrectly fitted bearing bolts, caps or keeps

Bearing clearances

Too little a bearing clearance would seize the pin or journal in the bearing. Too much clearance would lead to excessive lube oil leakage and low lube oil pressure, resulting in improper lubrication of the bearings and excessive wear.

Therefore it is important that proper clearances are maintained according to manufacturer's specifications. Clearances are measured with the use of feeler gauges or soft lead wire. The strips of soft lead wire are placed on the non load carrying bearing shell' (the end that should have the clearance) and the bearing bolts are tightened according to the specified torque. When the bearing is opened the clearance corresponds to the amount the lead wire is squeezed and can be measured with a micrometer.

However, lead wire may tend to damage (score), the more delicate bearing shells. As an alternative to lead wire, a special set of plastic wire, usually referred to as Plasti-Gauge can be obtained. The amount the plastic wire gets squeezed is relative to the clearance in the bearing and can be measured with the use of a comparator chart which measures the width of the squeezed strips of plasti-gauge and gives the corresponding clearance.

Thrust Bearings

Indirect drive main engines it is convenient to position the main thrust bearing within the engine. This makes use of the engine bedplate and seatings to distribute the propeller thrust to the ship's structure. It also allows the bearing to form part of the engine lubrication system.

A single collar tilting-pad type of bearing is usually fitted at the drive end of the shaft. Smaller engines for gearbox or auxiliary drives do not require a thrust bearing. There is little end-thrust generated in the engine and sufficient area on the radii on the shaft journals and corresponding main bearing bush ends will locate the shaft in its correct axial position.

On larger engines the axial thrust is contained by tilting 'Michel' pad type bearings, located at the end of the shaft. On smaller engines there is sufficient bearing area to absorb any axial forces transmitted to the propeller or prime mover.

Critical speed (barred speed)

Every diesel has a speed range at which the engine should not run. This range is called the **critical speed**, or **barred speed** range.

The power and corresponding torque transmitted to the crankshaft by each cylinder of a reciprocating engine varies throughout its cycle. The torque is greatest during the expansion stroke and least during compression, and is repeated from each cylinder in turn. The varying cyclic torques, tend to set up torsional vibrations in the engine and propeller shafting.

The frequency of any peak torque can be found as:

Number of engine cylinders x number of cycles per unit time.

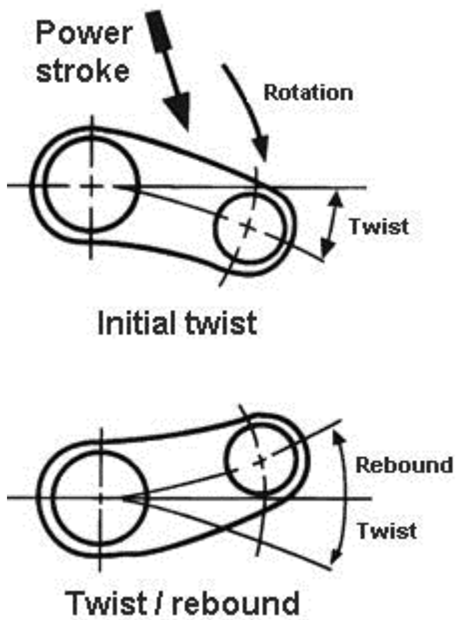
These vibrations are normally damped and their energy dissipated by the elasticity of mechanical parts, oil films at bearings, and the work absorbed at the propeller. All engine components including all the shafting, working parts, bearings, propeller etc. are manufactured from metal parts that have natural elasticity. There will be a natural frequency for the whole system at which it will tend to vibrate if caused to do so. Should the frequency of peak torque's from the running engine coincide with or be a multiple of the natural frequency for the system a condition of resonance is set up.

Resonance may cause unacceptable torsional vibrations and consequently induce stresses. Engine speeds at which this occurs are termed **critical speeds**.

To prevent the build up of these stresses, engines must not be run continuously or close to the critical speed(s).

Warning of any critical speed within the operating range of the engine must be given at any operating platform. Remote speed control systems must be programmed to avoid operating the engine at critical speeds.

Torsional vibration damper



Torsional vibration

Each time the air/fuel mixture inside a cylinder is ignited, the combustion that results creates a torque spike, an extremely rapid rise in cylinder pressure.

This pressure, applied to the top of the piston, becomes the force that is applied to the crankshaft through the connecting rod.

Each torque spike is like a hammer blow. In fact, it hits with sufficient intensity that it not only causes the crankshaft to turn, it actually deflects or twists it.

This twisting action and the resulting rebound (as the crank arm snaps back in the opposite direction) is known as torsional harmonic vibration.

If not adequately controlled, torsional vibration causes rapid main bearing and main journal wear and possible crankshaft breakage.

Controlling the vibration

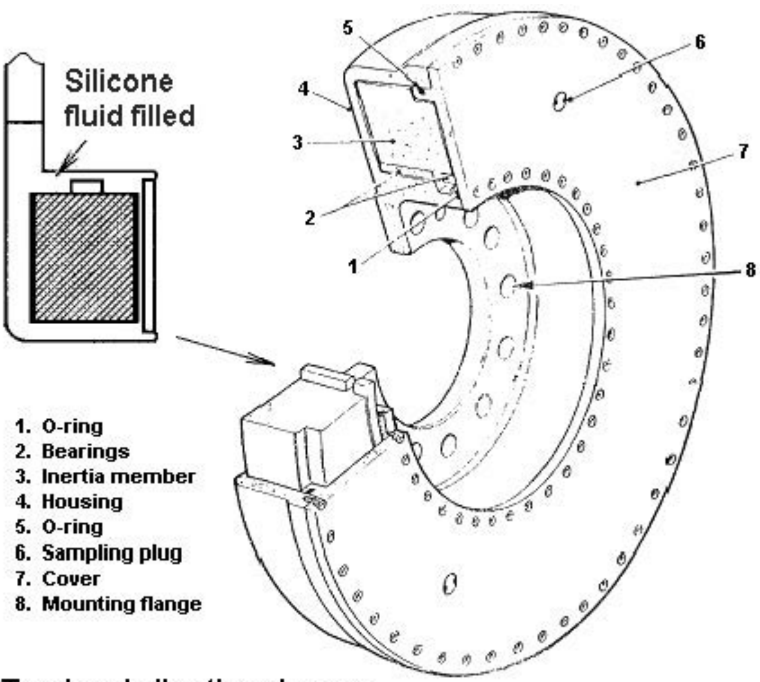
Harmonic vibration can be controlled by a vibration damper, which is also called a harmonic damper. The main purpose of a harmonic damper is to control harmonic vibration, not necessarily to balance the engine's rotating assembly.

Crankshaft vibration dampers are designed to reduce torsional vibration, the small but sometimes dangerous angular oscillations a shaft undergoes, as the combustion in each cylinder delivers torque spikes to the shaft via the pistons and connecting rods.

Crankshaft torsional vibration is inherent in all internal combustion engines and can be especially harmful in high horsepower, high rev applications.

Another common concern is that fluid and mechanical dampers contain moving parts, which are believed to impede proper balancing of the crankshaft assembly.

Fluid type damper



Torsional vibration damper

A fluid-type damper contains an internal inertia ring that is self-centring even at idle speed.

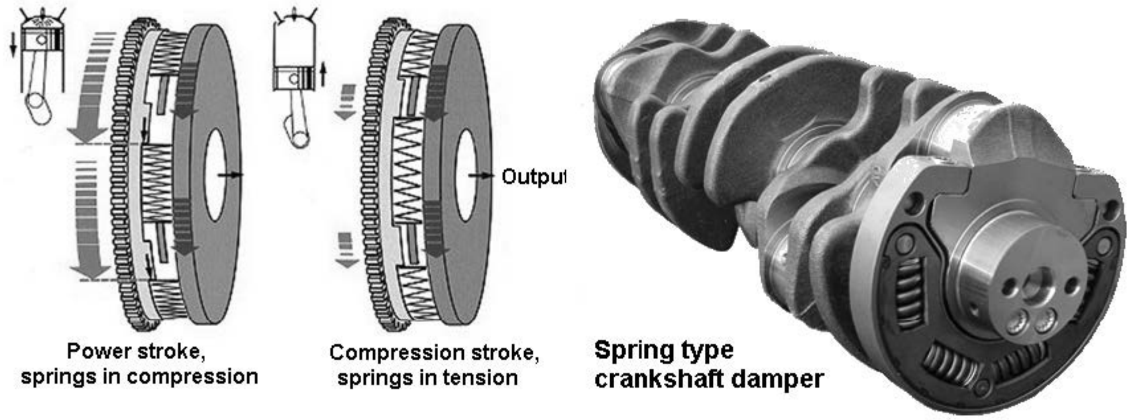
This is due to the balance of pressure and shearing forces in the viscous silicone fluid that surrounds the ring.

During the operation of a silicone viscous damper periodic samples of silicon are taken for analysis.

This is to check for any deterioration and to ensure correct performance. If there is any noticeable deterioration, it is usually recommended that the damper be changed.

In elastomer dampers, the outer inertia ring is fixed relative to the mounting hub through a ring (or rings) of elastomeric material.

Spring type damper



SECTION 4 – Basic Hydraulic and Electronic Governors

Governors

Diesel engine speed control

The function of the governor is to automatically control the engine speed by regulating the fuel supply. The governor is designed to respond to small changes in speed and then be capable of returning the engine to the pre-determined speed.

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

If the engine speed is maintained at a set value irrespective of changes of load or power, it is said to be **isochronous**.

When fitted to main engines, there must be a facility to adjust the set speed on the governor, which is then said to be a variable speed type.

An engine is required to be fitted with a governor, especially for engines driving alternators where the engine and governors have to be matched to maintain the speed within a close range and act quickly in response to any varying load demand. The type and size of a governor is be designed match the characteristics of the engine.

Types of governor

There are basically two types of governor control:

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

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

Mechanical governor

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

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

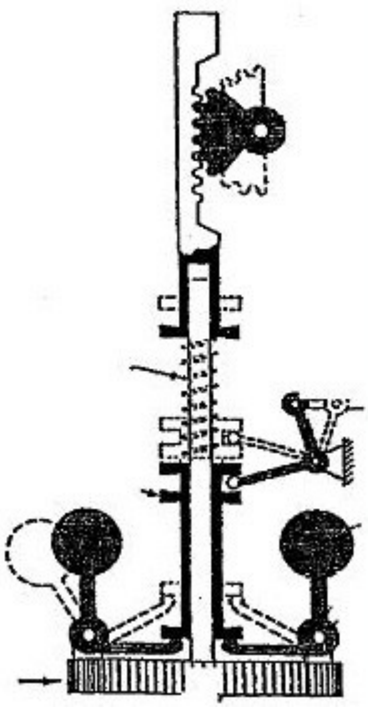
The steady decrease in the speed of an engine caused by an increase in load from no load condition to full load, without change in the adjustment of the governor is known as speed droop.

Hydraulic governor

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

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

Mechanical variable speed governor



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

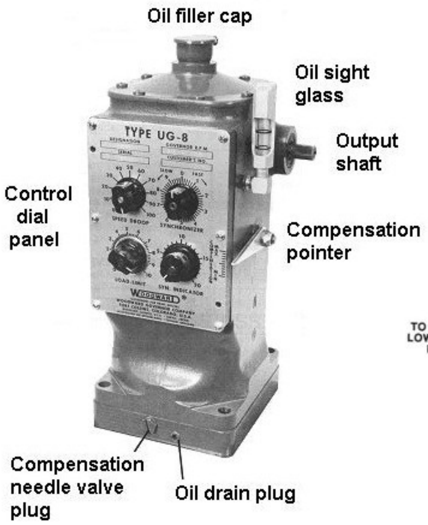
If the engine load decreases, the engine speed increases. The centrifugal force acting on the flyweights also increases, causing the flyweights to move outwards and the control sleeve upwards. This moves the fuel rack, delivering less fuel. The upward movement in the control sleeve increases the compression in the speeder spring and hence the speeder spring force. This increased spring force and the control sleeve remains stationary in the new position.

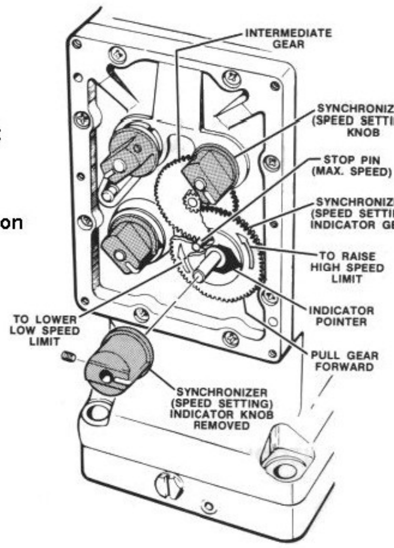
If the engine speed decreases the opposite to the above occurs. Thus the control sleeve moves up and down as the engine speed fluctuates because of load variations.

The operating speed of the engine can be adjusted by increasing or decreasing the speeder spring compression and hence the speeder spring force by the speed control lever.

Hydraulic variable speed governor

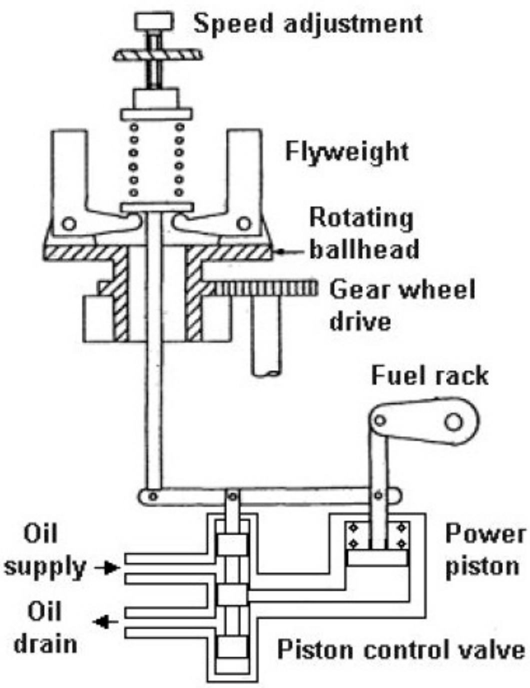
A common governor fitted to many diesels is the mechanical-hydraulic speed governor, this type uses a hydraulic servo-piston (power piston) to create sufficient power to operate the engine fuel rack and hence regulate the fuel to a pre-determined speed value. This action controls the speed of the engine without any loss in sensitivity of the speed sensing ballhead.





Hydraulic governors can be extremely complex pieces of equipment. A typical example is shown to the left. This type of governor can be found in use for main engine speed control, and for diesel alternators.

Two methods are available in supplying hydraulic oil pressure, one is to supply the oil direct from the engines lubrication system and secondly (the preferred option) is to supply oil from a separate system enabling the oil to remain in a clean condition.



Basic hydraulic governor

This diagram is simplified, showing the basic main components of the governor. The governor is engine driven which causes the flyweights to rotate.

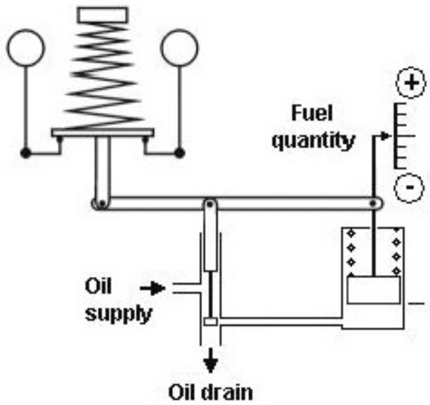
When the engine is operating at normal speed, the centrifugal force acts on the rotating flyweights and is balanced by the vertical ballhead spring force.

The piston control valve remains stationary. The power piston is used to exert a hydraulic force to move the main fuel rack.

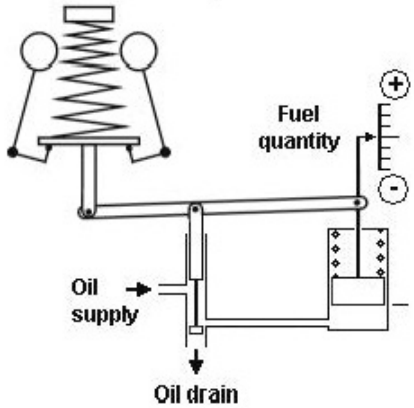
Decrease in speed

The following series of diagrams show the response of the governor to a decrease in speed, that may be caused by an increase in load. The governor is acting in a constant speed mode, and corrects the change in speed back to the set speed.

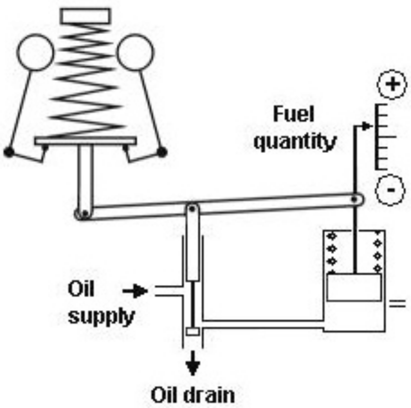
1 Engine running at constant speed



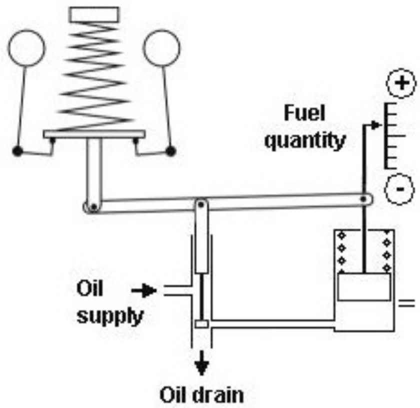
2 Weights move inwards, oil valve opens



3 Fuel rack increases, oil valve closes



4 Engine speed increases, oil valve closed

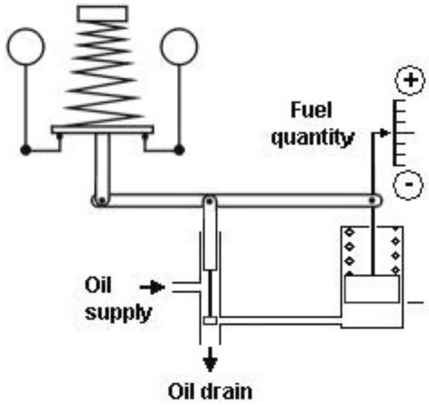


Basic hydraulic governor reaction to a decrease in speed

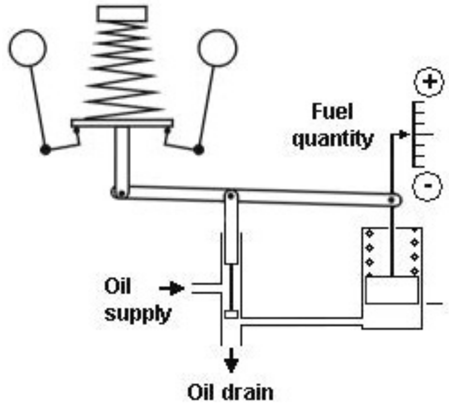
Increase in speed

The following series of diagrams show the response of the governor to an increase in speed, that may be caused by an decrease in load. The governor is acting in a constant speed mode, and corrects the change in speed back to the set speed.

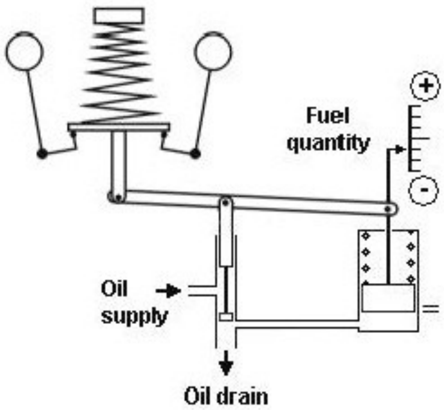
1 Engine running at constant speed



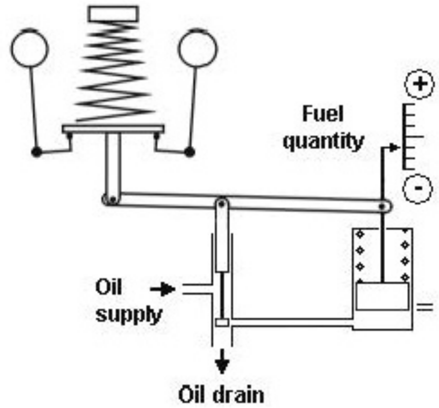
2 Weights move outwards, oil valve drains



3 Fuel rack decreases, oil valve closes



4 Engine speed decreases, oil valve closed



Basic hydraulic governor reaction to an increase in speed

Drive

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

Lubrication

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

Faults

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

Dirty oil is a cause of most hydraulic governor troubles.

Remote control of governors

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

Electrical-hydraulic governors

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

It consists of:

Magnetic pick up

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

Governor control

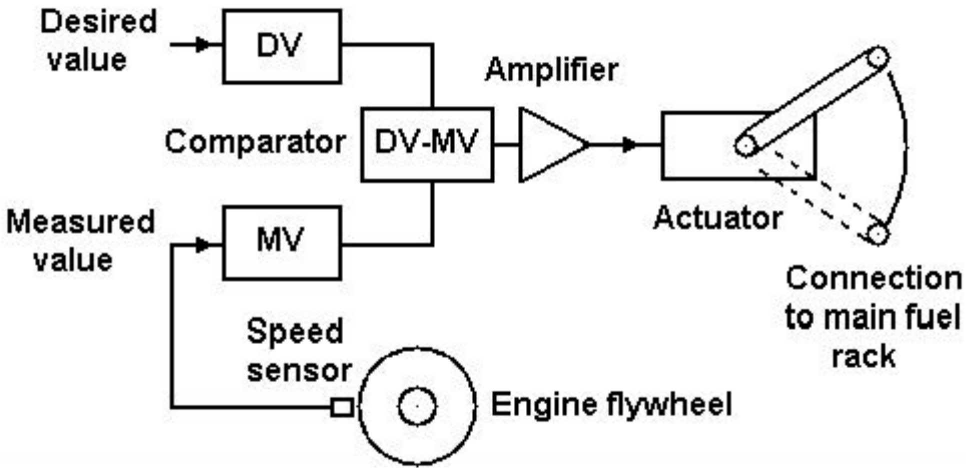
The governor control is an all-electric solid state module which compares the pulses (electric signal) from the magnetic pickup with a speed control reference point. A current output is supplied to the actuator that rotates the actuator shaft to control the fuel flow to the engine.

Actuator

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

Electronic governor

An effective alternative to the mechanical-hydraulic governor is the electronic governor. Apart from such facilities as load sharing, synchronising, power sensing etc., the electronic system can be incorporated as part of an overall control system to include engine starting and stopping, with additional facilities to avoid running at critical speeds and to prevent overspeed and other safety features.



Electronic governor

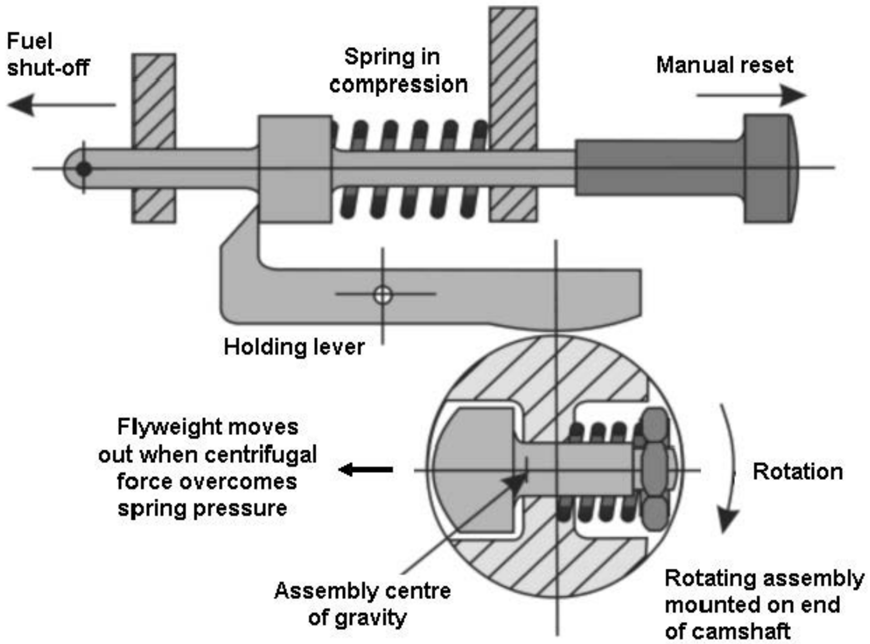
The operation of the electronic governor is as follows:

- A speed sensor such as a magnetic pickup transmits a signal representing the actual engine speed (the measured value, MV).
- The engine speed is compared with the set speed (desired value, DV).
- The error (DV-MV) is calculated by the comparator.
- The differential between the two references (the error) is amplified and transmitted to the controller and actuator.
- The response of the actuator is to generate sufficient mechanical force to operate the engine fuel controls.

SECTION 5 – Engine safety and protection devices

Safety devices

Overspeed trip



Mechanical overspeed trip

An over-speed trip will respond to a governor failure, and prevent the possibility of damage the engine. This unit acts independently of the main speed governor, and usually operates by returning the fuel rack to the shutdown position.

A commonly used type is the mechanical over-speed trip as shown above. The rotating assembly is commonly located on the end of the camshaft. If the engine over-speeds the flyweight will move outwards when centrifugal force overcomes the spring pressure on the rotating assembly. The flyweight will trip the holding lever releasing the fuel racks to the no-fuel position, thus stopping the engine.

The device is a latching device, that is it has to be manually reset (once the cause of the over-speed has been established).

The device may be tested by bolting a special additional weight to the flyweight, such that it will move outwards at a slower engine speed. The engine is then run up until the overspeed trips at the lower engine speed, as recommended by the engine manufacturer.

The system may also be utilised for other emergencies such as failure of vital engine operation systems. It may also be utilised as an emergency stop button.

Crankcase explosions

As mentioned previously the result of a bearing shell (even minor) failure can create a hot spot. The hot spot may also arise from the overheating caused by the following:

- Timing chain;
- Combustion gas or sparks from a piston blow past;
- Overheating bearings;
- Contamination of the lubricating oil by fuel oil causing a lowering of the flash point.

Crankcase lubricating oil should normally have a closed flash point above 200°C and this must be maintained in order to reduce the risk of explosions.

Under normal running conditions the air in the crankcase will contain oil droplets formed by the oil splashing from the bearings onto the moving parts. The mixture will not readily burn or explode under these conditions.

The cause of an explosion created initially by the 'Hot Spot' or overheated part within or adjacent to the crankcase of an operating engine will follow the following chain of events:

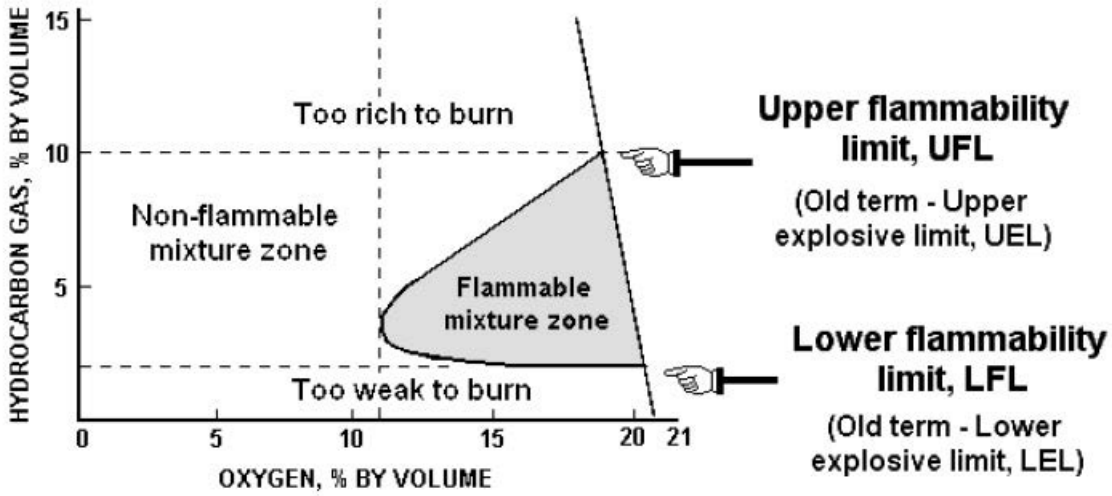
- **Existence of a hot spot.**
- **Oil comes into contact with the hot spot and proceeds to vaporise.**
- **The vaporised oil circulated to a cooler part of the engine and condenses to form a white mist of finely divided oil particles that mix well with air.**
- **The mist circulates back to the hot spot in such concentrations it will ignite.**
- **After ignition a pressure wave forms and accelerates through the crankcase, vaporising further oil droplets in its path.**
- **The pressure wave may build up to such a value that is sufficiently high that it can rupture crankcase doors.**

If the pressure wave is not relieved by the crankcase explosion doors, the low pressure wave may draw air back into the crankcase. By drawing air back into the crankcase it will mix with vaporised burning oil to cause a secondary (major) explosion that will cause extensive damage.

UFL and LFL

The oil mist when formed has to be between certain limits of mixture with oxygen to become combustible.

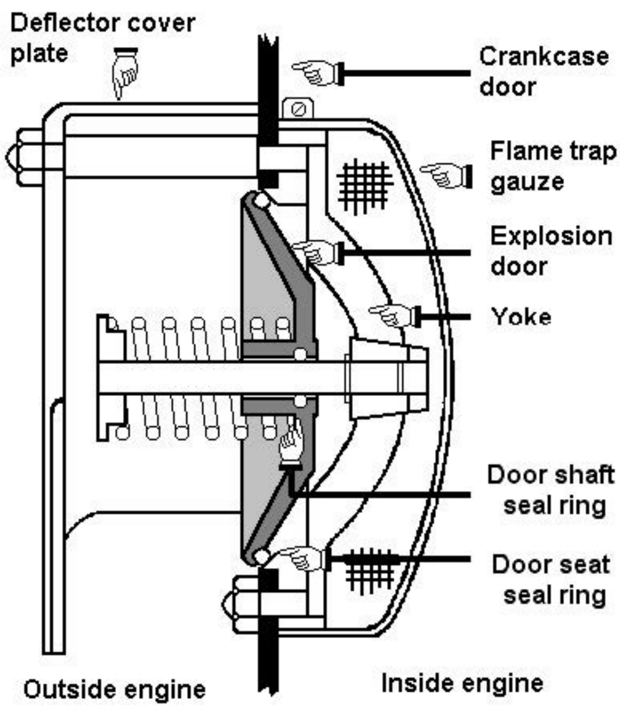
These limits are known as the **upper flammability level** (UFL) and the **lower flammability level** (LFL).



Typical values (depending upon the hydrocarbon fuel) would be 2% by volume for the LFL and 10% by volume for the UFL.

Crankcase explosion doors

The crankcase explosion door is fitted to all but the smallest diesels. The principal of the crankcase doors operation is to allow the door to open automatically at a moderate pressure allowing the pressure of the primary or minor explosion to be dissipated and prevent a rupture of the crankcase. The valve will instantly close when the pressure drops and therefore prevent the possibility of a secondary and major explosion.



The diagram shows a crankcase explosion relief valve that may be fitted to a diesel engine crankcase. It consists of a light spring-loaded non-return disc valve of simple construction.

The valve disc is of aluminium alloy that opens or closes rapidly. The large diameter spring will give sensitivity and allow the valve to float. The absence -of a valve spindle eliminates the risk of the valve jamming.

The valve landing must make a gas and oil tight seal when closed and a non-stick oil and heat resisting rubber ring is fitted to the disc face.

An external aluminium valve cover secures the valve spring and acts as a deflector to direct any gas to where it can do least damage. Inside the crankcase is a dome-shaped flame trap made of several layers of woven mild steel wire gauze. This projects into the crankcase where it will become wetted with oil mist or splash from adjacent bearings. When wet with oil the gauze dissipates heat at a greater rate and becomes more effective as a flame trap. Free area of the gauze must at least be equal to the area of the open valve.

The valve spring is designed to allow the valve to open under an internal pressure of approximately 5 kN/m^2 and will close automatically when pressure has been relieved.

Regulations require that for engines of over 300 mm bore, one crankcase relief valve of approved design is fitted to each crankcase and chain case. The combined area of the relief valves should be not less than 115 cm^2 per cubic metre of crankcase volume. The free area of each valve is to be not less than 45 cm^2

For smaller engines a reduction in the size and number of valves is allowed. Crankcase doors should be robust to prevent damage or rupture before relief valves operate to relieve pressure.

Valves will require little maintenance but should be tested periodically by hand; the spring should be inspected and the gauze cleaned.

Actions to be taken on detection of a hot spot

1. **The engine is to be slowed down and stopped as soon as possible.**
2. **All personnel to be warned to keep clear of the engine.**
3. **Allow the parts to cool down.**
4. **It may be advisable to operate the turning gear to prevent possible seizure of the overheated part.**
5. **Firefighting equipment to be prepared.**

On no account must the crankcase be opened until the parts have cooled. Such action may allow ingress of air and precipitate an explosion.

Should the conditions of a hot spot arise within the crankcase, a watchkeeper may detect them by: Irregular running of the engine.

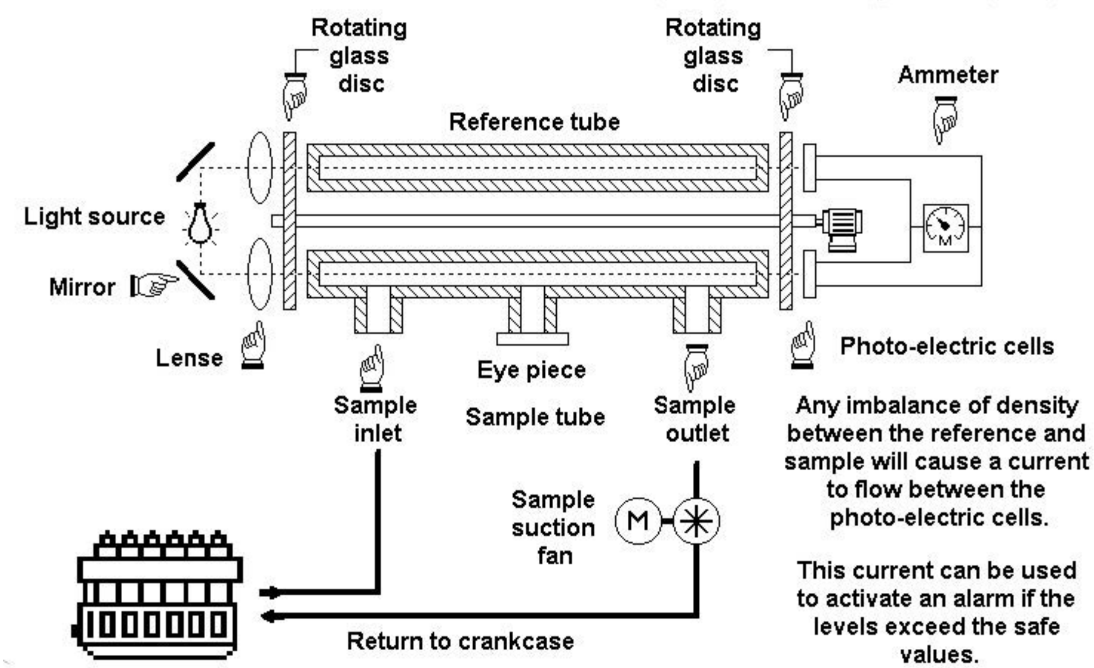
- Engine noise.
- Increase in temperatures.
- Smell.
- Appearance of a dense white mist.

In many cases these actions may not be sufficient as a crankcase explosion can develop in a very short time. Also with UMS operation there is not a watchkeeper present at all times. To overcome this problem engines may be fitted with special oil mist detection devices that can be integrated into the engine control system, to slow or stop the engine in an alarm situation.

Crankcase oil mist detector

The inclusion of an oil mist detector is to continuously sample and monitor the air and vapour from the crankcase. This device detects the presence of oil mist at concentrations well below the level at which an explosion may occur, therefore allowing action to be taken to prevent any incident arising.

Reference tube type OMD



Reference tube type oil mist detector

The detector consists of two parallel tubes of equal size, each having a photoelectric cell at one that generates an electric current proportional to the intensity of the light falling on the surface. Lenses are fitted to seal the ends of each tube but allow light to pass. Two identical beams of light from a common lamp are reflected by mirrors to pass along the tubes onto the cells that are the electrical balance.

One tube is sealed to contain clean air and is termed the reference tube. The other the measuring tube has connections through which samples of crankcase oil vapour are drawn by the electric extractor fan.

Sampling connections should not exceed 12.5 metres in length and must slope to ensure positive drainage of the oil.

The oil mist detector functions by repeatedly sampling each cylinder crankcase in turn by each cylinder sample brought to a rotary selector valve in sequence by the electrical fan and thus to the measuring tube.

Should a sample distribute an oil mist that may obscure the light beam in the measuring tube, an electrical in-balance will occur. This action results in the rotary fan stopping and issuing an alarm that will indicate the affected cylinder section of the crankcase.

Emergency stop device

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

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

Alarm systems

Regulations require that a propulsion engine shall be provided with an audible warning device to indicate a dangerous condition associated with:

- engine lubricating oil pressure;
- engine jacket cooling water outlet temperature;
- engine gear box lubricating oil pressure.

As noted, these protection devices give off an audible warning only. Automatically shutting down a propulsion engine without any warning could or the loss of the vessel.

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

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

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

Low oil pressure alarm

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

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

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

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

High temperature cooling water alarm

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

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

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

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

The water temperature switch consists of a temperature sensing valve and a micro-switch. The valve contacts a copper plug (heat probe) that extends into the exhaust manifold outlet. Engine coolant is directed over the power element of the valve. Should the water temperature exceed its setting, the valve will close the contacts in the micro-switch.

This closes the circuit and sounds the audible alarm. If a loss of coolant occurs, the heat of the exhaust gases will be transmitted through the copper plug to the temperature sensing valve, closing the circuit and sounding the audible alarm.

Testing of engine protection devices

The main engine protection and shut down devices are:-

- the overspeed trip;
- the low lube-oil pressure trip;
- the jacket cooling water high temperature trip.

There may be other temperature and pressure warning devices but their testing follows the same principles.

The overspeed trip

The only positive way of testing the overspeed trip is to physically overspeed the engine. This must be carried out in a carefully controlled manner, with the engine off load, by carefully adjusting the governor setting and monitoring the engine speed until tripping occurs. A person should be standing by to manually shut down the engine should a run-away occur. Overspeedtrips are typically tested following a major overhaul or survey.

Low tub-oil. pressure trip

If the trip switch is fitted with a pressure gauge and a bleed cock then it can be safely tested on the engine. With the engine running off load, the bleed cock is cracked open and the falling pressure carefully monitored until tripping takes place. The tripping pressure should be noted in the maintenance records and, if not correct, then the device should be adjusted accordingly and re-tested.
If the tripping device is not fitted with a bleed cock, then the only safe method of testing is to remove it from the engine and have it tested in a dead weight tester or similar.

Pressure tripping devices should be tested as routine every 2 - 3 months.

Temperature tripping devices

These should always be removed from the engine and tested in a suitable oil bath tester or similar. (A rough test can be carried out in a kettle of boiling water but is not very accurate).

The tripping temperature should be noted in the maintenance records and, if not

correct, then the device should be adjusted accordingly and re-tested. Temperature tripping devices should be tested as routine every 2 - 3 months.

Ten typical safety devices fitted to a propulsion engine and gearbox

1. Turning Gear engaged / disengaged Interlock
2. Low Lubricating oil pressure priming interlock
3. Overspeed trip
4. High Fresh water temperature trip
5. Low air start pressure interlock
6. Low sump level alarm
7. Cam direction sensor (reversing engines)
8. Gearbox lubricating oil pressure
9. Emergency STOP
10. Oil mist detector

Testing Shutdowns on Lub - Oil pressure and FW temperature

Lubricating Oil Pressure

To test the lubricating oil shutdown facility the engine should be shutdown made safe to work on and the Lube oil pressure sensor connected to a calibration device either insitu or in the workshop. increase the pressure on the calibration unit until it is at the normal oil pressure for the engine. the test pressure can be released slowly, and the pressure noted at which the shutdown switch operates by use of a multi metre in the workshop or if still connected to the engine when the alarm goes off continue to vent and record the pressure at which the engine shuts down.

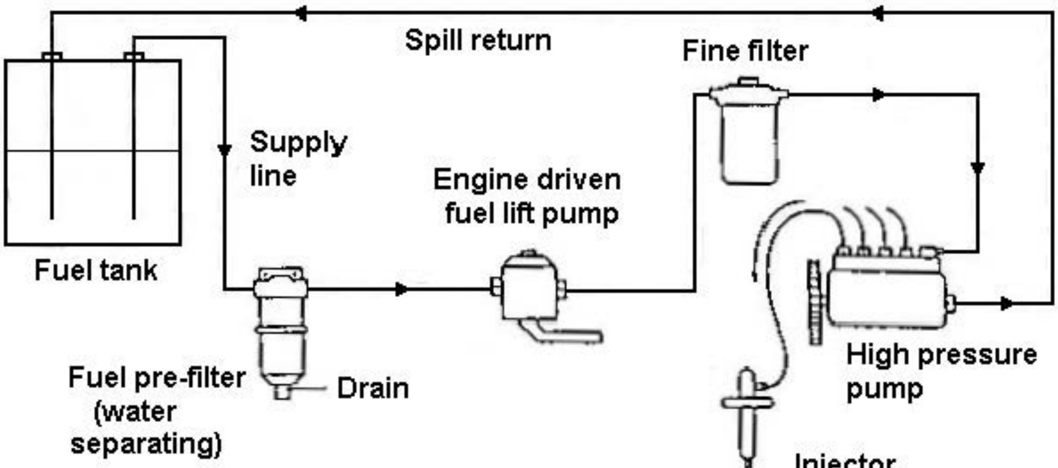
Coolant Temperature shutdown test

To test the coolant temperature shutdown facility the temperature sensor should be removed when it is safe to do so and inserted in the calibrating unit or container filled with water under thermometer. the temperature of the water should be raised in the workshop environment noting the temperature at which the sensor triggers the alarm or if still fitted to the engine that the monitoring system alarm goes off. the temperature should be continued to rise until the point at which the engine shuts down.

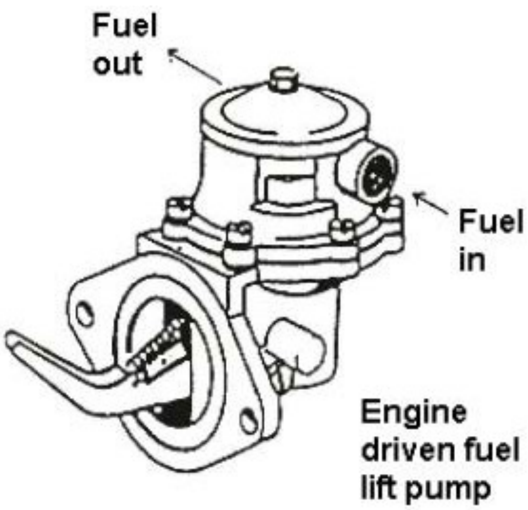
SECTION 6 – Fuel Oil Supply System

Fuel Lift Pumps

Fuel lift pumps are usually found on smaller marine diesels. The lift pump is employed in a fuel system as shown below where the fuel is drawn from the fuel oil tanks through the coalescent (water separating) filter to the lift pump, prior to being delivered to the fuel pump and fuel injectors.



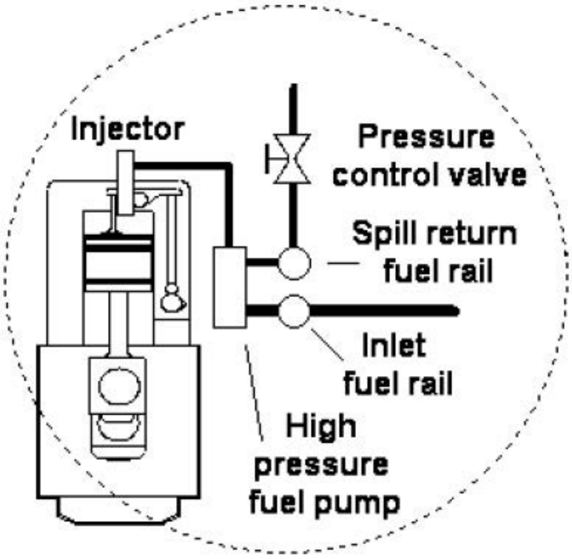
Basic fuel system



The fuel oil lift pump is driven from a cam off the engine camshaft.

The pump also often has the facility to be manually operated, for priming the fuel system.

Engine mounted fuel system



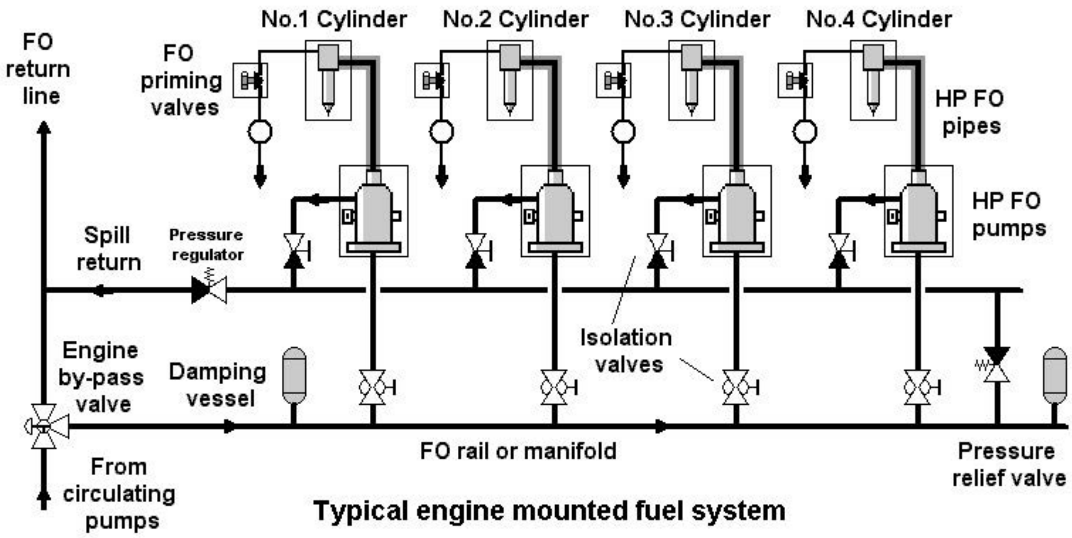
High pressure fuel system

This section covers the component parts of the high pressure fuel injection system that are commonly mounted on the engine.

The main components covered include:

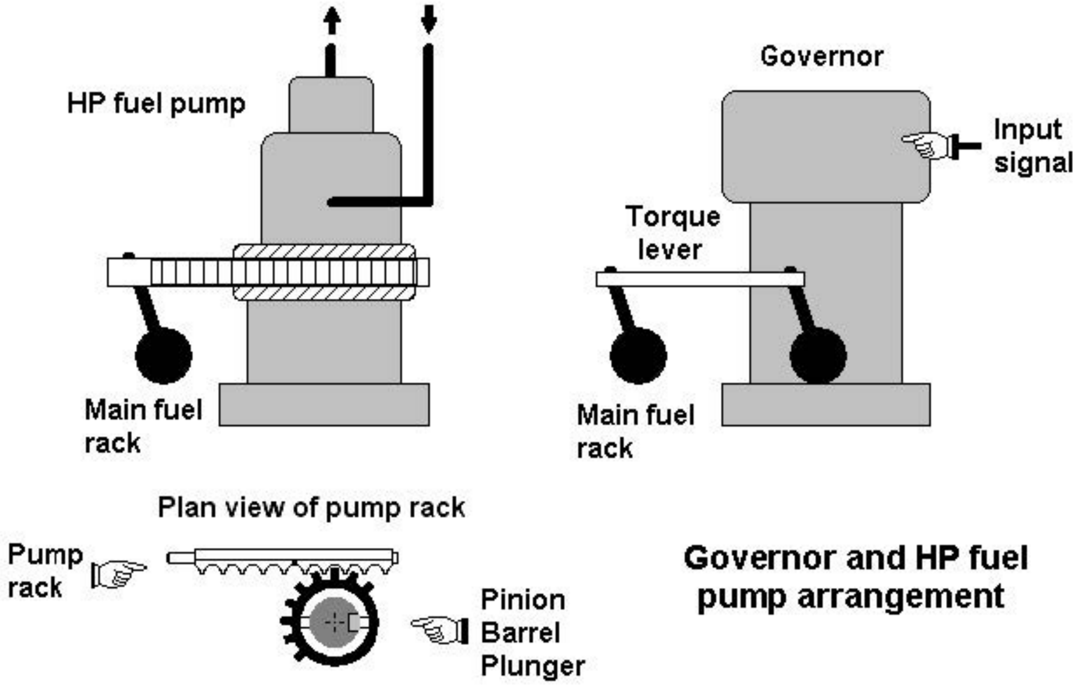
- The high pressure fuel pump;
- The double sheathed high pressure delivery pipe;
- The fuel injector.

Engine mounted fuel system



Typical engine mounted fuel system

The governor



The engine governor controls the amount of fuel delivered to the engine via a torque arm that sets the main fuel rack. Each individual fuel pump rack is connected to the main fuel rack.

HP fuel injection pumps

The Bosch type high pressure fuel injection pump is probably the most common found on medium and high speed diesel engines. It is named after its German inventor, Bosch.

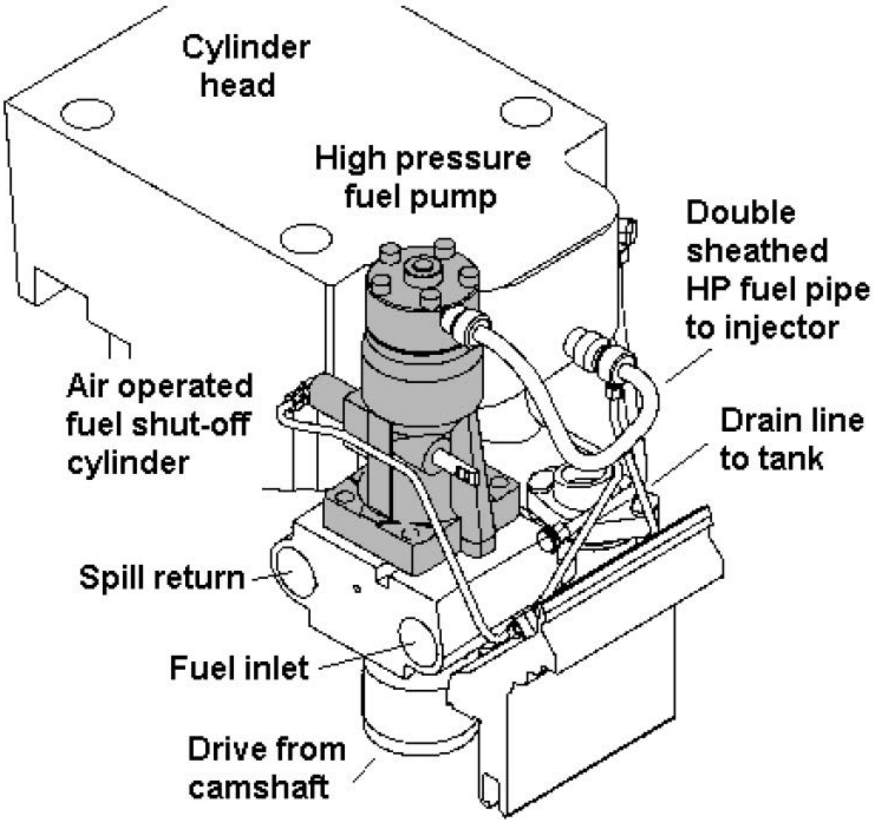
This type of pump is also commonly referred to as:

- The jerk pump;
- The scroll pump;
- The plunger pump;
- The high pressure (HP) pump.

Functions of the HP fuel pump

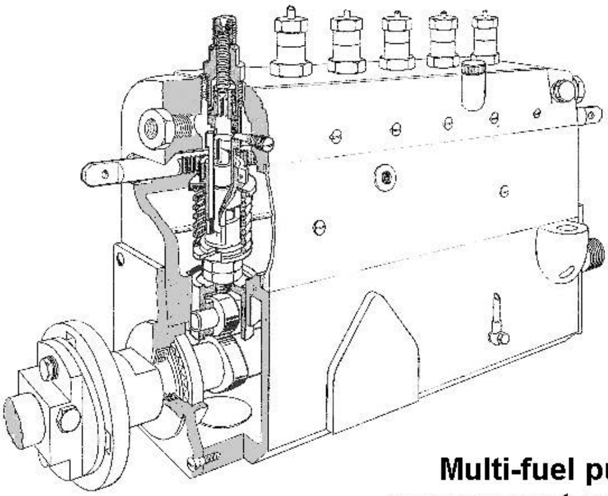
The functions of the high pressure fuel pump include:

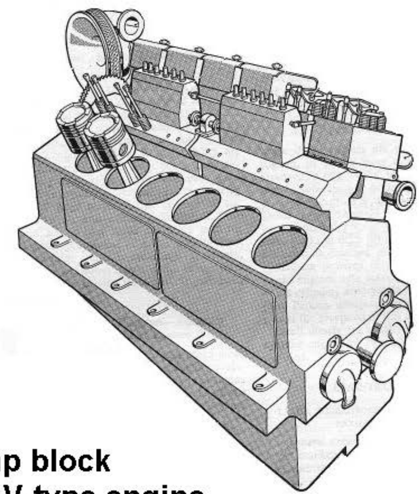
- To meter the correct amount of fuel for combustion;
- To raise the pressure of the fuel for atomisation in the injector;
- To time the delivery of the fuel charge to the injector.



Typical HP fuel pump installation

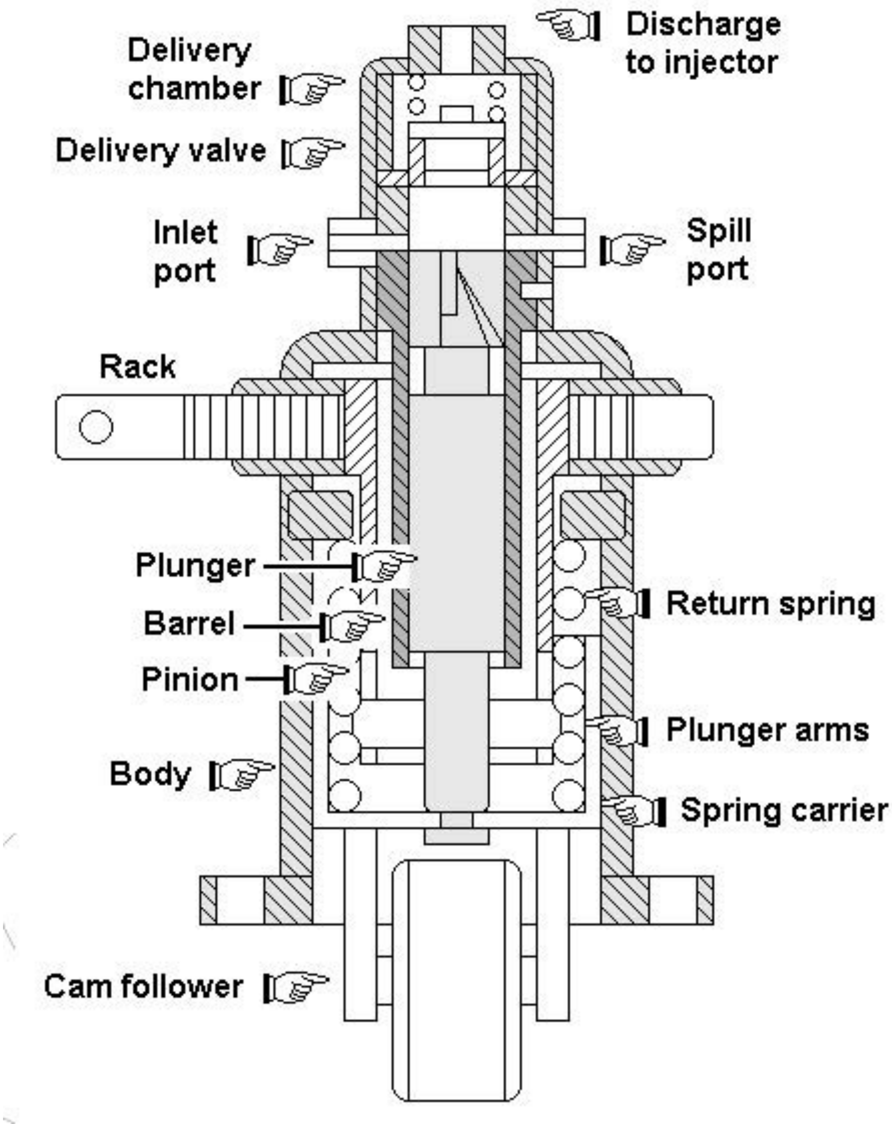
The Bosch fuel injection pump can be fitted as a separate unit for each cylinder, or multi-elements where a number of pump elements and a camshaft are housed in the one casing.





Multi-fuel pump block arrangement on a V-type engine

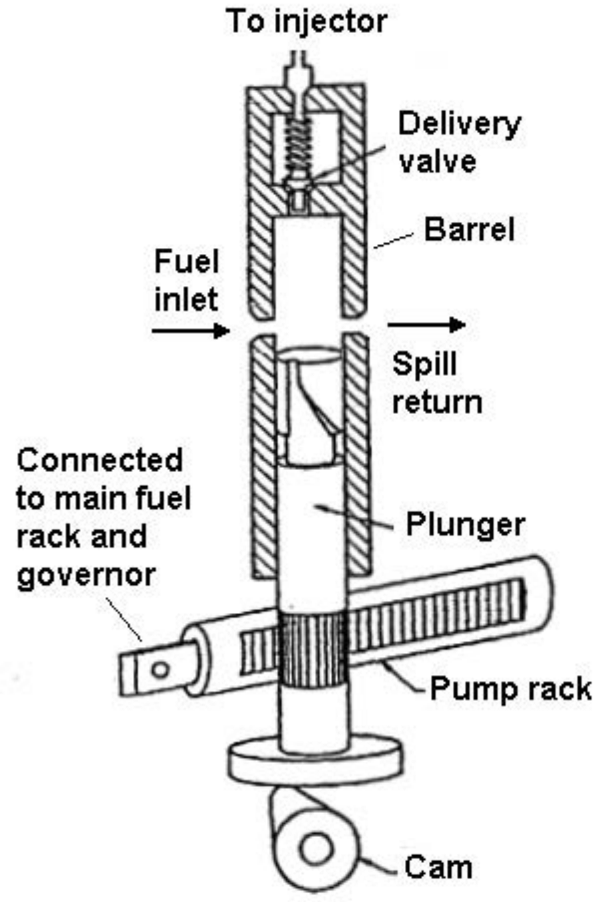
Pump main components



Main components of the Bosch fuel pump

The main component parts include:

- The delivery valve
- The rack and pinion
- The barrel and plunger (matched pair)
- The return spring
- The cam follower
- The inlet and spill return ports



Simplified HP fuel pump

Rack and pinion

A rack is fitted to the pump to engage with a pinion on the outside of a sleeve. The sleeve fits over the plunger and has slots engaging with keys.

This allows the plunger to be rotated by the fuel rack as the plunger moves up and down.

The end of the fuel rack is attached to the main fuel rack, that is in turn operated by the governor.

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

Barrel and plunger

The barrel is locked into the housing by a locating screw, and is aligned with the upper section of the body, which contains two ports placed at 180 degrees.

These ports are known as the inlet port and the spill port. The barrel is completely filled with fuel supplied by the fuel supply pump.

The plunger that operates within the barrel is driven on its upward stroke by a roller tappet operating on a camshaft. Contact is kept between the plunger and the tappet by means of a spring. The plunger has a slot and a special helix cut into it top.

The barrel and plunger are always supplied as a matched pair, and these components should never be inter-changed with others.

The surface finish is extremely finely honed and should never be touched, nor stored dry (always with a lubricant).

Delivery valve

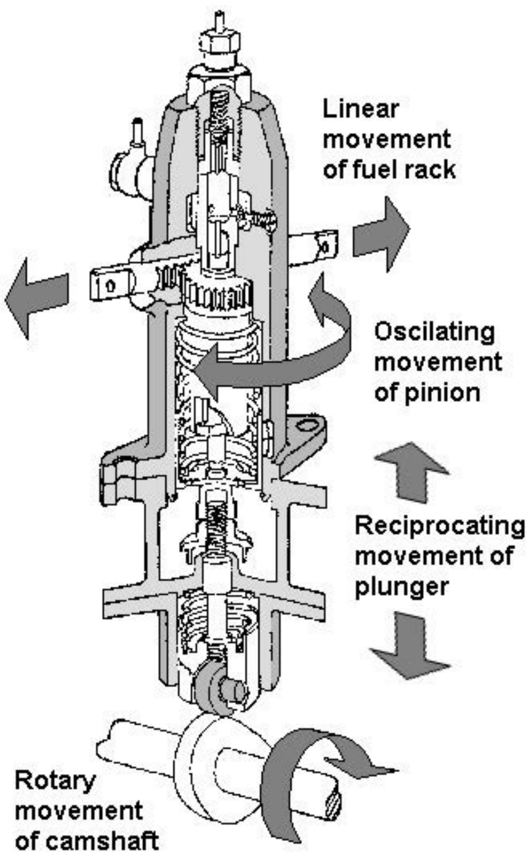
The barrel is closed at its upper end by a spring loaded pressure valve known as a delivery valve. An injector pipe is connected between the outlet of the discharge valve and the fuel injector.

Fuel pump pressure

The HP fuel pump raises the pressure from the fuel circulating pump, that delivers fuel at about 5 to 7 bar at the inlet to the HP fuel pump. The HP fuel pump delivery pressure can be anything between 130 and 800 bar, depending upon the engine type and design.

Commonly the HP fuel pump discharge pressure is between 260 and 650 bar.

Operation



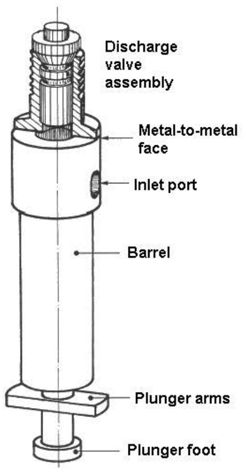
3D movements of HP pump

The operation of a HP fuel pump is a difficult concept to understand.

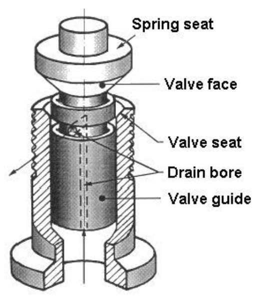
It is also extremely difficult to properly explain on paper, as there are many different motions in a three dimensional field.

These motions include:

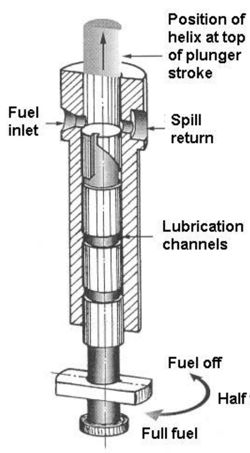
- The linear movement of the rack;
- The oscillating movement of the pinion, and the plunger;
- The reciprocating movement of the plunger;
- The rotary movement of the camshaft.



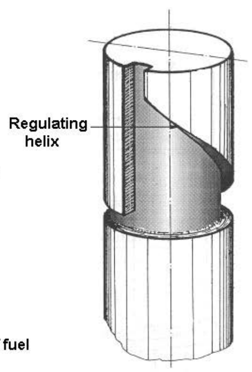
Plunger and barrel assembly



Discharge valve assembly

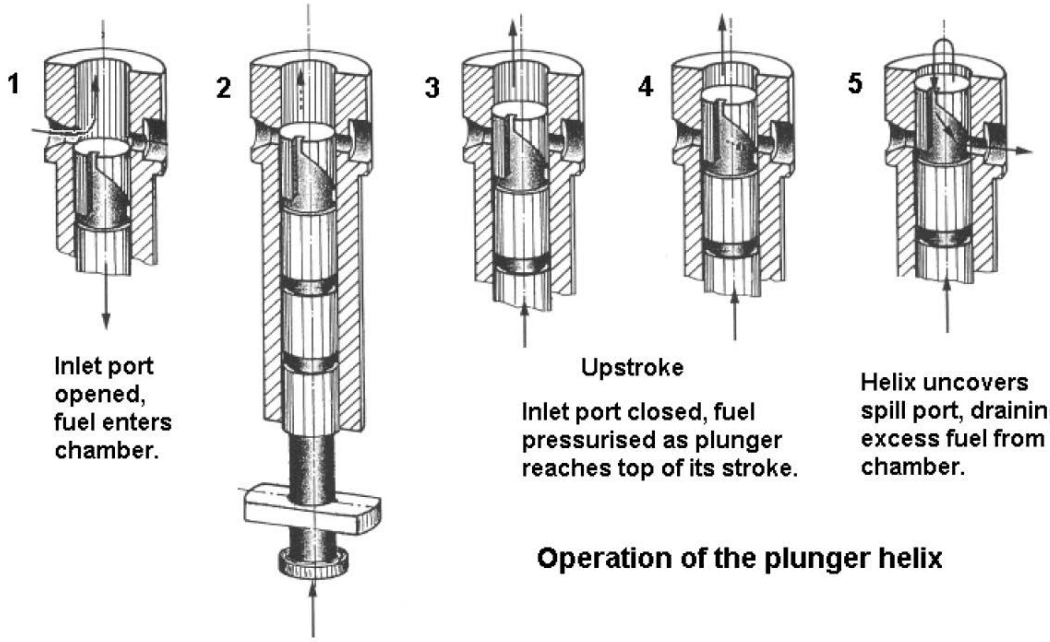


Detail of plunger and barrel



Detail of plunger helix

Metering the fuel

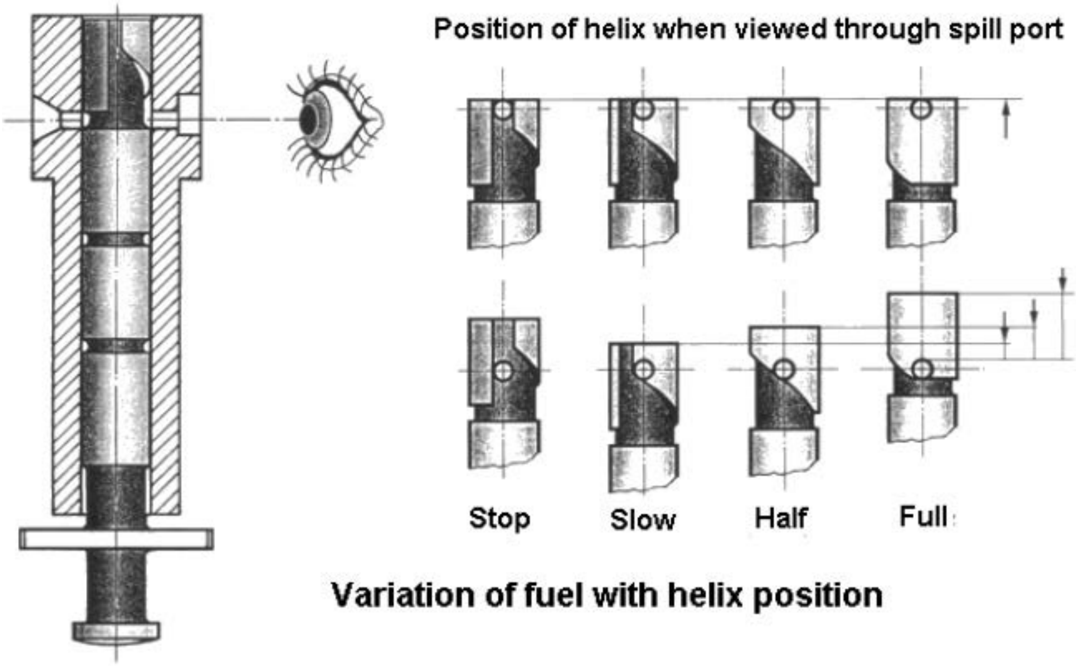


Operation of the plunger helix

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

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

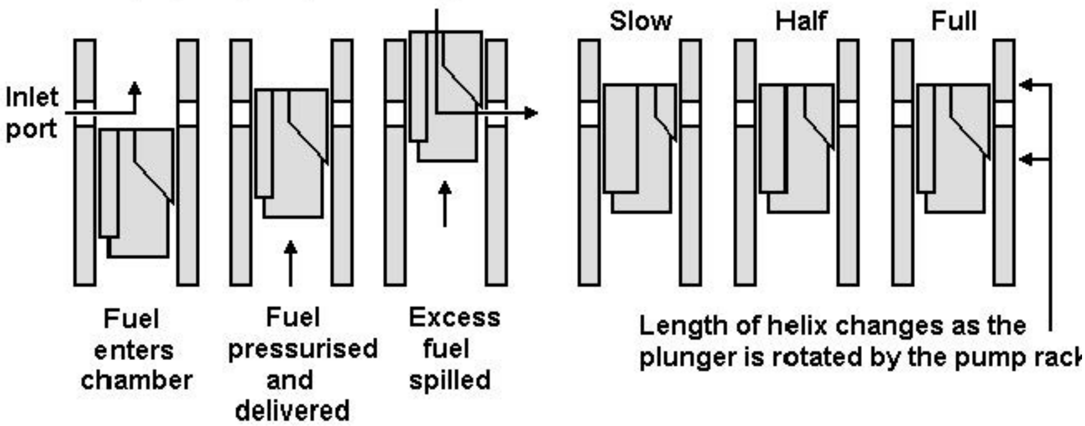
This allows the fuel pressure above the plunger to fall to the suction pressure through the vertical slot. The plunger will rise further to complete its stroke but no fuel will be pumped. As the lobe of the cam goes past top dead centre, the spring will cause the plunger to return to the bottom of its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



Variation of fuel with helix position

The fuel rack is attached to the governor. If for example the load decreases the engine starts to speed up, the governor reacts by moving the fuel rack, causing the helical groove to uncover the spill port earlier or cuts off the fuel altogether. As the load increases the engine starts to slow down and the opposite occurs.

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



Simplified diagram of plunger operation

Timing a fuel injection pump

Early injection

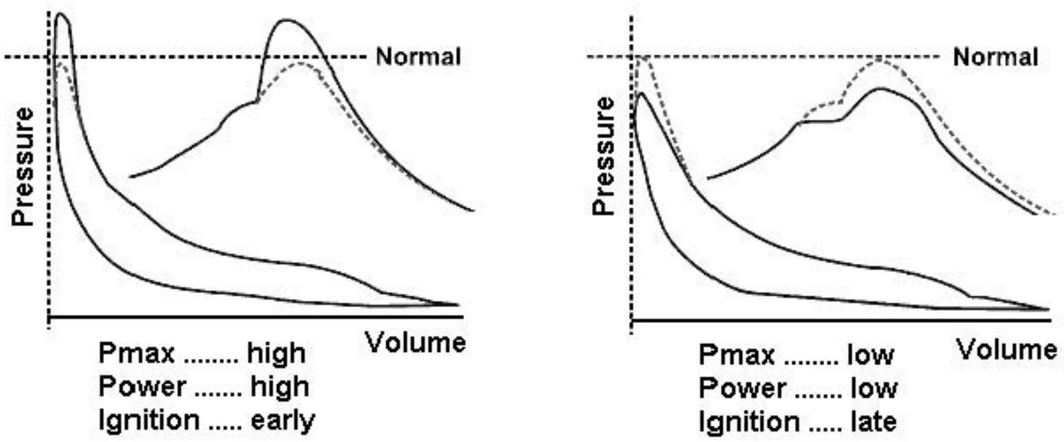
If the injection occurs too early on the compression stroke, it will result in high peak pressures. This will subject the engine to unsafe stresses caused by the tendency of the pressure to reverse the rotation of the engine and evidence by excessive detonation that is known as **diesel knock**. If the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

Late Injection

Retarded injection or late burning gives incomplete combustion causing too low a power output and overheating. High exhaust temperatures, which is caused by the after burning is an indication of late injection.

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

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



The effect of both early and late fuel injection is best illustrated by using a pressure-volume indicator diagram, as shown above.

Timing instructions

It will be necessary to follow the manufacturer's instructions in the manufacturer's manual to time the fuel pump to the engine as different methods are employed.

Timing principle

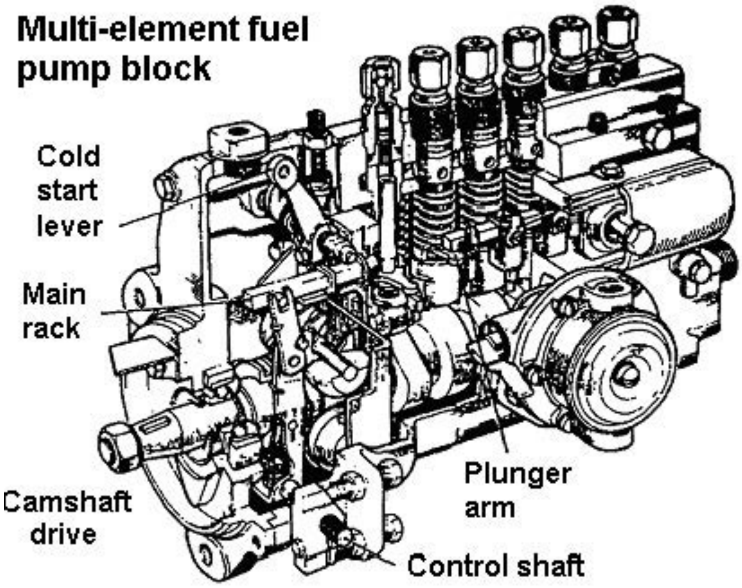
The principle is that fuel injection commences on the compression stroke just before top dead centre. With a 4 stroke engine, the piston also comes up to top dead centre on the exhaust stroke, ensure the injection takes place on the compression stroke near TDC.

Timing marks

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

The fuel injection pump must also be lined up on the cylinder element or port at the commencement of injection. The manufacturer's manual will identify the position of the lining up marks as brands of pumps differ. When the lining up marks on the pump correspond, the drive couplings can be bolted together.

Calibration and timing of a multi-element pumps



In a multi-element pump, each element is calibrated and timed on a special test rig.

To calibrate a pump, each element is connected up to a calibrated test tube.

The pump is run and then each test tube is checked to ensure that each element has delivered the same amount of fuel.

Each element is timed to ensure that injection commences at the precise time in the stroke.

Fuel Pump Defects

A worn barrel or plunger caused by abraision from debris, dirt, catalytic fines or just old age. This will cause a delay in the build up of pressure leading to late injection, after burning or high exhaust temperatures.

Seized plunger - can be caused by catalytic fines or debris no fuel pressure to affected unit. Low exhaust temperature and possible damage to delivery mechanism.

Broken Delivery Valve Spring - Due to age or fatigue, failure the spring may break and allow secondary delivery causing loss of power, due to poor combustion and result in high exhaust temperatures.

Leaking Seals Old age or poor fitting may cause leakage of fuel possible fire hazard or leakage of fuel into the lub oil system depending upon design.

Fuel Rack linkage This could be worn, damaged or seized and cause incorrect fuel pump operation, lack of fuel, low exhaust temperatures and will not respond to changes in load.

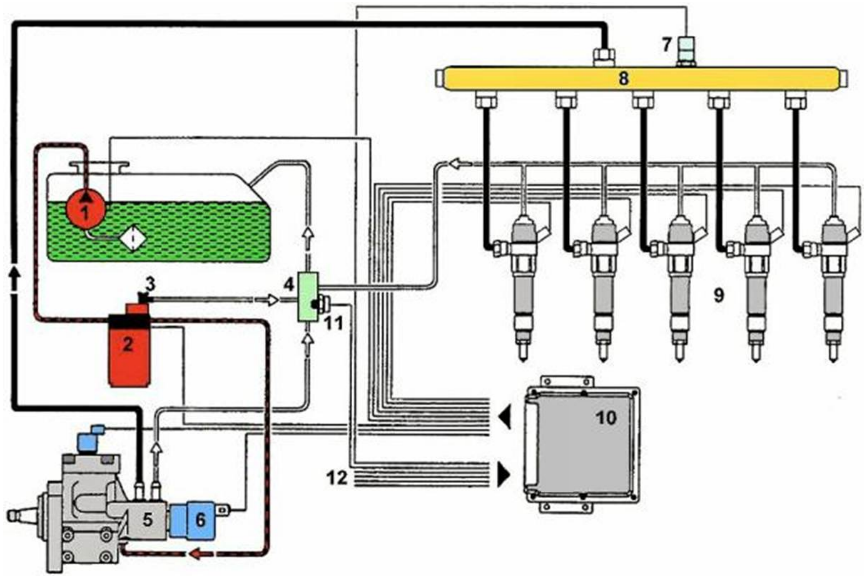
Common Rail Systems

Common rail diesel systems can generate pressure now in excess of 2,000 BAR (29,000 PSi) which offers a number of benefits over traditional diesel systems.

These high pressures improve the atomisation of the fuel thus improving ignition and combustion within the engine. In addition to the increased pressures, the electronic control significantly improves the flexibility of the system over older mechanical fuel injection systems – for example, during a single combustion stroke the injector may inject up to seven times per cylinder per stroke.
Electronic control fuel systems were introduced mainly to meet emissions legislation, with common rail systems being introduced to mainline manufacturing in the late 1990's.
In addition to reduced emissions, later generation fuel systems, most especially common rail has given:

- Improved performance
- Lowered fuel consumption
- Quieter engines

Common rail systems are electronically controlled, giving far more scope for adjustment and monitoring. These modern systems are a world apart from the mechanically timed fuel systems of the past.



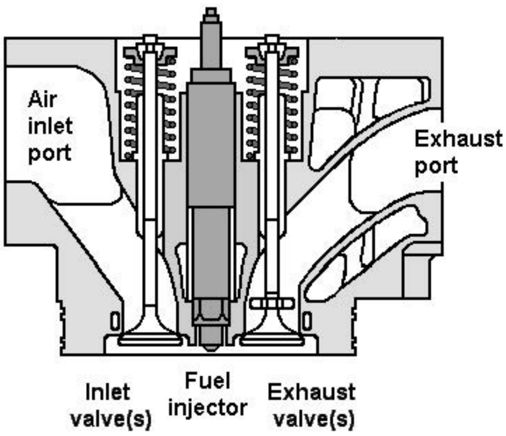
Fuel injectors

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

The fuel system of every vessel consists of two main parts:

- The fuel supply system
- The fuel injection system.

Location of injector

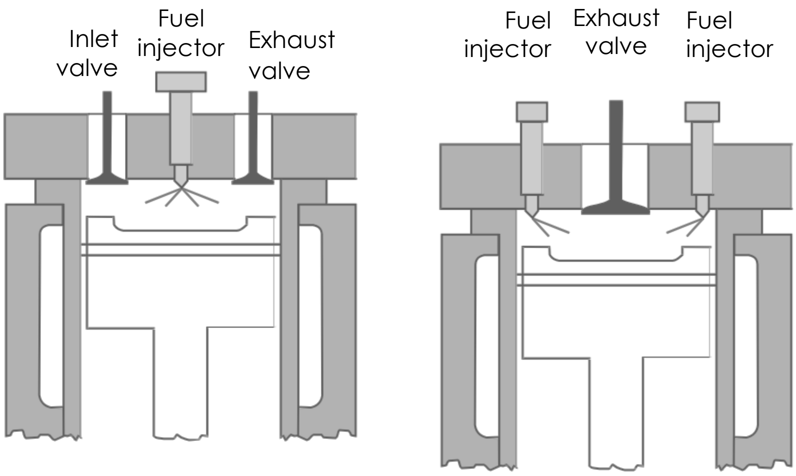


Section through cylinder head

There are various locations for the fuel injector, depending upon the engine design.

In general, there is one fuel injector located centrally in the cylinder head on a 4 stroke engine.

On a 2 stroke engine there may be one or more fuel injectors and they are located on the periphery of the cylinder head, around the centrally located exhaust valve.



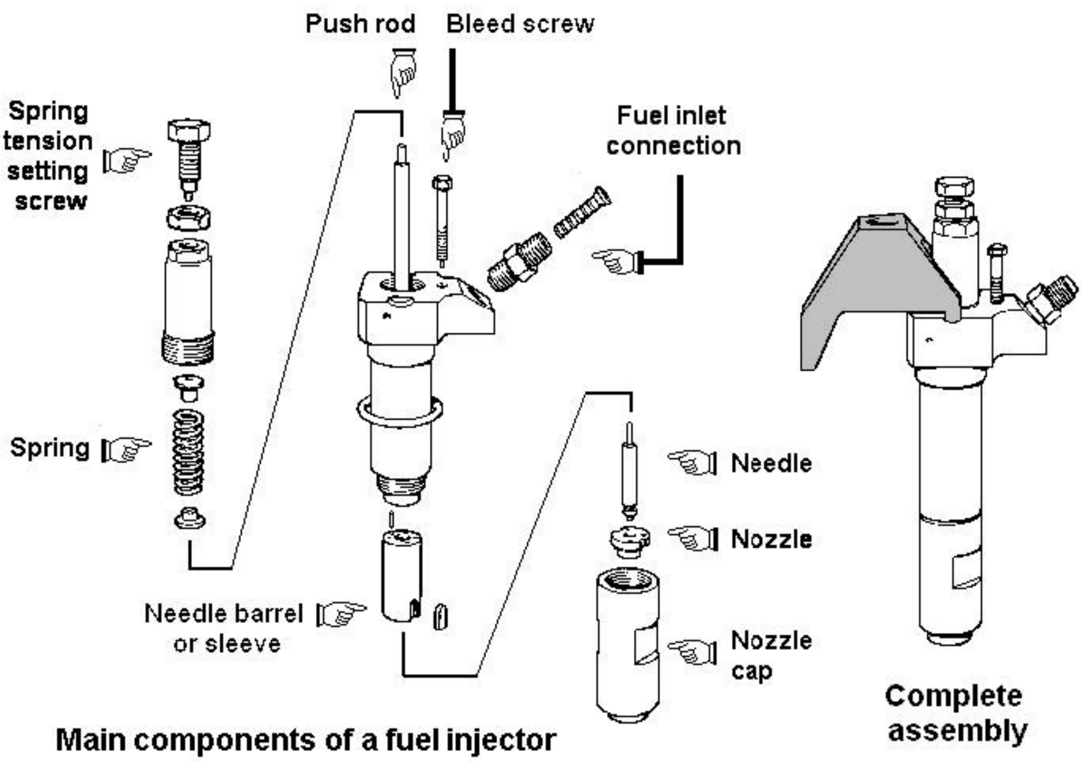
Fuel injector located centrally in cylinder head

4 stroke engine

Fuel injector located on the periphery of cylinder head

2 stroke engine

Main components



Main components of a fuel injector

Methods of operation

There are three methods of operating a fuel injector:

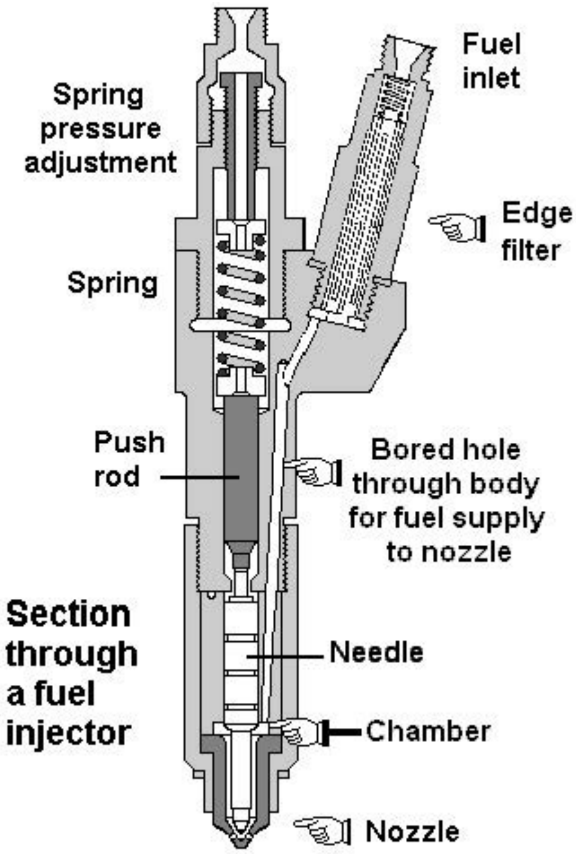
- Hydraulic actuation

  With this method the injector uses a spring loaded needle valve, operated by hydraulic pressure of the fuel itself, from the high pressure fuel pump.

- Mechanical actuation

  With this method the injector uses a spring loaded needle valve, operated by a mechanical device, such as a cam or push rod, the fuel being supplied from a common pressure rail.
- Electronic actuation

Hydraulic operated injector



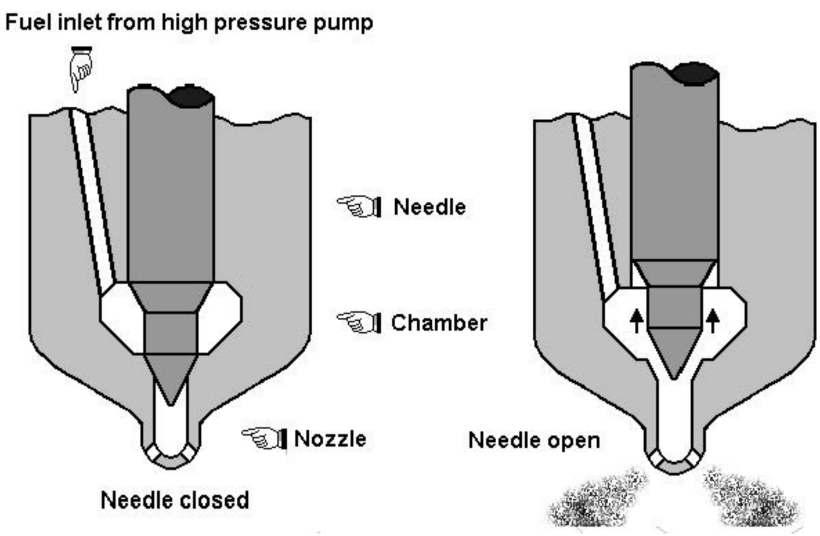
Hydraulically operated fuel injectors make use of a spring loaded needle valve.

Fuel under high pressure is fed down the injector body via an edge filter to a chamber just above where the needle valve is held on its seat by the spring.

The spring tension can be adjusted using the setting bolt at the top of the injector.

The spring pressure controls the **lift pressure** of the injector.

Needle operation



The fuel pressure builds up in the chamber, acting on the underside of the needle. When the pressure overcomes the spring pressure the needle valve lifts and opens the nozzle holes. Fuel flows into the space under the needle and is forced through the small holes in the nozzle cap, where it emerges as an atomised spray. The pressure drops at the end of delivery and the spring pressure acts on the needle, closing off the nozzle.

Spray nozzle assembly

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

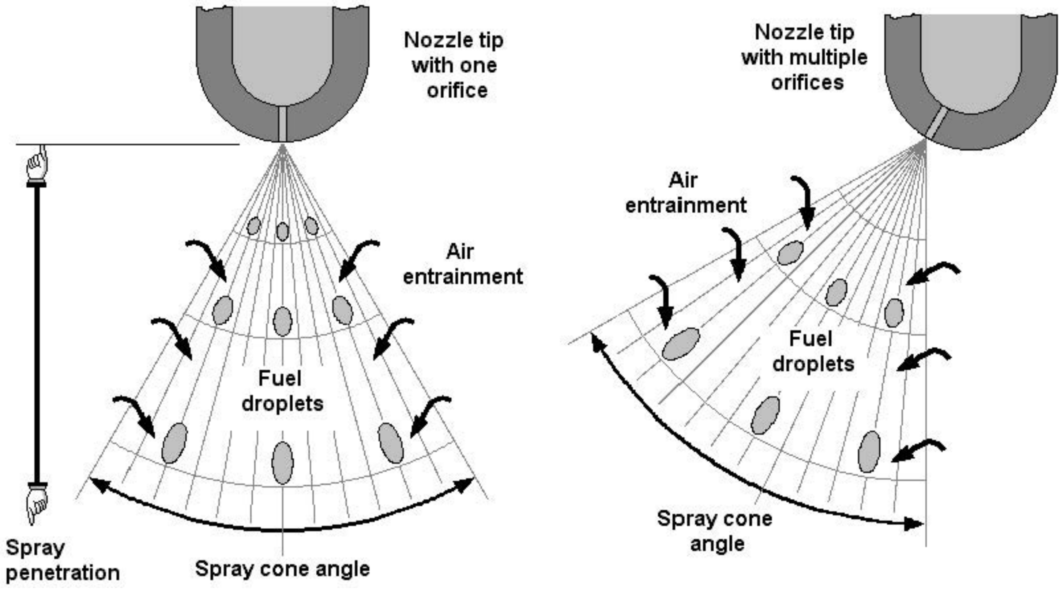
Lift pressure

The pressure at which a fuel injector needle starts to open is known as the **lift pressure**.

The lift pressure can be any setting between 130 and 550 bar, depending upon the engine manufacturers' design, different engines having different pressures.

Reference should always be made to the engine manufacturers' technical manual for the correct setting.

Spray cones



The atomised droplets are sprayed into the cylinder in a cone shape. There is a cone from each orifice. The injected cone is a solid, not a hollow, cone of fuel.

As the fuel stream is injected into the air charge it experiences friction along the outside surface of the cone. This friction has a twofold effect, firstly the packages or droplets of fuel on the surface tend to break up and mix with the air and secondly the friction has a small but measurable effect on the temperature of the droplet.

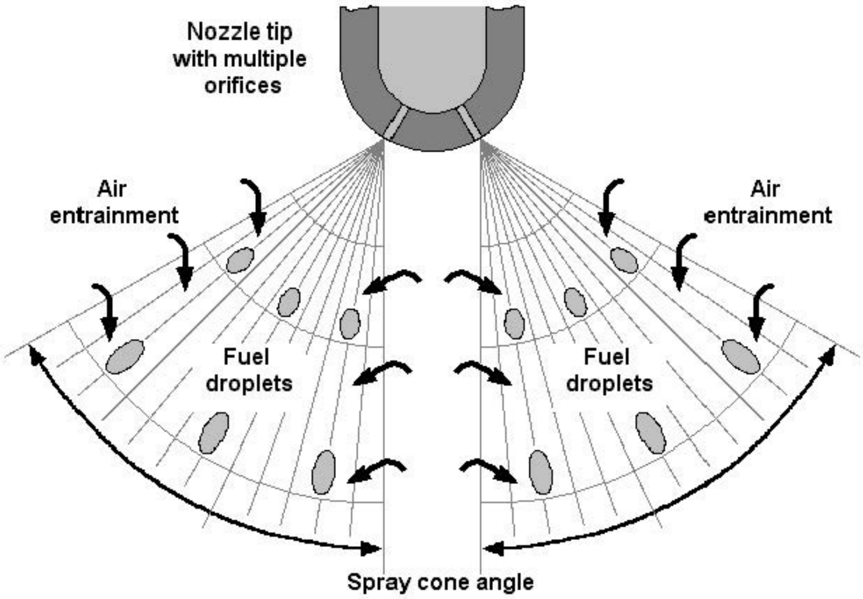
The net effect is that combustion starts once the fuel droplet has vaporised. The droplets in the centre of the cone will take longer to ignite. If this fuel (in the centre) does not ignite quickly enough it may well hit (impinge) on the cylinder wall, causing the liner temperature to rise, with obvious follow-on effects.

As the spray penetrates the surrounding air the outer droplets entrain air. It should be remembered how ever that the air in a combustion chamber is not necessarily static.

The air movement will have an effect on the cone and in particular on air entrainment.

The shape of the cone is clearer closer to the orifice and becomes more defuse as it travels further into the air charge. As mentioned above it is the resistance of the air that eventually breaks up the fuel spray and hopefully prevents the droplets from impinging on the cylinder walls.

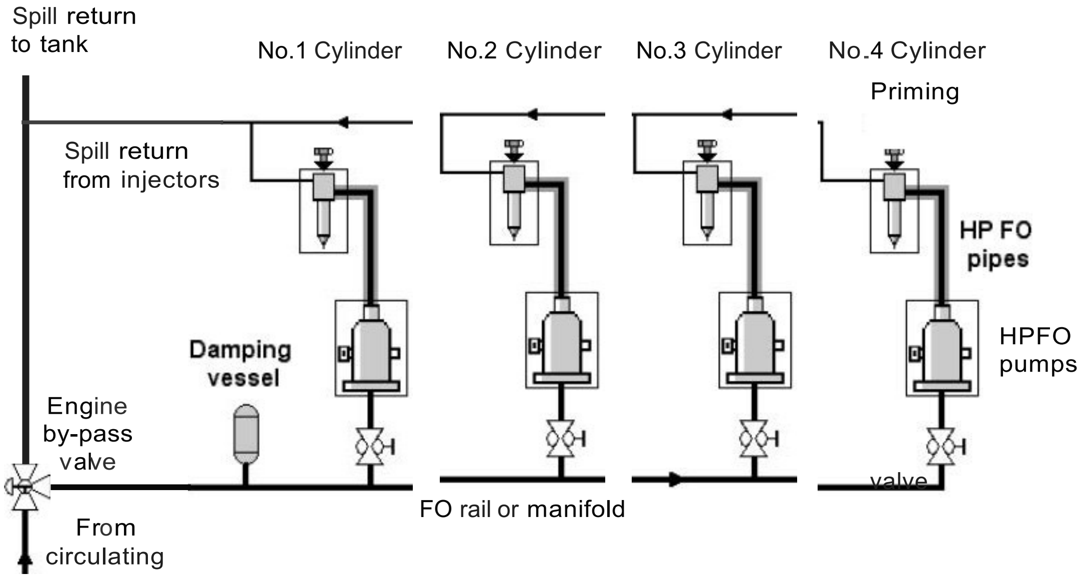
It follows therefore that at reduced speeds where the compression pressures are not so great, that over penetration may occur. That is the density of the air is not so great and the fuel may well travel through the charge allowing some of it to burn on the cylinder walls. Anything within the running of the engine that can affect the compression pressure (and hence the air density), the engine cylinders collectively, or indeed individually, will have the above effects (Cylinder wall temperatures rising and efficiency dropping.)



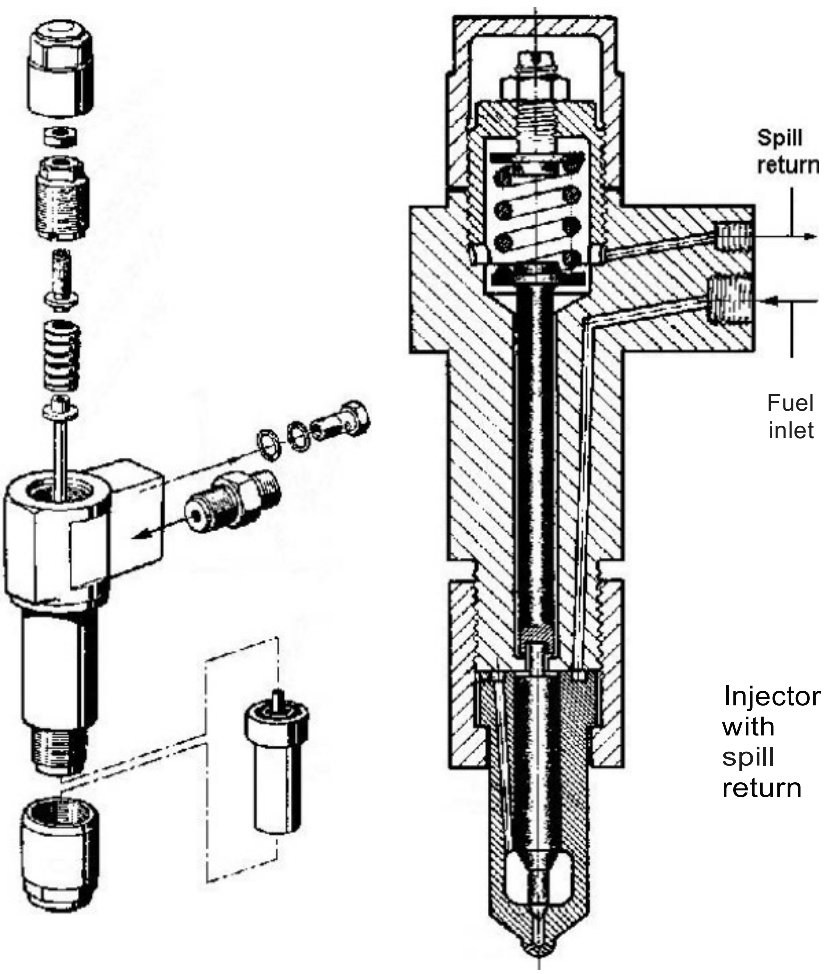
Multiple hole injector spray cone

Spill return

The injection system always supplies more fuel to the pump or injector than is required for combustion. The excess fuel that is not used for combustion is returned to the supply tank via the **spill return line**.



Fuel system with spill return from injectors



Injector with spill return

The excess fuel is supplied to allow for sudden fuel demands, for example if the engine speed is suddenly increased.

There are two common methods of spill return:

1 On larger engines spill return is from the high pressure fuel pump;

2 On smaller engines spill return is from the fuel injector.

Some engines, with the spill return from the injectors, are fitted with a fuel cooler in the spill return line after the engine.

Electronic timing

The first electronic engines were composed of both mechanical and electronic components. The fuel pumps electronically control delivery of fuel to the fuel pump. But because the pump itself is mechanically controlled, it doesn't deliver the optimum amount of fuel to the cylinders.

To improve the emissions from marine diesel engine exhausts there has been a requirement for more fuel efficient engines. To improve the emissions Electronic Unit Injection (EUI) engines were introduced.

The EUI design combines the fuel pump and nozzle into a single unit, allowing both injection timing and duration to be electronically controlled. This means the exact amount of fuel is distributed to the cylinders at precisely the right time for optimal combustion. The result is decreased fuel consumption, and because less fuel is burned, exhaust emissions are greatly reduced.

Emissions can be further reduced through computer software programs to minimise white and black smoke at start-up; black smoke during acceleration; and gaseous emissions throughout the operating range.

The monitor (sensor diagnostics) can function to observe additional parameters that relate to engine performance.

These can include:

- Atmospheric pressure.
- Turbocharger inlet pressure.
- Turbocharger outlet pressure.
- Boost pressure.
- Engine LO pressure.
- Air filter restriction.
- Battery voltage.
- Loss of coolant flow.
- Fuel filter restriction.
- High crankcase pressure.
- Low engine LO level.

These sensors assist the operator through the use of a monitor (laptop computer) to analyse a problem that may occur.

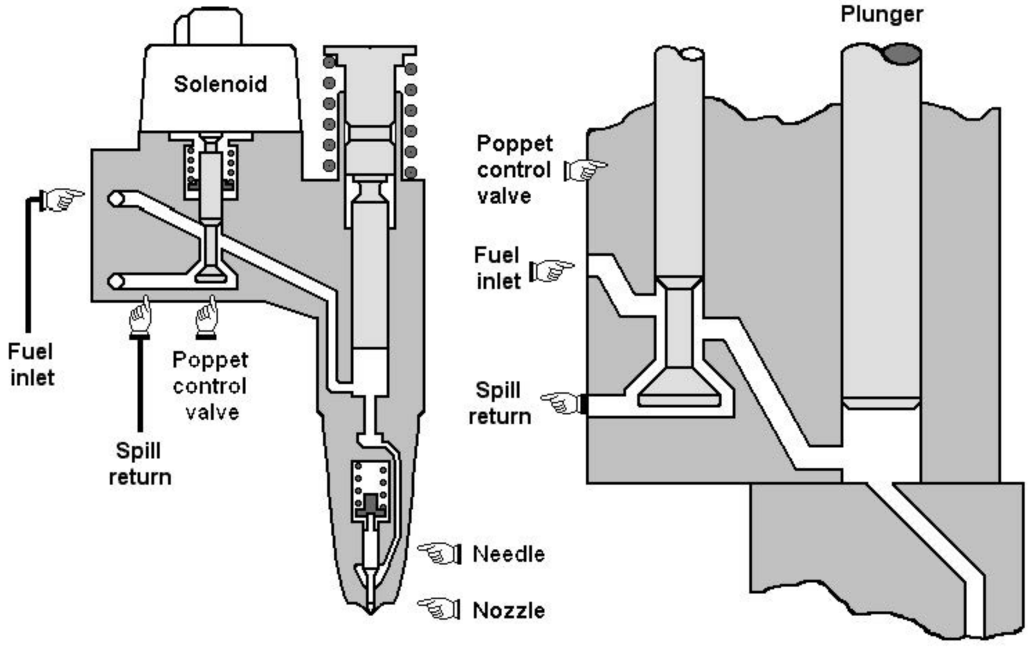
Electronic unit injector

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

The electronic unit injector (EUI) is built on their patented mechanical unit injector design.

The design simplifies the plunger and bushing. It also replaces the mechanical rack with an electronic solenoid that allows precise metering and injection timing.

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



Electronically controlled injector

Injector faults

A faulty injector can cause several operational problems, including:

- Poor combustion;
- Loss of engine power;
- Carbon fouling on valves;
- Fuel dilution of sump LO.

Any injector problem at sea can be rectified by replacing the injector with a spare.

Incorrect opening pressure

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

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

The spring adjusting screw has a lock nut which may have slackened off causing insufficient compression on the spring.

The spring may break. Replace the spring.

The correct opening pressure can only be obtained by placing the injector in a test rig and adjusting the tension on the spring until the correct opening pressure is obtained. Whilst on the test rig, the spray pattern of the fuel leaving the nozzle can also be checked.

Distorted spray form

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

Dripping injector

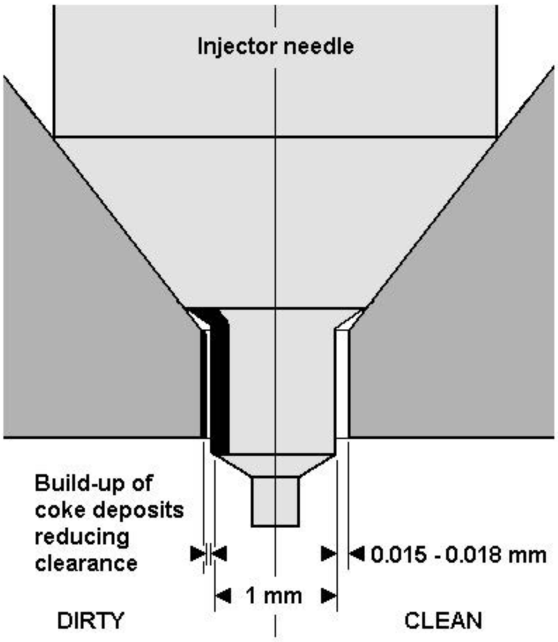
The valve is not sealing on its seat. Grind it in with the finest grade of grinding compound. Excessive grinding causes the valve to seat too deeply in its seat causing a lagging of the fuel admission which results in late combustion and therefore loss of power.

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

Dirt between the valve and its seating

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

Nozzle coking



Nozzle coking

A common fault with injector nozzles is the deposit of coke (carbon) around the nozzle and needle.

These deposits reduce the clearance of the needle in the nozzle, causing restricted fuel flow and poor atomisation.

Injector valve sticking in the nozzle body

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

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

Causes:

Overheating, dirt or abraisives in the fuel, poor filtration, contamination by water.

The **effects can be minimized** by:

Using correct fuel

Inspect filters regularly for damage / blocking

Drain filters daily

Use purifiers

Ensure Injectors are correct type and calibrated professionally

Too much fuel escaping at the leak off pipe

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

Unburnt fuel

The burning process should be completed before any fuel droplets can hit the relatively cold surface of the liner and piston. Unburnt fuel droplets that contact these cold surfaces can cause several problems, including:

- Dilution of cylinder liner lubricants;
- Excessive exhaust smoke;
- Production of polluting exhaust gases;
- Reduced combustion efficiency.

Exhaust emissions

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

Black smoke

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

- Blocked or partially blocked air cleaner

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

Blue smoke

Blue smoke indicates that lubricating oil is being burnt. This maybe caused by:

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

White smoke

White smoke or white exhaust vapour indicates water or moisture in the system.

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

Fuel injector reconditioning

With respect to maintenance on fuel injectors and fuel pumps refer to the maintenance procedures produced by the manufacturer.

Fuel injection equipment is precisely and accurately constructed with a number of the components having exceptionally small clearances between them. Any repair or overhaul must be made where the proper tools and equipment is available and where the maintenance area is kept scrupulously clean.

Periodically inspections are carried out on injectors in line with the manufacturer's recommendation. Prior to dismantling an injector it should be cleaned thoroughly

removing carbon deposits and ensuring the nozzle tip is not damaged. The sequence of dismantling an injector varies with the type and make of injector.

As a general guideline the following fundamental procedure should be adhered to:

- If the nozzle is fouled by a formation of carbon deposits, the carbon deposit should always be removed by using a copper or brass drift.
- During the dismantling of the injector components, a separate bowl containing paraffin should be made available for each individual injector.
- Carbon and lacquer should be cleaned from the parts using a nozzle fuel chamber scraper, nozzle hole pricker, a seat cleaning tool and a brass wire brush. These tools should be made available by the manufacturer.

Reassembly and testing of injectors

Before assembling injector components the parts should be thoroughly washed in light fuel oil and assembled whilst wet.

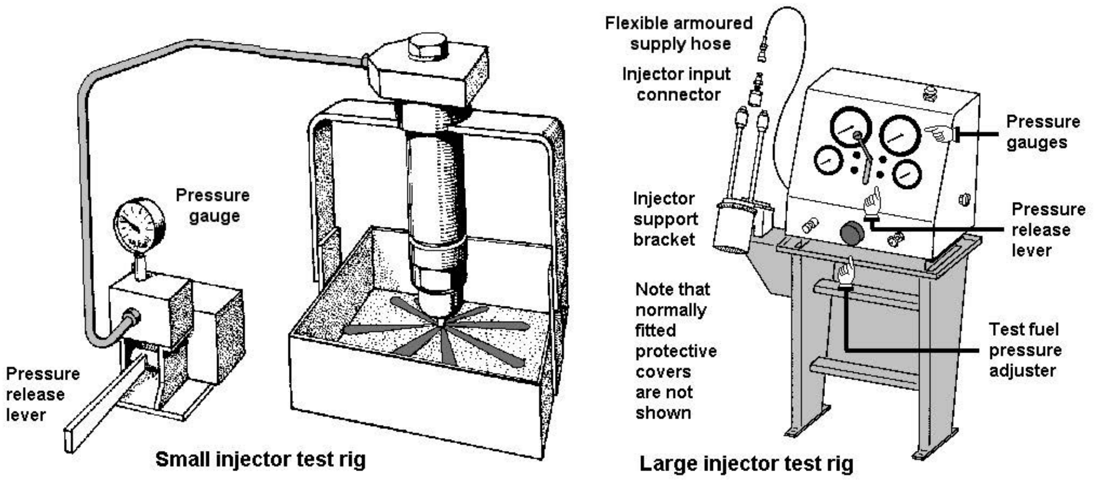
Before replacing a fuel injector it should be checked by connecting it to a test pump rig filled with a pressure gauge. The injector pressure is slowly brought up to the correct pressure. When the pressure reaches its correct value and 'cracks off,' observe the spray pattern whilst ensuring that the injector nozzle tip does not dribble after termination of injection.

Spraying should be set to commence at the recommended pressure set by the engine builder **(TYPICALLY 3-500 BAR)** and there should be no signs of leakage or dribble at any lower pressure.

There should be no significant drop in pressure (slow degradation of pressure) after injection. This shows the injector nozzle barrel is in good condition.

The spray pattern should be in the form of a fine mist free from streaks of un-atomised fuel. Each test should indicate symmetry about the centre line of the nozzle holes.

Injector test rig



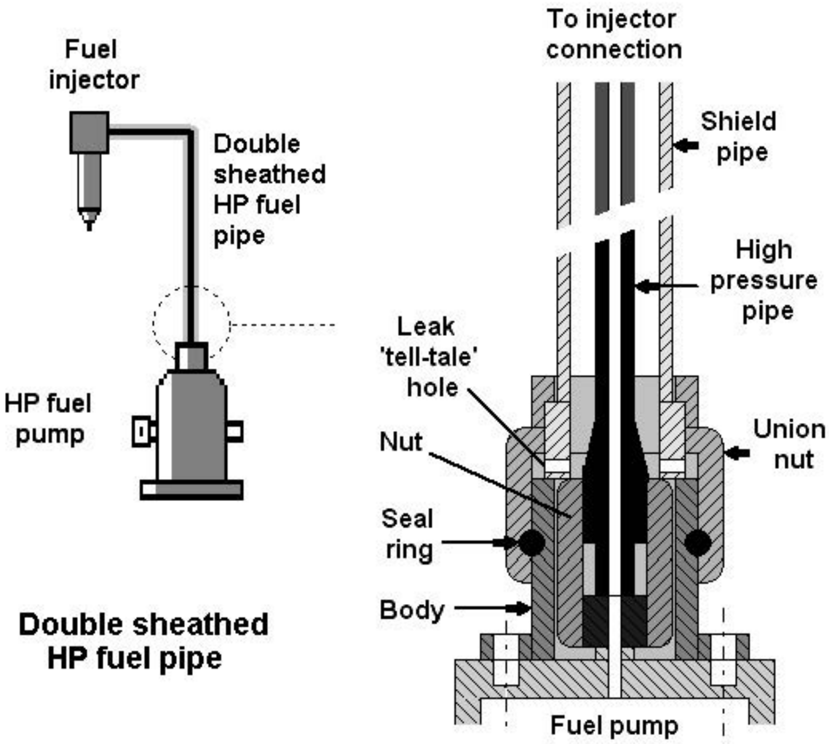
The injector lift pressure is set by adjusting the spring tension using a special injector test rig fitted with a hydraulic test pump.

Storage of injectors

A reconditioned injector not in use should be carefully stored, covered with a preservative grease, the pipe connections plugged and the complete unit wrapped in grease proof paper.

The injector ideally should be stored with the spring pressure lightly set, the correct setting should be made just before use. This can only be done if the ship has its own test rig on board.

HP fuel pipes



The high pressure fuel pipe connects the discharge of the HP fuel pump to the fuel injector. The pipe delivers fuel to the injector and is subject to very high pressure.

Historically there have been many cases where a fractured HP fuel pipe has been the cause of serious fires, when high pressure fuel has sprayed onto hot surfaces, commonly exhaust pipes.

As a consequence as a safety precaution the HP fuel pipes fitted on an engine must now be double pipes, commonly known as sheathed or shielded pipes. The outer pipe leads down to a drain tank fitted with a float alarm. In the event of the internal pipe leaking for any reason the fuel will drain down into the leak tank and sound the alarm.

Ideally the HP fuel pipe should be kept as short as possible to reduce injection delay (see later in the section on the combustion process).

Combustion of fuels

The general indications of good combustion are similar in any operating diesel engine; a clear exhaust, powers produced and exhaust temperatures normal for the throttle setting. There should be no uneven running, knocking from cylinders or the fuel system.

The efficient and complete combustion of the injected fuel is of paramount importance in any internal combustion engine. However achieving effective and complete combustion is extremely difficult due to the many variables that surround the problem.

Time available

The time period available for a fuel injector to operate is extremely short.

As an example, assume a 2 stroke engine is running at 600 revs/min.

The engine will complete 10 revolutions per second.

The engine will take 0.1 seconds to complete one revolution (or 360°).

A typical fuel injection period is about 20 degrees.

This means that the injector has [(20/360) x 0.1] seconds to work, which is 0.005 seconds!

Time is the first consideration, however there are many other factors that have a bearing on the combustion of the fuel charge, amongst which are:

Atomisation

For the fuel to burn completely and at the correct time it must be divided up into very small droplets. This process is known as **atomisation**.

These very small droplets of fuel must penetrate far enough into the combustion space so that they mix with the oxygen that is present in the air.

The temperature of the fuel droplets rises rapidly as they absorb the heat energy from the hot air in the combustion space. This causes the fuel droplets to vaporise.

When sufficiently hot enough the fuel droplets ignite and burn.

The droplet size will depend upon the size of holes and the pressure difference between fuel pump discharge and that of the compressed air in the combustion chamber. Consequently the size of droplets may vary over the whole injection period. Atomised droplets have a high surface to mass ratio giving good heat transfer from the hot compressed air in the cylinder causing rapid evaporation and mixing.

Penetration

Penetration refers to the distance the oil droplets travel into the combustion space before mixing with the air and igniting. This will depend upon droplet size (atomisation), velocity leaving the injector and the conditions within the combustion chamber.

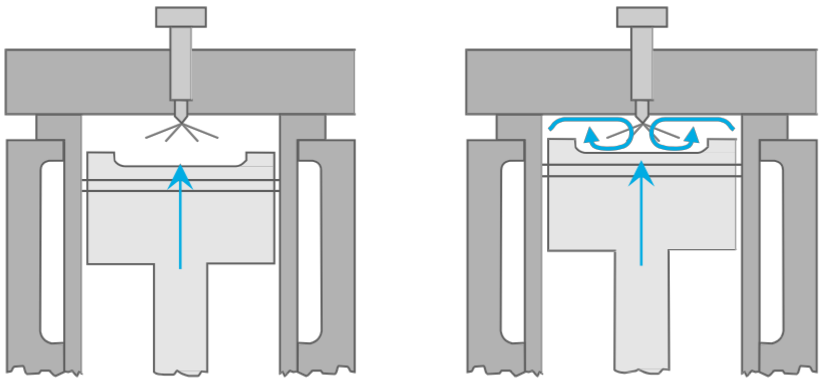
It is desirable that fuel should penetrate into the whole of the combustion space for good mixing, but droplets should not impinge on the internal surfaces before burning. The number of atomiser holes and their position will decide the spray pattern.

Squish

In an attempt to improve air fuel mixing in the short times available medium speed engines often adopt a method of forcing the air into a turbulent state at the end of compression, such a process is known as **squish**. It may also be known as **turbulence** or **swirl**.

This is simply a shaped piston crown that squeezes the air into the centre of the chamber as the shoulders of the piston close down the clearance volume. This air movement may well accelerate the break up of the spray cone mentioned above.

Swirl is imparted to the air during its entry into the combustion space. It may be further agitated by the fuel spray pattern and the shape and movement of the piston crown. Turbulence will improve the mixing of fuel and air for effective and rapid combustion. It is particularly desirable for rapid combustion of heavy fuels in medium or higher speed engines.



Fuel injection, just before TDC **Air squish at end after TDC**

The diagram above shows schematically a fuel injector spraying fuel into a combustion chamber. The convex piston crown is shown and it is in this space that the turbulent air forms after the so called squish process occurs. The air is squeezed into the centre of the combustion chamber such that an annulus of turbulent air is formed.

It is into this annulus that the fuel is injected, the combined effect of the moving air and the unidirectional fuel is to maximise the mixing and thereby improve the combustion of the fuel.

Fuel quality

There is an ever increasing demand to reduce fuel costs such that ships engines are expected to run on poorer quality, and cheaper fuels.

Fuel pressure

Generally dependant on the speed and efficiency of operation of the fuel pump, but may fall off a little with pump wear.

Fuel injector tip orifices

These are a design feature of the engine builder and as such should provide correct atomisation of the fuel. When the droplets are too small they will lack penetration into the combustion space and burn in the vicinity of the fuel injector tip. This slows down the combustion of the total charge, such that there will be higher cylinder wall temperatures, as well as the likelihood of an increase in turbocharger speed.

Important factors for correct atomization and penetration with respect to the nozzle holes are:

- The number of holes;
- The angle of the holes;
- The length of the holes;
- The diameter of the holes.

Density of the compressed air in the combustion chamber

This varies with the ambient air pressure.

The condition of the cylinder liner and the piston rings.

Charge air temperature and fuel temperature

The charge air temperature if a function of the ambient air temperature; the compression ratio of the turbocharger; the effectiveness of the after cooler; and the temperature of the combustion chamber boundary.

Recent research has revolved around the spray cone angle. This is the cone of fuel that is emitted from the fuel injector tip during the injection period.

Combustion process

Compression ignition is the term used to describe the combustion in diesel engines and they are often referred to as compression ignition engines.

The combustion process may be considered as the following consecutive phases:

Injection delay

The time required for the fuel to travel from the high pressure pump to the injector, via the high pressure fuel pipe, is termed the **injection delay**. The injection delay period is dependent upon the length of the high pressure fuel pipe. The fuel will travel down the pipe at speeds in excess of 1300 metre/second.

Ignition delay

1 The atomised oil droplets are emitted from the fuel valve nozzle into the combustion space;
2 The oil droplets will evaporate and mix with hot, compressed air and some chemical changes will also occur;
3 The mixture will reach an ignitable condition and spontaneous combustion will commence.

The time elapsed during this phase is termed the **ignition delay** or **ignition lag**. It is the time taken from when the injector opens and ignition begins.

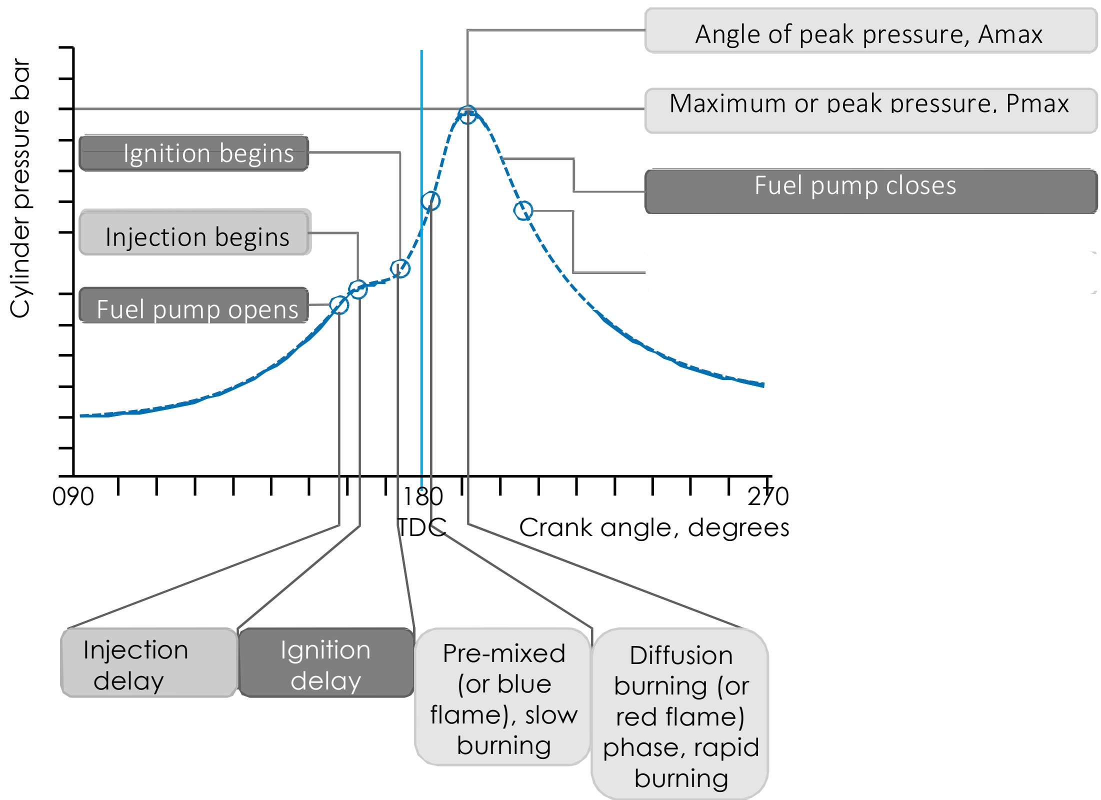
The blue flame period

The ignition and start of combustion will set up a flame front which will accelerate through the chamber, enveloping and burning all the other droplets present, causing a very rapid generation of heat with a corresponding rise in pressure and temperature.

(During the ignition delay, the injector continues to inject fuel and, if this has built up a sufficient quantity, the rapid combustion and pressure rise will be quite violent, causing detonation, the shock loading creating a noise termed **diesel knock**).

The red flame period

Following the rapid pressure rise in the blue flame period, hot, turbulent conditions existing in the combustion chamber will ignite and bum the remainder of the measured fuel charge as it is injected. This is termed the controlled part of the combustion process as pressure is regulated by the rate at which fuel continues to be delivered.



SECTION 7 – Fuel Oil Characteristics

Crude Oil

The majority of fuel and lube oil is derived from crude oil. There are many different types of crude oil, the characteristics of each depending upon which oil field they came from geographically.

All types of crude oil are **hydrocarbons**, that is a compound of hydrogen and carbon.

Refining

Besides hydrogen and carbon crude oil contains many other non-hydrocarbon elements, many of these are undesirable for the end products, and have to be removed or reduced in the **refining process**.

There are three basic groups of crude oil:

1 Paraffins

2 Naphthenes

3 Aromatics

These groups produce a variety of atomic structural arrangements that produce many hundreds of different molecules. Each molecule would have its own physical and chemical properties, such as density, boiling temperature, viscosity etc.

Depending upon these characteristics the particular crude oil would be used to obtain one or more of three basic products:

1 A fuel

2 A lubricant

3 A solvent

The refining processes divide the crude oil into a number of **fractions** or cuts (grades). A primary fraction can be further divided into narrow cuts.

The basis of such separation is **distillation**, a process that involves evaporation and condensation.

Refining processes

There are several refining processes, including:

1 Primary process

  a The straight run process

2 Secondary processes

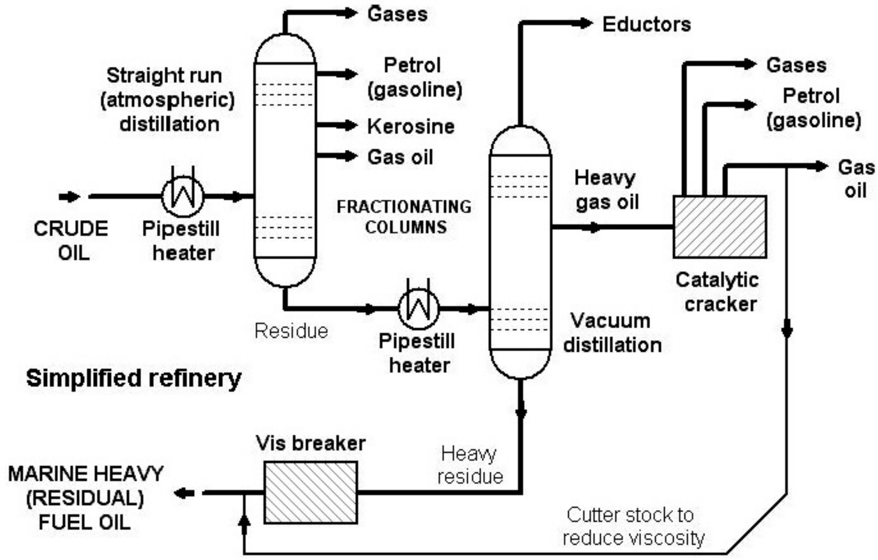
  a Thermal cracking

  b Vacuum distillation

  c Visbreaking

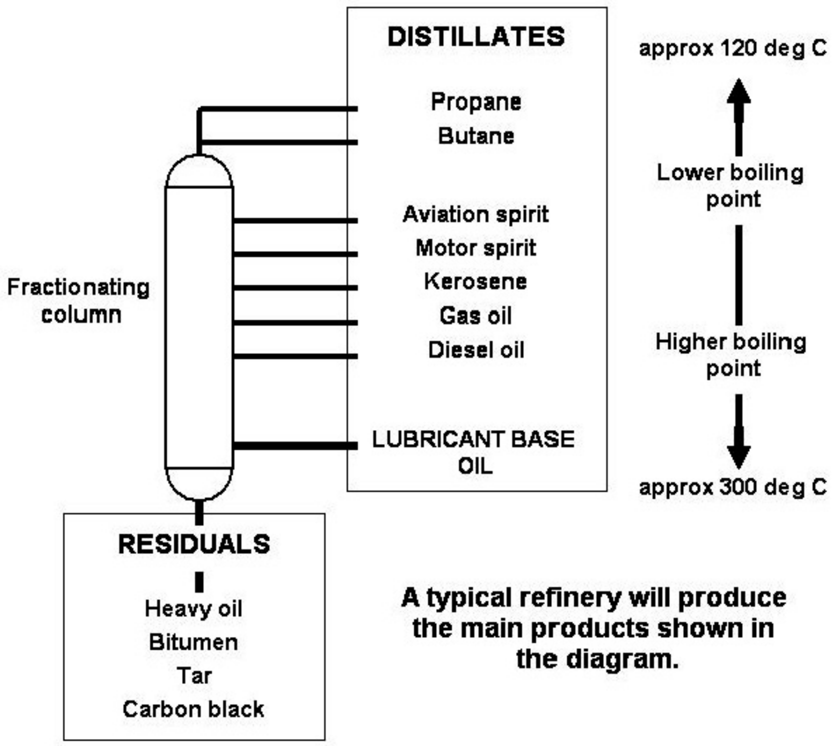
d Catalytic cracking

The processes are similar and differ mostly by the pressures and temperatures used. Catalytic cracking has some differences that cause problems in fuel (see later).



Simplified refinery

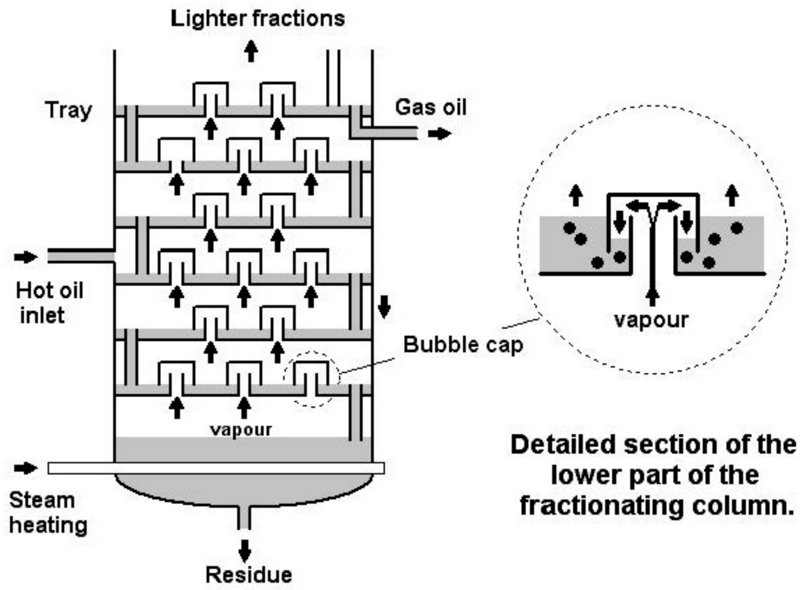
Refinery products



Products produced by distillation are called **distillates**.

The remaining products are known as **residuals**.

Fractionating tower

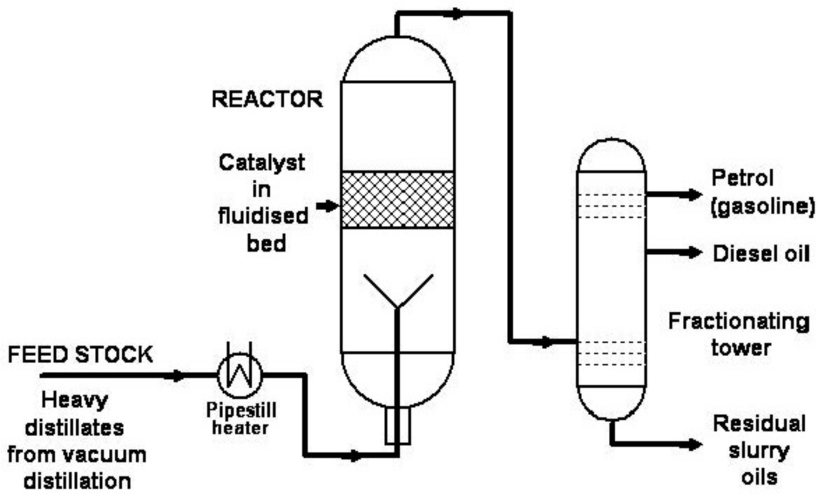


Detailed section of the lower part of the fractionating column.

Fuels and lubricating oils are obtained from crude primarily by heating the crude oil, so that vapours are boiled off and then condensed at different temperatures. The constituents or fractions are collected separately in a distillation process. The process is carried out in a fractionation tower or column.

The boiling process produces a residue that is very dense as the result of having lost the lighter parts. This high density remainder has much the same hydrocarbon make-up as the lighter fractions and is used as a fuel. Unfortunately, the initial refining process not only concentrates the liquid but also the impurities.

Catalytic fines



Catalytic cracking process

Catalytic cracking is a process that uses a powdered silica-alumina based catalyst with heating, to obtain lighter fractions.

A **catalyst** is a substance that aids and speeds up a chemical process, without itself undergoing any change.

The catalytic process is responsible for the fuel problem known as **catalytic fines**.

In the process catalyst powder is continuously circulated through a reactor then to a regenerator. Unfortunately, some of the catalyst powder can get carried over into the fuel oils.

These very abrasive fines can cause severe damage to fuel injection equipment and other parts of the engine, and are very difficult to remove.

Fuel characteristics and properties

Distillate Fuel

Distillate fuels are those lighter (high hydrogen to carbon atom ratio) fractions derived from the boiling off (distillation) of crude oil. Distillate fuel characteristics are that they have little or no colour (may appear translucent or bright green hue) have low DENSITY, low VISCOSITY, high VOLATILITY, good ignition/combustion properties and are clean with few contaminets.

Physical properties

Physical properties are the fuel characteristics that affect their safe handling, storage and effective delivery to the combustion chamber of the engine.

Chemical properties

Chemical properties are the fuel characteristics that describe its value in terms of energy content, ability to release that energy, and the combustion by-products effecting the working parts of the engine and the environment.

ISO 8217

Bunkers were once classified as Gas Oil (GO), Light and Marine Diesel Oil (MDO), Intermediate Fuel Oil (IFO) and Marine or Bunker (C) Fuel Oil. These terms are still frequently used to describe a fuel type in common everyday language, which now is not technically correct.

ISO 8217 is the international standard of fuel types and grades. The standard provides a guideline to the characteristics and their limits, and the tests associated with each particular grade.

There are generally four grades of distillate fuel:

- DMX;
- DMA;
- DMB;
- DMC.

Most fuels used by yachts are grade DMA or DMX or better (which fall off the ISO 8217 standard).

These grades are illustrated in the extract from ISO 8217 for distillate fuels shown in the following table.

ISO 8217 2017 FUEL STANDARD FOR MARINE DISTILLATE FUELS

MARINE DISTILLATE FUELS

<table>
<tr><th>Limit</th><th>Parameter</th><th>DMX</th><th>DMA</th><th>DFA</th><th>DMZ</th><th>DFZ</th><th>DMB</th><th>DFB</th></tr>
<tr><td>Max.</td><td>Viscosity at 40°C (mm²/s)</td><td>5.500</td><td colspan="2">6.000</td><td colspan="2">6.000</td><td colspan="2">11.00</td></tr>
<tr><td>Min.</td><td>Viscosity at 40°C (mm²/s)</td><td>1.400</td><td colspan="2">2.000</td><td colspan="2">3.000</td><td colspan="2">2.000</td></tr>
<tr><td>Max.</td><td>Micro Carbon Residue at 10% Residue (% m/m)</td><td>0.30</td><td colspan="2">0.30</td><td colspan="2">0.30</td><td colspan="2">-</td></tr>
<tr><td>Max.</td><td>Density at 15°C (kg/m3)</td><td>-</td><td colspan="2">890.0</td><td colspan="2">890.0</td><td colspan="2">900.0</td></tr>
<tr><td>Max.</td><td>Micro Carbon Residue (% m/m)</td><td>-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">0.30</td></tr>
<tr><td>Max.</td><td>Sulphur (% m/m)</td><td>1.00</td><td colspan="2">1.00</td><td colspan="2">1.00</td><td colspan="2">1.50</td></tr>
<tr><td>Max.</td><td>Water (% V/V)</td><td>-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">0.30</td></tr>
<tr><td>Max.</td><td>Total sediment by hot filtration (% m/m)</td><td>-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">0.10</td></tr>
<tr><td>Max.</td><td>Ash (% m/m)</td><td>0.010</td><td colspan="2">0.010</td><td colspan="2">0.010</td><td colspan="2">0.010</td></tr>
<tr><td>Min.</td><td>Flash point (°C)</td><td>43.0</td><td colspan="2">60.0</td><td colspan="2">60.0</td><td colspan="2">60.0</td></tr>
<tr><td>Max.</td><td>Pour point in Winter (°C)</td><td>-</td><td colspan="2">-6</td><td colspan="2">-6</td><td colspan="2">0</td></tr>
<tr><td>Max.</td><td>Pour point in Summer (°C)</td><td>-</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">6</td></tr>
<tr><td>Max.</td><td>Cloud point in Winter (°C)</td><td>-16</td><td colspan="2">Report</td><td colspan="2">Report</td><td colspan="2">-</td></tr>
<tr><td>Max.</td><td>Cloud point in Summer (°C)</td><td>-16</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td></tr>
<tr><td>Max.</td><td>Cold filter plugging point in Winter (°C)</td><td>-</td><td colspan="2">Report</td><td colspan="2">Report</td><td colspan="2">-</td></tr>
<tr><td>Max.</td><td>Cold filter plugging point in Summer (°C)</td><td>-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td></tr>
<tr><td>Min.</td><td>Calculated Cetane Index</td><td>45</td><td colspan="2">40</td><td colspan="2">40</td><td colspan="2">35</td></tr>
<tr><td>Max.</td><td>Acid Number (mgKOH/g)</td><td>0.5</td><td colspan="2">0.5</td><td colspan="2">0.5</td><td colspan="2">0.5</td></tr>
<tr><td>Max.</td><td>Oxidation stability (g/m³)</td><td>25</td><td colspan="2">25</td><td colspan="2">25</td><td colspan="2">25</td></tr>
<tr><td>Max.</td><td>Fatty acid methyl ester (FAME)</td><td>-</td><td>-</td><td>7.0</td><td>-</td><td>7.0</td><td>-</td><td>7.0</td></tr>
<tr><td>Max.</td><td>Lubricity, corrected wear scar diameter (wsd 1.4 at 60°C) (um)</td><td>520</td><td colspan="2">520</td><td colspan="2">520</td><td colspan="2">520</td></tr>
<tr><td>Max.</td><td>Hydrogen sulphide (mg/kg)</td><td>2.00</td><td colspan="2">2.00</td><td colspan="2">2.00</td><td colspan="2">2.00</td></tr>
<tr><td></td><td>Appearance</td><td colspan="5">Clear & Bright</td><td colspan="2">-</td></tr>
</table>

Characteristics and properties

Properties that are described in these notes include:

- Health and safety
- Ambient conditions
- Ash
- Carbon residue
- Cloud point
- Compatibility
- Density
- Flash point
- Ignition quality
- Pour point
- Specific energy
- Silicon and aluminium
- Sodium
- Sulphur
- Vanadium
- Viscosity
- Water
- Wax

Health and safety

M-notices

Attention is drawn to the following two M-notices:

MERCHANT SHIPPING NOTICE, MSN 1521

POSSIBLE HAZARDS TO SEAMEN FROM OILS USED ON SHIPS

The prevention of risks to the health and safety of a ship's crew is not only a **statutory duty** but also an essential part of the efficient running of a vessel. To provide information about health and safety on board ship the Department of Transport has published the "Code of Safe Working Practices for Merchant Seamen". The purpose of this notice is to draw the attention of Owners, Masters and Crews to the health hazards, which may arise from contact with some of the range of different oils used for fuel, lubrication and the operation of hydraulic systems on a ship.

In particular, Masters and Crew should be aware that materials such as residual fuel oil and used or spent engine oil contain substances (poly aromatic hydrocarbons, PAHs) which are known to be **carcinogenic (cancer causing)** and are therefore subject to the Control of Substances Hazardous to Health (COSHH) Regulations 1988 and more specifically the COSHH approved Code of Practice on the Control of Carcinogenic Substances. Although the COSHH Regulations do not extend to ships at sea, Masters should refer to guidance note EH58 "The Carcinogenicity of Mineral Oils" published by the Health and Safety Executive, which, if followed, will ensure that the safeguards recommended in the Code of Safe Working Practice for Merchant Seamen are met.

In addition to any carcinogenic effects, contact between oil and human skin may lead to a range of skin complaints ranging from mild irritation to severe oil acne. Thus contact must be avoided by the use of suitable precautionary measures such as barrier creams and protective clothing as recommended in the "Code of Safe Working Practices for Merchant Seamen". Advice on the safe handling of oils is given in the **product data sheets**, which the suppliers must supply with the materials (see "M" Notice No. 1520). Masters should ensure that the information on these sheets is available to all crewmembers who may come into contact with the materials.

Further information:

"The Carcinogenicity of Mineral Oils" Guidance Note EH58. Published by the Health and Safety Executive and available from HMSO.

"Code of Safe Working Practices for Seamen". Published by and available from HMSO.

MERCHANT SHIPPING NOTICE, MSN 1520

PROVISION OF PRODUCT DATA SHEETS

The prevention of risks to the health and safety of a ship's crew is not only a statutory duty but also an essential part of the efficient running of a vessel.

General advice and information about health and safety on board ship is given in the Department of Transport's publication **"Code of Safe Working Practices for Merchant Seamen".** However, more specific advice is frequently required to ensure that the wide range of materials and equipment supplied to ships are used in a correct and safe way. Therefore it is essential that suppliers of any materials or equipment for use on a vessel provide comprehensive data sheets and instructions.

It is a statutory requirement under the Health and Safety at Work Act 1974 and the Consumer Protection Act 1987 for suppliers to provide adequate information about the use for which a product is designed and any precautions which are necessary to ensure safety.

The purpose of this notice is to remind Owners, Agents and Masters of ships of their duty to ensure that product data sheets are provided by the suppliers of all goods delivered to a ship for use on board.

All product data and instruction sheets should be kept in a safe place and the information made available to all members of the ship's crew who use the materials.

March 1993

Protective clothing

Suitable protective clothing should be worn at all times when handling oils of any description, especially gloves and face masks.

MSDS for Diesel Fuel Oil

Diesel fuel MSDS states that the hazards may include: oil may cause drying out of skin or cause dermatitis and possibly skin cancer. The main hazards are to the eyes, skin and respiratory system causing irritation in small amounts but may be serious in larger quantities or exposure. Ingestion may lead to sickness, vomiting and diarrhea or intoxication of the brain or death in severe cases. Inhalation may cause dizziness, irritation to the nose or mouth, headache, loss of balance, coordination problems or even loss of consciousness.

First Aid. Eyes should be flushed with clean fresh water for 15 minutes. Skin – remove contaminated clothing wash with soap and water. For ingestion do not induce vomiting, do not give liquids and seek medical advice immediately. If inhaled move patient o fresh air admister CPR as necessary and give oxygen.

FIRE FIGHTING MEASURES Vapours can burn in open air or explode in confined spaces. Breathing apparatus will be necessary, class B fire extinguishers should be used on small fires, larger fires should use fixed systems of the CO_2, Spray foam or Hi-Fog type.

Ambient conditions

When studying performance data of engines care must be taken to check that the ambient conditions prevailing at the time the data was taken is also quoted. Engine performance data can be 'adjusted' to give more impressive results by quoting data at particular ambient conditions, and by using different quality fuels.

Ambient conditions have an effect on the specific fuel consumption of an engine.

There are three possible scenarios that could be quoted with ambient conditions:

1 The actual ambient conditions prevailing at the time;

2 Conversion to a manufacturers reference ambient condition;

3 Conversion to ISO reference ambient condition.

When comparing engine performance in different parts of the world the data should be converted to ISO reference ambient conditions to be meaningful.

Parameter	Units	Typical ambient condition	Manufacturers reference condition	ISO reference conditions
Inlet air temperature	deg C	16	20	27
Sea water temperature	deg C	10	15	27
Barometric pressure	mbar	1035	1013	1000
Humidity	%	40	40	60
Net specific energy	kJ/kg	38,600	42,900	42,00

Ash

Ash is defined as the products remaining after the combustible components of a fuel have been burnt. It is the products that do not burn.

This may include aluminium, calcium oxides, iron, lead, magnesium, nickel, silicon, sodium, quartz, zinc, vanadium etc.

The level of ash will depend upon three main factors:

1 The material naturally present in the oil;

2 The refinery processes used;

3 Contamination from sand, dirt and rust.

Typical levels are 0.03 % to 0.05% by mass. Levels greater than 0.2% will cause severe problems in engines as they may be abrasive.

Carbon residue

The carbon residue of a fuel is a measure of the formation of carbon deposits (coke) under high temperature conditions during the combustion process.

Carbon residue may be expressed in one of three ways, depending upon the test used to determine its value:

1 Ramsbottom carbon residue;

2 Conradson carbon residue (CCR);

3 Micro carbon residue (MCR).

Typical problems associated with carbon residues of more than 10% by mass include:

- Fouling of combustion spaces;
- Longer ignition delay times;
- Smokey exhaust emissions, especially at low loads;
- Formation of carbon ‘trumpets’ on fuel injector nozzles around the spray holes.

Cloud point

Cloud point is associated with distillate fuels and is applicable to ISO 8217 DMX.

The cloud point of a distillate fuel is the temperature at which wax starts to crystallise, and this is seen when the clear fuel becomes cloudy and opaque.

A test for cloud point would be visual.

Typical cloud point value for a DMX fuel is -16°C, which means that it can be used in temperatures above about -13°C.

Compatibility

Fuels can be described as compatible when there is no sludge formation when fuels from different sources are mixed.

Currently there is no guaranteed test for incompatibility. Two fuels with the same specification, but from different sources, may or may not be compatible.

The golden rule is:

The mixing and blending of fuels from different sources should be avoided as far as possible. This applies in particular to mixing bunkers.

Symptoms of incompatibility may be:

- Heavy **sludge** formation;
- **Stratification** (especially if the fuel is blended).

Stratification is where the fuel breaks down into its different densities and forms layers in the tank. Stratification may be accelerated by excessive tank heating, and can be delayed by lower tank temperatures. Formation of sludge can be partially controlled by chemical additives, but these can be expensive.

Density

The density of a fuel is its relationship between the mass of the fuel and its volume, at a stated reference temperature, commonly 15°C. Density is commonly measured in kg / m^3

Typical density for distillate fuel is 800 kg / m^3

Typical density for a residual fuel is 940 kg / m^3

Relative density is a measure of how much more (or less) dense the fuel is compared with pure fresh water. There are no units for relative density.

The density of water is taken as 1000 kg / m^3

Typical density for distillate fuel is 800.

Typical density for a residual fuel is 940.

Density varies with temperature.

Generally density will decrease by 0.64 kg / m3 per 1°C rise in temperature.

The formula for density correction to the reference temperature 15°C is:

Density at 15°C = density at T°C + (0.64 x (temperature T – 15))

Density is an important characteristic because:

- Density gives an indication of the specific energy of a fuel;
- Density gives an indication of the ignition quality of a fuel;
- If density is greater than 1000 kg / m3, there may be difficulty separating water in centrifugal separator (max density for conventional centrifugal separator is considered to be 991 kg / m^3).

Flash point

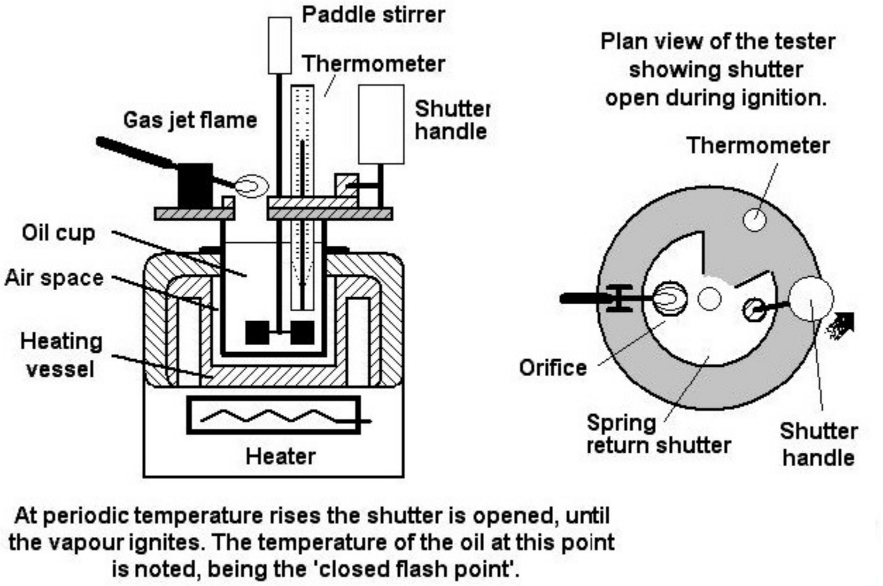
The flash point of a fuel is the lowest temperature at which vapour is given off to ignite on the application of a flame, under specified conditions.

There are two flash points:

The **closed flash point** (determined using the **Pensky-Marten apparatus**);

The **open flash point** (determined using the **Cleveland Open Cup apparatus**).

The closed flash point is generally used by the marine industry, as it is considered to be a safer value. The closed flash point can be 20 to 35 degrees C lower than the value obtained by the open flash point test.



Pensky-Marten apparatus

Important values to remember:

The minimum flash point for fuel used or stored in a main machinery space (governed by SOLAS) is 60°C

The minimum flash point for fuel used or stored outside a main machinery space (governed by SOLAS) is 43°C

Attention is drawn to the following extract from SOLAS:

SOLAS 1974, amendment 1, chapter 11-2, regulation 15

Arrangements for oil fuel, lubricating oil and other flammable oils.

Limitations in the use of oil as fuel

The following limitations shall apply to the use of oil as fuel:

Except as otherwise permitted by this paragraph, no oil fuel with a flashpoint of less than 60°C shall be used.

In emergency generators oil fuel with a flashpoint of not less than 43°C may be used.

Subject to such additional precautions as it may consider necessary and on condition that the ambient temperature of the space in which such oil fuel is stored or used shall not be allowed to rise to within 10°C below the flashpoint of the oil fuel, the Administration may permit the general use of oil fuel having a flashpoint of less than 60°C but not less than 43°C.

The flashpoint of oils shall be determined by an approved closed cup method.

Ignition quality

The ignition quality is a measure of how well a fuel will burn.

It is an important property as the purchase of fuel is one of the most significant costs for the operation of a vessel.

There are several methods or standards used for measuring ignition quality, most of them are based upon two properties:

1 Density

2 Viscosity

Ignition quality methods commonly used include:

1 Cetane Number;

2 Calculated Carbon Aromaticity Index (CCAI)

Cetane Number

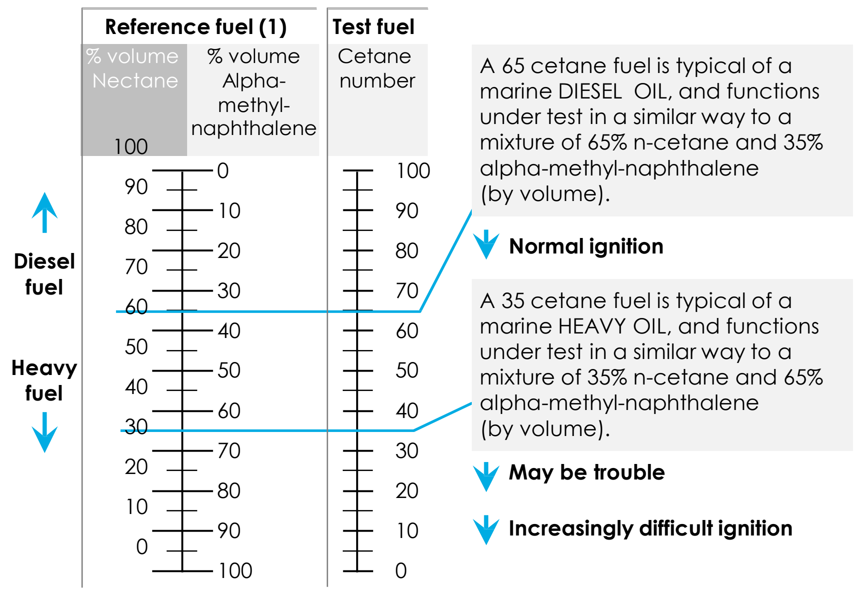
The Cetane Number for some distillate fuels is quoted in ISO 8217. Cetane is commonly quoted as a number between 0 and 100.

There are three methods of determining Cetane Number, which basically compares the combustion performance of the fuel being tested against that of a known special reference fuel, using a special test engine.

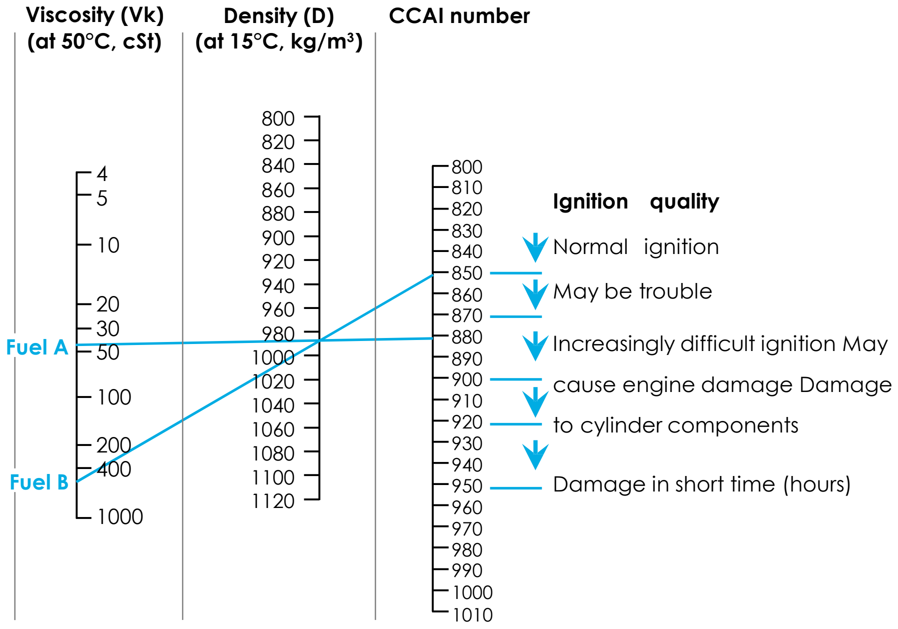
Typical Cetane Number (no units) values are:

- Distillate fuel, 65
- Residual fuel, 35

The Cetane Number may also be estimated by using a nomogram, as illustrated by the next table.



Cetane number nomogram


Viscosity (Vk) (at 50°C, cSt)
Density (D) (at 15°C, kg/m³)
CCAI number
Fuel A
Fuel B
4
5
10
20
30
50
100
200
400
1000
800
820
840
860
880
900
920
940
960
980
1000
1020
1040
1060
1080
1100
1120
800
810
820
830
840
850
860
870
880
890
900
910
920
930
940
950
960
970
980
990
1000
1010
Ignition quality
Normal ignition
May be trouble
Increasingly difficult ignition May
cause engine damage Damage
to cylinder components
Damage in short time (hours)

CCAI nomogram

The CCAI is determined by plotting the viscosity and density points of the fuel on the nomogram, joining the two points with a line, then extending the line to cut the CCAI scale. This gives the CCAI value.

Two example fuels, A and B, are shown, fuel A having a CCAI of 882 and fuel B having a CCAI of 850.

CCAI

The marine industry is tending to adopt CCAI as the standard for quoting ignition quality.

CCAI is a simple and sufficiently accurate means of calculating fuel ignition quality. It is a measure for carbon-aromaticity in relation to the ignition delay. It can be determined by the use of one of two formulae, or by using what is known as a nomogram. The formula used to calculate CCAI will give a number (no units) in the range of 760 to 870. The lower the number the better the ignition quality.

Pour point

The pour point is the lowest temperature at which fuel can be handled without excessive amounts of wax crystals forming. The figure quoted as the pour point is normally 3OC above the temperature that the fuel will gel, preventing flow.

Fuel storage temperature

Fuel should be stored at least 7°C above its pour point. Storing fuel above this temperature may not be cost effective.

If the temperature of a fuel has fallen below its pour point and has solidified, it may not be possible to reverse the solidification process and return the fuel to a liquid just by reheating.

Pour point can be controlled chemically by the use of **pour point depressants**. These can reduce pour point by up to 20°C.

Specific energy

Specific energy is a measure of the heat energy within a fuel that can be converted into useful work energy. It is measured in either kJ / kg or MJ / kg.

There are two forms of specific energy:

1 Gross specific energy (GSE);

2 Net specific energy (NSE).

The marine industry uses net specific energy when quoting values for fuel oils.

Note: With older, and now obsolete, systems of measurement, the specific energies were known as higher and lower calorific values (HCV and LCV). These terms are not SI terms and should not be used. They are not used in ISO 8217).

Net specific energy is calculated from a formula, and is affected by one property and four contaminants:

Property

1 The density of the fuel (the lower the density, the higher the NSE);

Contaminants

1 Water content (the higher the content, the lower the NSE);

2 Ash content (the higher the content, the lower the NSE);

3 Sulphur content (the higher the content, the lower the NSE).

Silicon and aluminium

The main source of aluminium and silicon (catalytic fines) is from the secondary refining process known as catalytic cracking (described earlier).

The catalytic fines are extremely abrasive (similar to the material used to make grinding stones) and are virtually impossible to remove, even by centrifugal separation, because of their size (4 to 8 microns).

The equipment most prone to damage includes:

- Cylinder liners and piston rings;
- Fuel pump plungers and barrels;
- Fuel injector nozzles and needles.

Sodium

The main sources of sodium are:

- Sodium naturally occurs in crude oil;
- Comes on-board with the bunkers, commonly from leaking tanks on bunker barges, or deliberately added to bunkers with sea water;
- Leaks from the sea into the vessel bunker tanks, that are frequently double bottoms.

Sodium on its own is relatively harmless. If sodium is present with other elements, in particular vanadium and sulphur, at certain proportions it can lead to severe corrosion.

The most critical combination is when sodium is present with vanadium in a **ratio of 1:2**. Sodium vanadates are formed which cause hot corrosion. If **vanadium pentoxide** is formed, and sulphur is present, it acts as a catalyst in the formation of sulphuric acid.

Sulphur

Sulphur occurs naturally in crude oil and may be present at levels of up to 5% by mass. Sulphur contributes to corrosion. It is during and after the combustion process that the effects of sulphur are most noticeable.

The severity of the effects of sulphur depend upon:

- The temperature in relation to the dew point (the temperature at which water will condense at the prevailing ambient conditions);
- The presence of vanadium pentoxide;
- The presence of water.

Sulphuric acid

The process of formation of sulphuric acid is not a simple one:

1 In the combustion process sulphur is first oxidised to **sulphur dioxide.**

Sulphur + oxygen = sulphur dioxide

$$S + O_2 = S\,O_2$$

2 Some of the sulphur dioxide is further oxidised to **sulphur trioxide.**

Sulphur dioxide + oxygen = sulphur trioxide

$$S\,O_2 + \text{oxidation} = S\,O_3$$

3 The amount of sulphur trioxide formed depends upon the quantity of excess air and the presence of vanadium pentoxide (a catalyst).

Vanadium pentoxide ($V_2\,O_5$)

S O_2 >>>>>>>>>>>>>>>>>>>>>>>>>>>>> S O_3

Sulphur trioxide is not corrosive, but it is an atmospheric pollutant.

4 In the presence of water sulphur trioxide condenses to form sulphuric acid, which is highly corrosive. This reaction only happens at temperatures below the dew point.

Sulphur trioxide + water = sulphuric acid

$$S\,O_3 + H_2\,O = H_2\,S\,O_4$$

NOx and SOx formation in the Internal Combustion process

Sulphur oxides

SOx (Sulphur dioxide) is the Sulphur Oxides chemical compound with the formula SO_2. SO_2 is produced by various industrial processes. Since coal and petroleum contain sulphur compounds, their combustion generates sulphur dioxide. Further oxidation of SO_2, usually in the presence of a catalyst such as NO_2, forms H_2SO_4, and thus acid rain. This is one of the causes for concern over the environmental impact of the use of these fuels as power sources.

The combustion process is started by heating the fuel above its ignition temperature in the presence of oxygen. Under the influence of heat, the chemical bonds of the fuel are split. If complete combustion takes place, the elements carbon (C), hydrogen (H) and sulphur (S) react with the oxygen content of the air to form carbon dioxide CO_2, water vapour H_2O and sulphur dioxide SO_2 and, to a lesser degree, sulphur trioxide SO_3

Nitrogen oxides

NOx is a generic term for mono-nitrogen oxides (NO and NO_2). These oxides are produced during Nitrogen Oxides combustion, especially combustion at high temperatures. At ambient temperatures, the oxygen and nitrogen gases in air will not react with each other. In an internal combustion engine, combustion of a mixture of air and fuel produces combustion temperatures high enough to drive endothermic reactions between atmospheric nitrogen and oxygen in the flame, yielding various oxides of nitrogen.

Low temperature corrosion

Low temperature corrosion is caused by sulphuric acid, and also known as **cold corrosion.**

Damage commonly occurs in:

- Piston rings;
- Cylinder liners;
- Piston ring grooves;
- Turbocharger casings;
- Exhaust valve stems (just below the valve guide);
- Exhaust systems.

Vanadium

Vanadium occurs naturally in crude oil.

Vanadium on its own is relative harmless, but as seen already in combination with sodium and sulphur can cause severe corrosion.

High temperature corrosion

Also known as **hot corrosion**. Corrosive vanadium ashes formed during combustion have relatively low melting points, some around 525OC, and cause hot corrosion. These ashes are sticky and deposit on exhaust valve seats. The ashes react with and dissolve protective layers of ferric oxide on the valve seats, exposing the underlying steel to oxidation followed by erosion by exhaust gases. This leads to what is known as a burnt valve.

Viscosity

Viscosity is a measure of the resistance of a liquid to flow, and is normally quoted at a specific reference temperature. Viscosity changes with temperature. As temperature rises, viscosity decreases.

The reference temperature (ISO 8217) for distillate fuels is 40°C.

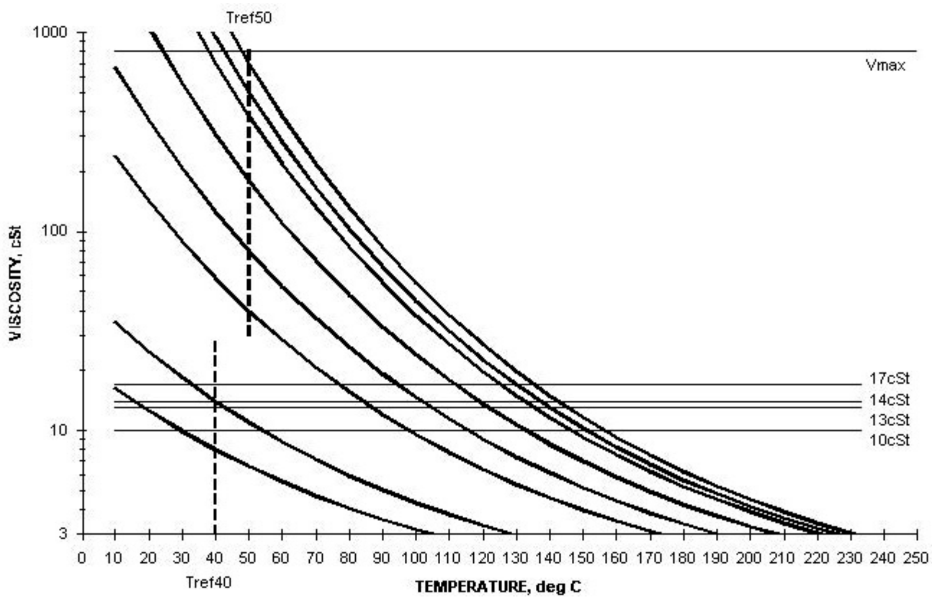
There are two forms of viscosity:

- Dynamic viscosity, measured in centipoises (cP);
- **Kinematic viscosity, measured in centistokes (cSt).**

Engineers tend to use kinematic viscosity, but normally just call it viscosity.

Viscosity-temperature

Viscosity-temperature graphs for different grades of fuel would appear as shown below. The graphs normally are drawn with a log scale for viscosity.



Viscosity-temperature curves of typical fuels.

Importance of viscosity

Viscosity is an important parameter because:

- Fuel is used as a lubricant in some equipment, (fuel pumps, fuel injectors) if the viscosity is not correct the lubrication film will not be established.
- Fuel oil viscosity governs the volumetric efficiency of high pressure fuel injection pumps, that must be kept within close limits. If the viscosity is not correct the fuel will not flow into the fuel pump in the very short time available.
- Ignition timing is affected to some extent by viscosity.
- The cleaning process of centrifugal separators is very dependent on the viscosity being within certain limits.

Condensation in tanks;

- Leaks from steam or hot water heaters.

Source of sale water may include:

- Delivered with bunkers;
- Leaks in the hull;
- Salt laden atmosphere;
- Leaking air vent pipes.

- If the fuel viscosity is not correct at atomisation there will be poor penetration resulting in poor combustion.
- Incorrect may make fuels difficult to pump or transfer. The maximum viscosity for effective pumping is about 800 cSt.

Viscosity scales

There were other viscosity scales traditionally used:

- Redwood (UK);
- Saybolt (USA)
- Engler (Europe)

With the SI system these scales are now considered obsolete.

Fuel injection viscosity

Irrespective of the make or design of the engine, or the fuel used, all fuel injection equipment is designed to operate between very narrow bands of viscosity. The actual viscosity required depends upon the speed of the engine, but all engines fall into an overall viscosity band limit of 10 to 17 cSt.

If the fuel cannot meet the viscosity at the ambient temperature then it has to be heated to ensure the viscosity is correct at injection.

Wax

There are two types of wax generally present in fuels:

- Paraffin wax;
- Micro-crystalline wax.

The micro-crystalline waxes have a very small crystal structure that forms with reduced temperature. These crystals seed the fuel ready for solidification by the paraffin wax as the temperature drops further.

Bio -Diesel

Bio Diesel is a replacement fuel which in the UK is mostly manufactured from feedstocks of recycled cooking oils or a blend of other renewable and recyclable materials - including animal fats and plant oils.

Biodiesel manufacturing process converts these oils and fats into a long chain molecules and these are referred to as *Fatty Acid Methyl Esters* more commonly referred to as FAME.

ISO 8217 and BS 2869 refers to an allowable limit of 7%

Advantages:

- Cheaper
- Environmentally popular due to recycling
- Zero Sulphur content
- Reduced CO_2 and CO_1 emissions
- Higher flashpoint

Disadvantages:

- Lower Calorific Value
- Retains water more readily than hydro carbon distillate fuel (corrosion, and MBC growth)
- Has a limited shelf – life, up to 6 months
- Added chemicals may cause compatibility problems
- Increase NO_x levels
- Some reports of damage to fuel pumps and injectors

SECTION 8 – Fuel Hygiene & Treatment

Fuel treatment

Fuels require treatment before being introduced to the engine.

This may involve one or more cleaning processes including:

- Storage;
- Gravity separation;
- Filtration;
- Centrifugal separators;
- Chemical.

The basic functions of the separation (cleaning) process are:

1 Separating solid particles from the oil;

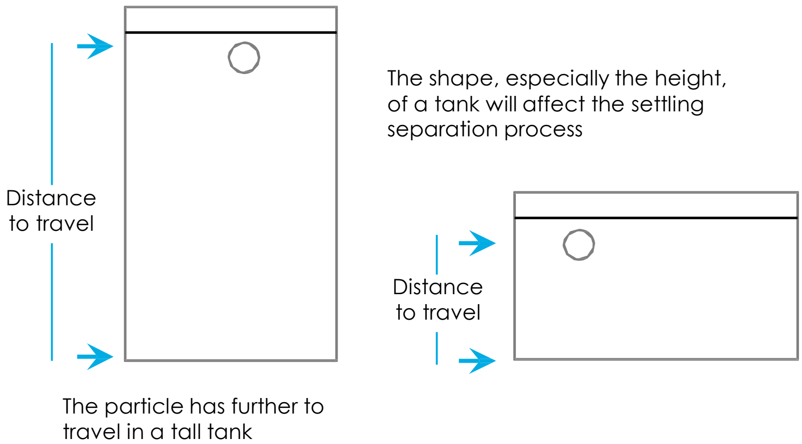
2 Separating sludge particles from the oil;

3 Separating water from the oil.

The following factors influence the separation process:

- Time available for the process
- Particle density, mass, size and surface resistance;
- Fluid temperature, viscosity and density;
- Distance travelled;
- Volume of oil to be treated (throughput);
- Degree of separation quality required;
- Cost of process

Distance travelled



Gravity separation

As a first step of the fuel cleaning process fuels are left in **settling tanks** over periods of time, where separation by gravity takes place. This first step is very basic, low cost and is meant to remove excessive water, sludge and sediment.

The time necessary for settlement depends on:

- the quantity and type of impurities present;
- the geometry and physical dimensions of the tank;
- the degree of cleaning sophistication that follows.

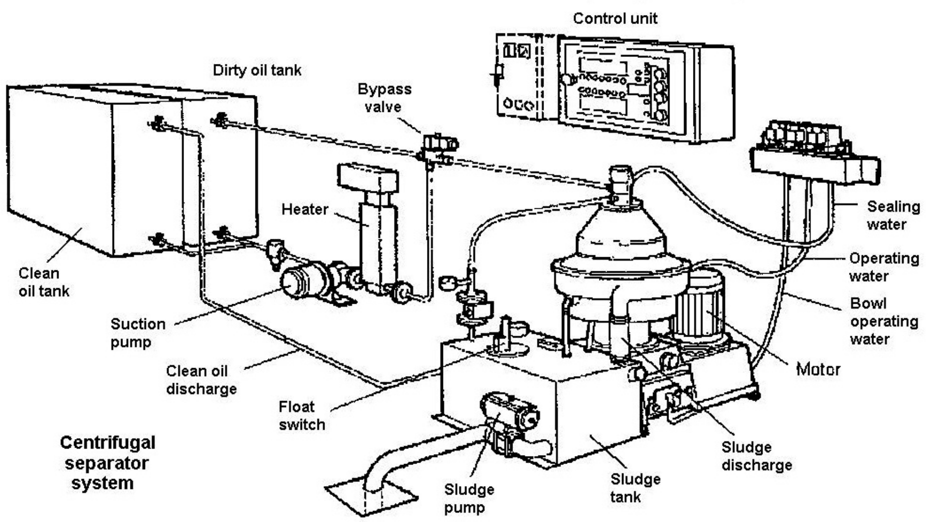
Settling tanks are provided on board, their size being proportional to anticipated fuel consumption. 24 hours is an average time and in some cases more than one settling tank may be provided. The settling process can be accelerated by the use of heaters fitted inside the settling tank.

Centrifugal separator

The **centrifugal separator** is used for higher volume cleaning of oils. The centrifugal separator may just be called a **separator**, or sometimes a **centrifuge**. The name is derived from the fact that it uses centrifugal force to accelerate the cleaning process.

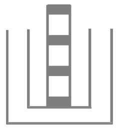
A separating force several thousand times greater than that of gravity is produced.

The centrifugal separator can be used for treating both fuel oils and lubricating oils.

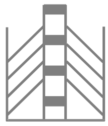


Typical centrifugal separator arrangement

Graphical symbols

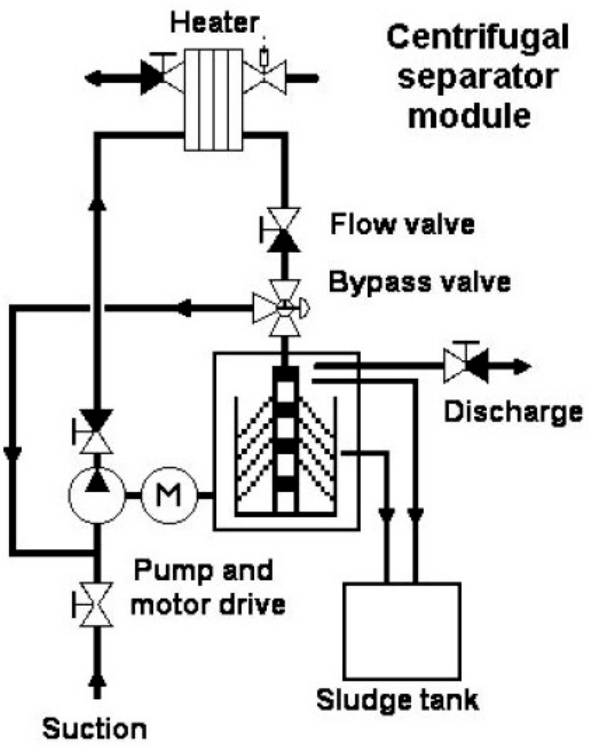


General symbol for a centrifugal separator



Symbol for a disc type centrifugal separator

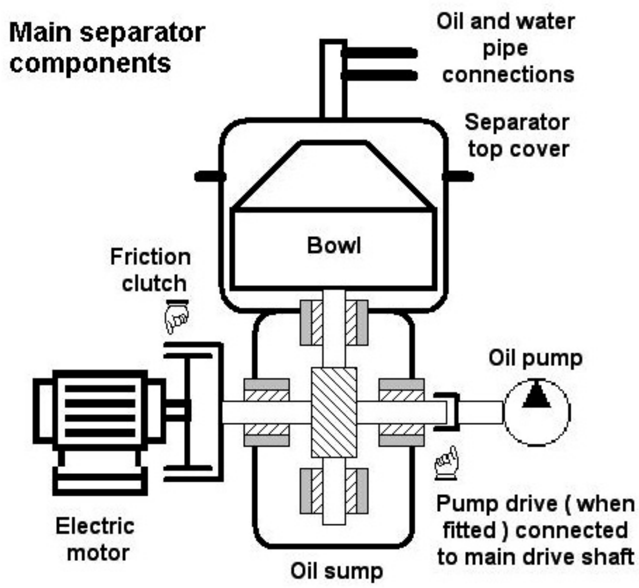
Separator module



The separator module comprises:

- The suction from the settling tank or storage tank;
- The drive motor (that may be common to the separator and pump, or the pump may have its own drive motor);
- The circulating pump;
- The heater (this is not commonly found on yachts);
- Flow control valve;
- The bypass valve;
- The separator;
- The sludge tank;
- The discharge to the service tank (or day tank).

Separator drive



The electric motor drives a horizontal shaft via a friction clutch.

The horizontal shaft is fitted with a gear wheel and worm to convert horizontal rotation to vertical rotation and also to increase the speed of the vertical shaft.

The bowl is mounted on the top of the vertical shaft with a taper and locknut. The locknut has a left-hand thread to prevent it undoing itself during operation.

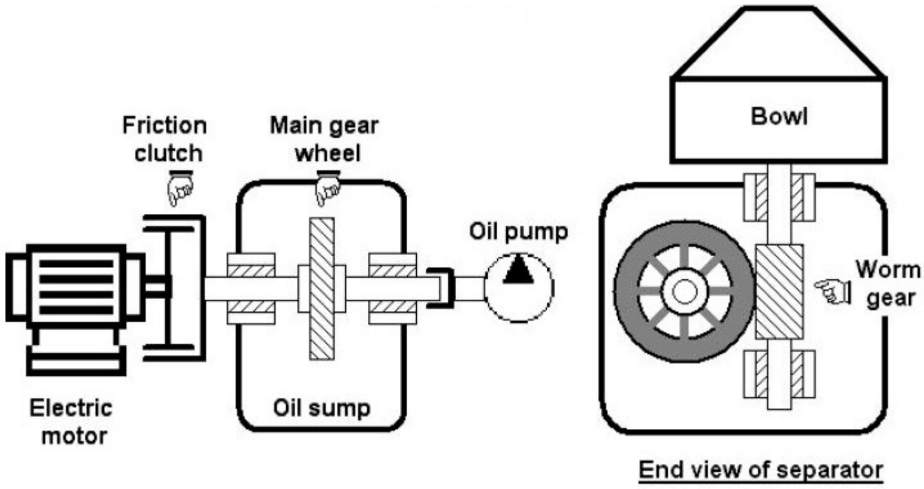
The main gear wheel is commonly made of a yellow metal, or softer material than the worm gear, which is commonly made of case hardened steel.

This is a safety feature, so that in the event of a failure, such as a bearing seizing, the worm gear will strip the teeth of the softer main gear wheel.

As a further safety device the main wheel is secured to the horizontal shaft by a tapered shear pin, designed to fracture in the event of any seizure or overload of the machine. Only the specially manufacturers designed shear pins should be used in the fitting.

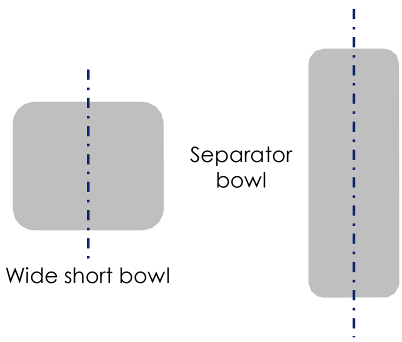
The speed of rotation varies according to design, but is in the range of 7,000 to 10,000 revs/min.

The positive displacement gear type oil pump is often driven off the end of the main horizontal shaft, again often secured to the shaft by a special shear pin.



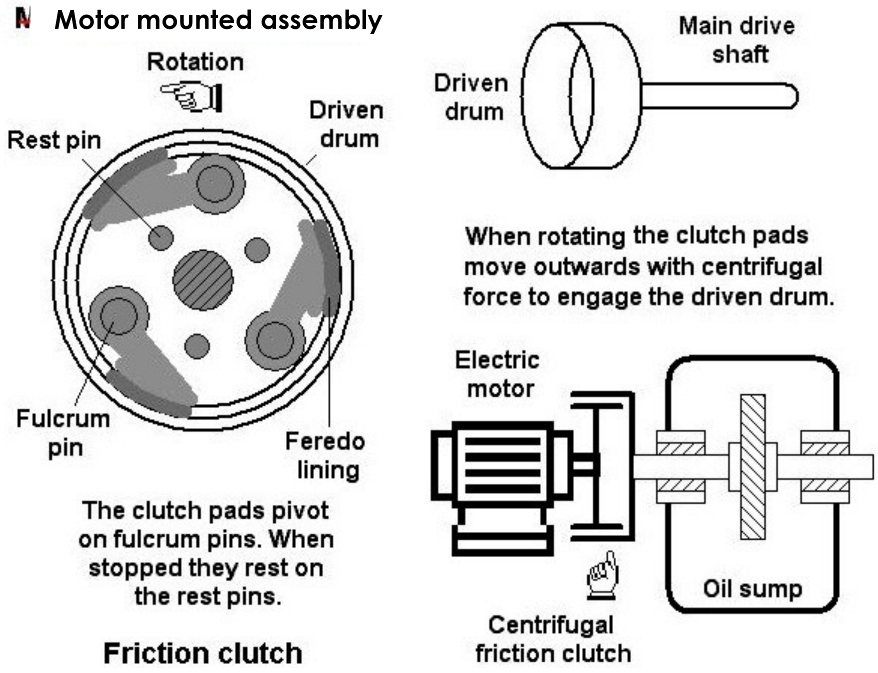
Separator drive assembly

Bowl diameter



The bowl diameter is determined by the required centrifugal force.
A wide short bowl gives an equivalent centrifugal force as a narrow long bowl, but at a much lower speed.
The wide short bowl shape is used in most separator designs in service today.

Friction clutch



The friction clutch is an important safety feature of the separator and has the following functions:

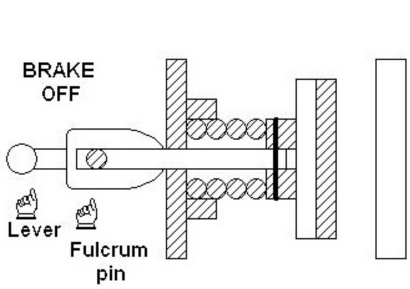
- To reduce the electrical starting load of the machine. The clutch is designed to slip on start up, gradually increasing the drive load as the speed builds. The mass of the bowl assembly creates a very high load on start up.
- If there is any form of mechanical obstruction or bearing failure the clutch will slip to reduce the load on the electric motor, reducing the risk of severe machinery damage.

The mineral fibre pads on the friction clutch are susceptible to damage from contamination by leaks of the oil passing through the separator. If this is the case the clutch will slip and the separator will not reach its full speed.

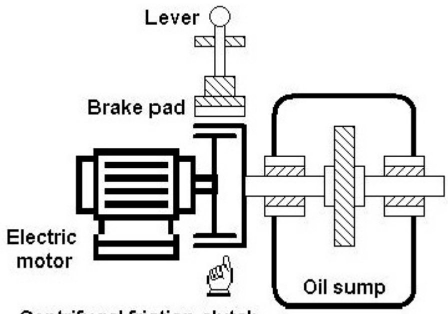
Separator brake

The driven drum on the main horizontal drive shaft is fitted with a brake. The brake is operated manually by a lever on a cam. The brake is applied to help slow down the separator when stopping.

A common operation mistake is to forget to take the brake off before starting the separator!

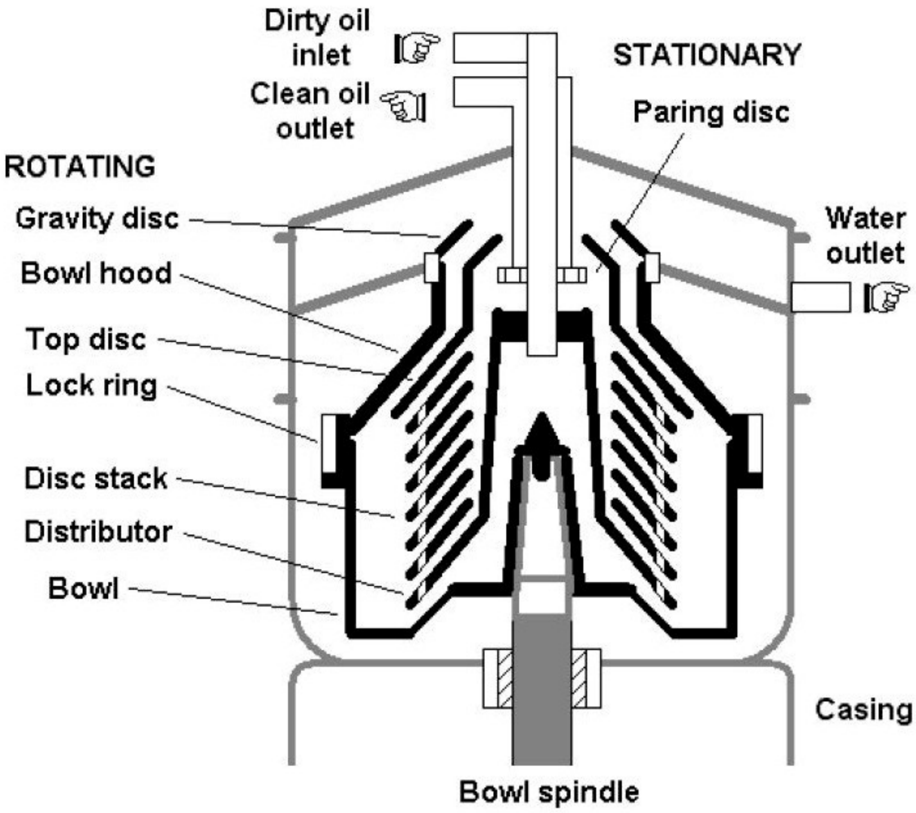


Separator brake



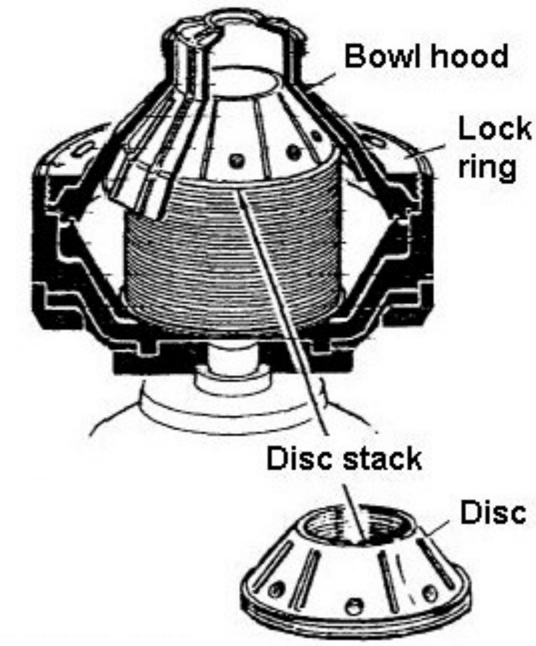
Centrifugal friction clutch

Separator bowl assembly



Section of upper separator

Disc stack



Separator bowl and disc stack

The discs are commonly made of an aluminium alloy.
They have 6 to 8 radial holes equally spaced near the bottom edge, and vertically pressed indentations.
The vertical indentations form the distance spacing between the discs.
The distance between each disc is about 0.6 to 0.6 mm.
The discs are numbered, and when taken apart for cleaning must be reassembled in the original order.
The disc stack is finely balanced and will cause vibration if not assembled correctly. The number of discs varies depending upon design, and varies between 30 and 150 discs.
On some modern small separators found on yachts the discs are made from plastic.

Purifier, clarifier

The separator can be set up to operate in one of two modes:

d As a **purifier**

A purifier will remove solids, sludge and water.

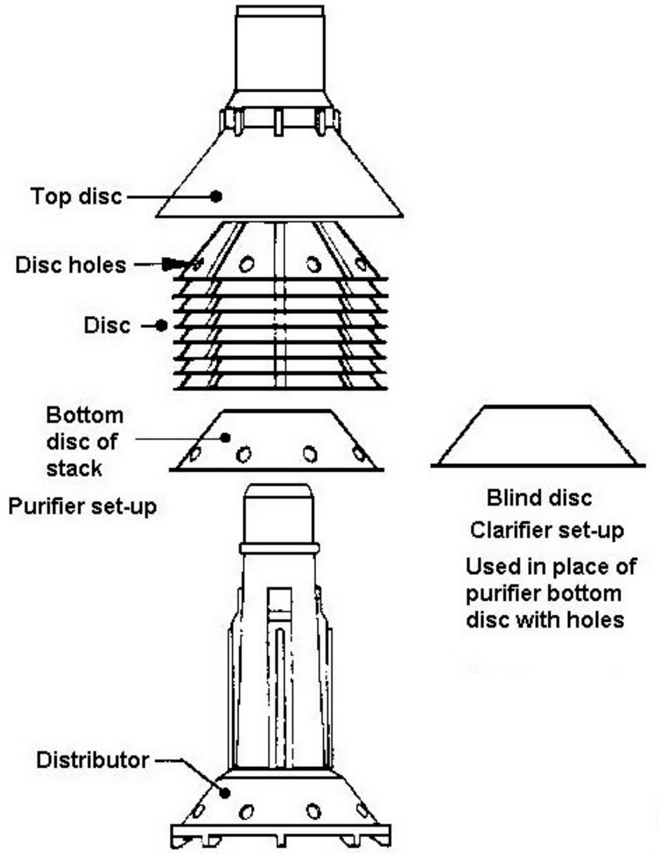
e As a **clarifier**

A clarifier will remove solids only.

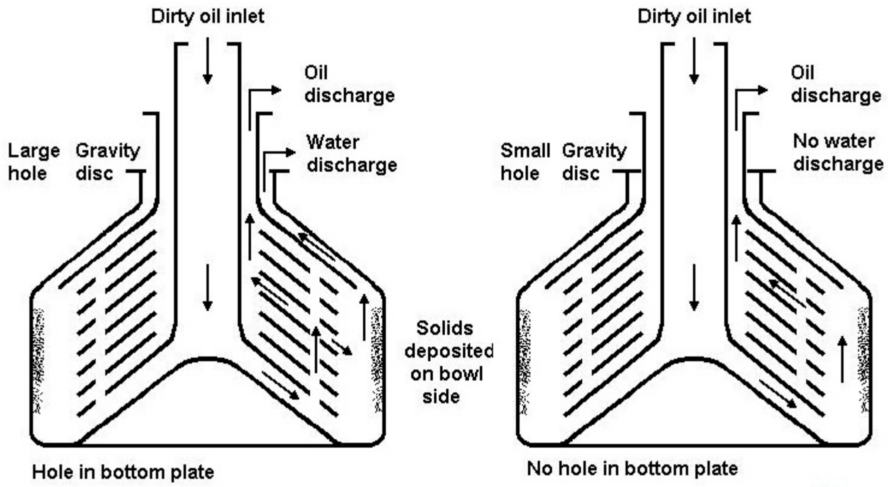
There are two differences with the arrangement of the separator if is set up as either a purifier or a clarifier:

1 The purifier is fitted with a gravity disc. The clarifier is fitted with a special disc in place of the gravity disc;

2 The bottom disc of the plate stack of a purifier has radial holes. The bottom disc of a clarifier is known as a blind disc, it has no radial holes.



Purifier and clarifier disc stack arrangement



Purifier arrangement

Clarifier arrangement

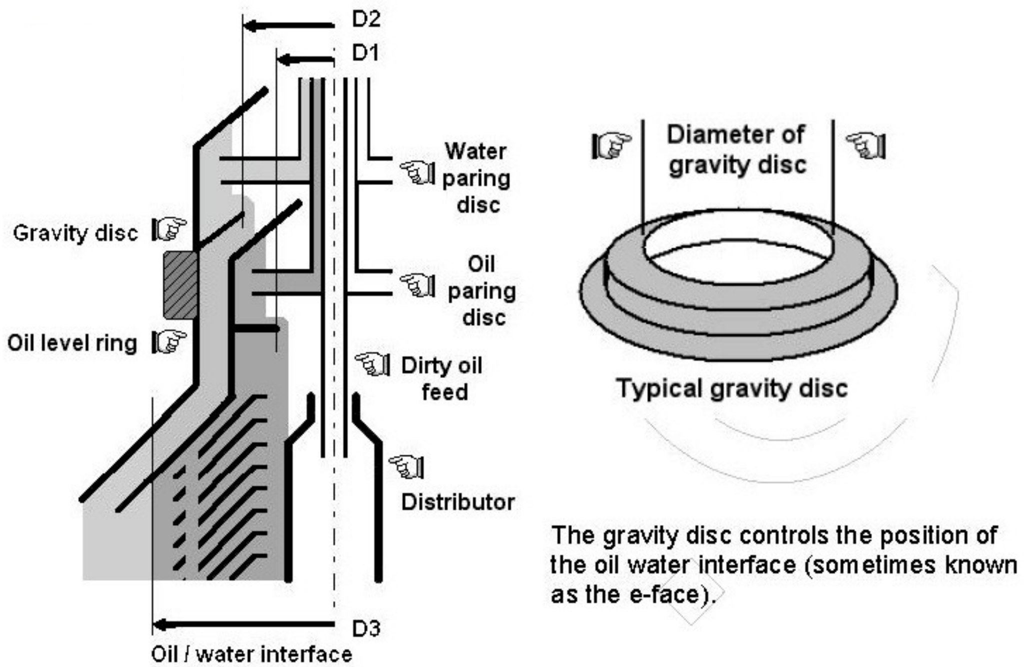
Purifier process

- The bowl is rotating at high speed. Sealing water is put in the bowl to form the outer seal. Water is run into the bowl until it spills out the water discharge.
- The dirty oil is allowed to enter centrally down the middle feed pipe. The oil is thrown outwards at the bottom by centrifugal force, until it arrives at the disc stack radial holes. The dirty oil rises up through the holes.
- Solid particles are thrown outwards by centrifugal force and collect on the side of the bowl.
- Any water present also is thrown outwards and passes upwards to the water discharge.
- Clean oil particles move inwards by the difference in density and passes upwards to the oil discharge.

Clarifier process

- The dirty oil is allowed to enter centrally down the middle feed pipe. The oil is thrown outwards at the bottom by centrifugal force, until it arrives at the outer edge of the disc stack. The dirty oil rises upwards.
- Solid particles are thrown outwards and collect on the side of the bowl.
- Clean oil particles move inwards by the difference in density and passes upwards to the oil discharge.

Gravity disc



Location of gravity disc

The gravity disc controls the position of the oil water interface (sometimes known as the e-face).

Each separator will be supplied with a set of gravity discs. The size of a gravity disc is measured by the diameter of the central hole.

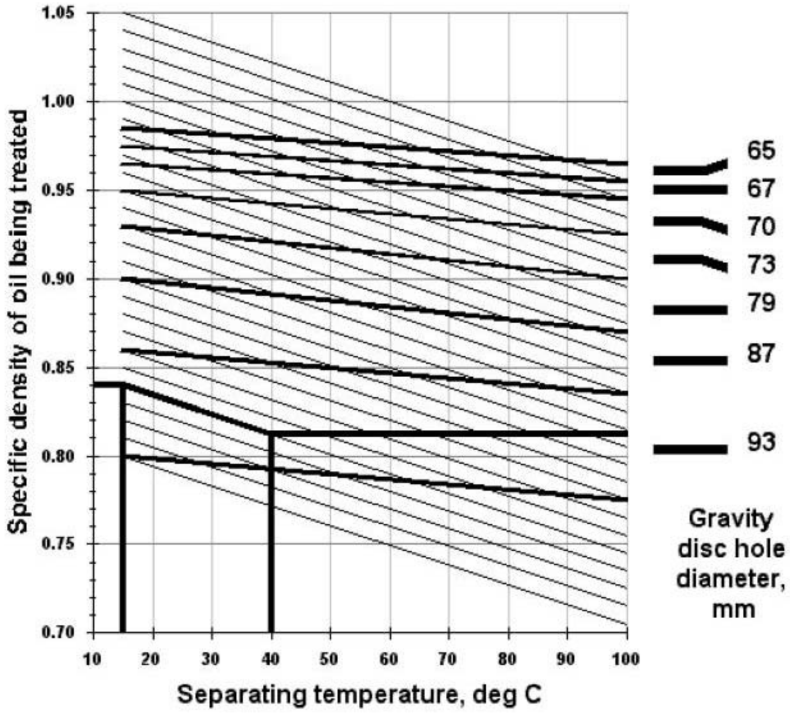
A typical set of gravity discs would be 65, 67, 70, 73, 79, 87 and 93 mm diameter (central holes).

The gravity disc size is calculated and depends upon:

- The type and diameter of separator being used;
- The specific density of the oil being treated;
- The temperature of separation.

The calculation is traditionally done using a nomogram type calculator.

The example plot shows an oil of 0.84 specific density at 15°C, with a separation temperature of 40°C. The gravity disc diameter required is 93 mm.



Gravity disc calculator

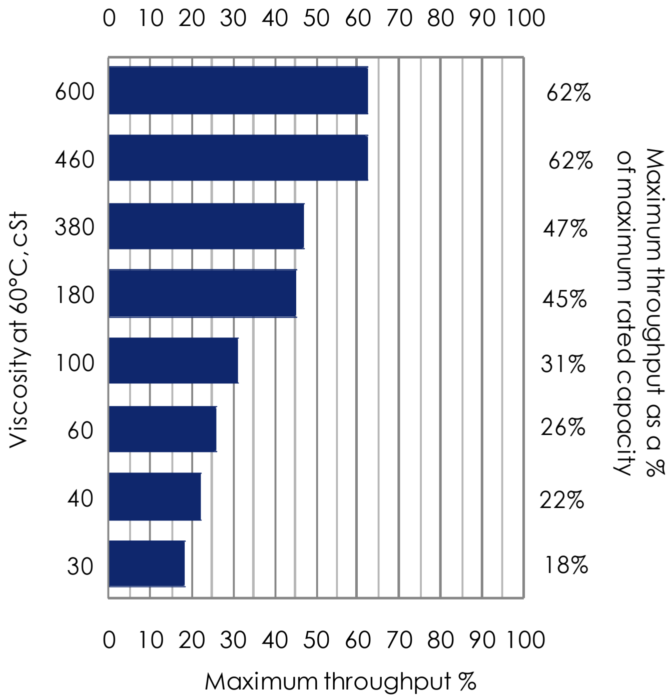
Centrifugal Separator efficiency and timed cleaning cycles.

FOUR factors that affect centrifugal oil separator efficiency are:

1. Speed of rotation of the centrifuge
2. The temperature of the liquids to be separated - affecting their viscosity
3. Any contaminants such as detergent will reduce the separation efficiency
4. The flow - rate through the separator

Oil loss may occur with the accumulated sludge / dirt discharge on the timed sludge clean. This can be minimised by reducing the cleaning cycle periodicity or displacing the oil with water where possible. The condition of the oil will usually determine the frequency of cleaning cycles.

Separator operation, throughput

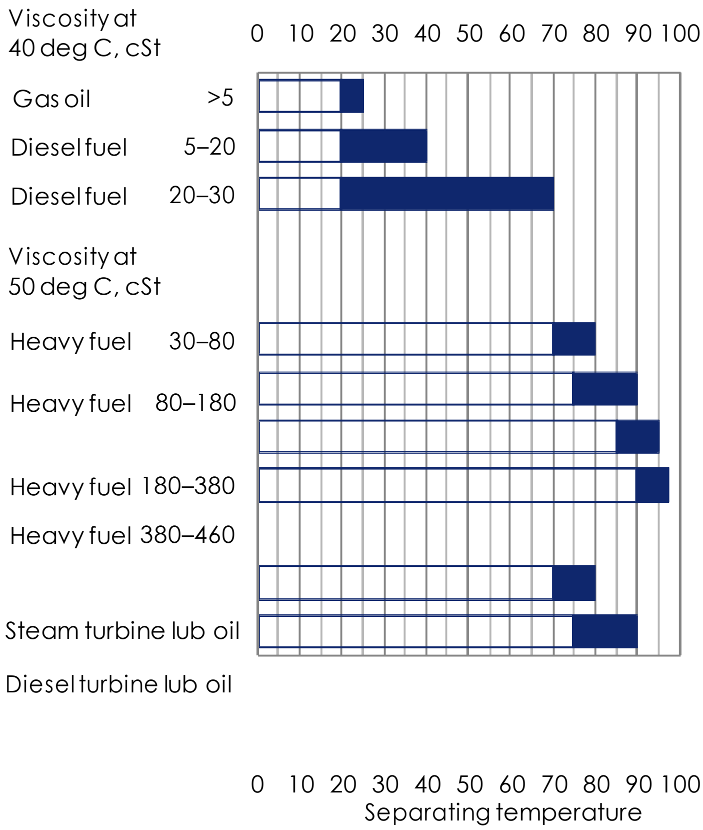


Separator throughput

The maximum throughput of a fuel separator is based upon the normal running power per hour of the main engine, together with any other auxiliary engines using fuel, such as alternators.
An engine manufacturer will recommend a value, such as 0.05 litres / kW.hour.
The actual throughput of the separator used in service will also be determined by:

- The demand for fuel;
- The fuel characteristics, especially viscosity;
- The amount of dirt and/or water in the fuel.

2 Separator operation, temperature

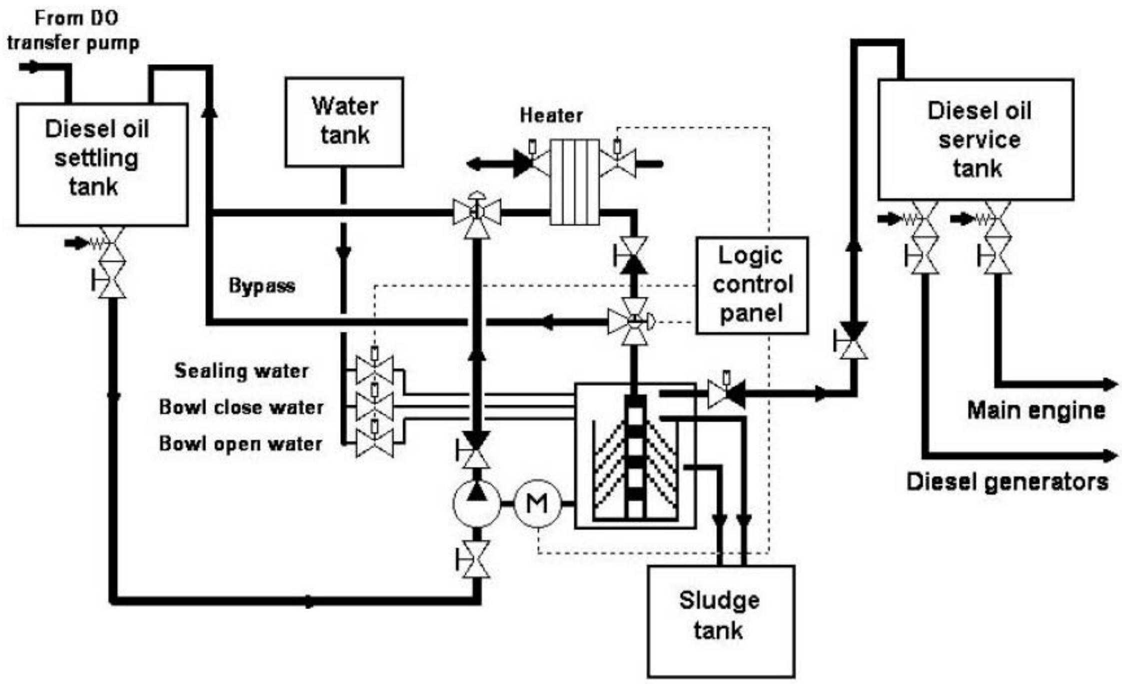


Separating temperature

The separating temperature is a critical factor in the separation process as it determines the viscosity of the separation.
The temperature is normally controlled using an automatic controller.
The separation temperature in service will be determined by:

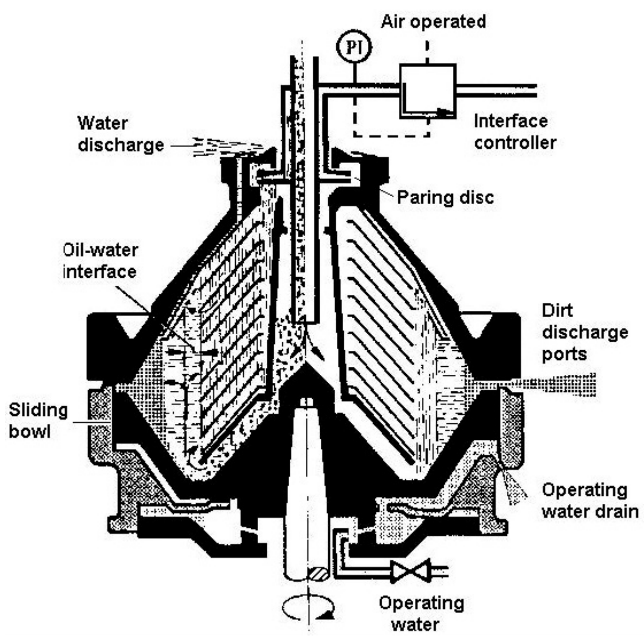
- The type and grade of fuel;
- The fuel characteristics, especially viscosity.

DO separator system



Fully automated self cleaning DO separator system

Self cleaning separator



Modern separators are designed to be self cleaning.

This is achieved with a sliding bowl held in place during operation by water pressure from operating water.

The sliding bowl is periodically opened by releasing the water pressure under the sliding bowl.

The bowl drops opening ports on the periphery.

Dirt is discharged from the bowl through the ports.

The bowl is then closed again using water pressure.

Self cleaning separator with interface control

The automatic cleaning action is carried out by opening the centrifuge bowl and discharging the excess mailer using the centrifugal forces set up by the high running speed of the centrifuge. This operation is carried out by a logic control which, uses:

- A timer to govern the time period.
- A control valve to operate the fuel and water (seal) valves.
- The opening and closing of the centrifuge bowl is carried out by water pressure created by the centrifugal forces created by the purifier bowl.

Separator operation safety

It is important that close attention be given to the assembly of the bowl.

The internal parts have locators to avoid being assembled in any way to distort its dynamic balance. Some left hand threads are used and all parts must be handled with care and according to the manufacturers' instructions.

The centrifugal forces imposed on the spindle by any out of balance forces has been known to fracture the spindle, leaving a heavy spinning bowl out of control, causing friction and instability of the purifier.

A centrifuge in an unattended engine room is fitted with vibration sensors which will shut the machine down should vibration exceed pre-set limits.

Centrifuges are often positioned in a separate room within the engine room. This room is considered to be an area of high fire risk. Near the door of this room and clearly marked, there will be a method of:

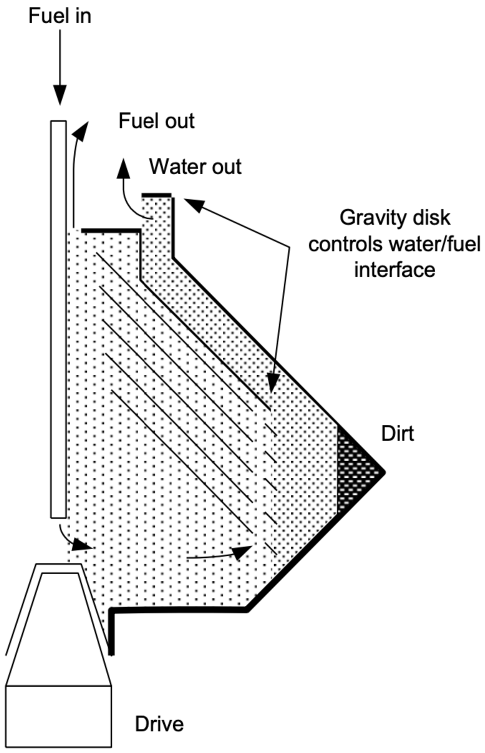
- Shutting down all purifiers and oil supplies.
- Shutting down all forced ventilation to the separator room.
- Extinguishing a fire (foam fire extinguisher).

Separator checks

- Feel the temperature of the electric motor driving the purifier and take note of the current being drawn.
- Check the purifier sump level and top as required. Take care that the gauge glass is giving a true reading, and not stained with oil.
- Place your hand on the purifier casing, to check for vibration.
- Check the speed of rotation using the spinner on the side of the sump casing.
- Check the water discharge for signs of oil carry-over.
- Look for any leaks or abnormalities.

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, most machines today can discharge the bowl contents while the centrifuge is running

The Coalescer Filter

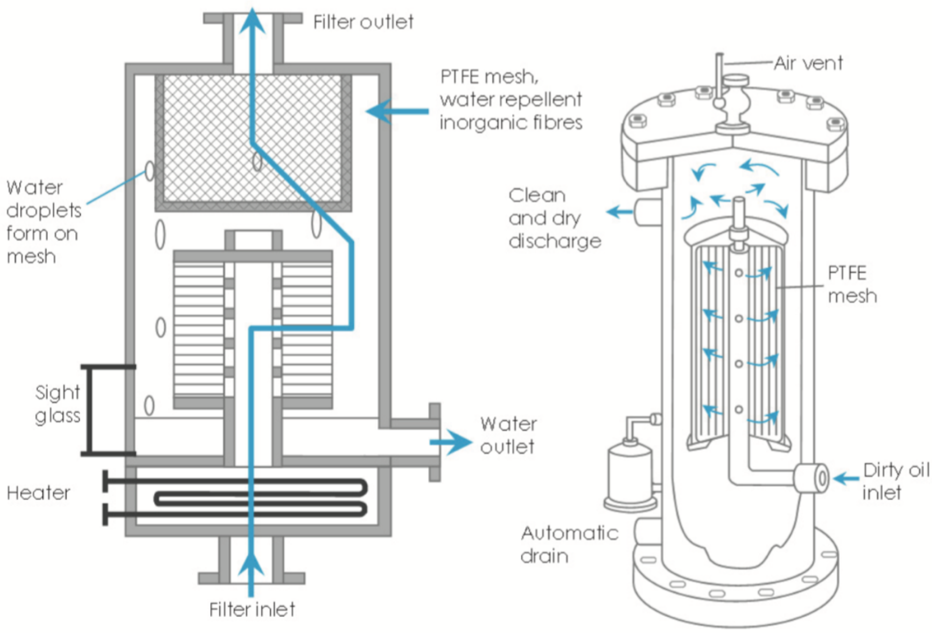
The coalescent filter not only removes solid particles, but also water. **Coalesce** means "to unite to form one mass".

The special filter mesh is coated with PTFE (polytetrafluoroethylene). PTFE has a very low coefficient of friction.

The coalescent action is relatively complex, but briefly it relies upon the fact that the molecular attraction between the water droplets and the PTFE mesh is greater than between the oil and the PTFE mesh. As a consequence any water forms as droplets on the PTFE mesh. When large enough the water droplets fall to the bottom of the filter unit, from where it can be drained off.

A two-stage process takes place in the filter cartridge, which is a single replaceable unit. The fuel flows radially outwards through the cartridge, first through a pleated inner element then through the outer coalescer stage. The inner element removes solid particles from the fuel and protects the outer part of the filter from excessive quantities of contaminants.

Manufacturers claim that these filters can remove up to 99% water and solids down to 3 microns, but this depends upon the rate of flow through the filter and the amount of water present. 2 variations of the filter are shown below.



Coalescent filter

Fuel contamination

Fuel contamination can be caused by;

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

Dirt

Dirt can get into the tank from dirty fuel taken when bunkering. It is difficult to prevent this as the receiver has very limited means of knowing if the fuel is clean or dirty when being loaded.

Dirt can get in by negligence, through filling lines, vent pipes and open inspection doors.

Effective filtration of fuel prior to use in the engine/s is necessary. In new vessels there is a possibility that the tanks may not be thoroughly cleaned prior to commissioning, resulting in dirty tanks. Ensure the tanks are thoroughly cleaned.

Water

Water can exist in fuel in one of three states:

a Free water

In this case the water will normally settle out in storage tanks, from where it can be separated by pumping or gravity draining.

b Suspended water

Normally found in lesser quantities in the form of suspended droplets. This from is more difficult to separate, except by settling tanks or centrifugal separators.

c Emulsion

Water in an emulsified oil is difficult to separate, but may be possible with chemical treatment or centrifugal separation.

The water may be either fresh or salt.

Source of fresh water may include:

- Delivered with bunkers;
- Centrifugal separator malfunction

Microbiological degradation

Microbiological growths in the marine industry are not a new phenomenon. Instead, they are such a common occurrence that we often forget they can be extremely detrimental to equipment and operating processes. They can present a severe limitation to effective energy utilisation, be a source of high maintenance costs, and can necessitate early equipment replacement. Few of the extremely serious corrosion problems in internal ship's fuel systems from microbiological attack are not noticed until they are almost out of control.

The **light and medium grades of marine fuels are particularly susceptible** to microbiological growths simply because these fuels provide a ready source of food. In many instances these petroleum products contain a small amount of moisture that is required for microbiological growth processes to occur.

The primary types of growths encountered in fuels are:

- bacteria,
- fungi or moulds,
- certain types of yeasts.

All of these are possible contaminants but the most common are of the bacterial and fungal types. These organisms are extremely small and can be easily transported from one location to another by air, soil, water, and other carriers. Microbial contaminants, for example, can be introduced into the fuel storage tanks via air vents that allow the tanks to "breathe." In other instances water leakage can inoculate a fuel system. With so many sources of infestation, it is imperative that an initial approach toward controlling fouling is to keep the storage tanks as clean and sterile as possible.

As fuels are produced in a refining process, they are usually sterile. Contamination with micro-organisms normally occurs during storage at the refinery, when the oil is transported to shore side distribution facilities or kept in fuel tanks on vessels.

Many biological life forms have a dormant stage in which they are called spores. Generally, spores that contaminate a fuel are inactive as long as there is no water present. This is true despite the presence of massive amounts of **nutrients such as carbon, hydrogen, nitrogen, phosphorus and sulphur** that may surround them. On the other hand, even very small amounts of moisture trigger activity, and growth commences in astronomical proportions. Sources of moisture include humidity, condensation, leakage and fuel washing processes.

Organisms normally live at the interface between the water and the fuel. The growth rate of micro-organisms increases in direct proportion to increases in the system temperature. Thus, the fuel gives an almost limitless source of food and moisture in one form or another plus the warm temperatures in the system complete the optimum growth environment.

It is important to kill microbial growths as soon as they are detected. At the same time, it is important to maintain sterilized conditions by good housekeeping practices and periodic biocidal shock treatments.

Many bacteria grow **aerobically** which require oxygen to sustain life. Others are **anaerobic** which can live and grow in the absence of air. The aerobic bacteria consume the organic material which, in this case, is the fuel, and they absorb dissolved oxygen from their surroundings. The anaerobic organisms, however, grow where there is no air beneath the interface surface of the fuel and water or on the tank bottom. These unique organisms utilize the sulphate constituents of the fuel as their food source. It is possible to have both the aerobic and anaerobic bacteria thriving together and each contributing to the overall deposit formation within the same tank.

These bacteria usually function in a **temperature range of 30–40°C** at neutral pH levels. However, they have been found to survive exposure to temperatures as high as the boiling point of water, 100°C, for several hours, or as low as -195°C, the temperature of liquid nitrogen. The spores, or dormant state of these organisms, can resist desiccation or complete dryness for years, and in some cases they have been restored to active life after as long as ten years in suspended animation.

Fungi, also called moulds, are microscopic plants which are not differentiated into roots, stems, and leaves. Various immature fungal species are seen as yellow and green colonies

Fungal contamination usually can be identified by its characteristic black, brown and green colours and its slimy or fibrous nature. These deposits can be found suspended at the fuel-water interface, on the tank bottom, plugging filters or centrifuges, and even in heating coils and in fuel injectors.

Yeasts are the third type of micro-organisms encountered in fuel systems. Like the fungi, they prefer a slight to moderately acidic environment in which to grow.

Problems in a marine fuel system.

- Deposits
- Corrosion
- Water emulsification
- Energy loss

The first line of defence against microbiological contamination is **good housekeeping**. Tanks should be kept as dry as possible and inspected at frequent intervals to make certain that there are no accumulations of biological material. Water ingress to the fuel system onboard a vessel should receive immediate attention.

From a mechanical standpoint, passing fuels through high quality filters is an excellent way of eliminating the transport of microbes from one area to another within a system, especially if the filters are frequently cleaned or replaced, depending on their type. Many systems are fitted with a fuel separator or purifier. Centrifuging equipment can remove water, suspended materials, and most but not all of the microbial contaminants.

As for the chemical aspects of good housekeeping, the application of an effective biocide is an extremely useful tool.

The most useful biocide for a fuel is one that is toxic to all of the micro-organisms normally encountered and is "dispersible or soluble in water". Generally, a biocide treatment, to be most effective, must be dosed intermittently on a "shock" basis rather than continually. The most beneficial shock method procedure is the dosing of the biocide during each fuel bunkering operation.

Approximately 100-200 ppm (1-2 litre) per 10 tons of fuel will be adequate for all but severely contaminated systems.

There are many conditions that can be found in the fuel storage and handling systems that are signs of system contamination.

Some of these indicators are:

- Objectionable odours, such as a "rotten egg" smell (hydrogen sulphide)
- Discoloration or blackening of copper bearing metals
- Necessity for unscheduled filter changes or cleanings
- Presence of green, black, or brown slimes or fibrous sludge in the fuel tanks, in lines, or on filters
- Evidence of corrosion, especially under deposits on tank bottoms

Fuel testing

The delivery note normally specifies the:

- Type of fuel,
- Amount of fuel,
- Viscosity,
- Specific density,
- Flash point,
- Water content.

Trouble frequently results from inferior fuels and there can be insufficient information to give warning. Fuel grading schemes and delivery notes that are more detailed are being used. Some of the Classification Societies and specialist firms provide testing services and on-board testing equipment is available.

Samples

A representative sample is needed to give an accurate test result and this is difficult to obtain unless a properly situated test cock is fitted in the bunker manifold where flow is turbulent. The sample is taken after flushing the test cock. Because of the variation in heavy fuel, small quantities are taken into the test container over the period of bunkering, to give a representative sample.

A full analysis can be given by the shore laboratory.

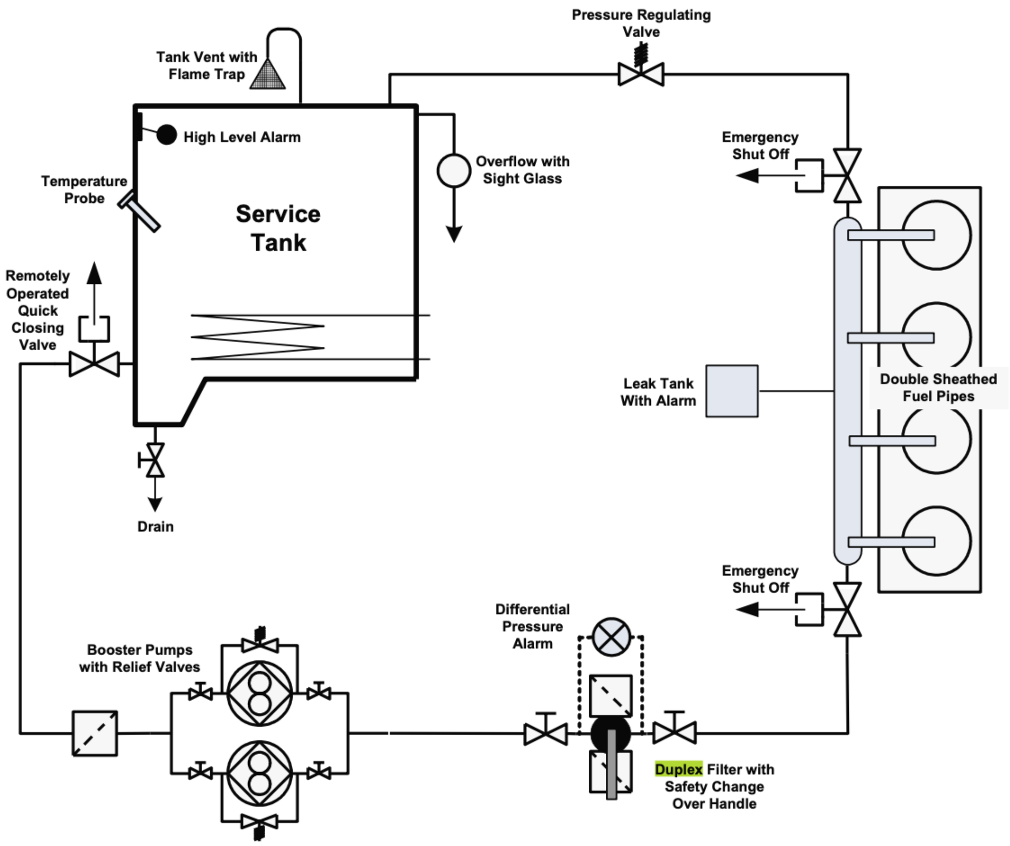
On-board tests

On-board tests are limited to those that give reliable results. Kits for specific gravity, viscosity, pour point, water content and compatibility are on the market. Flash point is found with a Pensky-Martin closed cup apparatus that is carried on some (deep-sea) ships. Water is a common contaminant of fuels particularly on board v essels. Prior to being used, fuels on board are treated for water removal through centrifugation.

Fuel system

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

Safety Devices fitted to a Distilate (Diesel) Fuel Supply System



Components of a fuel system

The main safety components of a fuel system include:

- Storage tank vents and flame trap
- Quick closing valves
- Overfill spill back line
- High fuel temperature
- High fuel pressure

Fuel tanks

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

Their function is storage of the fuel or as a daily service tanks topped up from the storage tanks. The tanks shall be provided with a manhole or hand hole to enable the tank to be cleaned and inspected.

Each tank needs to have ventilation pipe/s of a size to prevent generation of pressure in the tank.

Tank fittings

Vent pipe

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

The purpose of the vent pipe is to:

- allow the air and vapours to escape when the tank is being filled so it is not pressurised;
- allow air into the tank when fuel is being consumed so that a partial vacuum is not created in the tank resulting in stopping the engine; and
- allow normal expansion and contraction of the fuel due to temperature change.

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

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

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

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

Water

Water can accumulate in the tank:

- by coming with the fuel supply;
- condensation due to the level in the tank being kept low for a lengthy period;
- through the deck fitting due to it not being secured or being holed and rain or a wave entering; and
- being mistaken for a water tank and getting accidentally filled with water.

Filling pipe

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

Drain valve

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

Fuel contents gauge

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

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

Inspection opening

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

Baffle

They are fitted inside the tanks to prevent free surface effect. Free surface effect affects the stability of the vessel and in extreme cases can cause a vessel to capsize.

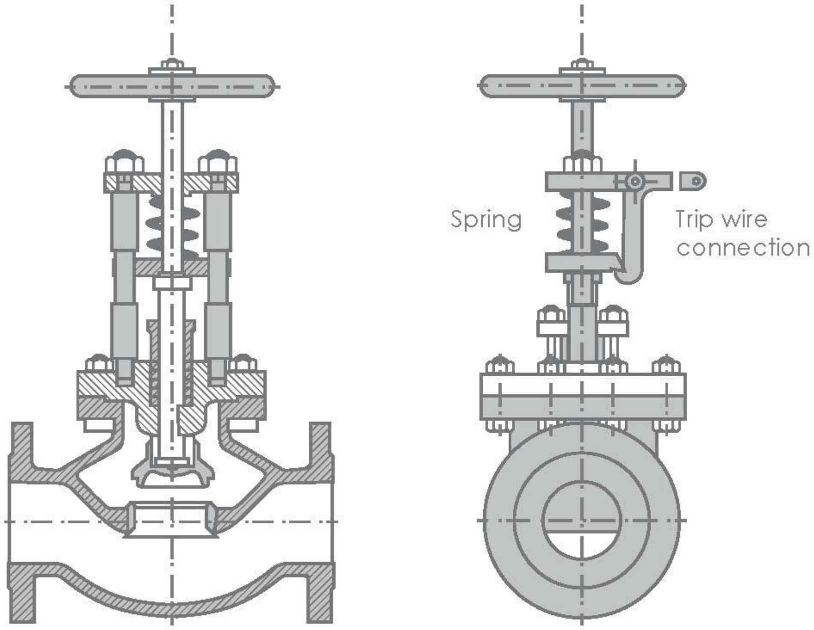
Safety devices — shut down

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

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

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

4 Emergency fuel shut off



Quick closing valve

This is fitted to allow the fuel to be shut off from outside the engine room in the case of an emergency.

It is fitted in the main fuel line. It cannot be fitted after any flexible fuel line.

These valves are also referred to as quick closing or collapsible valves.

System fittings

Filter/water trap

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

Sometimes additional filters are fitted to the system.

Fuel return

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

Fuel lift pump

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

Fuel transfer pumps

To assist in drawing fuel from the tank/s a fuel transfer pump is fitted between the tank/s and the fuel injection pump. Fuel transfer pumps are also commonly referred to as transfer, lift and charge pumps.

Pumps are used for transferring fuel between tanks. There may be a separate pump to supply fuel at pressure to the engines. Stop valves are to be provided on the suction and delivery sides of power operated pumps.

If the closed discharge pressure exceeds the maximum design pressure of the system a relief valve discharging back to the suction side of the pump shall be fitted.

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

Transfer pumps are of the positive displacement type, and will commonly be one of the following:

- Diaphragm type transfer pump
- Gear type transfer pump
- Vane type transfer pump
- Screw type transfer pump

SECTION 9 – Lubrication

Lubricants

Lubricants are hydrocarbon mineral oils derived from crude oil. The lubricating oil used in diesel engines has a high quality **base stock** to supply the lubricating oil film. Appropriate chemicals (**additives**) are added for particular applications, such as use as cylinder oil and engine oil. The base stock carries and distributes the chemical additives within the oil and provides a heat transfer medium, cooling the pistons and bearings, and sealing the clearance spaces between the piston rings and the cylinder walls.

Lubricant = base stock + additives

Lubricant states

A lubricant can exist as:

- A solid (graphite);
- A semi-solid (grease);
- A liquid;
- A vapour or gas.

Base stock

The base stock is normally not one type of oil but rather a blend of oils that meet the viscosity standards required by its use. Generally, a high viscosity neutral distillate is preferable.

The base stock has 3 major qualities:

a High thermal stability, which means the oil film will not carbonize in the hot areas of the cylinder

b High oxidation stability, which means the oil will not react readily with oxygen;

c Low volatility, which means the oil will not vaporize at the high temperatures encountered in the engine.

Additives.

Diesel engines require special lubricating oil, because of the diesel fuel and the higher pressures and therefore temperatures in the cylinder, compared to a petrol engine.

Additives are therefore used to assist the oil in performing its duties and also in overcoming contamination problems.

Listed below are some additives and why they are used:

Alkalinity reserve

For acid neutralization. The products of combustion form CO2 and SO2, which, in the presence of water, form an acid. The alkaline quality of the oil neutralizes this acid formation.

Anti-oxidants or oxidation inhibitors

Oxidation is the degradation of oil with age and is accelerated with high temperatures. **Anti - Oxidants** are used to prevent varnish and sludge accumulations on engine parts. They also prevent corrosion of alloy bearings.

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

Anti-corrosives, corrosion preventative or catalyst poisons

To prevent failure of alloy bearings and other metal surfaces by corrosive attack.

Inhibits oxidation so that no acidic bodies are formed or enables a protective film to form on bearings or other metal surfaces. Chemical film formation on metal surfaces decreases catalytic oxidation of the oil.

Detergents

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

Dispersants

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

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

Extreme pressure (EP) agents

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

Rust preventative

To prevent rust in new and overhauled engines during storage or shipment.

Preferential wetting of metal surfaces through added adhesives.

Pour point depressant

Pour point depressants, to lower pour points of lubricating oils.

Wax crystals in oil coated to prevent growth and oil absorption at reduced temperatures.

Viscosity index improves

To lower the rate of change of viscosity with temperature.

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

Foam inhibitors

To prevent formation of stable foam.

Enables foam to break up quickly and disappear.

Correct type and grade of oil

The engine manufacturers in conjunction with the oil companies work together to select or produce a lubricating oil that is suitable for a particular engine. They take into account the operating conditions and the contamination problems that could arise.

It is therefore essential that the correct type and grade of oil be used to prolong the engine's life.

General considerations

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

- Lubricating quality
- High heat resistance
- Control of contaminants

Colour and Odour

Most lubricant colors are naturally influenced by the color of the crude base-oil stock and its additive package. For example, when molybdenum disulphide (MoS2) is added in any quantity, it can significantly darken the lubricant. Manufacturers may, add colours to their respective lubricants to help identify different brands. Oil ages in service and it will deplete through contamination, heat, and oxidation. This causes a natural darkening in color. This clue should not be the indicator that the oil needs changing.

Clean fresh oil should be almost odourless, it may possess a slightly earthy or musty smell but is quite distinctive. Any unusual smells should be an indicator that some thing is wrong. The oil could be suffering from:

- Old age
- Oxididation
- Contamination (fuel / diesel MBC / Sulphur)
- Overheating (burnt smell)
- Bacteria (stench)
- Amino acids (fish smell)
- Esters / polymers (synthetic oil) – perfumed
- Nitro compounds (almonds)

Lubricating quality

The reduction of friction and wear by maintaining an oil film between moving parts is the primary requisite of a lubricant. **Film thickness and its ability to prevent metal-to-metal contact of moving parts is related to oil viscosity.**

High heat resistance

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

Functions and purposes of a lubricant

- To separate entirely the working surfaces to reduce friction (**lubrication**).
- To carry away heat (**cooling**).
- The protection of metals against corrosion.
- The cleaning of metals and carrying away carbon deposits (**cleaning**).
- To reduce or dampen noise.
- To act as a sealant (**sealing**).

Lubricant properties

Viscosity

This is a measure of an oils thickness or resistance to flow. This property changes with a change in temperature. The viscosity is reduced as the temperature increases. **It is important as this determines the ability of the oil to produce the required thickness under hydrodynamic lubrication. If the oil is to thin then a wedge may not be produced.**

The viscosity can be tested onboard by the use of a flowstick – this utilises two grooves that allow the sample oil and the reference oil to run down a tilted mechanism (at the same temperature) at a set angle. There is a reference point at the mid-point for the new oil indicating its suitability.

Viscosity is affected by temperature, contamination (fuel, water, dirt) emulsification and age.

Viscosity index

The viscosity index is a measure of the rate of change of viscosity with a change in temperature. Viscosity index is indicated by the gradient of the viscosity-temperature curve. Normally used for lubricating oils only.

The viscosity of an oil decreases with a rise in temperatures but to a varying degree depending on the type of crude, from which it is derived and the treatment it has undergone.

Alkalinity

The sump LO of a diesel engine is normally maintained in an alkaline state to counteract the acidic nature of contaminants from combustion that enter the oil via blowpast (worn rings or liner).

The alkalinity is measured as the **Base Number [BN]**. (Previously known as the Total Base Number [TBN]).

The engine manufacturer will recommend the correct BN for the LO of an engine, this is commonly determined by the sulphur content of the fuel being burnt. The higher the sulphur content of the fuel, the greater the BN.

	Typical BN
Less than 1% sulphur	**2 to 3 ***
1% to 1.5% sulphur	5 to 6
Greater than 2. 5% sulphur	12 to 15

Anti-foaming

All oils foam when agitated and in high detergent oils this foam could be persistent thus building up in an oil system. This can be prevented by adding an anti-foam agent.

Detergency

This is a measure of the cleaning ability of the oil. Detergent oils are used in diesel engines to prevent the build up of carbon.

Lubricating quality

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SECTION 10 – Lubricating Oil Systems

Lubrication and engine systems

Metal surfaces moving in close relationship with each other, pistons and cylinders for example, must be lubricated or they will become overheated through friction, fuse together and seize up. Oil is the lubricant that is used to prevent this happening by maintaining a film between the moving metal at all times that the engine is running. The oil takes up the shape of a wedge which as the engine speed increases, becomes more powerful and the bearing surfaces are forced apart.

Oil or grease?

Whether an oil or grease is most suitable as a lubricant for a particular is job is often decided by the working conditions.

Oil lubrication

Advantages

- LO reduces friction more than grease (i.e. it is a better lubricant).
- LO is more suitable for higher speeds, shaft loads and temperatures than grease.
- LO has the ability to carry away heat (i.e. act as a coolant).

Limitations or disadvantages

- LO needs a more complex housing design to supply and remove the oil.
- LO needs a pumping system.
- LO bearing housings need a more complex sealing arrangement.

Grease lubrication

Advantages

- Grease is relatively lower cost than LO.
- Grease is easier to apply than oil.
- Grease stays where it is put and thus protects against corrosion when the machinery is at rest.
- Grease can be used to lubricate objects which are inaccessible and that must operate with infrequent attention.

Limitations or disadvantages

- Grease is not be suitable for bearings running at a high temperature or speed.

Summary

LO is a more reliable lubricant than grease and is essential where high shaft speeds are used. Grease is more convenient and protects equipment from the elements.

Trunk piston engine LO requirements

The trunk piston type engine requires that the oil provide the following protective services:

- Alkalinity
- Detergency

- Thermal stability
- Oxygen stability
- Load carrying ability
- Anti-rust
- Water separation ability
- Anti-foam characteristics

The additional characteristic of oil is its load carrying ability. Because of the side thrust of the piston against the cylinder wall, the oil film must remain to deter metal- to-metal contact.

LO contaminants

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

Listed below are some causes of contamination:

Fuel dilution

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

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

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

Combustion products

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

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

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

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

Fresh or salt water leakage from cooling systems

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

Fresh water can also enter the sump from leaking water jackets, cracked cylinder heads or liners, faulty cylinder liner seals ("0" rings), loose cylinder head or a blown head gasket from a cylinder to a cooling water passage and the water could leak into the sump when the engine is stopped.

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

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

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

Fresh water contamination of the lubricating oil will result in an increased level on the dipstick and a drop in the fresh water level in the header tank.

Indications of a leak in the tube of the cooler cooled with sea water can be seen in oil being discharged overboard with the sea water cooling whilst the engine is running.

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

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

Dust and metallic particles from wear

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

It may deposit and/or form a sludge.

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

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

Catalytic Fines (Aluminium and Silicon) –very abraisive

Sand (Abraision)

Vanadium and Sodium (Hot Corrosion)

Microbial Contamination (Blockages and may become acidic)

Wear metals

Although classed as wear metals, not all the elements are actually metals.

The table below shows the 22 elements commonly monitored by laboratory analysis, and their most likely source:

Element	Typical source	Element	Typical source
Aluminium	Wear	Molybdenum	Wear
Barium	Additive	Nickel	Additive
Boron	Contaminant	Phosphorous	Additive
Cadmium	Additive	Silicon	Contaminant
Calcium	Contaminant	Silver	Contaminant
Chromium	Wear	Sodium	Contaminant
Copper	Wear	Sulphur	Contaminant
Iron	Wear	Tin	Wear
Lead	Wear	Titanium	Wear
Magnesium	Additive	Vanadium	Contaminant
Maganese	Wear	Zinc	Additive

Note that some of these elements have several sources, e.g. iron may come from engine wear, or from fuel contamination.

LO analysis

Regular laboratory analysis of the oil should be carried out, especially when a centrifugal separator is fitted and periodic oil changes do not take place.

The oil sample tendered for analysis should be taken from the circulation system, preferably while the engine is running, so that it is a true representation of the oil. If this is not possible, it should be taken as soon as the engine is stopped.

An analysis will give valuable information as to:

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

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

Onboard Analysis of Lubricating Oil

The general condition of Lubricating oil can be established by some simple onboard tests such as:

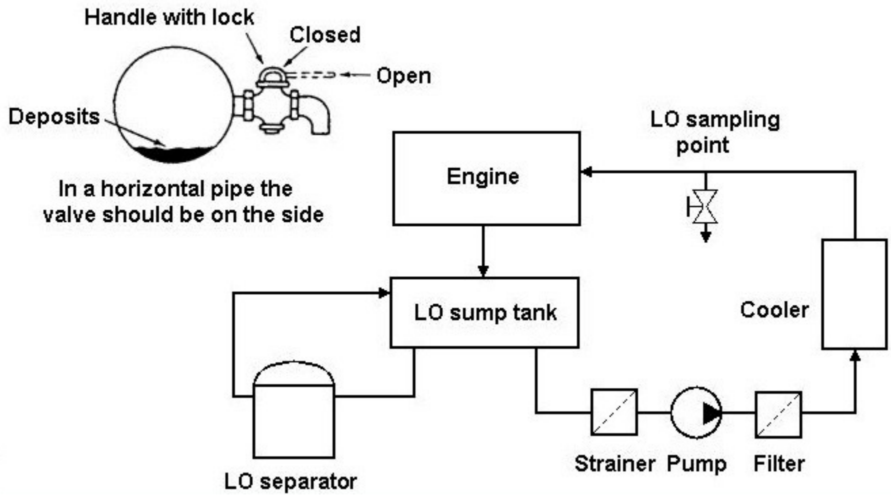
Feeling a sample between fingers for debris or roughness / or by passing through a fine lint

Taking a 500ml sample in a Glass beaker allow to stand and observe:

- Colour – dark oil may be old or oxidized
- Smell – should not smell of eggs or sulphur – this may indicate MBC
- Separation of water through gravity
- Shine torch or LED light through glass observe for debris or dirt

Trend analysis of filter Changes and Purifier sludge formation may indicate rate of degradation.

Oil sampling



The frequency of oil sampling for analysis varies with the type of engine and with the use of the engine: auxiliary versus main, high and medium speed versus slow speed. Should a lube oil sampling connection be fitted to a pipe that is horizontal, the sampling valve should be midway up on the pipe, so that any sludge or deposits that form in the lower half of the pipe would not be included in the oil sample, giving a false value to the oil characteristics.

Engine oil changes

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

Time between changes

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

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

It can be seen that there is a variation between oil changes. However if there are contaminants present the oil may have to be changed sooner than the recommended intervals.

Factors affecting oil change periods

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

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

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

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

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

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

Shipboard LO treatment

To maintain oil purity, there are four general techniques of lube oil treatment that may be used aboard ship:

d Chemical treatment.

Not recommended because it removes additives from the oil.

e Filtration.

Removes solids but does not normally separate water from oil, unless the filters are of the coalescent type. Water and solids are the major contaminants of lubricating oil.

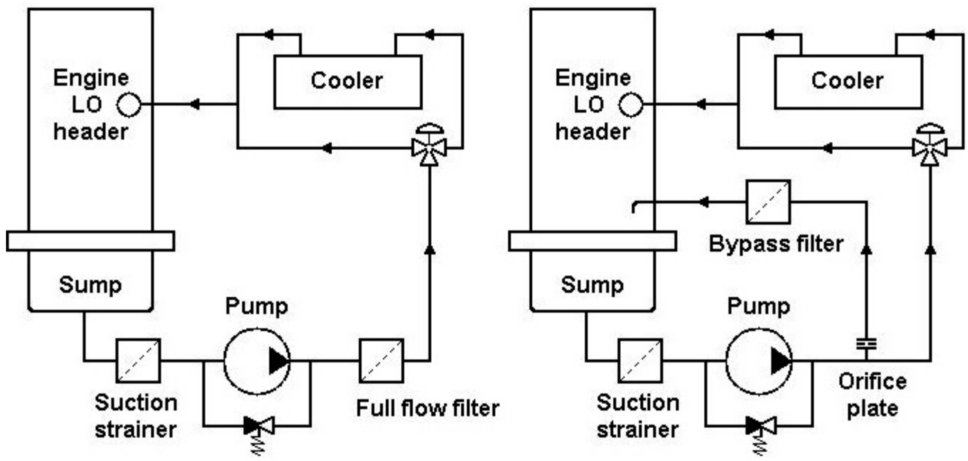
f Centrifugal separation (centrifuging).

This method is the most effective, both solids and water are separated from the lube oil by centrifugal force.

g Air blowing (not commonly found on ships).

When large amounts of water have mixed with lube oil, the mixture is put in a storage tank. Normally oil and water would be expected to separate but this will not happen if they are in a fine emulsion. Such an emulsion can sit for many days and even be centrifuged without separating. To correct this, warm air is bubbled through the oil from air distribution pipes (drilled pipes) in the bottom of the storage tanks. The water in close proximity to the air will evaporate and be carried away in the dry warm air.

LO filtering systems



There are two main types of lubricating oil filtration system found aboard ships:

1 **A full flow filter system.**

The pump takes suction directly from the engine sump, and all the hot oil from the engine passes through the filter, is cooled, and is returned to the engine.

2 **A bypass system.**

In this case, the pump takes suction from the engine, but only about 10% of the oil flows through the filter and back to the engine crankcase or sump. The orifice acts as a restrictor to achieve the 10% oil flow. The remaining 90% is simply cooled and returned to the engine.

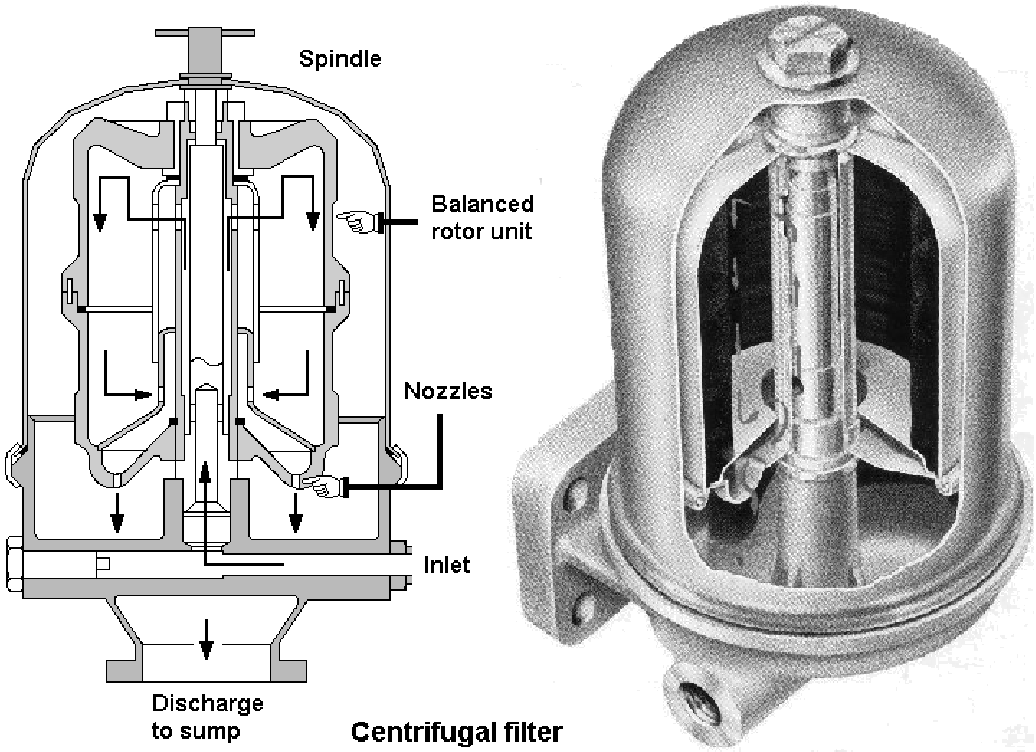
In both cases differential pressure gauges are located across the filters to ascertain the filter cleanliness. Should the pressure drop across the filter become greater than the specification, the filter must be cleaned.

There is also the **shunt system** that is similar to the full flow system, with a pressure valve on the filter bypass. This valve allows a constant bypass of hot oil at all times; thus, not all the oil is filtered, but it is all cooled.

Centrifugal Lubricating Oil Filter

This type of filter is usually located on the discharge side of the oil pump prior to entering the engine via a control valve. The process relies upon centrifugal force. As the oil enters the cyclone chamber it is forced upwards by the supply pressure into the rotor assembly.

The swirling action causes it to rotate and the higher density impurities are forced out to the periphery and retained for cleaning. Usually on a paper strip.



Centrifugal filter

Precautions when changing over DUPLEX type filters

When changing over filters on the discharge side of a pump, there is a danger that if the correct procedure is not followed a dangerous condition may exist if the wrong filter body is opened up. Additionally, if the sequence is incorrect the machine or system may lose its supply with serious consequences. Engineers should ensure that watch-keepers are familiar and competent with the correct procedure, standards monitored and instructions are posted adjacent to the valve body.

The correct procedure is:

- Establish the off - line filter by checking the T mark on the changeover spindle
- Open the air vent on the top of the OFFLINE filter slowly
- Open the balance line until oil flows out of the vent (avoid spillage

  with a suitable container)

- Ensure there is no leak from the OFFLINE filter
- Swing the handle over to bring the clean filter online monitoring

  pressure

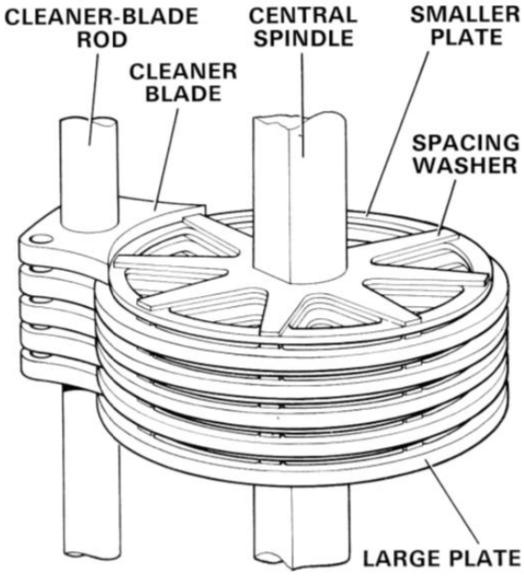
- Shut the balance line connection
- Drain off the now OFFLINE filter slowly into a container ensuring that

  it is not pressurised

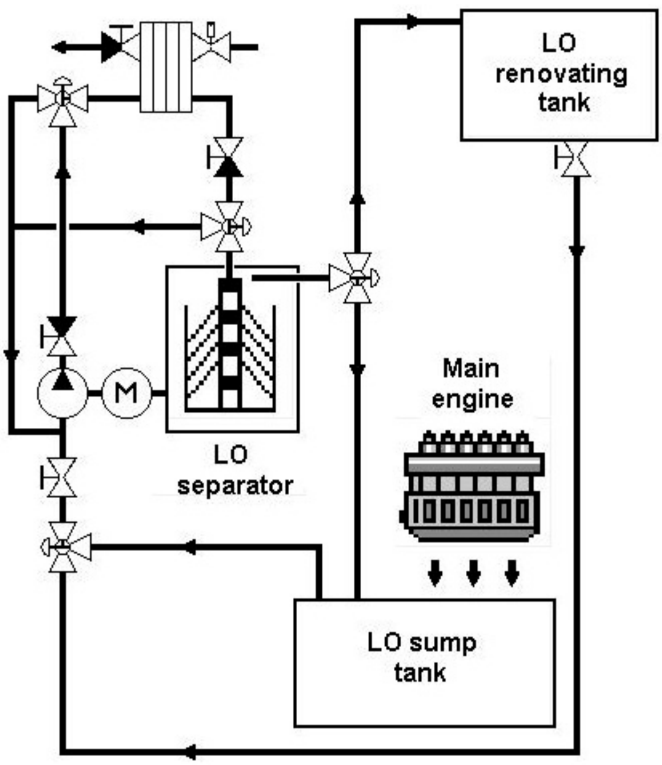
- Once pressure falls to zero open the vent filter body should fully drain
- Remove filter top carefully and replace filter
- Replace cover securely, shut filter drain
- Open balance line until oil flows out of the vent
- Shut vent ensure no leaks
- Shut balance line

‘Auto-Klean’ filters

Auto-clean filters are relatively coarse and use a series of disks separated by spacers and cleaner blades. The micron size of the filter is determined by the gap between the disks. The filter is cleaned by rotating the disks, the cleaner blades then scrape the dirt from the disks, which then drops and collects at the bottom of the filter bowl.



Centrifugal separators



Where a large quantity of lubricating oil is used in an engine, it is not cost effective to carry out oil changes. A separator is therefore fitted in the system to remove impurities and water to extend the life of the lube oil, practically indefinitely.

Lube oils used with a purifying system are usually nondetergent oils, as the water used in the purifier dissolves the detergent additive.

It is preferable to install the separator in a continuous bypass system.

The oil is drawn from the lowest part in the system, heated up to 80°C to 90°C, passed through the separator and returned to the system. Heating the oil helps to separate the water from the oil.

Continuous separation

This is probably the most frequently used set-up. The lube oil circulates from the sump via the separator back to the sump. This method is known as **continuous separation** or **sump to sump separation**. The process is normally used when the engine is running.

The disadvantage of this method is that there is no guarantee that **all** the oil in the sump tank will be treated over a period of time.

Batch separation

To ensure that all the lube oil is treated **batch separation** will be used. The process may include three operations:

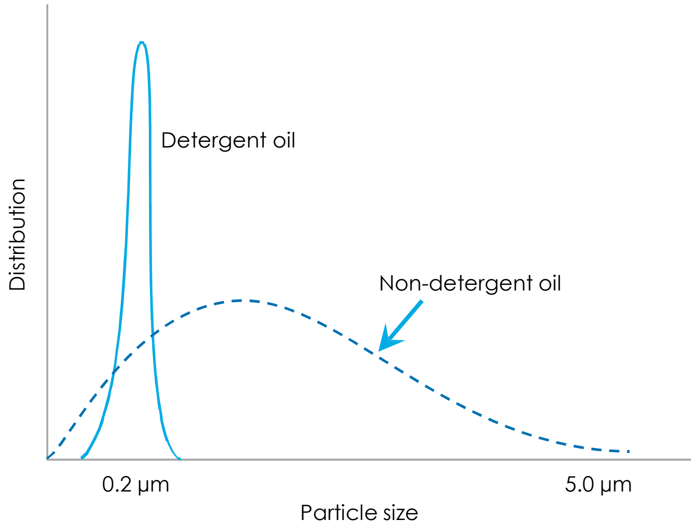
h The lube oil is transferred via the separator to the renovating tank (sump to reno).

i The oil may then be separated over a period of time from the renovating tank via the separator back to the renovating tank (reno to reno).

j Then the lube oil will be transferred back to the sump from the renovating tank via the separator (reno to sump).

This process would normally be used when the vessel is in port and the engines are not running. The advantage of this method is that all the oil in the sump will be treated.

5 LO throughput



In centrifuging lubricating oils, the throughput of the centrifuge should be about 50% of its maximum capacity if the oil is non-detergent.

This results in a minimum contaminant level as indicated in the diagram.

Should the lubricating oil be of the detergent type, the throughput should be about 25% of the total centrifuging capacity to achieve the same minimum level.

The difference is due to the smaller size the contaminant particle found in detergent oils. Because of the small size of the solid particles, separation by centrifugal force does not readily occur and the flow-rate through the LO centrifuge must be lower i.e. slower.

Bunkering LO

Lubricating oils may arrive on board a vessel in two ways:

a Delivered in bulk

b Delivered in drums of various sizes, the most common being the 205 litre (45 galls) or 25 litre (5 gall) drums.

Oil delivered in bulk

This arrives by road tanker or barge. It is pumped straight into the ships storage tanks via a connection hose and the ships pipework.

The delivery connection is made at the bunkering station, and delivered down into the engine room (by gravity) to where the LO storage tanks are located.

Oil delivered in drums

Drums usually arrive by road vehicle and are delivered on the quay.

The oil is usually stored close to where it is needed, either in the engine room or deck oil store. Later the oil can then be transferred using a barrel pump.

Storage and handling LO

The oil delivered in bulk will be stored in tanks designed for it. These will be clearly labelled with the type of oil and the name of the machinery that the oil is to be used in.It is important the labels, or in some cases brass tags, are kept clean and not painted.

The more specialised oil, which arrives in the drums, may not have specific tanks to be stored in and may have to be stored in the drums. The drums should be marked clearly and stored so that the labels can be easily seen.

The drums may be stored in racks or free standing. If free standing they should be lashed tightly and, wherever possible, off the deck on wooden pallets. Damage to the drum can occur with sustained contact with the deck.

- When moving drums of oil around care must be taken not to strike any objects, the drum could split very easily.
- Too much exposure of the drum to the wet (sea spray) could cause the identification to be obliterated, which could lead to confusion when dispensing the oil.
- When transferring the oil (from drum to tank) is the time that it could become contaminated with dirt, therefore:
  - Use a clean container
  - Make sure it is covered.
- The amount of oil added to a piece of machinery should be noted to obtain a record of the consumption. Any transfers should be entered in the Oil Record Book.

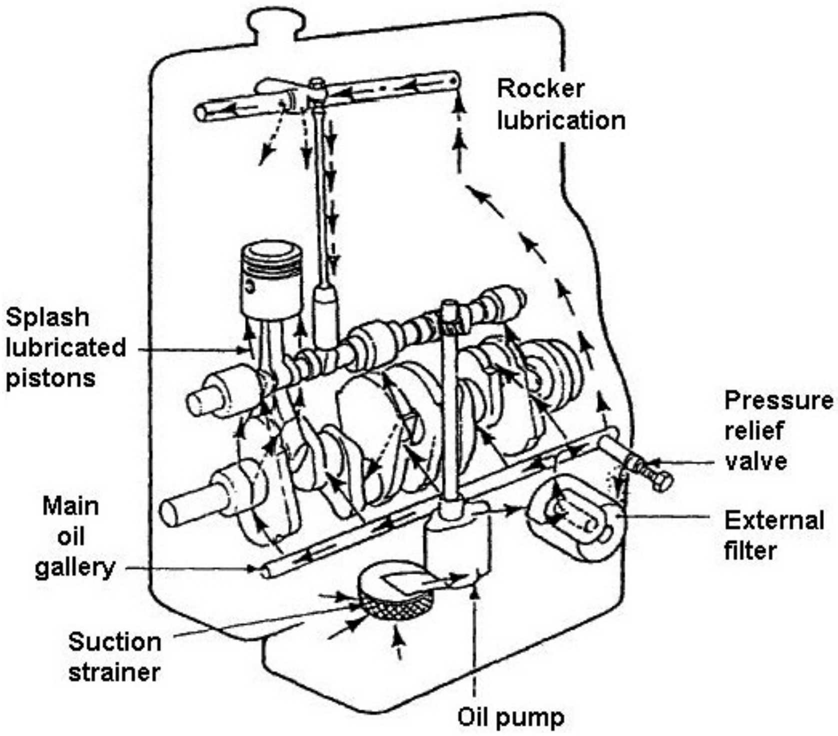
Engine lubrication

From the sump the oil is pumped through pipes, feed holes or drilled passageways to the main bearings and through the crankshaft to the bottom or big end bearings. From the big end bearings, the oil is fed up the connecting rod to the gudgeon pins.

Subsidiary passages known as bleeds or galleries are provided for the oil to reach the camshaft rocker shaft bearings, and rocker arms. Other passages supply oil to timing gears or chain and the chain tensioner.

In all these arrangements, the oil is supplied to the engine parts under pressure. The pressure is provided by a pump that draws oil from the sump and circulates it via the various oil-ways and passages. The actual pressure is determined by the engine designers and regulated by a pressure relief valve.

Oil distribution



Engine lubrication system

Most engines have a supply line from the main lubricating oil pressure header to each main bearing.

The crankshaft is drilled so the oil will flow from the main bearing to the connecting rod bearing.

The oil then passes through another drilled hole to the gudgeon pin bearing.

Excess oil from the gudgeon pin may spray under the piston crown for additional cooling of the piston, or if there is a separate cooling system for the piston, it will drain back to the crankcase. The lubricating oil level the crankcase should be below that of the crankshaft, so the crankshaft itself does not dip into the oil reservoir. Oil leaking from the main and connecting rod bearings is thrown up onto the cylinder walls by rotary motion of the crankshaft, thus lubricates the cylinder walls.

This is not splash lubrication in the true sense; that occurs when the crankshaft itself dips into the oil reservoir and oil is thrown by the crank webs.

There are also branch lines from the main lubricating oil header to the cam-shaft bearings, to the gear trains, to the rocker arm assembly, and to other moving parts, as the header supplies more than lust the main bearing lubricating oil.

Engine system components

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

- pumps;
- relief and regulating valves;
- full flow and bypass filters, magnetic filters;
- heat exchangers; and
- centrifugal separators (purifier/clarifier)

Oil pumps

Lubricating oil pumps are of the positive displacement type.

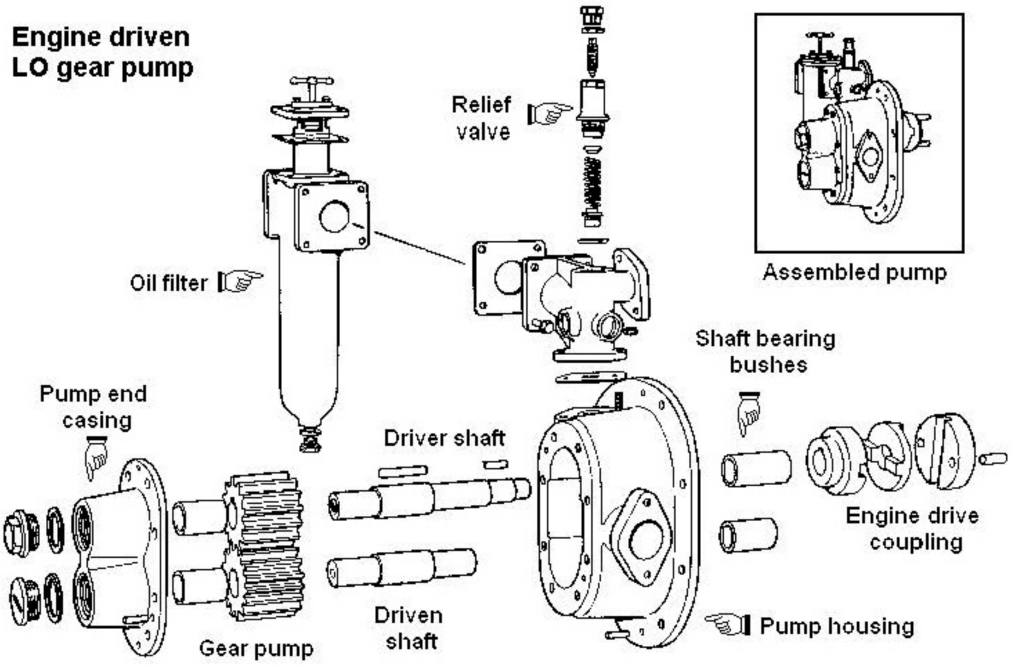
They are commonly **gear, rotor (lobe)** or **vane** type.

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

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

Gear type pump

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



Rotor (lobe) type pump

In a rotor type pump, there is an inner rotor driven by the engine. The inner rotor has a number of cam like lobes which mesh with mating parts in a rotor ring. The inner rotor causes the rotor ring to revolve within a housing.

In the housing, there is an inlet and outlet port at 90° to each other. Oil entering the inlet is carried to the outlet by pumping chambers formed between the cam lobes. As the inner rotor and rotor ring are meshed at the outlet, there is no place for the oil to go but out.

Vane type pump

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

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

Pump relief valve

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

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

Regulating valve

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

Heat exchangers

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

- Tube type cooler;
- Plate type cooler.

Cleaning tube coolers

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

Cleaning plate coolers

Special soft brushes should be used for the removal of deposits, so that the plates do not get scratched or damaged. Chemically cleaning may be recommended where hard deposits have accumulated. Before cleaning, coolers are isolated from the system by valves and blanks or by removing pipes and blanking the cooler flanges. Flushing is necessary after the cleaning agent has been drained from the cooler.

Advantages of plate coolers

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

Disadvantages of plate coolers

In comparison with tube coolers in which leaking tubes are easily located and plugged, leaks in plates are sometimes difficult to find because the plates cannot be pressurised and inspected with the same ease as tube coolers. Deteriorating joints are also a problem; they may be difficult to remove and the new joints may be difficult to bond. Tube coolers may be preferred for lubricating oil because of their pressure differential. The joints and plates are expensive, making the plate cooler more costly.

Bearing material

The requirements of a bearing material are:

- The ability to develop a good surface finish with a low frictional coefficient.
- The ability to retain an oil film.
- Ability to resist corrosion attack from any acids formed by products of combustion, water or oil additives.
- Have a low enough melting point to allow it to deform locally to accommodate asperites (this is known as **conformability**). Asperites are small high spots and ridges.
- Be soft enough to absorb hard particles, avoiding scoring of the journal (this is known as **embedability**).
- Have sufficient mechanical strength and ductility to resist very high loadings without spreading/flattening or becoming brittle.

The above statements are conflicting and to achieve them, a compromise is reached. Thin tri-metal shell bearings (a steel backing with a thin copper and white- metal bearing surface) are now common. If the white-metal is kept very thin then the fatigue strength and therefore load bearing capability is increased enormously but at the expense of poor conformability and embedability.

Damage to bearings

Damage to bearings may have many causes, including:

- Dirty oil (filtering).
- Contaminated oil (water, solids, bacteria).
- Incorrect grade of oil.
- Low oil pressure. (leaking internal pipework, choked oilways).
- Misalignment.
- Excessive bearing clearance.
- Insufficient bearing clearance.

- Damaged pin or journal.
- Overloading.
- Poor bonding or wrong grade of whitemetal.
- Fretting on back of bearing shell. Overpeeding may cause oval housing (bottom ends).
- Incorrect tightening.
- Insufficient warming through before starting.

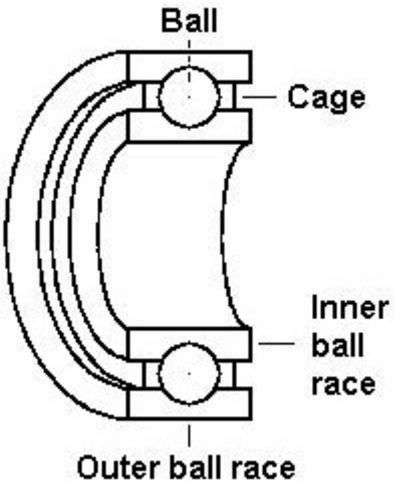
Prevention of damage

- Correct bearing size.
- Correct fitting of the bearings.
- High surface finish of journal/pin.
- Ensure good quality and clean lubricating oil.

Solid lubrication

A number of solid substances have the capacity to reduce frictional resistance between two bearing surfaces. These compounds nearly always have a molecular structure weak in the sliding direction, so that high spots shear easily rather than interlock. **Graphite** and **molybdenum disulphide** are the best known of such substances, the former being particularly useful at very high temperatures.

Bearings may also contain theft own solid lubricant such as graphite in cast iron or PTFE in certain sintered bushes. In most cases the solid lubricant is either incorporated in a fluid lubricant as a precaution or used alone as a solid film. Such solid lubricating films may be produced by deposition on the surface by diffusion or by a suitable chemical addition.



Solid and semi-liquid lubrication are commonly associated with ball type bearings, that are lubricated with grease.
Solid and semi-liquid lubrication can also be found on slow speed plain bearings, such as winches, windlasses, etc.

Thin-film or boundary lubrication

Boundary lubrication is best defined as the lubrication of surfaces by fluid films so thin that the friction coefficient is influenced by the structure of the lubricant and the nature of the surfaces, but is largely independent of viscosity.

This definition avoids confusion with both solid and full fluid-film lubrication.

A fluid lubricant introduced between two bearing surfaces may spread to a microscopically thin film that reduces the sliding friction between the surfaces. The peaks of the high spots may still touch, but interlocking occurs only to a limited extent and frictional resistance will be relatively low.

A variety of chemical additives can be incorporated in lubricating oils to improve their properties under boundary lubrication conditions. Many of these additives react with the bearing surfaces to produce an extremely thin layer of solid lubricant, which helps to separate the surfaces and prevent seizure. Oils such as these are known as extreme pressure (EP) lubricants.

Slide-ways and flat thrust bearings operate for at least part of the time in a regime of thin film or boundary lubrication. Thrust bearings of this kind are virtually obsolescent apart from in marine tail-shafts. They generally consist of a simple collar mounted on the shaft and bearing against a fixed pad. To decrease the specific loading within a predetermined diameter, a series of collars may be used, but considerable difficulties are experienced in maintaining identical clearances under variable conditions and thus equalising the load on each thrust collar.

Thick-film or full fluid-film lubrication

If two bearing surfaces can be separated completely by a fluid film, frictional wear of the surfaces is almost eliminated. Resistance to motion will be reduced to a level governed by the viscosity of the lubricating fluid, which may be liquid or gaseous.

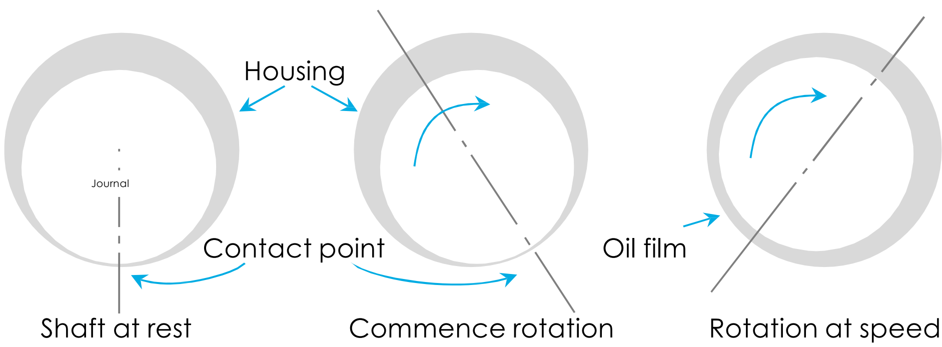
To generate a lubricating film within a bearing, the opposed surfaces must be forced apart **by pressure** generated within the fluid film. The simplest means is to introduce the fluid under sufficient pressure at the point of maximum loading, but this hydrostatic method, although equally effective at all speeds, needs considerable power and is avoided whenever there is a satisfactory alternative.

Above a certain critical speed, that depends mainly on the size and loading of the bearing the viscosity of the lubricant, stable hydrodynamic forces are set up in a journal bearing that force the surfaces apart and permit full fluid-film lubrication.

By suitable design, hydrodynamic lubrication can also be provided in certain other types of bearing.

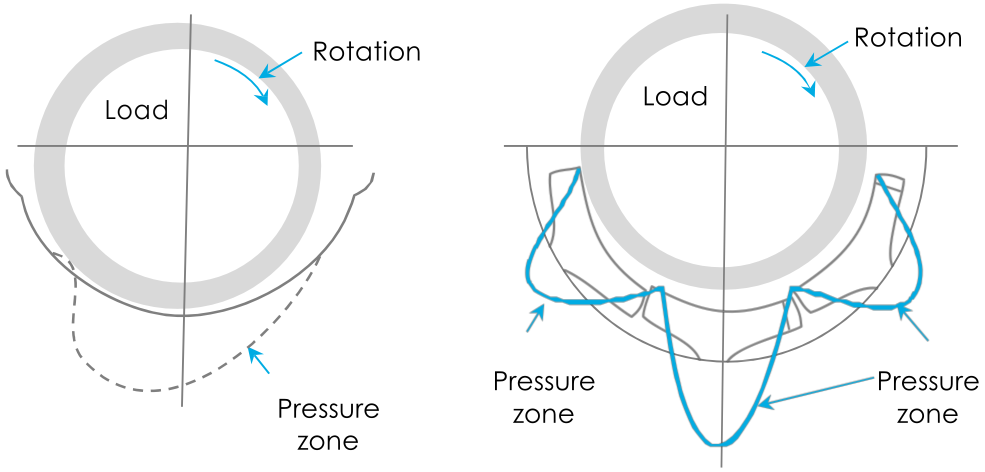
Hydrodynamic lubrication of journal bearings

The mechanism of **full fluid-film lubrication** in journal bearings is illustrated below.



At rest, the fluid film has been squeezed from beneath the shaft, leaving only an adsorbed film on the contacting surfaces. As the shaft starts to revolve, friction between the journal and the bearing bore causes the shaft to climb up the inside of the bearing until torque, together with the increased thickness of lubricant film, overcomes frictional resistance and the shaft starts to slip at the point of contact. The rotating shaft then takes up its equilibrium position, where it is supported on a fluid film drawn beneath it by viscous friction.

The pressure distribution in the lubricant film with the bearing in its equilibrium position is shown below.



Plain journal bearing **Tilting pad bearing**

Equilibrium position and pressure distribution in the oil film at steady speed load. The bearing clearance is full of oil.

Tilting bearing

The pivoted segments take up an optimum position according to the speed and loading. A simpler arrangement that is sometimes applied is to cut tapered grooves into one or both thrust bearing surfaces, creating a series of constant-form wedges, these are, however, of maximum efficiency only under fixed conditions, and hydrodynamic lubrication may not be possible with all combinations of speed and load.

4 factors that affect fluid film wedge formation

1. Temperature of the liquids to be separated (Viscosity)
2. Flow rate through the centrifuge
3. Speed of rotation
4. Emulsifying agents / Detergents

Hydrostatic lubrication

There are a number of instances in which hydrodynamic lubrication is either impossible or inconvenient, but where contact between surfaces must be avoided. In such cases the lubricating film must be induced by external pressure, the only exception being the magnetic bearing, in which the shaft is suspended in space within a magnetic field.

Hydrostatic lubrication can be applied to almost any type of bearing, regardless of shape, material or operating conditions. It has particular application to slide ways, completely eliminating slip-stick problems in machine tools and similar equipment. Bearing friction approaches zero at very low speeds, in contrast to dynamically lubricated bearings, where friction increases markedly under the boundary lubrication conditions obtaining when speed is very low.

Very heavy loads can be supported hydrostatically i.e. hovercraft and similar vehicles.

These ride on a hydrostatic, or more accurately, an aerostatic or pneumostatic gas bearing. It is possible to design hydrostatic journal bearings that keep the shaft accurately aligned irrespective of load and speed, and the constant outflow of lubricant prevents the ingress of dirt and other contaminants.

The advantages offered by such bearings are offset by the need to provide considerable ancillary equipment in the form of pumps, compressors, filters etc., the expenditure of power in pressurising the lubricant and the sensitivity to mechanical failure or blockages of the system as a whole. Self acting hydrodynamic bearings have no auxiliary apparatus to go wrong or consume power, and are thereby much simpler and cheaper to operate.

LO system faults

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

Low oil pressure

Oil pressures will differ between types and makes of engines.

A lower minimum oil pressure is acceptable at a lower speed compared to a minimum at a higher speed. This is due to the lower loading on the bottom end bearings during the power stroke.

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

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

Should there be no oil pressure within 10 to 15 seconds after starting the engine, immediately stop the engine and check the lubricating oil system.

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

Insufficient level of oil in the sump

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

LO pump strainer clogged

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

Faulty LO pump

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

Lubrication - Definitions

Scuffing particles are large discoloured or twisted metallic pieces broken off usually as a result from lubrication failure.

Fatigue chunks thick pieces of debris usually indicative of severe wear.

Laminar particles are usually associated with roller bearings which have been flattened.

Sludge Can occur in oil usually as a result of ageing or contamination.

lacquer is a term to describe the deposit harder than varnish resulting from oxidation and polymerization of the oil usually at high temperatures.

Faulty relief valve

The pressure relief valve may be stuck in the open position or its spring may have broken. Should the relief valve stick in the open position or the spring break, the oil pressure will drop below normal.

Filter partially clogged

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

Oil temperature too high

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

Faulty oil pressure gauge

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

Fractured LO pipes

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

Excessive clearance in a bearing(s)

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

SECTION 11 – Cooling Water Systems

Cooling systems

Abbreviations

The following abbreviations are used in this section:

CW	Cooling water
FW	Fresh water
FCW	Fresh cooling water
SW	Salt water
SCW	Salt cooling water
LO	Lubricating oil
HT	High temperature
HTCW	High temperature cooling water
LT	Low temperature
LTCW	Low temperature cooling

Cooling system functions

The cooling systems of diesel engines have two main functions:

1 The first is to remove between 30 and 35% of the heat from the engine, primarily from the heat of combustion;

2 The second is to cool the engine lube oil. The lube oil cooling may be accomplished by either fresh or salt water.

Engine cooling mediums

Engines can be cooled:

- By fresh water;
- By salt (raw) water;
- By oil;
- By air;
- By any combination of the above.

Cylinder liners, cylinder heads are commonly fresh water or raw water cooled.

The temperature variation is between 50°C to 100°C for cylinder heads. For piston crowns it will be 75°C to 100°C. Cylinder liners show greater temperature variation throughout their length, but in the highly critical area at the top of the liner the variation is kept to about 100°C.

Small high-speed engines are air cooled by forced air flow passing over fins fitted on the outside of cylinders and covers. Air cooled diesel engines can have lower cylinder wear.

Piston crowns are cooled by excess lubricating oil from the gudgeon pin bearing and by heat transfer to the walls of the piston, which are then in turn cooled by the cylinder liner. The temperature of the combustion chamber surfaces of cylinder covers, piston crowns and cylinder liners varies between 200°C and 300°C.

Air cooling — advantages

40% of the failures with water cooled engines are due to the cooling system.

Air cooling has none of the following problems:

- Freezing or boiling of cooling water;
- Radiator hoses or clamps, with possible leaks;
- Water pump or sealing, with possible leaks;
- Cavitation or corrosion.

Cylinder wall temperature will rise quicker in the air cooled engine and thus the rate of wear due to cold corrosion will be reduced.

The air-cooled engine is more compact for a given power output. Maintenance of the air cooled engine is easier because the cooling system does not have to be drained first.

Air cooling — disadvantages

The cooling system has to be sized for maximum load operation this could lead to undercooling at part load operation leading to cold corrosion.

Due to there being no water the noise reducing effect is lost. An air cooled engine is more noisy than an equivalent water cooled engine.

Water cooling — advantages

- The water circulating pumps take less power to drive than the equivalent air cooled engine fan(s). The water cooling pumps can be driven off the main engine.
- Using thermostatic control the temperature around the cylinder is more constant which is better for the engine.
- It also allows good cylinder temperatures in all climates.
- Quick stopping from high load does not lead to a rapid cooling in the cylinder and cold corrosion is avoided.
- Water cooling is essential for turbocharged engine that have intercoolers.

Water cooling — disadvantages

- Increased maintenance and complexity needed with the water system.
- Antifreeze is needed in cold weather.
- Pre-heating should be employed under some circumstances.
- The system is prone to corrosion.

Water cooling systems

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

The engine requires cooling for:

- The cylinder jackets;
- The cylinder head.

In addition cooling is required for auxiliary systems, including:

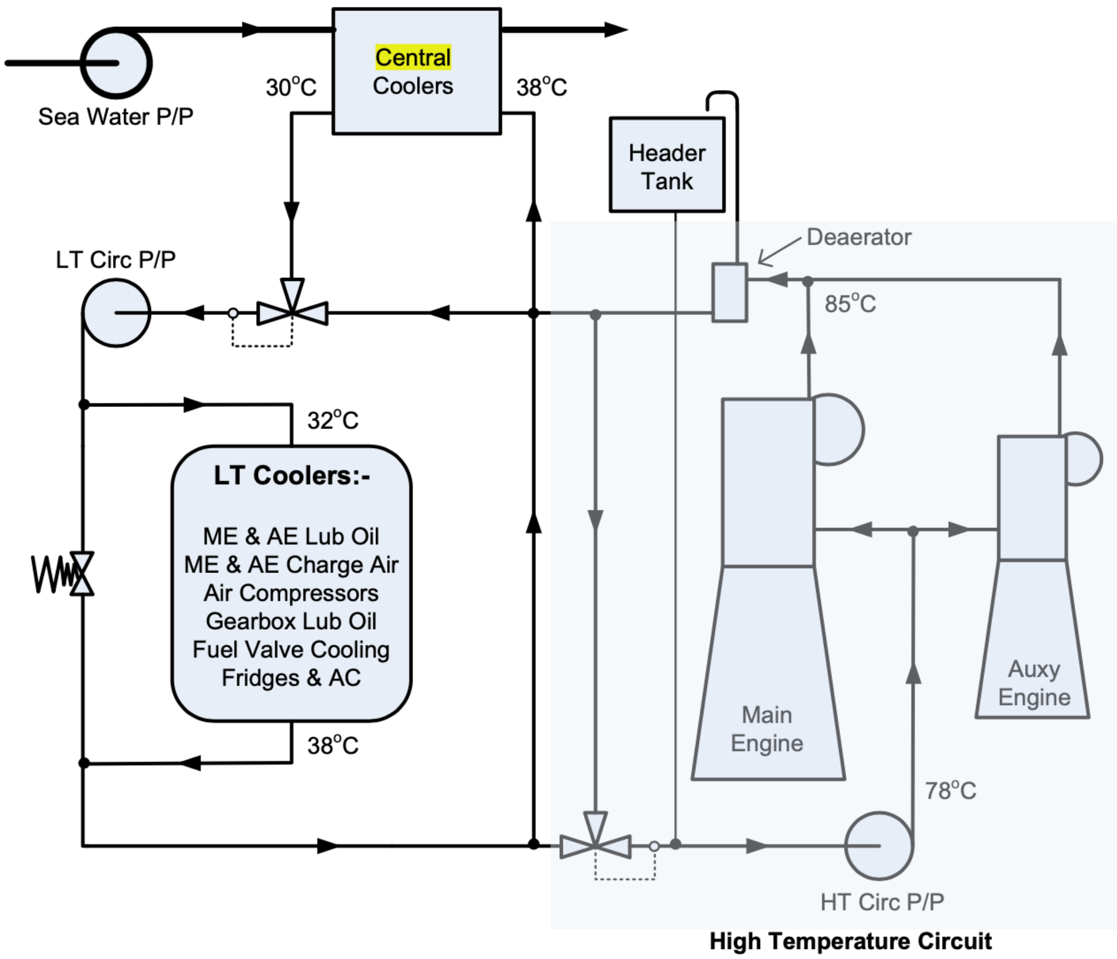
- Engine lubricating oil;
- Gearbox lubricating oil.

There are many methods for engine cooling that include:

- Direct SW cooling system;
- FW closed system;
- Central cooling system;
- Keel cooling.

Direct SW cooling system

The sea water is in direct contact with the cooling passages of the engine. It is not often found aboard diesel engine powered vessels (except older or smaller vessels) anymore mainly because of corrosion and scaling problems. The advantages of direct sea water cooling are that the plant is simple and running costs are low (sea water is plentiful!).



Problems associated with direct salt water cooling include:

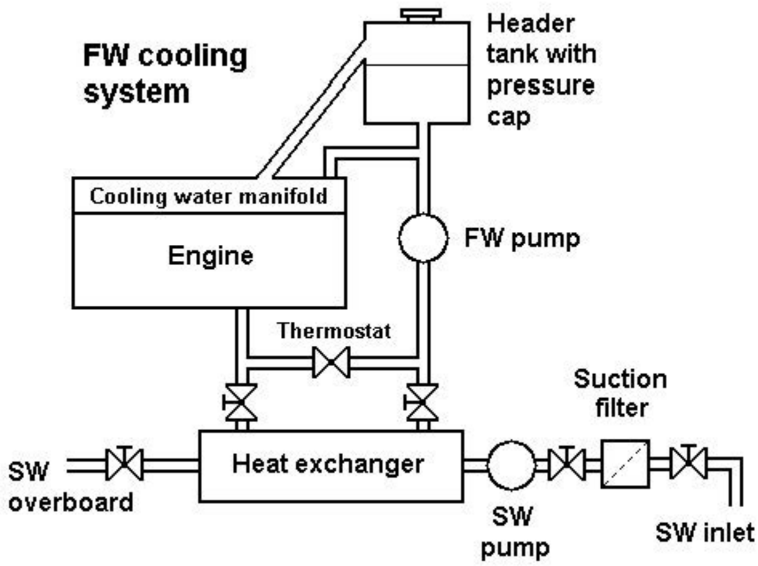
- The maximum outlet temperature is limited to about 50°C. If the temperature exceeds that, salt will precipitate on the engine block causing scaling which is an insulator (reducing heat transfer);
- Cold sea water can create thermal stresses within the engine;
- Sea water is corrosive.

FW closed system

To overcome the disadvantages of the SW open system, a FW closed cooling system, using fresh water, is used. Only FW passes through the engine passages, the FW is cooled by SW in a heat exchanger.

The fresh water is circulated through the engine starting at the bottom, where the engine is coolest and the water is also coolest (jackets). It circulates vertically to the top where the engine and the water are warmest (cylinder heads). It is considered desirable to have a temperature differential of only 10°C to 20°C across the engine to prevent the build-up of thermal stress.

There is an expansion tank above the engine. This tank must have a minimum capacity of 5% to 10% of the engine cooling water by volume. Its purpose is to compensate for the density (and thus, volume) variation in the water due to increases or decreases in temperature. In addition, make-up water for the cooling system is supplied to the expansion tank.

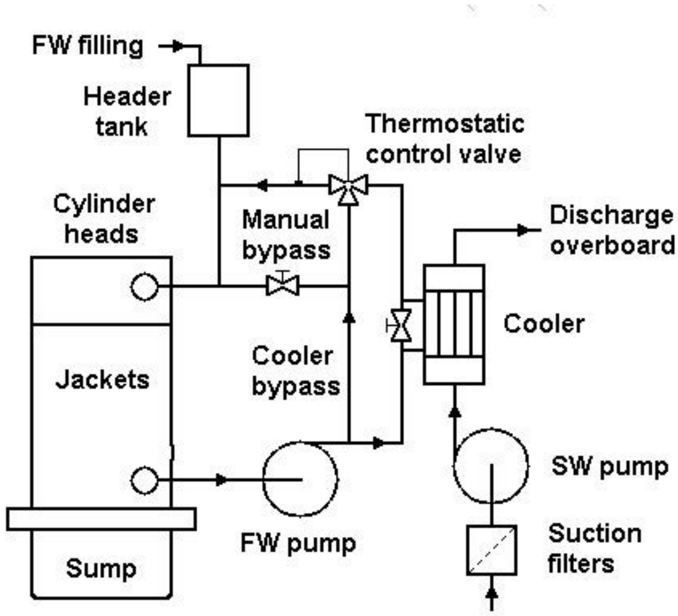


With this system two pumps are used and both maybe engine driven.

One pump circulates sea water from the sea suction strainer through the engine mounted cooler (also referred to as a heat exchanger).

The other pump is used to circulate fresh water through the engine water jackets and the heat exchanger.

A cooling system is designed to operate between specified temperatures which will vary between engine models and manufacturers. One example engine is a jacket temperature discharge of 85° C to 90° C, with a 1.03 bar pressure cap in place on the header tank. The engine can operate intermittently up to a temperature of 96°C. The cooling water high temperature alarm is set at 96° C.



Engine cooling water system

A three-way thermostatic valve controls the engine water temperature.

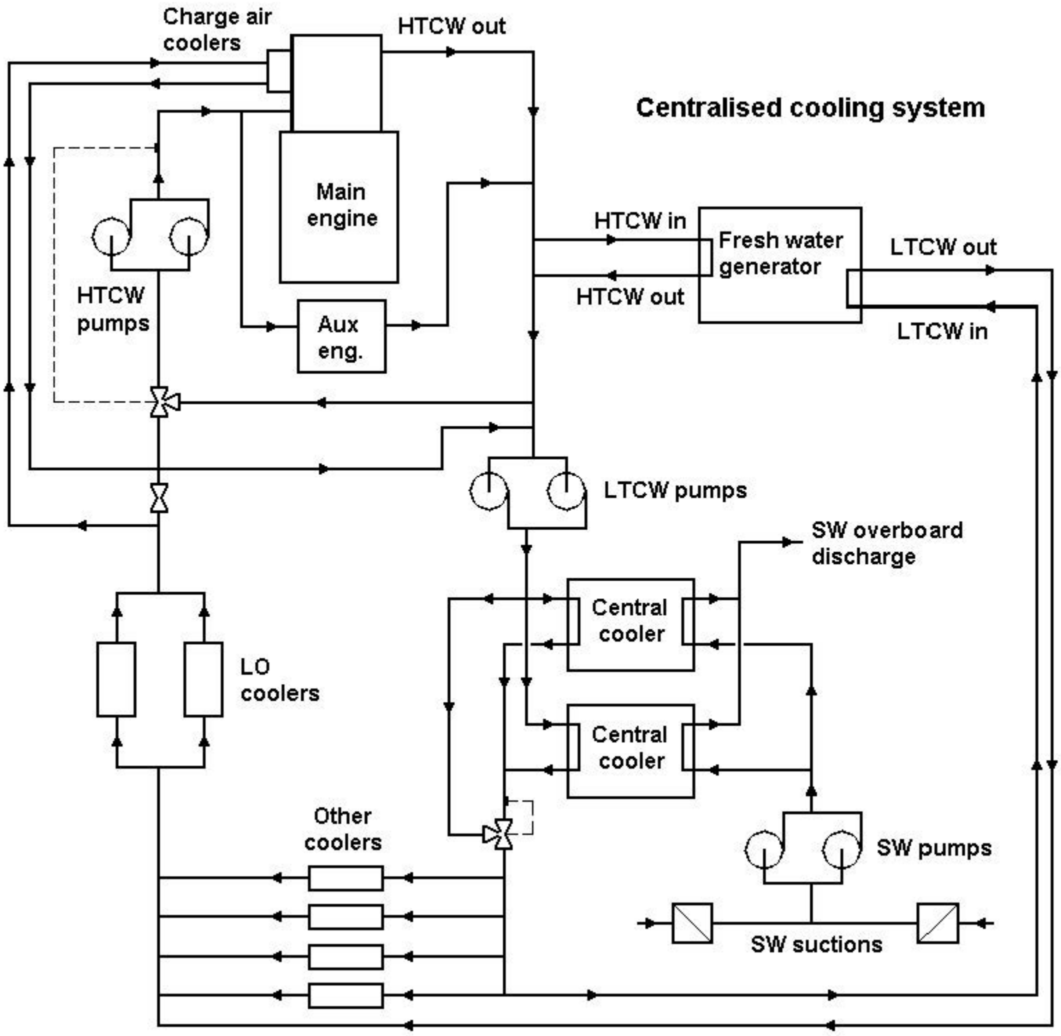
The thermostatic valve bypasses the cooler to increase the temperature of the water entering the engine.

Bypassing typically occurs during start up and will also occur on a bleed basis during actual engine running as the fresh water engine outlet temperature varies.

There is a manual bypass of the cooler in case the threeway thermostatic valve fails.

It is desirable to maintain an average temperature of approximately 80°C in the engine. This necessitates mixing the bypassed warm water and the remainder, which is cooled in the heat exchanger before the mixture re-enters the engine. The water cooler uses sea water for cooling, with high and low water suctions through a strainer and salt water pump to the fresh water cooler.

Central cooling system



The operation of this system is as follows:

Sea water is only used through the two main central heat exchangers, no sea water enters the engine or other components. This reduces the problems associated with cleaning and corrosion.

The sea water is circulated through the central coolers and then discharged overboard. To ensure the correct performance of the system a low temperature and high temperature circuit exists in the fresh water system.

The fresh water in the high temperature circuit circulates the main engine and may, if required, be used as a heating medium for the fresh water generator.

The low temperature circuit circulates the fresh water through such equipment as the lubricating coolers for the main engine, the auxiliary diesel engine cooling system and if required the main engines turbocharged air coolers.

A regulating valve controls the mixing of the water between the high and low temperature circuits. The temperature sensor provides a signal to the control unit that operates the regulating valve to maintain the desired temperature setting. A temperature sensor is also used in a similar control circuit to operate the regulating valve that controls the bypassing of the central coolers.

Note: It is also possible, with the appropriate control equipment, to vary the quantity of sea water circulated by the pumps to precisely meet the cooler requirements.

LO coolers

The lubricating oil cooling systems usually employ a heat exchanger to remove heat from an engine. The engine lubricant flows around the outside of the tubes restricted by baffle plates to optimise the heat transfer affect in the heat exchanger with the raw (seawater) flowing through the tubes. The engine lubricant leaves the heat exchanger and is recirculated through the engine by the engine LO pump. The raw water flows in through the raw water pump, through the heat exchanger tubes and is then ejected overboard.

Essential features of the tube type heat exchanger include the facility to allow the tube stack to expand due to the different materials reacting to the different expansion rates associated with the material used e.g.aluminium brass tube stack and cast iron shell.

To limit and prevent corrosion in the system anodes are situated usually in both the inlet and out of the cooler.

Piston cooling

Standard practice for many years was to use lube oil for piston cooling, and it is still in practice on many large engines. With the design of the new very large bore engines and the correspondingly large amount of heat that must be removed, however, it was found that water removes heat more efficiently. Since the specific heat of water is about twice that of lube oil, half as much water must be circulated to remove the same amount of heat. Pump size and power can be correspondingly reduced. When water is used for piston cooling, there is a separate water circulating system for the pistons, independent of the main engine cooling water system.

Cooling systems may also be found on the fuel injectors to prevent tip overheating. If a tip should overheat, oil contacting it would carbonise, causing coking of the injector nozzle.

Methods of temperature control

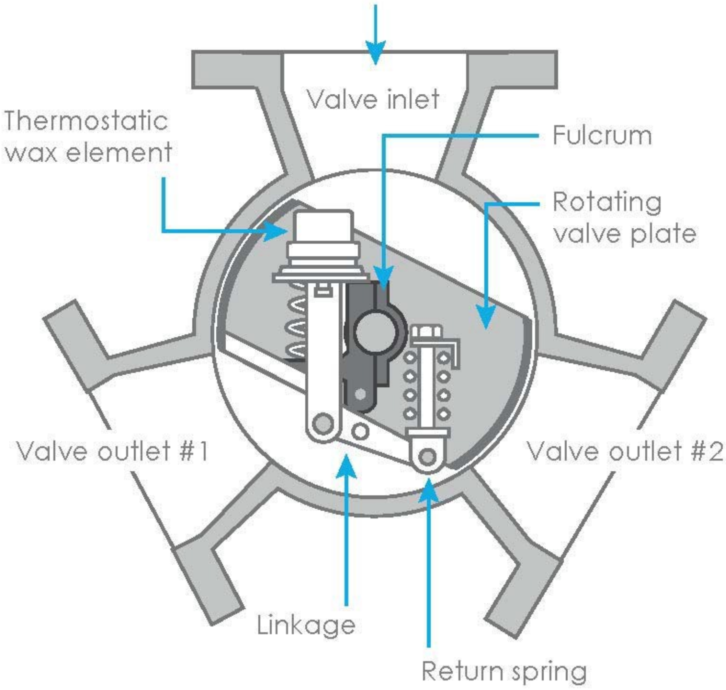
There are three methods of temperature control in a cooling system using two coolers arranged in parallel;

1. Manual control

2. Semi-automatic control

3. Fully automatic control

Thermostatic 3-way valves



Thermostatic 3-way valve

The thermostatic element is a copper capsule containing a wax which expands as the temperature increases.

This acts on a rubber sleeve around the top of a piston, forcing the piston down, compressing the spring, thus turning the rotating valve plate.

Fresh water system

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

Fresh water pump

Usually engine driven, but there may be externally driven pumps as well.

Fresh water circulation

It circulates fresh water through the block and cylinder head. The hottest part of the engine is the combustion space. This is at the top of the cylinder liner and the inlet and exhaust valve area where combustion takes place.

There are spaces around the cylinder liner and the block that are called jackets. The fresh water circulates through them. The fresh water then flows through the holes in the top of the block and corresponding holes in the cylinder head gasket and cylinder head. In the cylinder head the water circulates around the inlet and exhaust gas passages to the thermostat.

The fresh water in some engines may be fed through the exhaust manifold and turbo charger. Cooling them minimises the radiant heat given off thereby keeping the engine space cooler and providing better engine power. Fresh water cooling of these parts does not leave the deposits that sea water cooling does.

Thermostat

A thermostat allows an engine to reach its normal operating temperature quicker, thus preventing wear. If the engine is cold, the thermostat will operate and by-pass the cooler. When the engine reaches its normal operating temperature the thermostat will close and direct the water to the cooler or the keel cooling pipes before going to the engine.

When the thermostat is closed, fresh water will flow through the tubes of the cooler to reduce its temperature and then to the engine. Some coolers arrangements maybe situated before the fresh water pump.

Header tank

Also called the expansion tank. This allows for the expansion volume of the fresh water. The tank provides an adequate method of venting air and combustion gases from the fresh water system during engine operation. Since diesel engines inherently allow some combustion gases to enter the fresh water system, it will be necessary to remove these gases before they cause deterioration of the cooling water system performance. Gases in the system reduce coolant flows and may result in engine failure if adequate venting capacity is not provided.

On some engines the header tank is situated above the fresh water cooler to form one unit. Initial venting of the system is critical in order to ensure that the system is completely filled with coolant.

Fill the engine slowly to allow the coolant to fill from the bottom up. Quickly filling the expansion tank can fill the vent pipes with coolant and result in slow or incomplete fill of the engine. If vent cocks are fitted, they are to be used to help any air to escape. After initial filling of the system, run the engine, keep checking and if necessary top up the water level until the coolant operating temperature is reached. Any trapped air should make its way up to the header tank in the form of bubbles.

Electrically driven fresh water and sea water pumps

On larger engines, the fresh water and sea water pumps are driven by electric motors, as opposed to being engine driven.

Usually no thermostat is fitted, so the fresh water circulates through the engine as well as the cooler. However a control valve maybe fitted to by-pass the cooler when necessary.

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

If the engine is pre-warmed a sudden and high rise in temperature does not take place when the engine is started. This avoids thermal stressing. To control the temperature of the fresh water, a control valve maybe fitted for the sea water to by-pass the cooler until it is required for cooling.

Maintenance

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

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

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

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

Repair leaks as they occur as they can only get worse.

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

Any anodes are to be inspected regularly, cleaned, checked for weakness and replaced if circumstances dictate. Anodes are commonly fitted in the SW housings of tube heat exchangers.

FW inhibitors

Care should be taken to ensure:

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

It is very important that the water used in the engine be distilled or at least softened. Otherwise scale may form, reducing the heat transfer rate, causing overheating of the piston and cylinder, accelerating wear, and, in some instances, causing binding of the rings.

It is important that the water cooling systems on engines be kept free of rust, scale, and sludge so that the engine heat may be carried away by the cooling water. Since these contaminants are deposited in a non-uniform manner, they can cause hot spots on cylinder liners or engine blocks. Hot spots result in uneven stresses and can eventually cause material failure. Since an oil film cannot be maintained in an overheated area, rapid piston ring and liner wear may occur. To guard against such conditions, only fresh, soft water that has had **inhibitors** added should be used as a coolant.

The function of the inhibitors is to deposit a film on the metal faces of the cooling system to protect them from corrosion and erosion attack. Erosion may be caused by cavitation at the liner or engine surface. This occurs when vibration causes vapour bubbles to form wearing away the metal. When the inhibitor has coated a metal surface, the cavitation effects act on the inhibitor rather than the metal surface. The inhibitor is maintained in the water, so as it is depleted by cavitation it is replaced by chemical coating.

To be effective, the cooling system treatment program must meet four conditions:

1 The cooling system should be clean so that the inhibitor will be able to act on the bare metal surfaces of the water jacket.

2 The coolant must be checked periodically for alkalinity, chrome, and chloride content. The inhibitor must be maintained at the strength specified by the manufacturer.

3 The coolant must be clean, mineral-free, soft, fresh water containing a minimum of dissolved gases.

4 The cooling system must be mechanically tight to prevent leakage of the water out of the system or of gases into the system.

It is important that hard water and water that is known to be contaminated with chemical or industrial waste be avoided, because these contaminants tend to form sludge and scale within the engine. The chrome inhibitors used for chemical treatment of the water contain no chemical ingredients to soften the water. For engines operating continuously in hard water areas, the installation of water softeners is a viable option. Jacket water softeners are often standard equipment on new diesel engines.

Safety

An important safety consideration is that most corrosion inhibitors are poisonous. Sodium dichromate inhibitors are classified as a health hazard and must be handled carefully. In addition, chromate-type inhibitors are toxic and may produce severe dermatitis (skin inflammation).

Engine cooling water systems must never be directly connected to the potable water supply. Personnel should avoid any contact of the skin or eyes with chromate-type inhibitors. If chromates come in contact with the skin, the affected areas should be washed with plenty of soap and water immediately after exposure.

The typical cooling water inhibitor is a chromate-alkaline inhibitor consisting of sodium dichromate, sodium hydroxide, and distilled water. When these ingredients are in a solution, the sodium dichromate changes to sodium chromate, which is the active chroming agent. This is the agent that coats the water jacket surfaces.

In ships where the engine cooling water is used as a fresh water evaporator heat source, nitrite borates are often used as part of a total inhibitor system. The inhibitor system is composed of a blend of the nitrite borates and organic compounds. These compounds are not regarded as being as effective as chromates and require high concentrations (3500- 4000 ppm) and a higher alkalinity than chromates. However, nitrite borate has low toxicity, is non-staining, and is compatible with glycol antifreezes. The crystals that may form at pump glands are not as abrasive as chromate crystals.

Tests

There are test kits available to measure the chromate level in the jacket cooling water. Typically this is at least 1000 parts per million (ppm) of chrome, but the engine manufacturer will detail the exact minimum levels of concentration. A concentration level below 550 ppm should not be allowed.

It is also important that alkalinity control be maintained. The chrome inhibitor is designed to establish an alkalinity below a pH of 9.8. Should the alkalinity of the jacket cooling water rise above 9.8, the cooling water must be drained and the system refilled. There is no general test for an acidic solution, since it is known that if the concentration of chrome is proper, the solution will have an alkalinity above the minimum required.

A third test is for chloride content. The inhibitor does not affect the chloride content of the cooling system. Salt water leaking from the heat exchangers is the most common source of chloride. Once any chloride is detected, the system must be drained and repaired.

The cooling water system of each engine should be tested weekly to determine the chrome inhibitor level and the chloride and alkalinity levels. When new parts that have not been treated with engine jacket water are installed on an engine, it is recommended that daily chromate tests be made until the chrome concentration in the cooling water stabilizes. This is because the coating of the fresh metal parts will reduce the chromate level and additional treatment with chromate will be necessary.

Alarms and shut downs

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

To test the probe it can be inserted into a container of water with a thermometer making sure they do not touch the container. Heat and agitate the water to ensure uniform water and probe temperature. Place a meter over the contacts of the micro switch. The contacts should close when the thermometer reaches the temperature within the required tolerances. If the water is left to cool, the contacts will open. An electric kettle or an immersion heater could be used for heating the water.

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

Some manufacturers supply a shut down device that would energise a solenoid to shut off the fuel when the cooling water temperature reaches a set temperature above the high level alarm (high-high alarm). The shut down would be set at about 2–3°C above the high temperature alarm.

A pressure switch may also be incorporated in the system to give an alarm if the water pressure drops. This can be tested by closing the cock leading to the pressure sensor and bleeding the line.

Cooling system faults

Corrosion and electrolysis

Galvanic corrosion is the corrosion of the more active (or less noble) member of a pair of metals in physical contact in a corrosive environment.

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

Where corrosion on dissimilar metals occurs, the particular metal that will corrode can be determined from what is known as the Galvanic Series. Regular inspections of anodes must be carried out. They should be cleaned with a wire brush so they are more effective. If they are excessively eaten away, they are to be replaced. If in doubt about the condition of the anode, strike it sharply against a hard surface. A weakened anode will break.

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

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

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

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

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

Sea water system faults

Sea water temperature high

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

SW intake

Could become clogged over a period of time so there would be a gradual increase in the fresh water cooling temperature. Reduce the engine speed until the normal operating temperature is obtained.

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

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

Blocked SW strainer

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

Reduce the engine speed gradually and stop the engine. Clean out the strainer. Start the engine and let it idle until temperature stabilises. If two strainers are fitted carefully change over to the clean strainer and clean the dirty one.

Faulty SW pump impeller

The impeller in the sea water pump could be damaged. Damage usually occurs when the pump is run dry. Indications would be the pump discharge pipe would be warm and not at the same temperature as the sea water. In addition there would be no or a reduced sea water discharge overboard. If a pressure gauge is fitted, a reduction in pressure will be observed.

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

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

Faulty SW pump seal

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

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

Air in SW cooling system

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

The air can be bled off by opening any bleed cocks, or loosening a joint in the sea water cooling pipe on the suction side of the pump that is below the water line.

Insufficient SW pump speed

On some vessels the sea water pump is belt driven from the engine. The adjustment of the belt may cause it to slip. It may be that the pump does not attain sufficient speed as the driver or driven pulleys may be the wrong size.

Dirty or fouled SW cooler

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

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

Electrolysis in the SW cooler

The zinc anode(s) may have wasted and require replacing.

Leaking SW hoses or pipes

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

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

Marine growth

Marine growth can occur over suction grids, in suction boxes, in suction pipes and over keel coolers. This causes a gradual increase in the fresh water temperature.

Reduce the engine speed gradually until the normal operating temperature is obtained. The vessel will have to be slipped to clean any hull fouled devices and pipes.

Keel cooling pipes leaking

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

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

Fresh water system faults

Low water level

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

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

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

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

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

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

Thermostat not opening fully

The thermostat is in the closed position when the engine is cold and first started. In the closed position, the water is circulated through the engine only. As the engine reaches its operating temperature, the thermostat opens and allows the water circulating through the engine to pass through the fresh water cooler.

Should the thermostat stay in its closed position or not open fully, the engine will overheat. Feeling the pipe from the thermostat housing to the fresh water cooler will indicate whether or not water is flowing through it.

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

Faulty FW pump impeller

The impeller in the fresh water pump could be damaged.

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

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

Faulty FW pump seal

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

Leaking FW hoses or pipes

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

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

Scale on cylinder water jackets

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

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

Air in the FW System

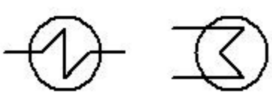
Not normally a problem when the engine is running. Air can get into the system when repairs are carried out and the cooling system is refilled. On starting the engine, bubbles will be sighted in the header tank as the air makes its way out. As the water replaces the air, the water level in the header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

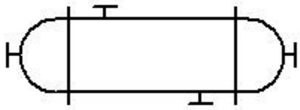
SECTION 12 – Heat Exchangers

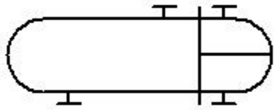
Heat exchangers

Symbols

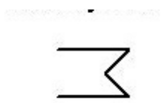
Heat exchanger, basic symbols | **Shell-tube, fixed tube plates** | **Shell-tube, U-tube or with floating head**

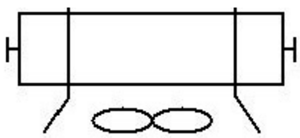


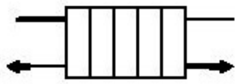




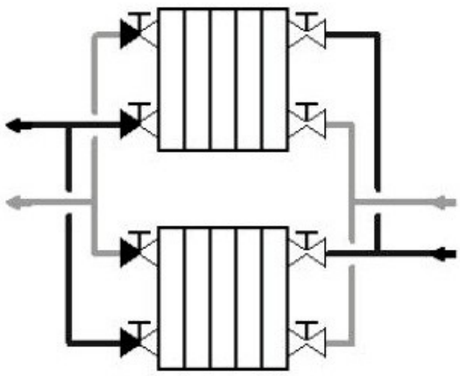
Heating / cooling coil, basic symbol | **Air blown cooler** | **Plate type heat exchanger**

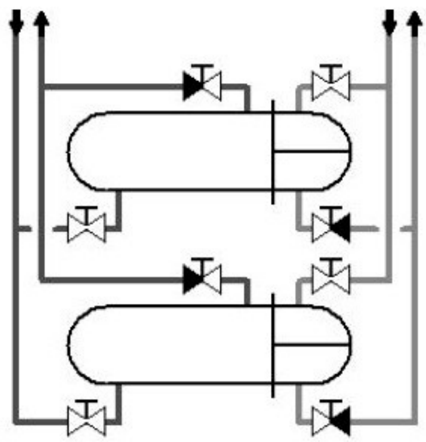






The heat exchangers are plate type, connected in parallel | **The heat exchangers are shell U-tube type, connected in parallel**





Example heat exchanger symbols

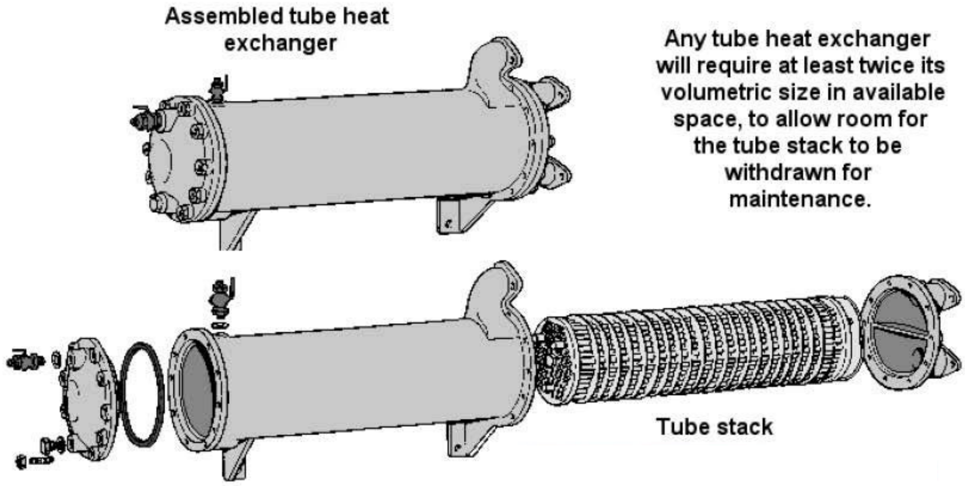
Types of heat exchanger

There are basically two types of heat exchangers used in water systems:

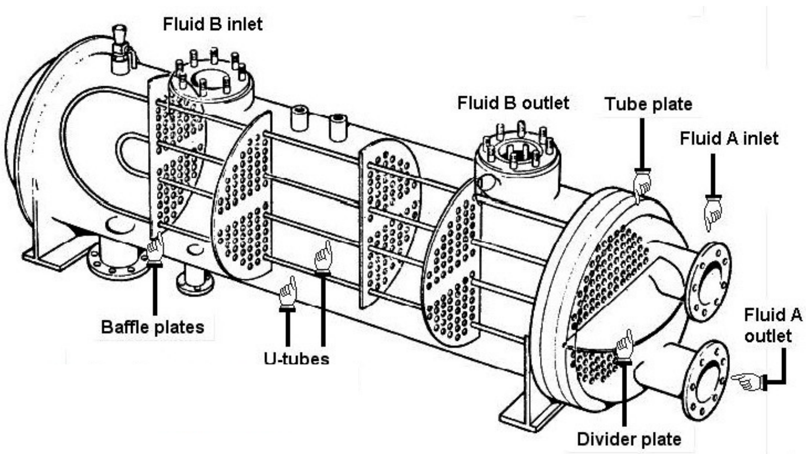
1 Shell tube heat exchangers;

2 Plate heat exchangers;

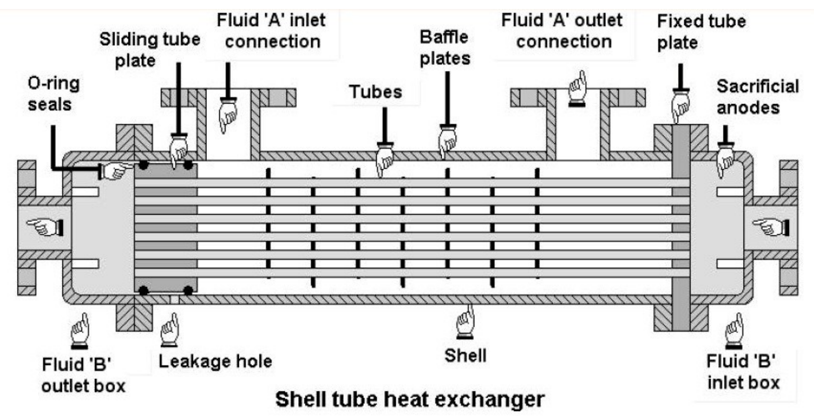
Shell tube heat exchangers



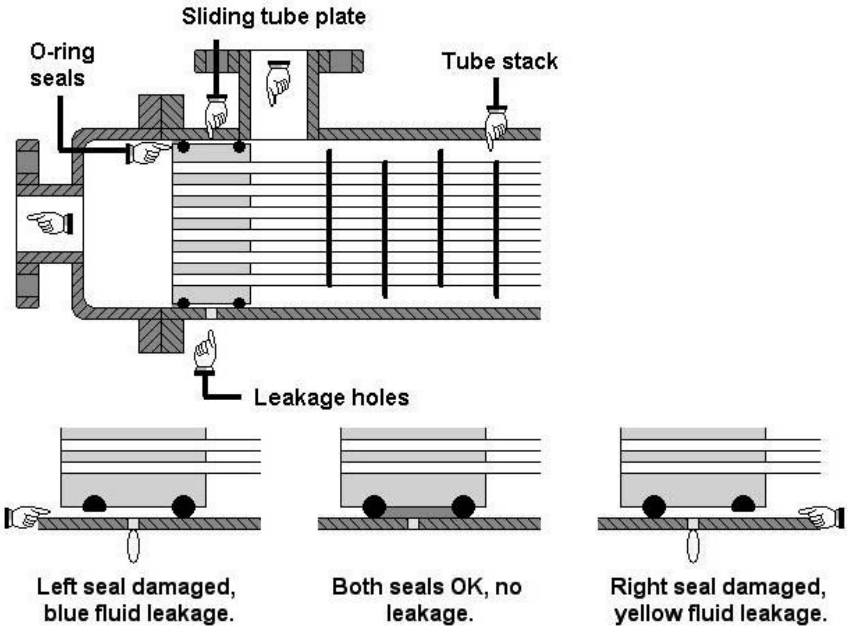
Shell and tube heat exchanger



Section through a U-tube heat exchanger

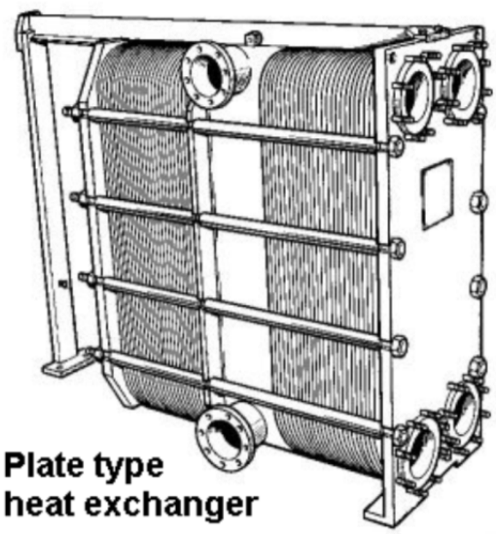


Shell tube heat exchanger



Leakage holes on a tube heat exchanger

Plate heat exchangers



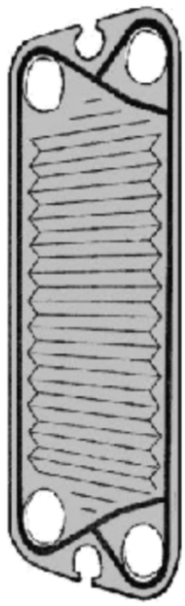


Plate element

The plate cooler comprises a set of plate elements grouped together between end plates and secured with horizontal tie bolts.

The plates are commonly made from high quality pressings made of either aluminium brass or titanium steel.

The seals between the plates are made of neoprene, or similar material, resistant to the fluids flowing through the heat exchanger.

The plates are pressed with corrugations. This has the effect of:

- Increasing the surface area of contact;
- Increasing the strength of the plate;
- Allows the plate to be made thinner increasing the rate of heat transfer.

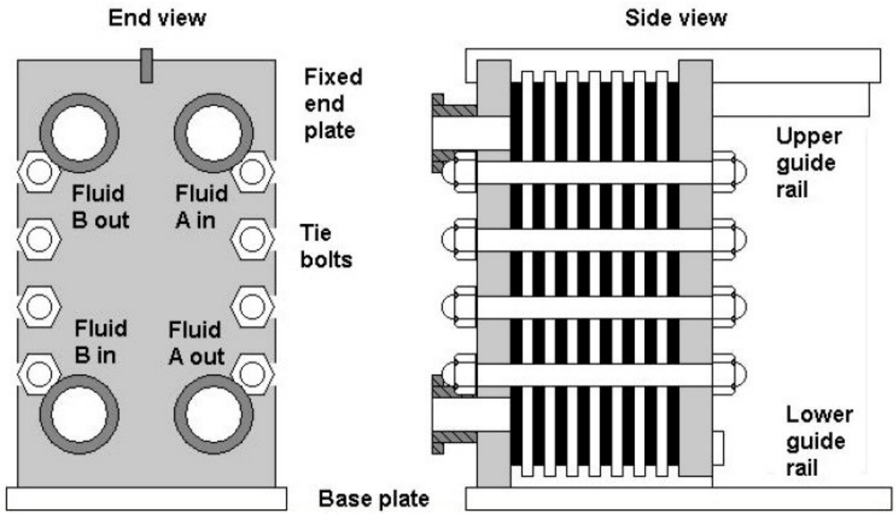
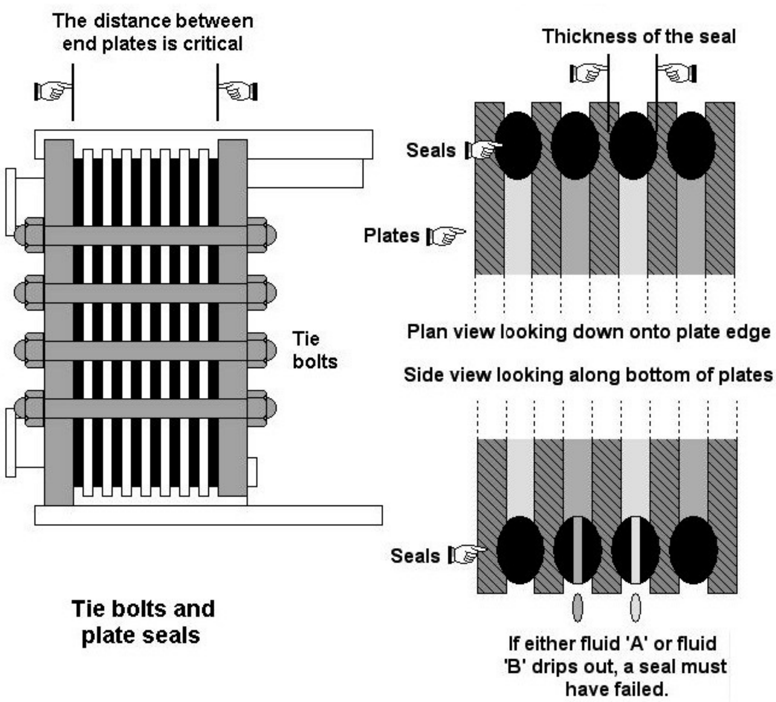


Plate type heat exchanger

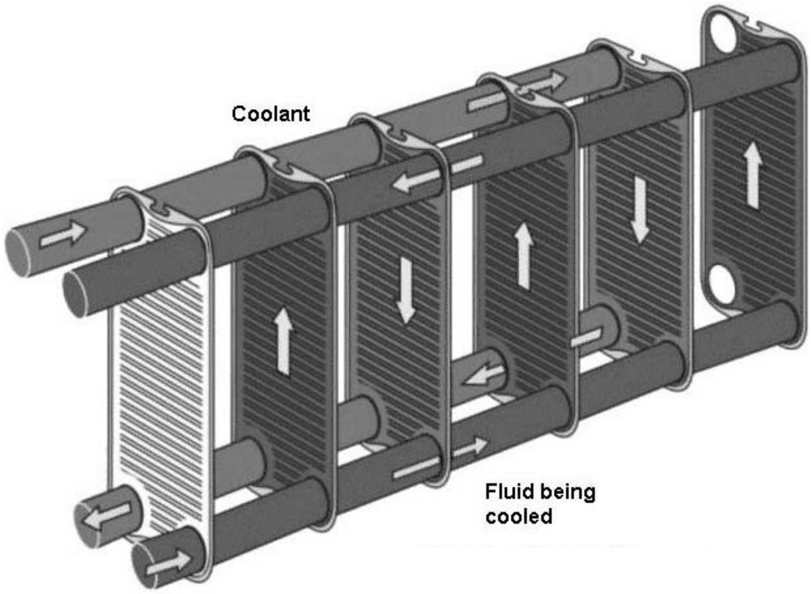


Tie bolts and plate seals

The spacing between the plates depends upon:

- The thickness of the plate seal;
- The compression pressure when the tie bolts are tightened.

In the event of a failure of one (or more) plate seals the leaking fluid will drip out of the heat exchanger, giving easy warning of the failure.



Counter flowpath through a plate cooler

Design criteria

There are many design criteria to be considered in a heat exchanger, including:

- Physical shape and size (floor area and height required);
- Surface area of contact for heat transfer;
- System resistance to flow (pressure drop across cooler);
- The time fluids are in contact in the cooler;
- Maintenance and cleaning;
- Materials used in construction.

The two most important are:

The surface area of contact. The greater the surface area of contact then the higher the rate of heat exchange.

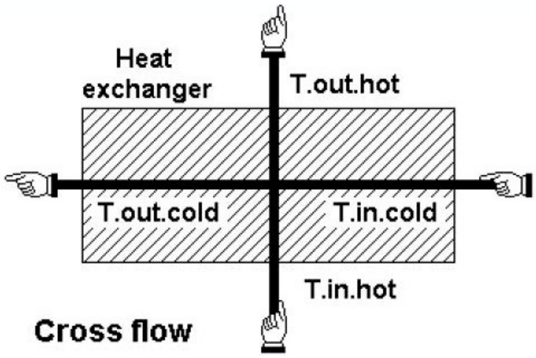
The time fluids are in contact. The longer the fluids are in contact then the higher the rate of heat exchange.

Flow through coolers

There are three basic methods of arranging flow through a heat exchanger:

1 Parallel flow; 2 Counter flow; 3 Cross flow.

The fluids flow in directions at right angles to each other through the heat exchanger.



What becomes important is the temperature differential across different parts of the cooler. If this is not correct distortion and thermal stressing can occur, together with undesirable expansion of materials.

The cross flow pattern is probably the most commonly found in heat exchangers.

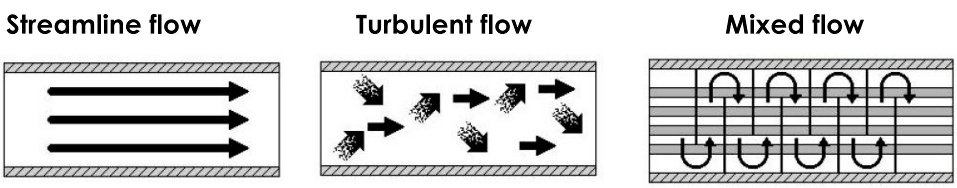
Types of flow

There are three basic type of flow:

1 Laminar;

2 Turbulent;

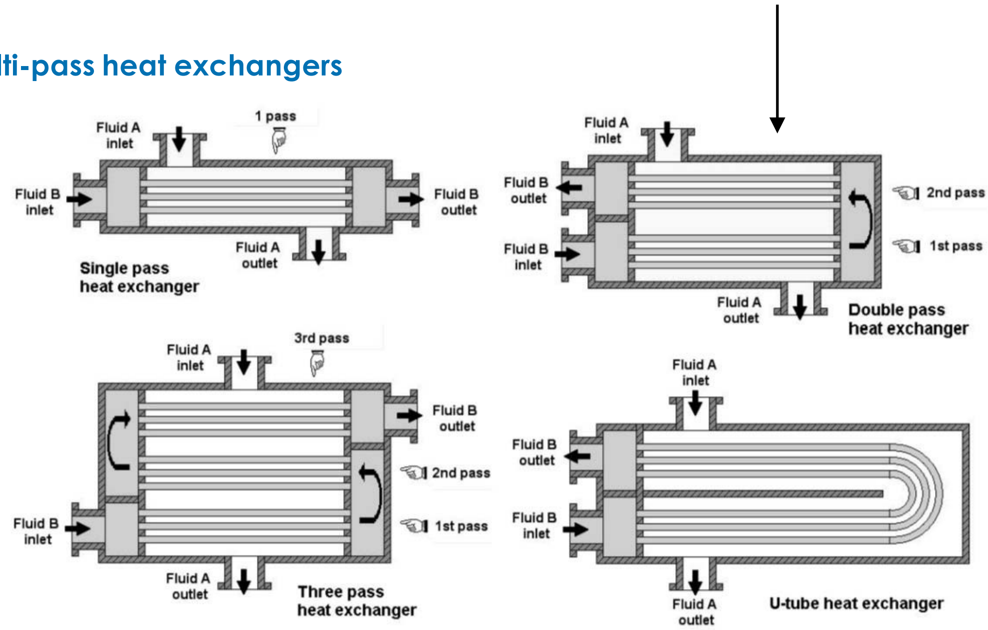
3 Mixed (a combination of laminar and turbulent).



Streamline flow	Turbulent flow	Mixed flow
Smooth flow, high velocity	Rough flow, velocity reduced.	Smooth flow, lower velocity
Low erosion effects	High erosion effects	Lower erosion effects
Fluid velocity higher, reduced heat transfer rate	Fluid velocity lower, increased heat transfer rate.	Fluid velocity lower, increased heat transfer rate.

The mixed flow is a combination of laminar and turbulent flow. There are various ways of achieving the mixed flow pattern, such as fitting a series of baffle plates that guide the fluid around the heat exchanger. This keeps the fluids in contact for a longer time increasing the rate of heat transfer. **A two - pass cooler is shown below**.

Multi-pass heat exchangers



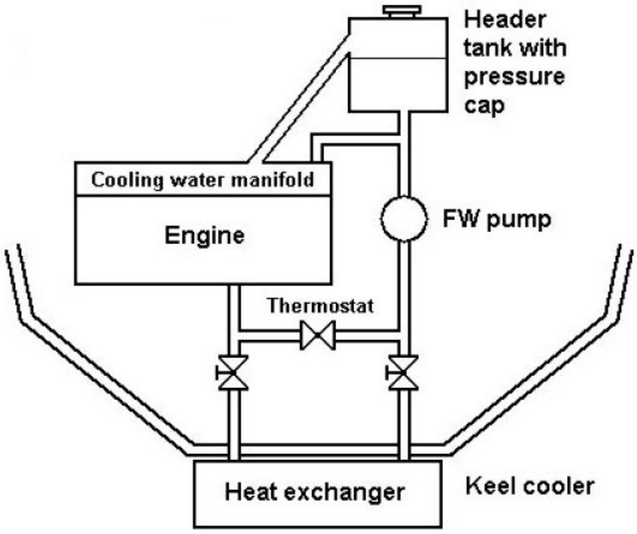
Fluid contact time can be increased by using multi-pass heat exchangers. This also increases tube surface area further increasing heat transfer.

A problem associated with the U-tube heat exchanger is cleaning the internal side of the U-tube, as it cannot be punched using a conventional tube cleaning brush.

Leaking Tubes

If one tube is found to be leaking a fine tapered brass plug can be hammered in place at both ends. Up to 10% of blanked off tubes is generally considered acceptable.

Keel cooling system

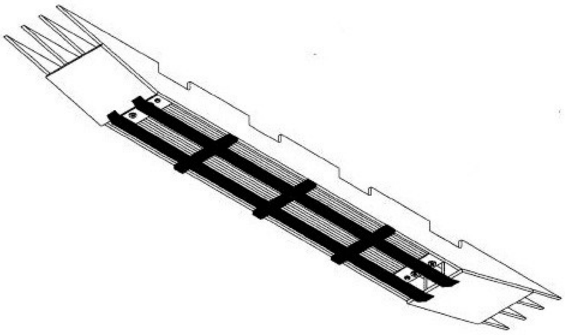


- **Keel cooler system**

The coolers are usually of shell and tube type construction. Some vessels have a device called a keel cooler.

This is a shell and tubing cooler mounted on the outside of the ship's surface.

The shell is open to water currents so that the outlet from the engine's cooling water passes through tubing in the keel cooler to a pump and back to the engine.

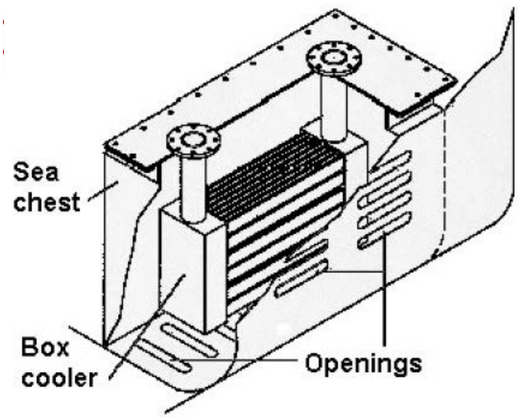


Keel cooler

The keel cooler relies on either water current or vessel motion to create the water motion on the outside of the tube surface.

An advantage of the keel cooler is that it prevents dirt and matter from entering the shell and tube exchanger.

Keel cooling has the advantages that the sea water pump is eliminated and there is no external water inlet that may become clogged and restrict engine cooling. The disadvantage is that marine growth on the pipe heat.



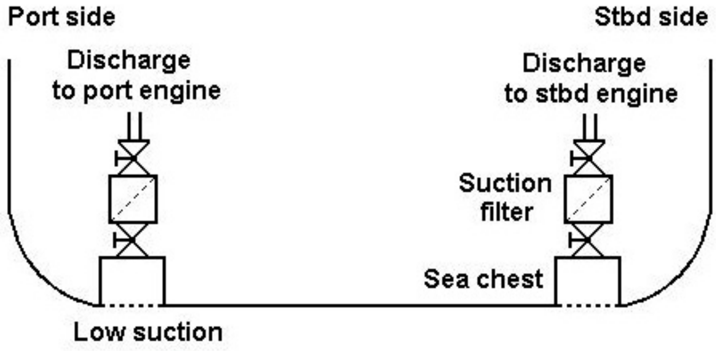
Sea chest cooler

A derivation of the keel cooler is the sea chest box cooler, a heat exchanger mounted in a sea chest at the turn of the bilge.

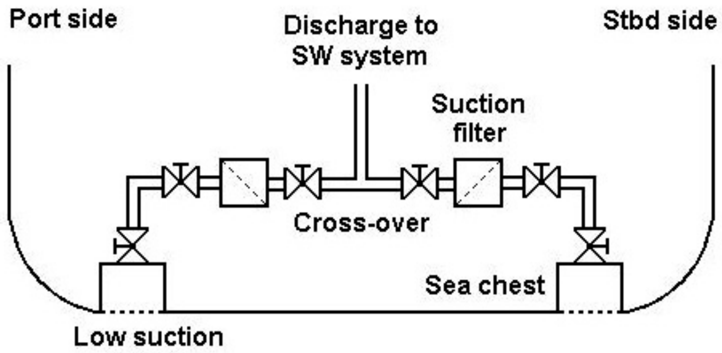
Sea water passes over the heat exchanger via openings cut in the hull plating.

SW intakes

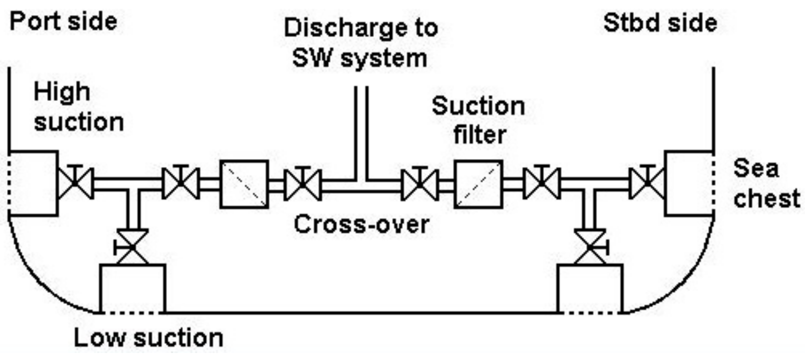
There are several methods of arrangement of SW intakes on a vessel, some common arrangements are shown below.



Independent low suctions



Low sea suctions with cross-over



High and low sea suctions with cross-over

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

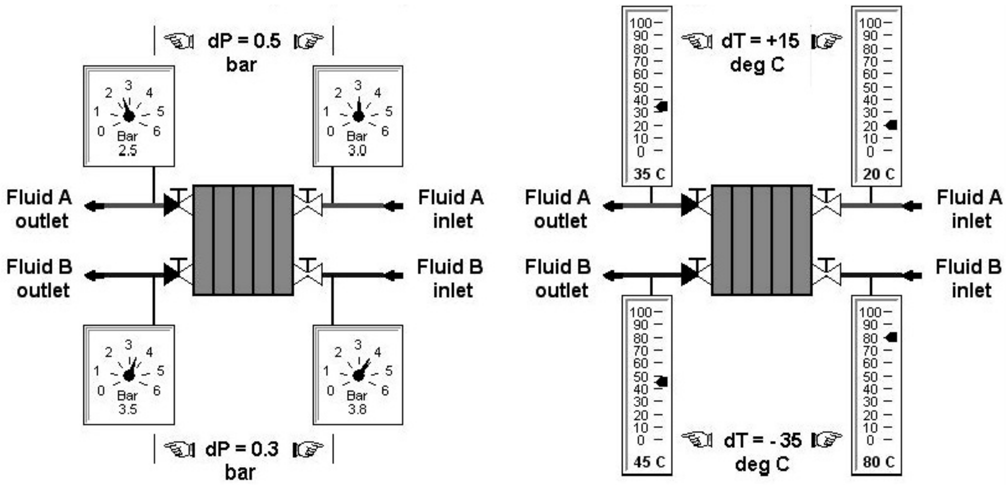
Sea water flow alternatives

Some sea water flow alternatives are as follows:

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

Monitoring heat exchangers

By monitoring the differential pressures and temperatures and using trend analysis the time when a heat exchanger needs cleaning can be predicted. The differential pressure is sometimes known as the **pressure drop** across the heat exchanger, and is a measure of the resistance.



Pressure and temperature monitoring

The differential pressure is sometimes known as the **pressure drop** across the heat exchanger, and is a measure of the resistance.

The following parameters can be monitored on a heat exchanger:

Fluid	Parameter	Calculated or measured
A	inlet temperature	differential temperature
A	outlet temperature	
B	inlet temperature	differential temperature
B	outlet temperature	
A	inlet temperature	differential pressure
A	outlet temperature	
B	inlet temperature	differential pressure
B	outlet temperature	

SECTION 13 – Engine Start Systems

Diesel engine starting systems

Starting methods

There are various methods of starting diesel engines that include:

1 Hand cranking;

2 Electric start;

   a Inertia starter motor

   b Pre-engaged starter motor

3 Pnuematic;

   a Air motor;

   b Air distributor with air start valves;

4 Hydraulic;

   a Rack and pinion;

   b Hydraulic motor;

5 Spring tension motor;

The method used to start the engine depends upon several factors, including:

- The size and power of the engine;
- Function of the engine (main, alternator, emergency alternator etc.);
- Type of power supply available;
- Cost of installation.

Hand cranking start systems

The most favoured method of starting smaller diesel engine is perhaps by hand cranking.

There is nothing wrong with hand cranking except, perhaps, that it requires physical effort and in boating, no less than other activities, human exertion is considered to belong to a past era. But as a starting system, hand cranking is just as effective as electric, inertia, gas or any other method. Why? Hand cranking provides the required action, rotating the crankshaft and setting the engine's mechanical parts in action so that the engine is started.

It also has certain advantages especially that it is cheap. It requires no ancillary equipment adding to costs and maintenance. But perhaps its chief attribute is to bring the operator into a close relationship with the engine, providing a person sensitive to mechanical things with quite an insight into its whims and fancies, and engines do have these moods, being affected by atmospheric differences as, for example, dryness or humidity, heat or cold and variations in fuel.

Electrical starting systems

Electrical starting systems

The electric starting motor requires a large current and imposes a big drain on the battery. This requires that the engine should be a good starter, that the battery should be kept in good condition and that the power cables from battery to starter motor should be of adequate size and that all terminals and joints should be kept absolutely clean. An electrical starting system could be either a 12 volt or a 24 volt battery system.

The Bendix drive is used for petrol engines, but diesels, with their higher compression ratios, require a somewhat tougher starting effort and the arrangement, which places the pinion in contact with the flywheel ring first, is favoured.

In the **axial** starter the complete armature assembly and pinion moves forward axially to engage the pinion with the flywheel.

In the **co-axial** starter the pinion and pinion sleeve travel along the armature shaft to engage the flywheel.

There is the **non-axial** type in which the pinion moves forward slowly under controlled conditions to become gently, but fully engaged with the flywheel before full current is fed to the motor.

Whatever the system used, all these mechanical and electrical arrangements are operated automatically, it merely being necessary to press a button or turn a switch to bring them into operation.

Electric starter motors

There are two main types of starter motor fitted to diesel engines, the difference being in the method of engaging with the flywheel ring. They are:

1 The inertia starter;

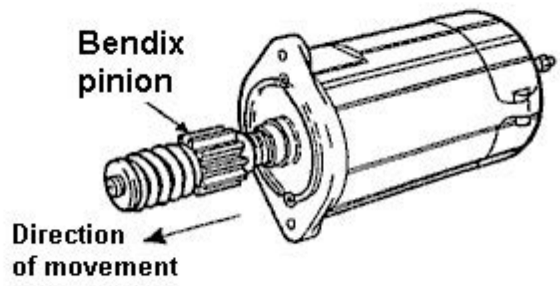
2 The pre-engaged starter.

In operation, the principle the starter motor is no different from any other electric motor. It has a revolving armature located on a central shaft, or spindle, which rotates inside fixed coils, attached to the motor body.

Current is fed to the armature windings via brushes and the commutator and the attraction and repulsion between magnetic fields set up by the energised coils causes the armature to rotate. There is no speed control. The motor draws from the battery the current it requires to turn the engine and it is automatically cut out as soon as the engine fires.

The connection between the starter and the engine is through two gear wheels, a toothed ring fitted around the flywheel perimeter and a small matching toothed pinion located on the starter-motor spindle. The ratio between these two is about 10:1, which means that the effort exerted by the motor is multiplied ten times.

Bendix drive inertia starter motor



Inertia starter motor

On engines up to moderate horsepower the Bendix drive is used in which part of the starter motor spindle is threaded, the thread being of the rather coarse pitch type somewhat like a wood screw. The toothed pinion is a loose fit on this thread and is free to move along it.

The pinion is mounted on a screwed sleeve. When the motor turns at a fairly fast speed the pinion is thrown along the shaft and engages with the gear teeth on the flywheel.

When the speed of the engine becomes higher than the motor speed the pinion is thrown out of mesh with the flywheel starter ring. When the starter switch is released the motor slows down and the pinion returns to its original position.

This action is automatic, occurring every time current is fed to the starter motor by pushing the starter button or turning the ignition switch to the 'start' position. As soon as the engine fires the switch must be released.

The starter takes a heavy, current on load, sometimes up to 60 amps, so it is essential to use heavy duty cables from the battery to the starter motor.

These cables should be as short as possible so generally the battery is located as near to the engine as possible. A problem can occur when the control for starting the engine is required on bridge/wheel house.

The out of mesh clearance is very important in a Bendix or inertia type starter motor. It is the distance between the leading edge of the pinion and the facing edge of the starter ring. This distance is important so that the starter pinion does not foul the facing edge of the starter ring and does so with the minimum amount of rotary movement.

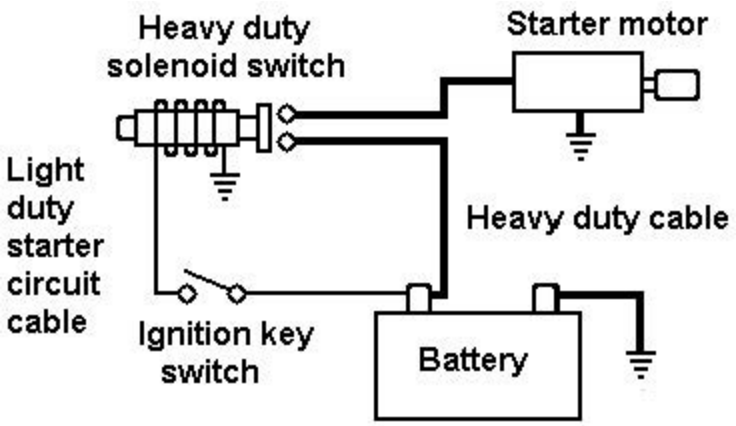
It can be checked by taking two measurements:

1. **From the leading edge pinion to the fixing flange of the starter**
2. **From the leading edge of the flywheel to the starter fixing flange**

The clearance is the difference between the two measurements

Typically 1/8th of an inch (3-5mm) is common. Always check manufacturers data.

Starter switch



Inertia starter electrical circuit

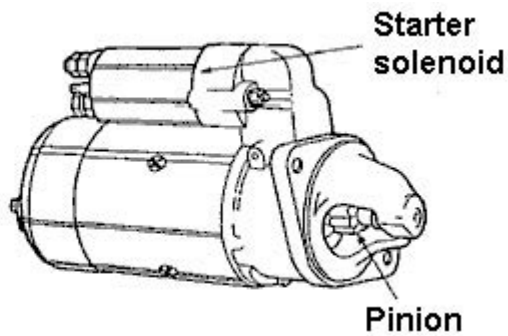
The high current used by the electric-starter motor requires a suitable heavy duty switch having substantial contacts.
The duty of closing the contacts is undertaken by a solenoid.

When current flows through the coil it sets up a magnetic field that moves the plunger that in turn closes the contacts.

The heavy current then flows from the battery to the starter motor. The advantage of this system is that a light duty ignition switch is suitable because the solenoid is energised by a low current. High current circuitry is thus kept right away from the engine control panel or console.

The ignition switch may be located in the wheel house, all the other units are in the engine room. The solenoid is situated near the starter motor on the cylinder block. Sometimes the starter motor has a local button for local manual operation.

Pre-engaged electric starter motors

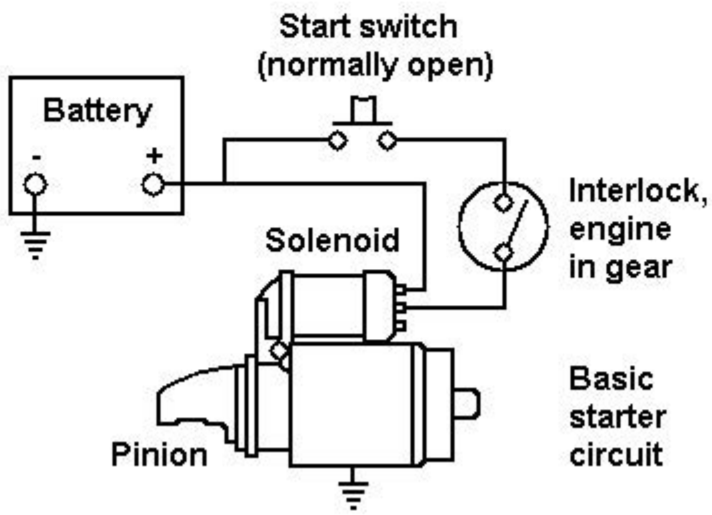


Pre-engaged starter motor

On larger engines involving higher starting loads, pre-engaged type starters are used, the prime object being to prevent premature ejection of the pinion from the flywheel.
In this system the pinion is moved into engagement with the flywheel ring electrically, before full current is supplied to the motor.

Overload and over-speed protection is taken care of by a plate or roller clutch. Earlier pre-engagement motors were equipped with manual operation of the pinion through mechanical linkage controlled by the operator, but in current practice this has been superseded by electrical control and the whole action of the starter motor and engine starting is automatic.

There must be immediate disconnection when the engine fires as otherwise the flywheel would drive the starter motor and the excessive armature speeds would soon result in damage to the unit.



The solenoid on this starter is moulded on the housing.

When the ignition switch is turned current flows to the starter.

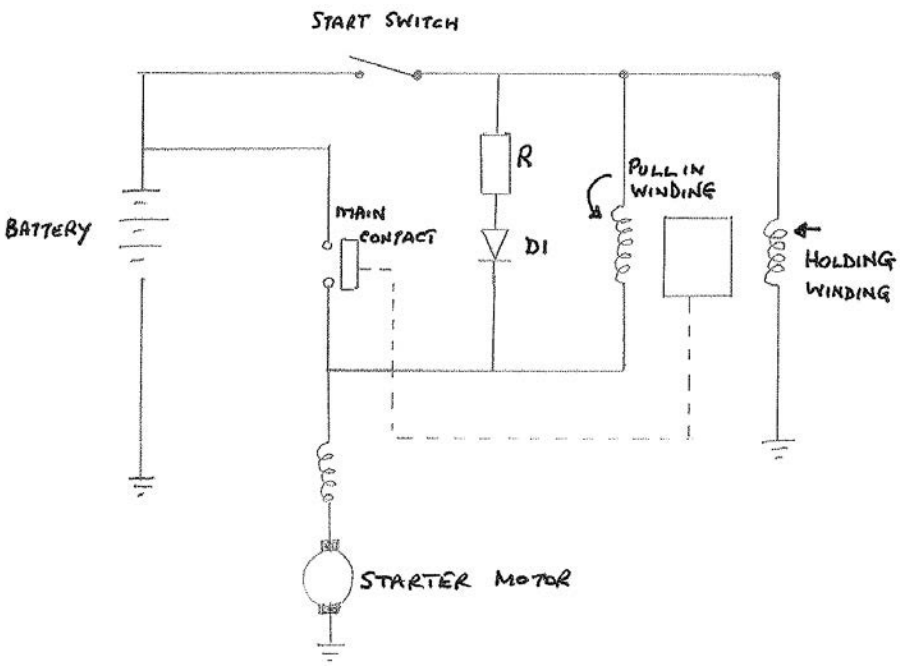
The solenoid pulls the pinion into mesh with the flywheel and only when this happens is the full current allowed to flow to the starter.

The pre-engaged starter is more popular as it greatly reduces wear because the pinion is already engaged with the flywheel gear ring before the motor turns in the starter circuit a safety interlock device has been added. This prevents the engine being started if it is in gear. An interlock maybe defined as a safety device that will prevent something happening unless certain conditions are met.

Typical interlocks that may be fitted include:

- Turning gear interlock, that prevents the engine being started if the turning gear is engaged.
- Zero pitch interlock, that prevents the engine being started if the vessel is fitted with controllable pitch propellers(CPP), and the propellers are not at zero pitch.
- Gearbox or Engine LO pressure, that prevents the engine being started unless there is sufficient LO pressure present.
- Emergency stop push — manual reset

The 2 winding electric starter motor



This type of starter motor utilises 2 windings, one heavy duty winding to pull in the starter shaft and the other to hold on until the start switch is released. When the switch is closed current flows through R and D1 and through the pull in winding and the motor begins to turn as long as the switch is held closed. The pull in winding and the holding winding energise the main contact and full current (through less resistance) is applied to the motor directly and not through the switch.

Starting air systems

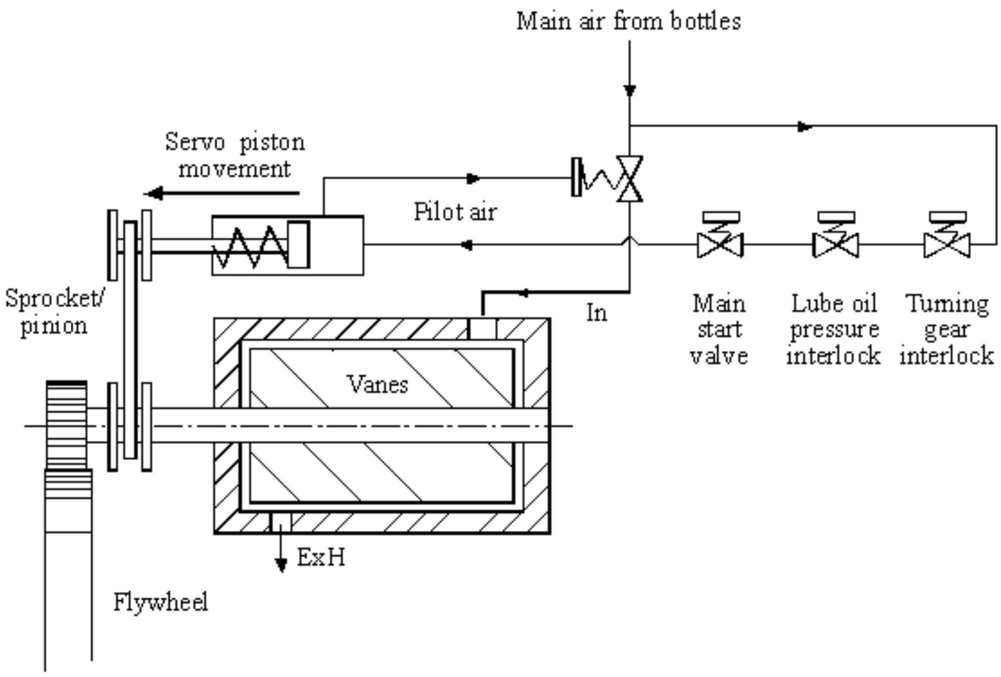
Methods of air start

There are two common methods used to air start an engine:

1 An air start motor;

2 An air start distributor with air start valves.

Air motor start system



When the start button is pressed pilot air passes to the pinion servo cylinder. The piston moves the pinion to engage the flywheel, and at the same time uncovers the pilot air supply to the air operated main valve.

The main valve opens allowing an air supply to the air operated vane motor (or similar type). The motor turns the flywheel thus starting the engine.

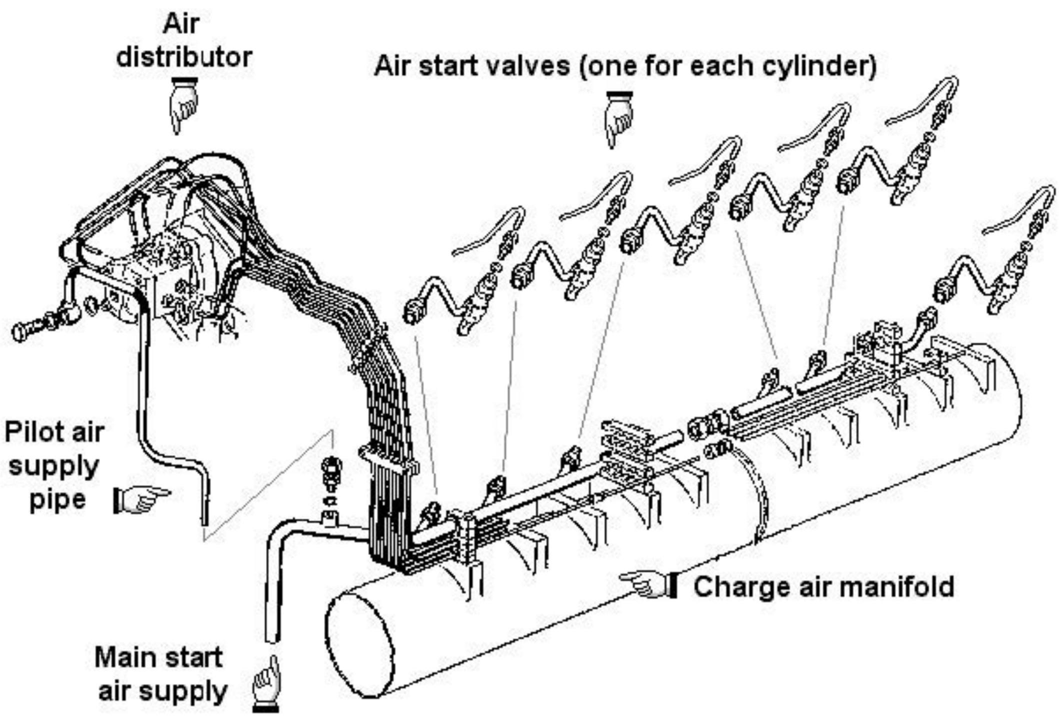
When the start button is released the pilot air is shut off the pinion is withdrawn and the main valve is closed.

Air start system with air distributor

Main components

The main components of the system include:

- The air supply;
- The air distributor;
- The pilot air system;
- The main start air system;
- The air start valves;
- Safety devices.

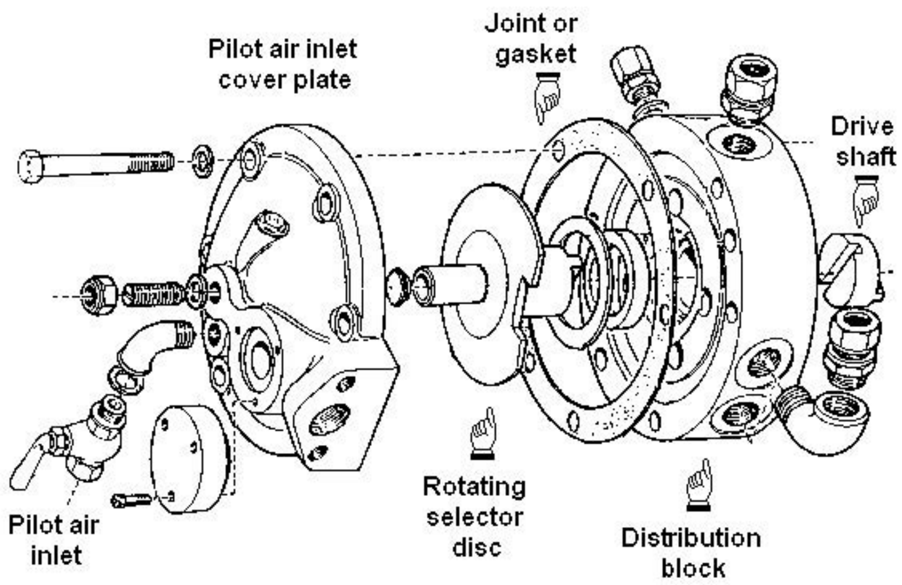


Components of an air distributor air start system

The air distributor

The method of starting diesel engines with the air distributor is by supplying compressed air into the cylinders in the appropriate sequence for the required direction. This sequence normally follows that of the firing order of the engine.

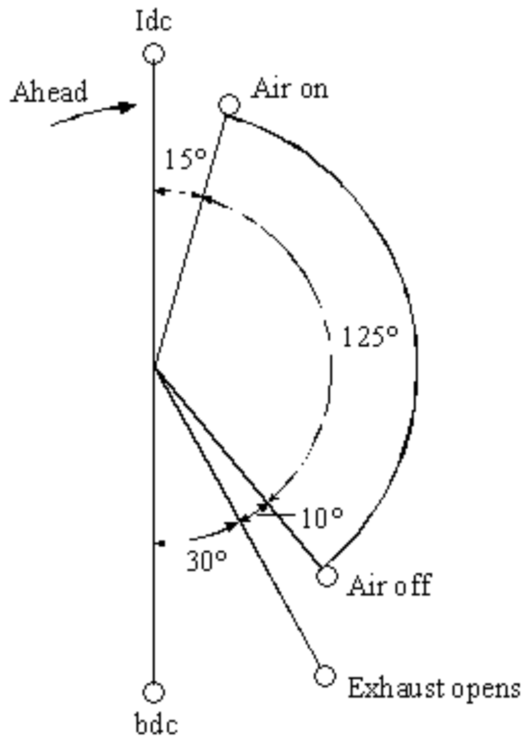
The sequence of air supply is controlled by the air distributor, which is commonly driven from the end of the engine camshaft. The air distributor is a rotating selector disc that supplies pilot air to the air start valves to open and close the valves with the correct timing.



Section showing the components of an air distributor

Air start timing

Starting air is admitted just after top dead centre (TDC) on the power stroke, and is closed off just before the exhaust valve opens.



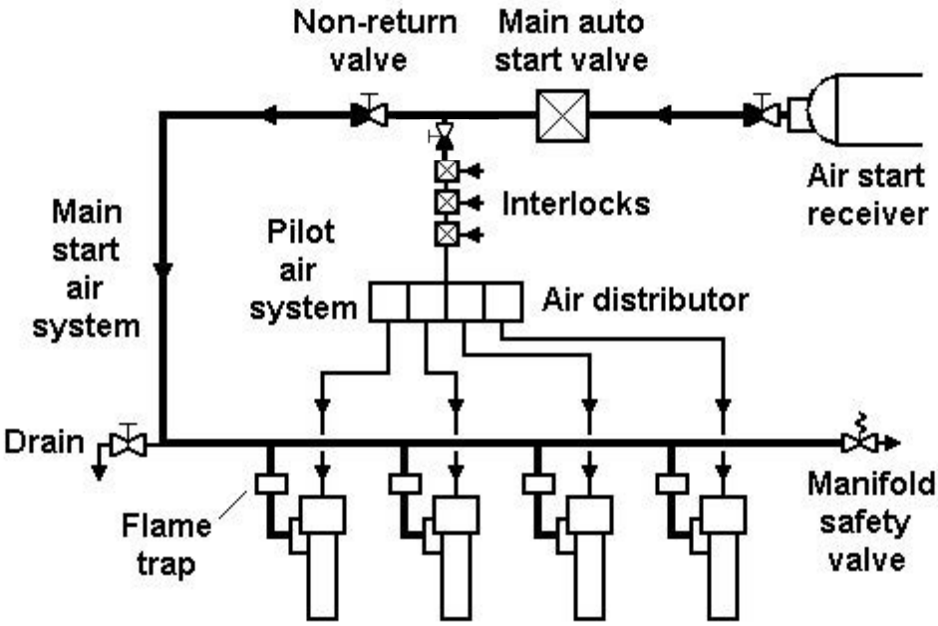
Start air timing, 4 stroke engine

Air start system with air distributor

Compressed air at starting pressure (commonly 30 bar) is stored and supplied to the system from the main air start receivers.

The main starting valve (automatic valve) is operated by a pneumatic actuator. Similar actuator controls are fitted to the distributor or timing, valves. The main starting valve can be locked shut and this must be done before the engine turning gear is engaged. When this valve is open, air passes through a non-return valve to the main manifold supplying pressure to the cylinder valves, one of which is fitted to each cylinder of the engine.

The cylinder air start valves are normally held closed by a compression spring together with cylinder pressure acting over the valve lid. Air from the manifold enters these valves, via a flame arrester, where it forms a pressure balance between the underside of the valve lid and a balance piston of equal area on the valve spindle. Consequently, this does not cause the valve to open.



Start air system with air distributor

Cylinder valves are opened when operating pilot air, transmitted from the distributor, applies pressure to the larger operating piston on the valve spindle. As the valve is forced open, starting air from the manifold enters the cylinder, applying pressure on the piston and causing the engine to rotate in the corresponding direction. To close the cylinder valves the connection from the distributor is opened to atmosphere, allowing the spring to close the valve and return the operating piston.

Starting air is shut off from the engine as soon as sufficient starting speed has been reached; fuel is then applied and engine speed increased.

Safety devices

The following safety devices are fitted to an air start system:

- The air start manifold is fitted with a pressure safety valve in the event of an air start valve leaking combustion pressure into the system;
- Each air start valve is fitted with a flame trap to prevent hot combustion products leaking back into the system in the event of an air start valve jamming open or leaking;
- Pipework is fitted with adequate drains to keep the system free of oil and water;
- The main air start supply line is fitted with a non-return valve;
- Interlocks devices to prevent the engine being started unless it is safe to do so.

Interlocks

An interlock may be defined as a safety device that will prevent something happening unless certain conditions are met such as stop not reset or throttle not at zero.

Typical interlocks that may be fitted to the pilot air system of an air start system include:

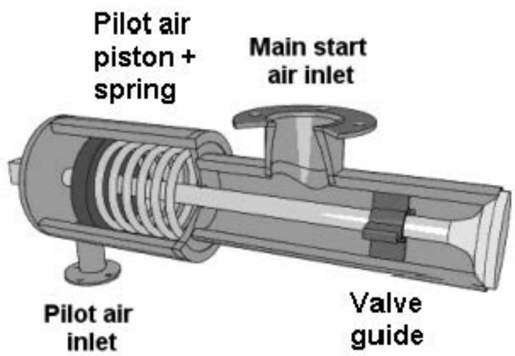
- Turning gear interlock, that prevents the engine being started if the turning gear is engaged;

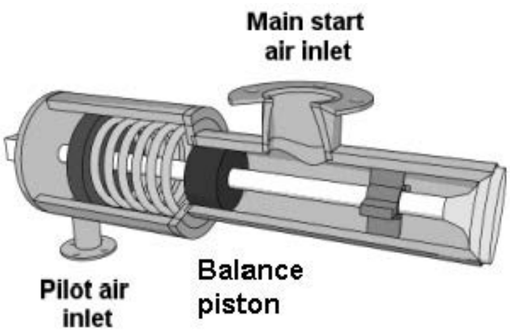
- Zero pitch interlock, that prevents the engine being started if the vessel is fitted with controllable pitch propellers (CPP), and the propellers are not at zero pitch;
- Gearbox LO pressure, that prevents the engine being started unless there is LO pressure within the gearbox.

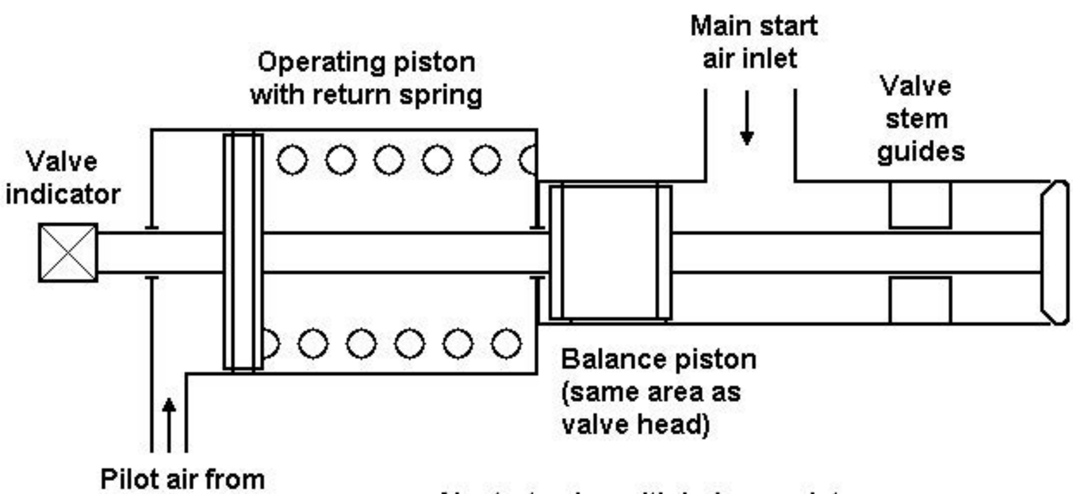
Air start valves

There are commonly two basic types of air start valve:

1. A standard air start valve;
2. An air start valve with a balance piston.







Air start valve with balance piston

Number of air start valves

A main engine must be capable of starting from any position and it is normal to have air start valves fitted in each cylinder.

The air is admitted into the cylinder just as the engine comes overtop dead centre on the power stroke and is shut off just before the exhaust valve starts to open. The actual angle the engine turns through while air is admitted to the cylinder is dependent on the number of cylinders and the degree of overlap.

For instance a four cylinder 4 stroke engine will have no overlap between the air start valves that must be open for the maximum time allowable. For the engine to be able to start from any position of rest a 4 stroke engine must have at least 6 cylinders with an air start valve on each cylinder.

A 2 stroke engine must have at least 3 cylinders with an air start valve on each cylinder.

If the engine has less than the number of cylinders required to start from any position, or if there is not an air start valve on every cylinder, then the engine must be barred into a position which will enable starting to take place.

This will be a position where a piston has just gone over TDC in a cylinder with an air start valve. **Air start pressure in one cylinder overcomes the compression in the other cylinders due to the amount of work done.**

Multi-cylinder V-type engines may only be fitted with air start valves to one bank of cylinders. Because of the firing order and the number of cylinders it is not necessary to fit air start valves to both banks of the engine.

Leaking air start valves

Leaking air start valves and oil in the system have been responsible for explosions in air start lines (see MSN 474). A high velocity explosive wave travels down the pipeline seeking out oxygen and fuel and can destroy pipelines and valves, causing fires and injuring personnel.

A non-return valve is located between the engine and the starting air receiver. Situated as close to the engine manifold as is practically possible, so that any explosion in the starting air manifold is contained in as small a length of piping as possible and prevented from getting back to the air bottles.

To vent the build-up of pressure as quickly as possible some form of relief should be fitted between the non-return valve and the air start valves.

Checks must be made that cylinder starting air valves do not leak.

These checks can be carried out while the engine is running by feeling the temperature of the air pipe adjacent to the valve. If an air start valve is leaking the paintwork near the valve will become discoloured and blister.

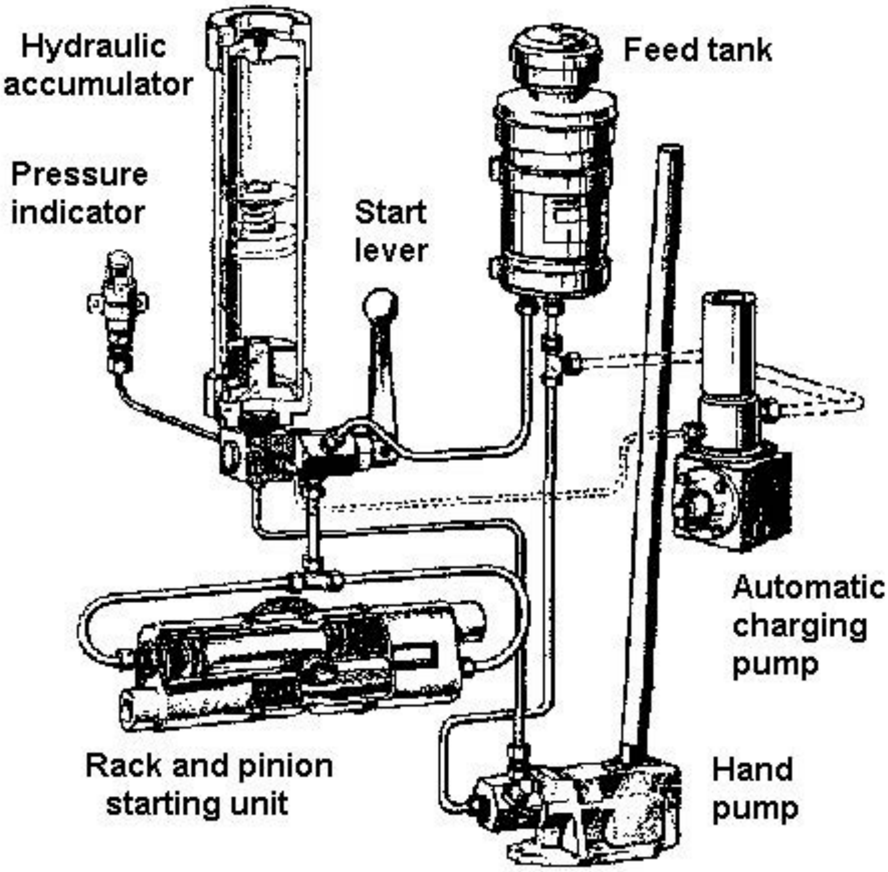
Checking pipeline drain valves for excessive pressure will also give an indication of a leak.

Tests while the engine is stopped require starting, air to be applied and the main valve opened, after first blocking off air to the timing valves. Pressure will escape into the cylinder of any leaking, air valve and this can be detected by listening at the open indicator cock (if fitted)

Hydraulic starting systems

Bryce-Berger hydraulic system

This compact system provides the highest cranking speeds and the fastest start. It is commonly found as the starting system on emergency diesel alternators.



The Bryce-Berger hydraulic start system

The principal component is the hydraulic accumulator in which a simple free piston operates. The cylinder space above the piston contains the nitrogen compressed to approximately 190 bar and permanently sealed in.

To provide energy for operating the starter unit hydraulic fluid is drawn from a feed tank by hand pump and pumped into the accumulator below the piston. Further pumping forces the piston up the cylinder until the nitrogen is further compressed to 290 bar. A relief valve protects the system, and an indicator shows the pressure reached.

The other main component is the starter unit, which consists of two opposed cylinders each containing a piston and rack. The racks engage with a common pinion, which in turn is integral with a toothed dog mating with a corresponding dog on the end of the engine crankshaft. **Dog** is an engineering term used to denote a particular form of linkage between the mechanical components, in this case toothed wheels, or cogs. The pinion and racks have a helical tooth form that throws the pinion dog into engagement with the crankshaft dog in similar manner to that of the Bendix drive.

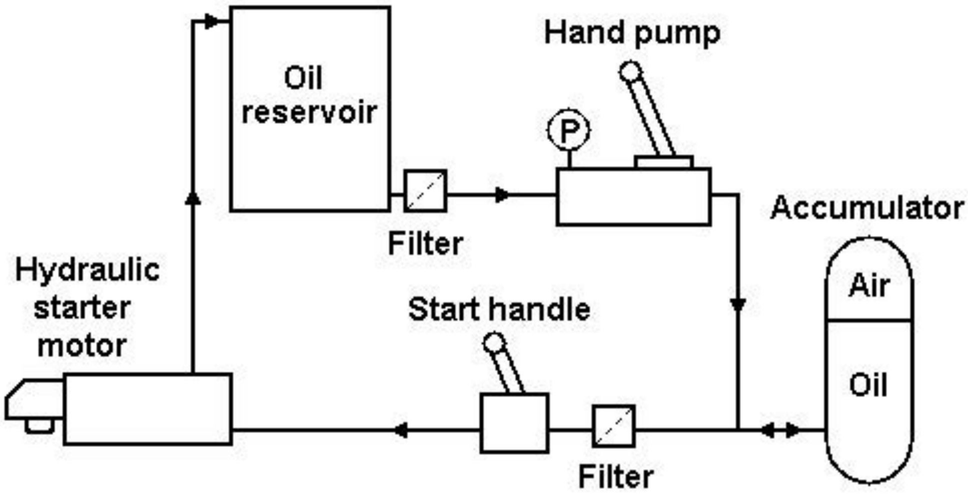
To operate the starter the starting lever is pulled which is the point at which the pinion and crankshaft dogs engage.

It is a two-stage operation. First a slow feed of pressurised fluid to the starter pistons cause the gradual turning of the starter dog. Then a full pressure is admitted to the heads of the piston-racks causing high-speed rotation of the crankshaft with a high starting torque. The pressurised fluid acting on the starter piston-racks comes from the accumulator unit motivated by the pressurised nitrogen.

After the engine starts, or at the end of the starting operation, the starting lever is released, the fluid returns to the feed tank and the piston again rests on the bottom of the accumulator cylinder and the system is set ready for re-use. The cycle can be repeated indefinitely.

If the hand pump is operated with the accumulator uncharged and the starting lever in the open position, slow, precise rotation of the engine crankshaft can be obtained, for tappet and fuel supply adjustments. Remote starting control can be arranged and there are a number of combinations covering, partial to fully automatic operation.

Hydraulic starter motor

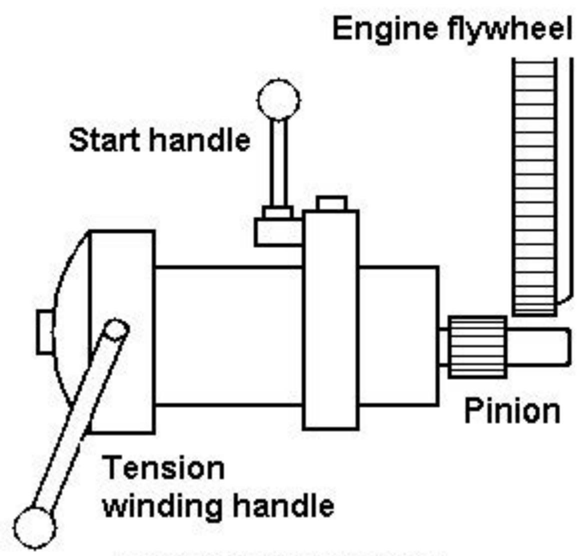


Hydraulic starter motor system

A hydraulically operated starter motor is fitted in the same location as an electric starter motor unit. The accumulator contains high-pressure oil produced by the hand pump.

When the starting valve is operated high-pressure oil turns the motor that engages with the engine flywheel thus starting the engine. When the engine starts, the pinion of the starter motor is thrown out of mesh. With this system, the engine is started from the engine room.

Spring tension motor



Spring loaded starter

The spring tension starter looks much like the normal electric starter motor and is fitted to the engine in the same way.

Its action is mechanical and it eliminates the need for batteries, generators and heavy-duty cables.

In some instances it could be carried as a spare to be used in an emergency.

A winding handle is used to compress a spring fitted inside the casing. When the spring is released, it drives a pinion in the same way as the electric starter. When the engine fires the pinion is thrown out of mesh.

Apart from being very simple to operate it will start diesel engines of six cylinders each up to 1000cc in capacity. It offers additional advantages that by being dust and damp proof it is particularly suitable for marine use in all climates and conditions. But perhaps its most unique feature is the facility it offers of turning the engine over slowly through its own reduction gear when tappet adjustment, spill timing and fuel system priming is required.

The working principle is simple enough. A winding handle is used to turn a mechanism that compresses a spring consisting of dished spring washers located on a common sleeve. The drive to the engine flywheel is the normal Bendix arrangement and as soon as the winding handle is turned the pinion engages with the flywheel teeth. Further winding of the handle, up to about twelve revolutions, compresses the springs, while the main shaft is held stationary. The starter is then fully charged and ready for use.

To release the stored energy and start the engine a hand-operated trip lever is pulled and the main shaft rotates rapidly until the springs have returned to their normal uncompressed position.

For starting a hot engine full compression of the springs is not necessary. When the engine fires and overruns the starter the pinion is thrown out of mesh in the normal way. The winding adaptor, to which the winding handle is fitted, can be varied in position in increments of 30° so that the most convenient angle can be chosen. Loadings on the handle, which operates through a reduction gear, are not excessive and, although more physical effort is required than with electric starting, it is a starting system offering high output with ever-ready, virtually cost-free operation under any conditions, requiring no ancillary equipment and only minimal maintenance.

Engine fails to Start

The most common reasons for an engine failing to start are:

- Reduced or loss of start energy battery, compressed air, hydraulic pressure
- Loose and or dirty electrical connections
- Valve line up for fuel system incorrect
- Governor fuel rack locking pins left in
- Emergency stop not reset
- Overspeed trip not reset
- Loss of governor electrical supply or battery back up
- No fuel
- Wrong fuel – cetane value, N.S.E.
- Contaminated fuel – Water,
- Interlocks not reset – turning gear, throttle at zero, zero pitch, clutch engaged etc
- Air start motor pinion jammed in flywheel
- Clutch engaged
- Luboil pre-lub pressure not established or faulty sensor
- Cold engine
- Cold fuel - reduced N.S.E
- Seizure

SECTION 14 – Engine Operation and Maintenance

Preparing for Sea

Preparation for sea entails a multitude of tasks to ensure the diesel auxiliaries and propulsion equipment is running in a safe and efficient condition. The tasks are as follows:

Auxiliary & Propulsion Diesel Fresh Water Systems

Before any shut down of the diesels ensure that the circulation heater is operating especially in cooler climates.

a) Ensure that both the fresh water systems for the auxiliary and propulsion diesels are full. Fill the fresh water expansion tank as appropriate.
b) Ensure all the appropriate valves are open for the fresh water systems, making sure that the fresh water expansion tank levels are maintained.
c) If the fresh water system is a centrally cooled system, note the fresh water pump discharge pressure (or flow indicator) and walk the line ensuring that there are no visible leaks.

Note: If there is a persistent drop in the level of the expansion tanks. The reason for the drop in level is to be investigated and rectified.

Seawater Cooling System

a) Ensure that the seawater inlet strainers are clean.
b) Open the appropriate seawater valves throughout the auxiliary and propulsion diesel cooling system. This is to include the sea suction air vent valve.
c) If the seawater pump is a stand alone pump start the pump ensuring that a full flow of seawater is visible from the discharge from the diesel cooling system. Note the seawater flow by visually inspecting the flow indicator (after the seawater heat exchanger to sea discharge) if fitted or the seawater pump discharge pressure.
d) Check for any seawater leaks (investigate and rectify as appropriate)

Fuel Oil System

a) Check the fuel oil in the tanks is sufficient for the voyage plus sufficient for any change in the voyage plan.
b) Drain any water residue from the fuel oil tanks. Note the amount of water if any).
c) Ensure the fuel oil service tank is full.
d) Check that the deck vents are operating correctly ensuring that seawater cannot enter the fuel system from any wave splash on deck.
e) Open all the appropriate valves to both the auxiliary and propulsion diesels.
f) If there is a separate fuel oil booster pump start the pump note the pressure and check for any visible leaks.
g) Check the condition of the inline fuel oil duplex filters. Clean as necessary.

h. The auxiliary diesel and main propulsion diesel linkage between the governor and the fuel pumps should be checked for freedom of movement; any tendency for it to be stiff or sticky in operation should be rectified and the whole system lubricated. Particular attention should be paid to the fuel racks to ensure free movement, with each rack in turn being pushed to the maximum fuel position. The spring in the rack linkage should promptly return the rack to the 'no fuel' position.

Starting/Instrument Air

a) If applicable ensure the starting air receivers are fully charged and any residual water is removed by draining the reservoirs.
b) Ensure the air dryers valves and tower control valves (if installed) are open and are operating correctly.

Auxiliary & Main Engine Starting

a) If fitted open the individual cylinder indicator cocks.
b) Turn the engine over by using the turning gear or manual barring mechanism to ensure that there are no restrictions that may cause the engine to stall and cause damage.
c) Turn the engine over by using the electrical or air starting motor..
d) Close the indicator cocks if applicable.
e) Open the engine starting valves and start the engine.
f) After reaching full speed allow the diesel to run until the optimum jacket water temperatures have been reached (refer to manufacturers details).
g) Make a thorough check of the diesel for any abnormalities.
h) Ensure the diesel(s) jacket water and lubricating oil temperatures have warmed up to within their operating parameters. This ensures that the thermal stresses within the engine have been reduced sufficiently to commence normal operations.
i) Prior to handing over the controls of the main engine all ahead and astern functions must be tested to ensure correct operation.

Shutting Down & Securing for Maintenance

The reverse procedure should be adopted when shutting down any operating diesel. This action ensures that the thermal stresses within the engine are able to reduce slowly and steadily. For the period of running at no load prior to the engine shutdown, refer to the manufacturers instructions.

Prior to starting any maintenance, an appraisal of the equipments safe isolation should be carried out e.g. Risk Assessment. The risk assessment should encompass a full inspection of the system ensuring that a correct and safe isolation of the equipment is carried out, which will render the equipment safe to work on with any operational factors taken into consideration.

General Safety Precautions taken prior to an internal Inspection or Component Overhaul

The procedure to follow for the overhaul of a 'Unit' is dependant on the manufacturers instruction, and the implementation of the safety guidelines using the Permit to work and Risk Assessment however, there are standard guidelines that must be followed which may entail the following:

- Ensure that the engine is secure, with the turning gear in place, and the fuel shut off and isolated.
- All methods of rotating or staring the engine are isolated and locked off
- Post a notice displaying the fact that the diesel is being worked on.
- Drain the engine of jacket water.
- Ensure access to the COSHH data sheets for the exposure to lubricating oils, water inhibitor and fuel oil.
- Ensure correct PPE is worn and correct tools are in place.
- Ensure that the work area is clear of any hazards.
- All lifting equipment is to be certified and fit for use.
- Follow the manufacturer instruction for removal ensuring that in special equipment for the removal is available.
- All electrical supplies including sensors and heaters isolated and locked off
- Adequate lighting and ventilation
- Special tools, equipment and spares are available before work commences

Large Crankcase or Gearbox Inspection

Assuming the engine is safe to work on and a risk assessment and permit to work has been issued:
The crankcase or gearbox must be considered a confined or dangerous space, therefore the risk assessment needs to be comprehensive with regards to Oxygen content is over 20%.

Only competent persons should enter a crankcase or gearbox and the following engineering observations made:

- Inspect lubricating oil and possible presence of MBC
- Internal surfaces should be free from signs of overheating / discolouration, cracks, corrosion, pitting, flaking paint or evidence of leaks
- Inspect fasteners
- Inspect sensors and wiring for integrity, security and fraying
- Inspect wiring / looms cable trays and supports
- Look for signs of damage to sprayers or blockage of ports and galleries
- Observe for evidence of blow by
- Test oil mist detector
- Inspect crankcase inspection door if fitted
- Check suction strainers and pipework / supports

For Gearboxes

- Inspect gear teeth for flaking, scoring, abraision, cracks, discoluration, scuffing or pitting
- Inspect for load line wear abnormalities – greying, polishing or roughening
- The meshing function should be checked
- Bearings should be inspected for wear and security
- De humidifiers checked
- Vents checked clear and free from corrosion
- Sources of any leaks identified and recorded
- Observe for any signs of MBC

Cylinder Head Removal

Assuming the engine is safe to work on (risk assessment and permit to work issued) and all methods of starting and rotating the engine are isolated, the engine should be cool and drained of fluids. The removal of the cylinder head normally requires the removal of associated pipework, lagging and possibly exhaust or turbo removal for safe access. The rocker gear should then be removed and additional bolts may need removal before the head can be lifted off with a hoist or crane ensuring the head is clear of the threaded studs to avoid damage. The cylinder head should be landed in a safe and soft area.

Overhaul of a Unit (Piston, Rings & Cylinder Liners)

After the above has been carried out, proceed with the removal and dismantling of the piston, piston rings and cylinder liner and connecting rod.

After removal of the piston and associated components, cleaning should first take place prior to inspections should being carried out. The inspections should proceed as follows:

Piston & Piston Rings Inspection

The piston should be inspected to see it is free from cracks and there are no ridges or grooves on the bearing surfaces other than the ring grooves. If scores cover more than 5% of the contact area with the liner the piston is unacceptable.

The axial clearance of each piston ring should be measured at about four places round the circumference. This is carried out by pressing the ring down on the bottom land of the groove and using feelers to measure the clearance between the top of the ring and the top of the groove.

The rings should be inspected to see that they are free from ridges, cracks and grooves. The gap clearance of the rings should be measured by inserting each ring in turn in a ring gauge. If no gauge is available, the most practical method is to place each ring in the bottom unworn portion of a cylinder liner and then use a depth gauge or a piston crown to make sure that it is positioned symmetrically. The gap is measured by feeler gauges between the end of the rings.

If the axial clearance of the piston rings is unacceptable, this may not only be down to the ring wear, the groove landing may have worn. If it is grooved that is worn then some manufacturers offer oversize rings as a replacement. If this facility is not available then a replacement piston is required.

The piston should be examined for signs of overheating then cleaned. In good light the piston should be examined for signs of cracking, damage, corrosion, wear and a dimensional check against the original specification made. The gudgeon pin should be removed and inspected along with any securing arrangements (circlips etc) and the skirt of the piston checked.

Cylinder Liner and Bore Inspection

The inspection of the liner and bore will require a risk assessment and permit to work to be issued to allow for safe removal of the cylinder head, liner and piston. The bores of the cylinder liners should be inspected and measured. The bores should be free from scores, cracks and ridges. If scoring of the surface is evident, the corresponding part of the piston should be examined to see if gas blow past is occurring. The inspection should concentrate on looking for cracks, cold corrosion, fretting, groove wear, burning, pitting or signs of overheating or leaks.

The wear of the liner is measured by taking readings with an internal micrometer at parallel to and at right angles to the centre line of the crankshaft at the top of the crankshaft. The measured positions are taken at the top of the liner e.g. piston ring travel, half way down the liner bore, and at the bottom of the liner bore where usually little wear is evident. The readings should be then entered into the maintenance schedule or log for reference.

Any liner, which found to be badly cracked or scored causing gas blow past, should be replaced.

Refer to the engine manufacturer instructions for the required permissible wear and limits.

The Connecting Rod Inspection

The rod and the bottom end bearing should be examined for fretting and cracks. If they have visible defects they should be replaced.

If the piston has seized or if the new bottom or top end bearings has been fitted, then the connecting rod alignment should be checked. Refer to the manufacturer recommendations for this procedure.

If the misalignment fault is shown to lie in the bearings then new shells or a new small end bush should be fitted.

Bottom End Bolts and Bearings

This has been a critical point to many failures, therefore the bottom end bolts should be inspected before being replaced and tightened. If a bolt has completed the manufacturers recommended running hours, the bolt should be replaced whatever its condition. Bolts should also be renewed if the engine has experienced a piston seizure or if there has been a failure of an overspeed trip such that the engine unintentionally runs at a very high speed.

Before replacing each bolt it should be inspected to see whether it is scored, bent or twisted. It can be checked for straightness by rolling it on a surface plate using engineer's blue.

The free length of the bolt should be measured by the method specified by the engine manufacturer. This will be a measurement of either the overall length or the length from the underside of the head to a mark made on a flat on one of the threads.

The nut should be inspected for distortion and cracks and it should be checked that it screws easily onto the bolt.

Any unacceptable bolt/nut must be replaced. When reassembling the bottom end bearing the bolts must be tightened to the correct tension using either a torque spanner or an extension gauge as advised by the engine manufacturer. The nut castellation should be brought in line with the split pin hole by careful filing of the nut face NOT by slackening or further tightening of the nut.

The bottom end bearing is normally removed by using turning gear to position the bearing in to an accessible position through the crankcase door. Once the engine has been made safe to work on (permit to work and risk assessment) and all methods of rotating the engine have been isolated, the bolts can be loosened and removed. The bottom half bearing on larger engines will require support and the piston and con rod can be removed upwards at **T.D.C** after the cylinder head has been removed using a crane or suitable hoist. The bearings can then be removed from their positions.

When fitting new bottom end bearings, the protective layer should be removed and the bearing halves cleaned and inspected before insertion. The halves will be a matched and numbered pair. Cleanliness between the new bearing half and the crankpin is critical to the longevity of the bearing. The bearings should be pre-lubed with cleaned engine oil to prevent wiping on first turn and the bolts tightened in accordance with manufactures specifications. **The new bearing should last from 8-12000 hours.**

The bottom end bearings on some engines may be removed without removing the piston using a similar process as above, however great care must be exercised when rotating the crankshaft to support the piston and con-rod clear of the crankshaft to avoid damage. Also care should be taken when rotating the crankshaft to avoid the loss of the bearing half shells into the sump.

Gudgeon Pin Inspection

The gudgeon pin should be removed from the piston (an aluminium piston should be heated in boiling water to free the gudgeon pin) and inspected for distortion by rolling it on a surface plate using engineer's blue. It should also be inspected for cracks and scores on its surface. Any pin indicating these faults should be replaced.

The gudgeon pin bosses in the piston and the small end bush in the connecting rod should also be inspected for scores or cracks.

The maximum and minimum diameters of the gudgeon pin should be measured and also the bores of the gudgeon pin bosses in the piston and the internal bore of the small end bush. The clearances will vary dependant on the size of engine, the material used and whether the engine is a 4 stroke or 2 stroke.

Refer to the engine manufacturer instructions for the required permissible wear and limits, and if a replacement is required.

Overhaul of a Main Bearing

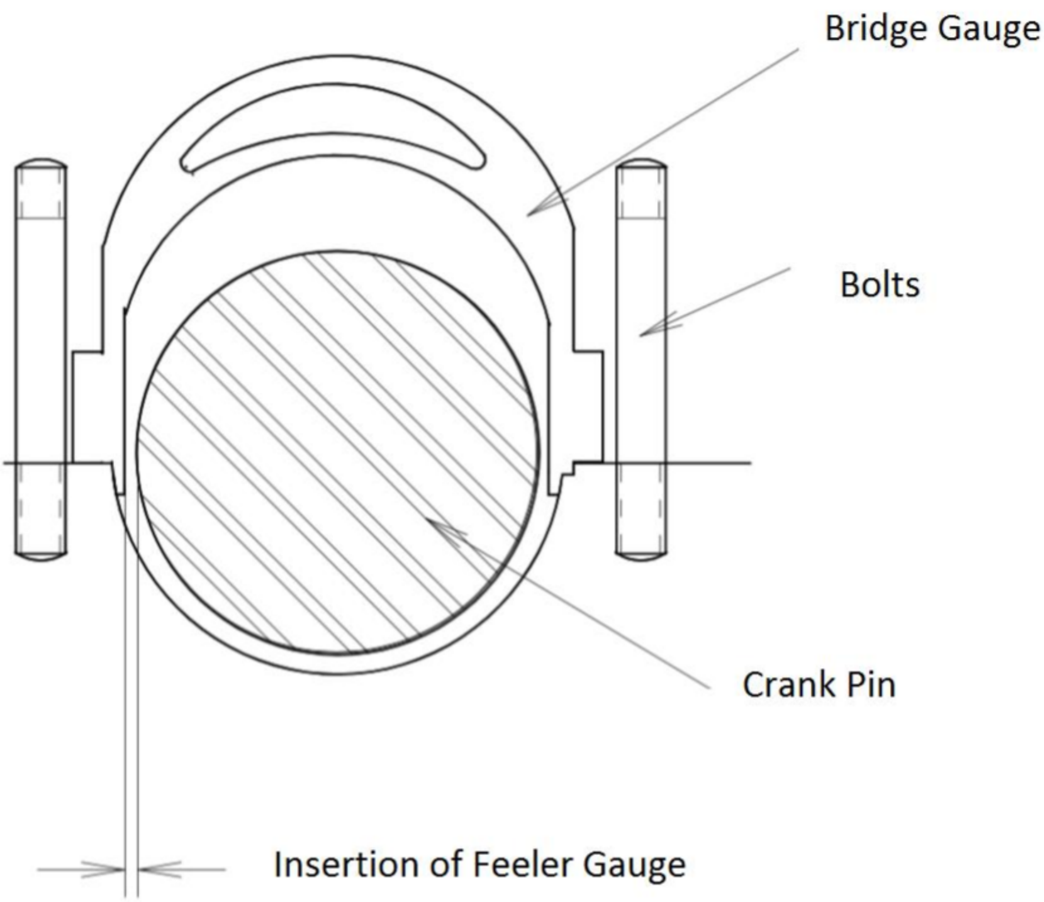
During an inspection of the main bearing only one main bearing lower half shell should be removed at a time, with the others being left in place to give the crankshaft adequate support.

Each journal and pin should be examined for ridging and grooving. Ridges are formed in the way of oil grooves in the bearing shells. Grooves are formed by abrasive particles entering the bearing and scoring the shaft, if the effective bearing area has been reduced by more than 10%, then remedial action is required.

Any burrs or sharp dents are unacceptable.

The diameter of the crankpins should be measured using a micrometer. The measurements should be taken at two positions along the length of each pin at eight positions around the pin at 45° intervals.

An alternative method of measurement should the measurement of the pin not be accessible, then a measurement can be taken by a special bridge gauge and feelers used to measure the diameter. The measurements are always taken in the horizontal plane with the crankshaft turned at 30° or 45° intervals.



Bearing shells should be replaced:

- The bearing metal is cracked or broken.
- The bearing surface is grooved over more than 10% of its area.
- The arc of contact between the journal or pin and its bearing is less than 140 and the area of contact is less than 90% within the arc. This refers to 4-Stroke engines, with the 2-Stroke engine this contact area applies to the loaded half of the bearing.

- The steel back has been fretting in the housing.
- There is less than 90% contact area between the back of the bearing and the housing.

Badly worn or damaged journals or pins require regrinding of the crankshaft, this is a specialist job and should be contracted to firms that undertake such work. If there is slight damage this can be rectified by stoning by hand.

Prior to undertaking any such work all oil-ways should be carefully plugged and precautions taken to ensure that no debris remains in the engine where any abrasive material may cause wear.

Manufacturer's Procedures

Each major component of the ship's machinery both electrical and mechanical will have a manufacturers operational procedure and maintenance parts list. These important books should be correctly catalogued and indexed with the manufactures bulletins correctly catalogued. If the 'Yacht' is governed by the ISM procedures these may become a prerequisite of the companies 'Safety Management System'. If the ship does not come under the ISM procedures then it is still strongly advisable to maintain a effective working catalogue of manufacturers procedures.

Ship's Written Procedures

The ship's written procedures encompass those procedures required by MARPOL regulations e.g. Pollution Control Procedures for ship's crew as well as 'Bunker Procedures' etc. With regards to the engineering crew, it is usual to have a 'Chief Engineers Standing Orders'. This document outlines the duties required by the engineering staff and

encompasses items such as cleanliness in the machinery room and the requirements to maintain cleanliness. The document also requires the various duties required of personnel in the machinery rooms e.g. vigilance on any malfunction of equipment and the necessary actions required.

Engineering Drawings

Engineering drawings range from the:

Design & Construction Drawings which feature for example:

- The hull and the fittings associated with the hulls structure e.g. frames and their positions and dimensions in relations to the structure.

- The accommodation modules and their associated structures e.g stairwells , fire proof integrity.

- Engine supports frames and their positions.

- Material construction and their details.

The Pipework Drawings indicating the route the pipework takes, hull and deck penetrations, materials and dimensions.

Additional drawings made available from the shipyard which are essential for the operation of the vessel include the Pipework and Instrument Drawings (P & ID's) or more commonly known as Schematics. These give the route, penetrations of any instrument or fluid pipework associated with the vessel systems, their valve positions, pipework reductions eg diameters and associated equipment. For example:

- Fresh water systems.
- Fuel systems.

- Seawater systems.
- Compressed and Instrument air systems.
    - Potable water systems.

Other drawings essential to the ship's operation include the electrical systems drawings giving essential information of all the ship's systems.

It is essential that any alterations effecting any of the systems must be entered on the appropriate drawing as a correction (Red Line Correction). This action assists in the correct operation of the ships systems. This can be a requirement under the ISM Code

Diesel Engine Performance Faults

Fault	Cause	Remedy
Engine Fails to Start.	Shut off solenoid fails to energise.	Investigate fault and rectify.
	Fuel Supply Shut off.	Open the correct valves on the fuel system. Kinked fuel suction lines.
	Fuel system air locked.	Bleed the fuel system.
	Blocked air filter.	Clean/replace the air filter.
	Incorrect fuel pump timing.	Check the fuel pump timing.
	Loose high-pressure fuel line connections from the pump to the injector.	Locate and tighten connections.
	Improper inlet and exhaust valve clearances.	Check and adjust as required.
	Badly blocked exhaust.	Clear the exhaust restriction.
Engine starts, but stalls immediately.	Fuel pump requires priming.	Prime the system.
	Air in the fuel system.	Prime the system.
	Incorrect fuel pump timing.	Check the timing.
	Fuel lever not set to start position.	Move the fuel lever to the start position.
	Air in the fuel system.	Prime the system.
	Water in the fuel system.	Check water in the fuel system and drain as necessary.
	Incorrect valve clearance.	Check valve clearances and adjust as necessary.
	Engine to cold.	Ensure engine heaters are operational. May require cold start if fitted.
	Clutch engaged (if fitted)	Disengage clutch.
Unstable engine speed and engine loses power.	Fuel tank contents low.	Ensure tank has sufficient fuel.
	Clogged fuel filters.	Check and replace.
	Clogged air filter.	Replace the air filter.
	Insufficient fuel oil pressure at the fuel pumps.	Check fuel boost pump pressure.
	Improper fuel pump timing.	Check the fuel pump timing.
	Water in the fuel system.	Check water in the fuel system and drain as necessary.
	Air in the fuel system.	Prime the system.
	Low (cylinder) compression.	Check cylinder compression pressures.
	Governor not functioning correctly.	Check governor adjustments: broken springs; linkage binding; problems with flyweights or servo.
	Injectors are defective.	Test injectors repair or replace.
	Cylinders misfiring.	Check for air in the system. Check for plugged air filter. Check for after-cooler restrictions (if fitted). High intake air temperature (reduce temperature)
		Check for incorrect valve clearances. Faulty fuel injector.
Engine has a poor response to fuel increase.	Governor not functioning correctly.	Check governor adjustments: broken springs; linkage binding; problems with flyweights or servo.
Excessive black smoke.	Engine overload	Reduce the load.
	Water in the fuel system.	Check water in the fuel system and drain as necessary.
	Unbalanced fuel injection pump(s) :- Indicated by high exhaust temperature.	Check rack settings for each pump (refer to manufacturer's recommendation on rack deviation).
	Improper fuel pump timing :- Indicated by high exhaust temperature.	Check pump timings.
	Dirty oil filter.	Clean/replace filter.
	Low cylinder compression	Check cylinder compression values.
	Air inlet.	Checked for plugged air filter. After-cooler restrictions. Check for carbon build up or restricted movement of the turbocharger impeller. Replace if necessary.
Excessive blue smoke.	Excessive lubricating oil in the engine combustion space.	Worn, stuck or broken piston rings and/or oil control rings. Replace as necessary.
	Valve guides worn.	Inspect for bent, broken, severely worn or damaged. Replace as necessary.
Excessive white smoke.	Engine misfiring.	Check pump timings.
	Air in the fuel injection system.	Prime fuel injection system.
	Water in the fuel system.	Check water in the fuel system and drain as necessary.
	Injectors are defective.	Test injectors repair or replace.

Diesel Engine Performance Faults (continued…)

Fault	Cause	Remedy
Engine overheats	Lack of coolant in the system.	Check the coolant level in the expansion tank. (Replenish as required and check for leaks).
	Fan belt loose (If fitted)	Check fan belt tension and adjust.
	Water temperature regulator (thermostat)/gauge.	Check the regulator (thermostat) for correct opening and closing function. Check temperature gauge and replace as necessary.
	Restricted lubricating oil or fresh water heat exchanger. Air locked in the heat exchangers.	Clear restriction. Bleed the air from the system.
	Fresh water pump failure	Investigate fault and repair the fresh water pump.
	Engine overload.	Reduce load.
	Late fuel pump injection timing.	Check pump injection timing and correct.
Excessive lubricating oil consumption.	External engine oil leaks.	Locate leaks and repair as necessary. Leaking tubes on lubricating heat exchanger (Repair as necessary).
	Excessive valve guide clearances.	Replace the valve guides.
	Worn piston rings or oil control rings.	Check the affected cylinder by checking the compression pressure and replace rings as required.
	Excessive high oil temperature.	Clogged or dirty oil filter (Replace or clean as required). Restricted oil heat exchanger (Clear restriction).
Low lubricating oil pressure.	Dirty or clogged oil filters.	Check condition and replace as necessary.
	Fuel oil dilution.	Locate internal fuel leaks and repair. Change the lubricating oil.
	Faulty oil pressure regulator.	Check and reset.
	Worn lubricating oil pump.	Repair or replace as necessary.
	Incorrect oil (low viscosity) for operations.	Change to the correct lubricating oil grade.
	Excessively worn main and rod bearings.	Replace (Refer to manufacturer’s instructions).
	Oil crankcase suction bell.	Check and clear any obstructions.
	Restricted Lubricating Oil Heat Exchanger.	Clear any restrictions.

Actions to be taken in the event of:

High bearing temperature.

Following advice to the bridge, the engine should be slowed, the bearing temperature monitored and arrangements made to safely stop the engine as soon as possible for further examination. Additional staff will be required in the machinery space to render assistance.

High oil mist detector alarm

This is potentially more serious than a bearing high temperature and the bridge should be advised that the engine must be stopped immediately. Once the engine has been stopped then the machinery spaces should be evacuated for at least 30 minutes to allow the engine to cool. The lub-oil and cooling pumps must be left running during this time. The ship's staff should be put on fire alert and the necessary equipment made available. After the engine has cooled, the crankcase should be ventilated by carefully removing one access door and following a further period of venting and cooling checks can then be made to ascertain the cause of the problem.

Exhaust temperature problems

If the engine exhausts are universally high then the load on the engine must be reduced and fault finding carried out to ascertain the cause of the problem.
If the engine exhausts are universally low, for no apparent reason, then fuel problems may be suspected and the fuel supply to the engine checked for possible problems e.g. water, blocked filters, low fuel pressure etc.
If there is wide deviation between exhaust temperatures at each cylinder then fuel injection problems or possibly leaking exhaust valves may be suspected and the engine should be stopped at the first safe opportunity in order to carry out an investigation.

High crankcase pressure

High crankcase pressure may be caused by a blocked vent, which can usually be cured while the engine is running. A more serious cause may be leaking piston rings and blow-past into the crankcase. If this is suspected, then the engine must be slowed down and stopped as soon as possible because of the risk of oil mist forming in the crankcase.

Leaking Air Start Valves.

Checks must be made that cylinder starting air valves do not leak.

These checks can be carried out while the engine is running by feeling the temperature of the air pipe adjacent to the valve. If an air start valve is leaking the paintwork near the valve will become discoloured and blister.

Checking pipeline drain valves for excessive pressure will also give an indication of a leak.

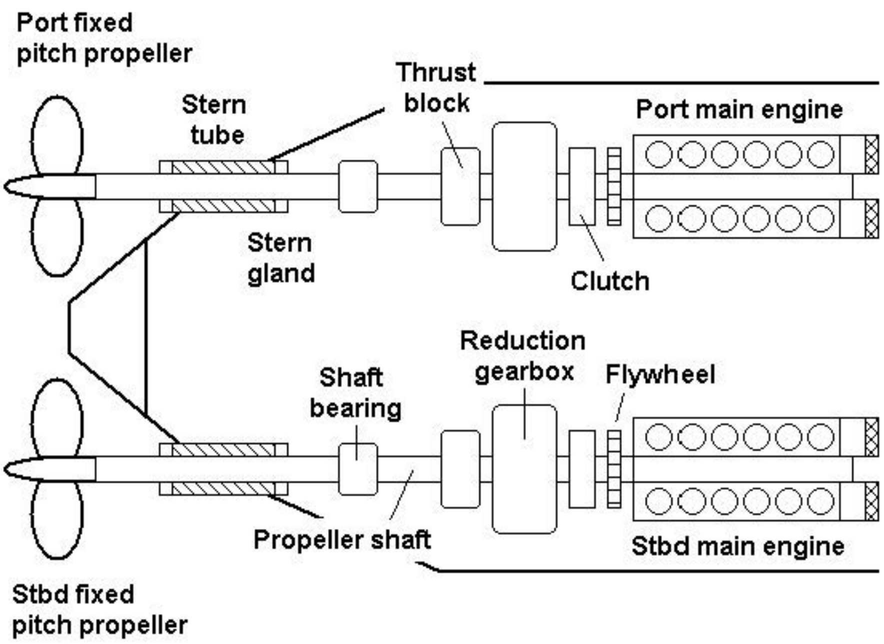
Tests while the engine is stopped require starting, air to be applied and the main valve opened, after first blocking off air to the timing valves. Pressure will escape into the cylinder of any leaking, air valve and this can be detected by listening at the open indicator cock (if fitted).

SECTION 15 – Clutches

General arrangements

The following diagrams show typical transmission arrangements of a medium speed diesel engine installation. The main components are:

- prime mover (diesel engine);
- clutch;
- gearbox;
- thrust bearing;
- shafts;
- shaft bearings;
- shaft couplings;
- stern tube;
- stern tube seals; and
- propeller.



Two main engines, two shafts, FP props

Clutches

A clutch is a device to connect or separate a driving unit from the unit it drives. With two engines connected to a gearbox a clutch enables one or both engines to be run, and facilitates reversing of the engine.

A clutching mechanism may be integral with the gearbox, or fitted independently between the engine and the gearbox. The clutch allows:

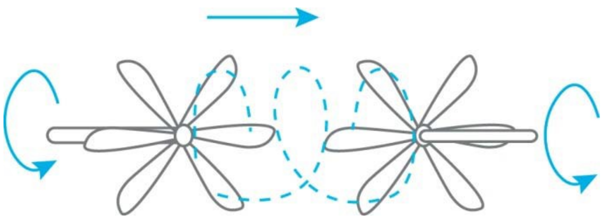
- the engine to be started without propeller load,
- the drive to be disengaged to allow the direction of rotation of the shaft to be reversed.

Fluid clutch (coupling)

The fluid clutch is also a flexible type coupling. It can also be used as a damper or detuner. It is not favoured as a main transmission clutch because of the time that it takes to take up or take off power. This can be used to an advantage in some cases, but a main transmission clutch requires to be instant make or break. The hydraulic or fluid coupling uses oil to connect the driving section or impeller with the driven section or runner.

No wear will thus take place between these two, and the clutch operates smoothly.

The runner and impeller have pockets that face each other which are filled with oil as they rotate. The engine driven impeller provides kinetic energy to the oil that transmits the drive to the runner. Thrust bearings must be provided on either side of the coupling because of the axial thrust developed by this coupling.



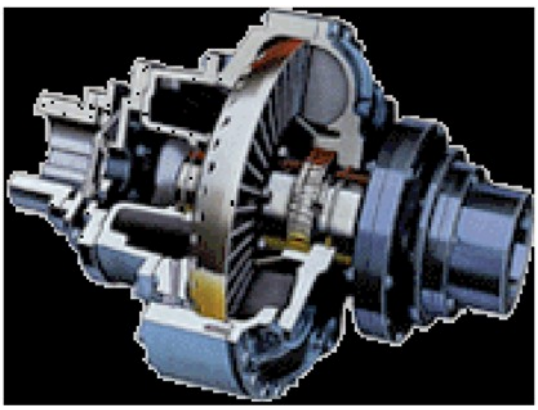
Principle of the fluid clutch

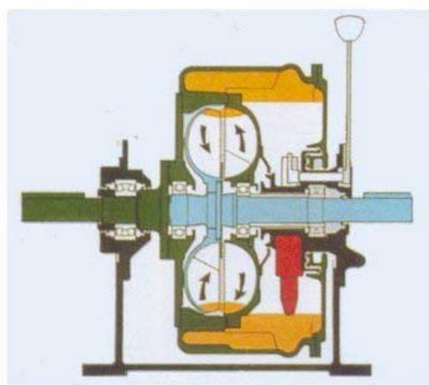
The fluid coupling consists of two rotating parts fitted with vanes, one of which is the driving unit and the other the driven unit. The driving unit is connected to the engine and the driven to the output shaft or gearbox.

The impeller in the drive unit throws the oil outwards and then into the impeller of the driven unit where the oil is then circulated back to the drive impeller.

Advantages:

- No shock can be transmitted through the coupling
- Overloads will not affect the prime mover, or stall the engine.
- No heavy torque when starting the engine   Driven machinery is not subject to torsional vibrations

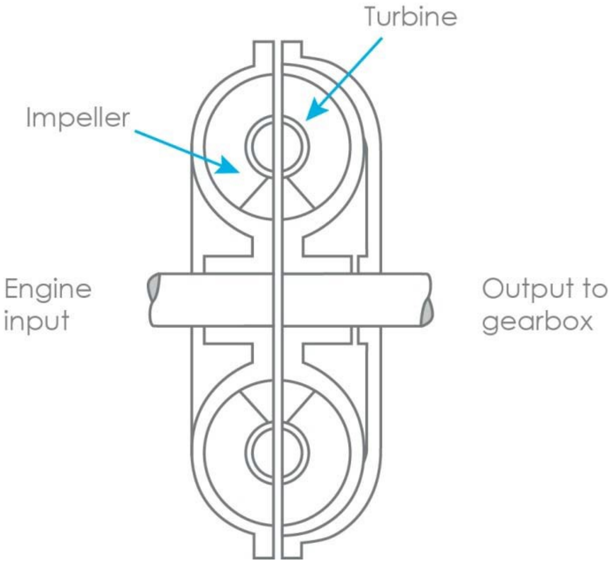




A hydraulic or Fluid coupling (cut away view)

Disadvantages:

- **Time to take up drive or release drive can be long. It is not an instantaneous make-break.**
- Slip is about 3%
- Costly to make



The circulating oil drives the driven impeller at an increasing speed until it is at the same speed as the drive unit. The fluid coupling therefore provides smooth take up of speed.

By controlling the oil flow through the rotating parts of the fluid coupling, the slip of the coupling can be changed, resulting in a variable output speed of the driven shaft.

Oil coolers are incorporated into the system to dissipate the heat generated by the fluid coupling.

Any angular misalignment would result in an increased gap between the faces reducing TORQUE. The design clearance and viscous friction may overcome some misalignment.

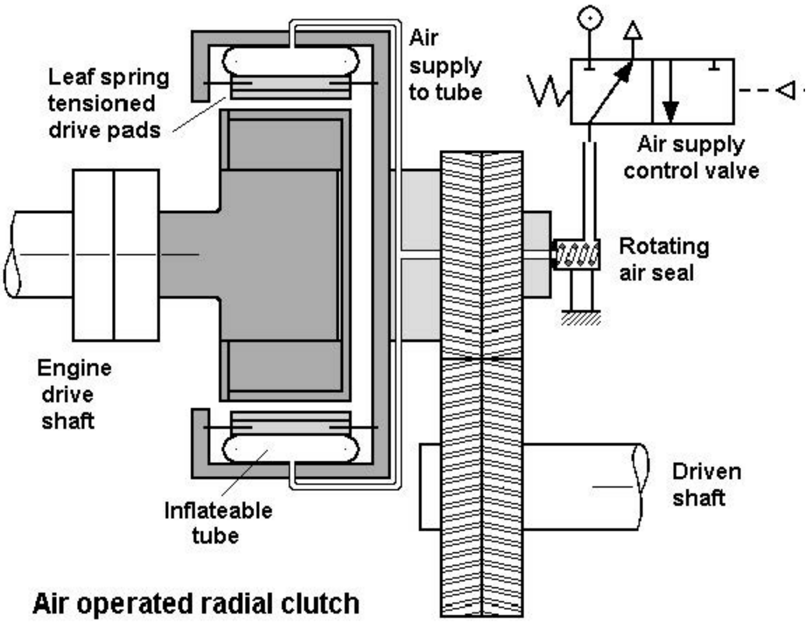
Air operated clutches

Clutches that are not part of the gearbox, are usually air activated, with pads or linings, which make either radial, or axial contact. The application force for the friction pads or linings is supplied by compressed air in a reinforced neoprene rubber tube. The compressed air is filtered and drains provided in the system remove moisture. Air pressure is monitored and the low-pressure alarm is particularly important. Some form of rotary connection between the air supply pipe and the clutch is necessary, with the valve controlling the air supply to the clutch tube being operated by hand or remotely controlled by a solenoid or air pressure.

Radial air operated clutch

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

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

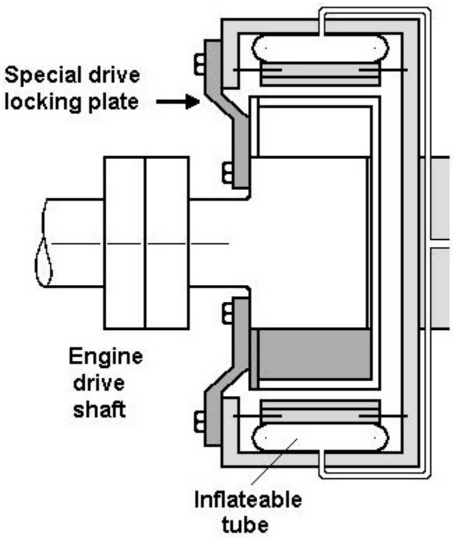


Air operated radial clutch

The transmission of torque relies on the air pressure, thus loss of air pressure would allow the clutch to slip. In the event of a reduction in the control air the clutch is designed to disengage otherwise excessive slip could cause excessive temperatures Control air pressure 8 to 15 bar.

Wear of the friction pads is compensated for by the expanding tube, the maximum wear on the friction pads is 50%.

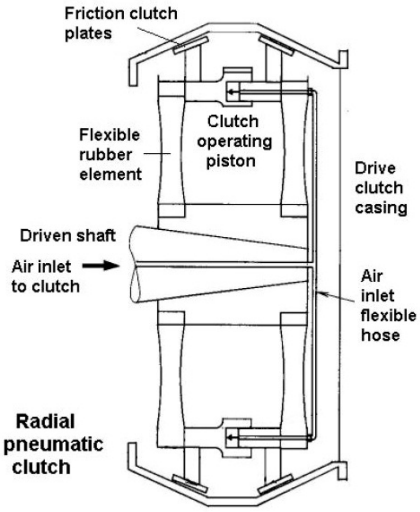
Emergency operation



Emergency operation

Failure of the air supply or other fault could render a clutch inoperative. To make provision for this eventuality, an emergency drive locking plate or set of temporary coupling bolts is provided.
Prolonged use of the emergency solid coupling arrangement can result in serious damage to gear teeth.

Operation



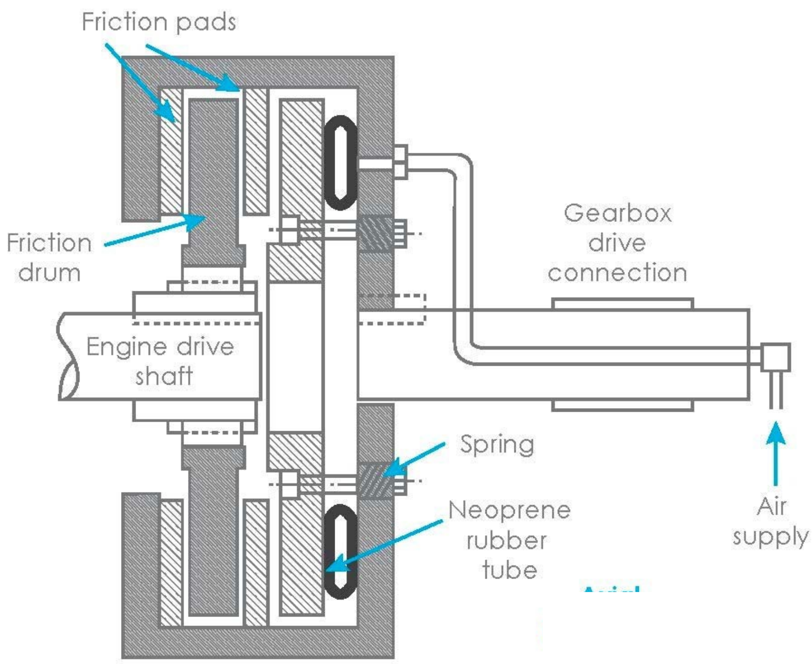
Axial pneumatic clutch

The casing of the clutch is bolted to the flywheel of the engine. With no air supply to the unit the casing is free to rotate independently to the gearbox. This allows the engine to be run without turning the propeller shaft.

The clutch is engaged by supplying compressed air through the input shaft to the clutch cylinder via the flexible hose.

As the pressure in the cylinder increases, the piston and the cylinder are moved axially causing the friction linings to come into contact with the casing. This results in a driving torque from the engine to the gearbox input shaft.

Axial air operated clutch



Axial pneumatic clutch

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

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

Plate type clutch

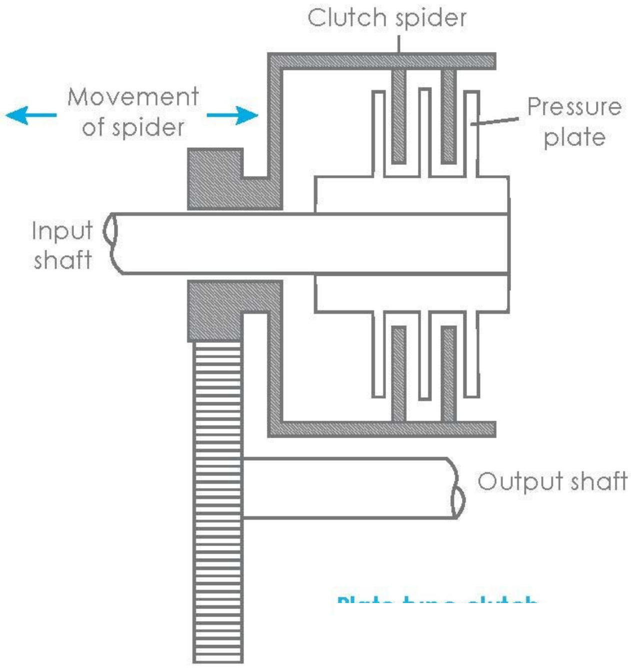


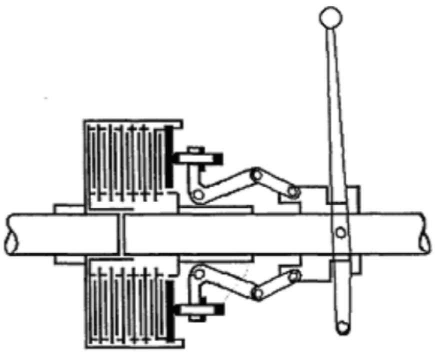
Plate type clutch

The clutch unit consists of pressure plates and clutch plates.
The engine drives the pressure plates via the hub unit. Since the clutch plates are not in contact with the pressure plates the output shaft will remain stationary.
Engagement of the clutch is achieved by moving the clutch housing by means of an actuator (mechanical or hydraulic). This will result in the friction plates coming into contact with the pressure plates. The torque is then transmitted from the input shaft through the friction contact between the plates to the output shaft.

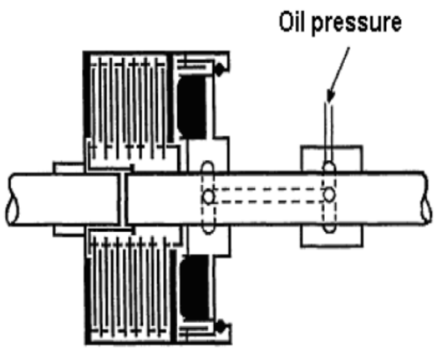
With this type of clutch, for emergency control, the clutch can be operated using a bolt, which is manually screwed in.

Small amounts of **misalignment** can be absorbed by the interleaving the drive and driven plates and suitable design clearances. Excessive angular misalignment may result in slip, vibration and overheating.

Mechanical and hydraulic operation



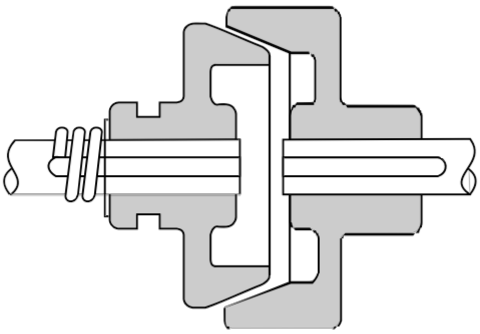
Mechanical operated plate clutch



Hydraulically operated plate clutch

Mechanical gearboxes require regular adjustment of the clutch operating mechanisms to ensure the correct force is being applied to the clutch to prevent slipping.

The Cone Type Clutch

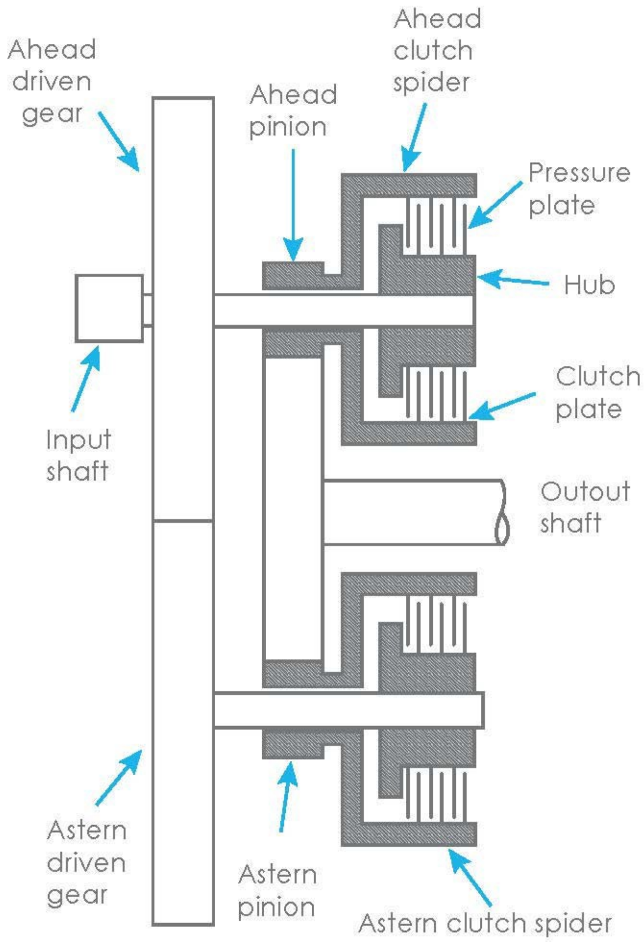


The Diagram left shows the Cone Type Clutch. Thus named due to the cone shaped or angled mating faces of the clutch. The clutch may be air, hydraulic or cable operated and relies upon frictional contact to pick up drive from the input to the output. A cone clutch serves the same purpose as a disk or plate clutch. However, instead of mating two spinning disks, the cone clutch uses two conical surfaces to transmit torque by friction. The cone clutch transfers a higher torque than plate or disk clutches of the same size due to the wedging action and increased surface area. Cone clutches are generally now only used in low peripheral speed applications although they were once common in automobiles and other combustion engine transmissions. They are usually now confined to very specialist transmissions in racing, rallying, or in extreme off-road vehicles, although they are common in power boats. Small cone clutches are used in synchronizer mechanisms in manual transmissions.

Ahead and astern plate clutches

A plate type clutch consists of pressure plates and clutch plates arranged in a clutch spider. A forward and an aft clutch assembly are provided, and an externally mounted selector valve assembly is the control device that hydraulically engages the desired clutch.

The forward clutch assembly is made up of the input shaft and the forward clutch spider. The input shaft includes the forward driven gear and, at its extreme end, a hub with the steel pressure plates of the forward clutch assembly spline-connected, i.e. free to slide. Thus when the input shaft turns the forward driven gear and the forward clutch pressure plates will rotate. The forward clutch plates are positioned between the pressure plates and are spline-connected to the forward clutch spider or housing. This forward clutch spider forms part of the forward pinion assembly that surrounds, but does not touch the input shaft. The construction of the reverse clutch spider is similar.



Gearbox with ahead and astern plate clutches

Both the ahead and astern pinions are in constant mesh with the output gear wheel that rotates the output shaft.

In the neutral position the engine is rotating the input shaft and both driven gear wheels, but not the output shaft.

When the clutch selector valve is moved to the ahead position, a piston assembly moves the clutch plates and pressure plates into contact. A friction grip is created between the smooth pressure plate and the clutch plate linings and the ahead pinion rotates. The ahead pinion drives the output shaft and ahead propulsion will occur.

The procedure when the selector valve is moved to the astern position is similar but now the astern pinion drives the output shaft in the opposite direction.

Clutch problems

Slipping clutches

Apart from mechanical failure of gearbox components, which is quite rare and will generally render the gearbox inoperable the most common fault is slipping clutches.

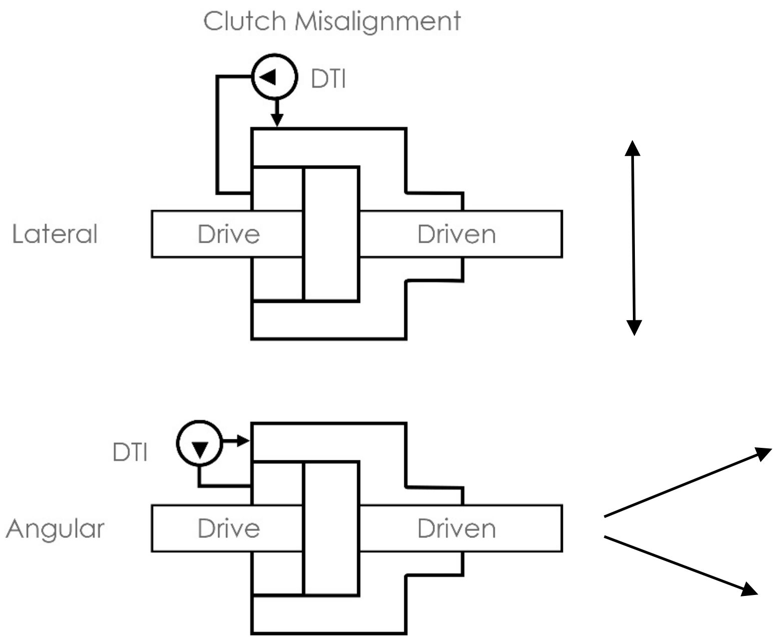
This will show up with the engine surging, particularly at full power, or the gearbox overheating. The first action in the event of a slipping clutch is to reduce power, this will reduce the amount of torque the clutch has to transmit and can stop the slipping as a temporary measure.

In manual gearboxes the clutches require adjustment at regular intervals, the manufacturer's instructions will give the amount of force required on the operating lever to apply the clutches at the correct adjustment.

Hydraulically operated clutches usually have no provision for adjustment although most manufactures have installed a "Get Home" feature to be used in the event of complete clutch failure.

The manufacturer's instructions must be carefully followed when using this feature as incorrect operation can cause considerable damage to the gearbox.

Clutch Misalignment Measurement



Adjustment is usually made by the use of screw jacks or shims

Binding clutches

All gearboxes can suffer from a problem known as ***clutch bind*** or ***clutch drag***, this occurs if a clutch is not releasing properly if only one clutch is biding this will show up as prop shaft turning when neutral is selected.

Binding is generally caused by:

- Clutch or clutches incorrectly adjusted
- Warped clutch plates from overheating or previous slipping
- Incorrectly adjusted gearbox controls

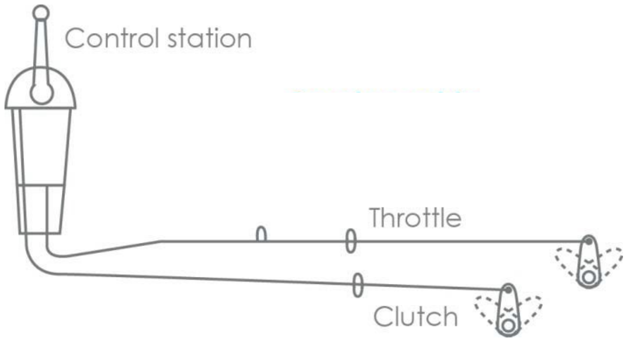
If the binding is excessive or has been happening over a long period the gearbox will generally require dismantling to repair the damage.

The amount of bind and which clutch is the cause will be indicated by the direction the prop shaft is turning and its speed. A binding clutch will generate heat when the gearbox is turning in the opposite direction and will cause significant wear on the clutch plates and can also result in a power loss.

Clutch and engine control systems

Control systems can vary from the basic system using the Bowden cable to the pneumatic remote control system.

Bowden cable



Bowden cable control system

The Bowden Cable is a flexible hand control cable encased in a plastic type sheath (to prevent corrosion, thus limiting failure) connected to the transmission operating gear at a 90° position during neutral gear operation.

The Bowden cable system is invariably linked to the fuel pump rack by a system of rods and levers, therefore giving the system a dual operation:

1 changing the direction of the transmission from Ahead / Neutral / Astern

2 increasing/reducing speed.

Frequent maintenance of the cable and rods is essential. Points to observe:

- Check for any cable corrosion. This may lead to cable strand deterioration and subsequent failure, especially at the stressed points.
  - Check for any plastic coating deterioration.
- Observe the orientation of the cable ensuring the position is 90° to the transmission gear when in the neutral position. It is possible that any misaligned position may result in rubbing of the clutch plates, and eventual slipping, resulting in failure of the clutch.
  - Avoid sharp bends.
  - Ensure anti-friction rollers are in good condition.
- Ensure cable tensions are maintained. If not the neutral position and subsequently the ahead and astern position for the clutch may not properly engaged or disengaged. If this occurs, the friction clutch may become hot and subject to wear.

Clutch and Gearbox Protection Devices.

Depending on the application and design it is quite common to have a number of protection devices fitted. The main aim is to avoid damage or excessive wear through overheating or incorrect operation. They may include:

GEARBOX

- Low Oil Pressure – to ensure free flow of oil for lubrication and cooling
- High Oil Temperature – to ensure oil does not overheat, decreasing viscosity and may lose qualities.
- Oil Filter Differential Alarm. – As above to prevent reduced flow from blocked filters

CLUTCHES

- High temperature alarm – to prevent burnout due to slip
- Slip differential alarm – as above
- Low air pressure alarm
- High vibration alarm

GENERAL TRANSMISSION

- THROTTLE NOT AT ZERO – for starting
- Pitch not at ZERO – as above
- Clutch failed to disengage
- Synchronous speed differential alarm (SSS clutches)
- High Vibration alarm

Note: Even when Controllable Pitch Propellers (CPP) are used, clutches are still required to allow for disconnected engine runs, maintenance and clutching in/out multi engine configuration changes (father and son engines) etc.

Clutch Interlocks

Normally when the propeller shaft is stationary there are certain conditions that must be satisfied before the control system allows engagement:

- Pitch at Zero
- Throttle at Zero
- Oil pressure correct
- Minimum RPM differential (shaft at zero / throttle minimum)

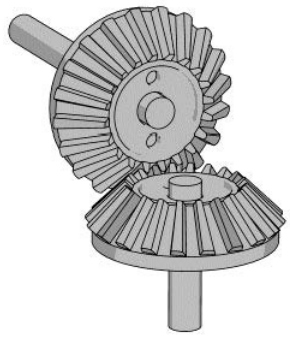
When the shaft is rotating (introducing or disengaging)a second engine the engine must be **at minimum RPM** unless a “self shifting synchronizing” (SSS) clutch is used and the control system ramps up the oncoming engine speed to match that of the clutch.

SECTION 16 – Gearboxes

Gears and gear systems

Gears are used to transmit rotary or reciprocating motion from one part of a machine to another. At one time various mechanisms were collectively called gearing. Now, however, gearing is used only to describe systems of **wheels or cylinders with meshing teeth**. Gearing is chiefly used to transmit rotating motion, but can, with suitably designed gears and flat-toothed sectors, be employed to transform reciprocating motion into rotating motion, and vice versa.

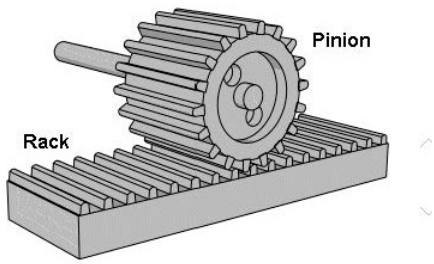
Bevel gears



Bevel gears

These are employed to transmit rotation between shafts that do not have parallel axes.
These gears have cone-shaped bodies and straight teeth.
When the angle between the rotating shafts is 90°, the bevel gears used are called mitre gears.

Rack and pinion



Rack and pinion

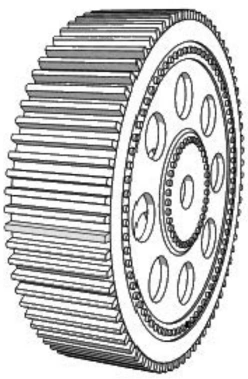
These are gears that usually drive or are driven by a pinion, a small gear with few teeth.
A rack, a flat, toothed bar that moves in a straight line, operates like a gear wheel with an infinite radius and can be used to transform the rotation of a pinion to reciprocating motion, or vice versa.

Axial or spur gears

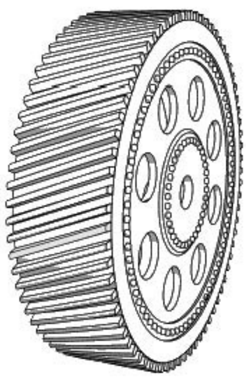
The simplest gear is the axial or spur gear, a wheel with teeth cut across its edge parallel to the axis. Spur gears transmit rotating motion between two shafts or other parts with parallel axes. In simple spur gearing, the driven shaft revolves in the opposite direction to the driving shaft.

If rotation in the same direction is desired, an idler gear is placed between the driving gear and the driven gear. The idler revolves in the opposite direction to the driving gear and therefore turns the driven gear in the same direction as the driving gear.

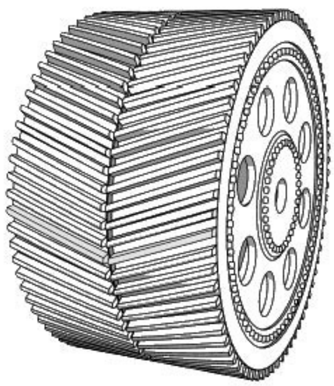
In any form of gearing the speed of the driven shaft depends on the number of teeth in each gear. A gear with 10 teeth driving a gear with 20 teeth will revolve twice as fast as the gear it is driving, and a 20-tooth gear driving a 10-tooth gear will revolve at half the speed. By using a train of several gears, the ratio of driving to driven speed may be varied within wide limits.



Axial teeth gearwheel



Single helical teeth gearwheel



Double helical teeth gearwheel

Helical gears

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

Simple helical gearing has the disadvantage of producing a ***longitudinal thrust*** that tends to move the gears along their respective shafts. This thrust can be avoided by using ***double helical***, or herringbone, gears, which have a right-handed helical tooth and a lefthanded helical tooth.

On given pitch diameters double helical gearing has a greater load carrying capacity. Double helical gearing allows the selection of large helix angles, thereby greatly improving the tooth meshing conditions, because of the large number of teeth being simultaneously in contact, i.e. a large axial overlap ratio. This gives a strong tendency towards quiet running.

Gear trains

Two or more gears, transmitting motion from one shaft to another, constitute a **gear train**.

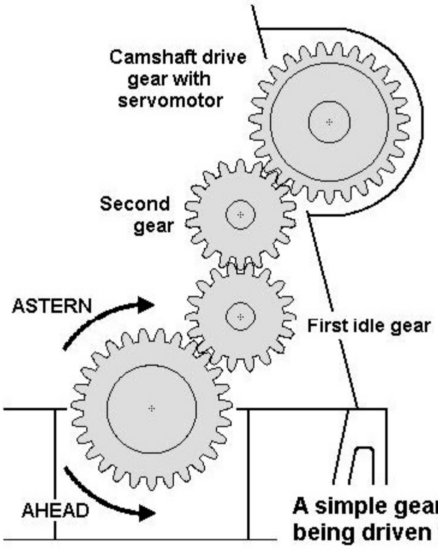
There are two basic forms of gear train:

1 The **simple gear train**.

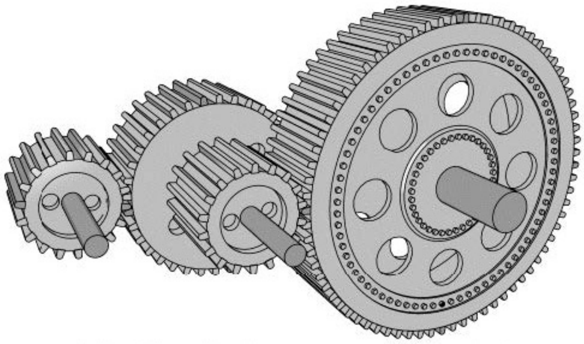
Each shaft is fitted with just one gearwheel.

2 The **compound gear train**.

Each shaft may be fitted with one or more gear wheels.



A simple gear train, a camshaft being driven from the crankshaft



A double reduction compound gear train

Types of gearbox

There are basically two forms of gearbox:

1 The step-up gearbox;

The output shaft speed is higher than the input shaft speed.

2 The step-down (or reduction) gearbox;

The output shaft speed is lower than the input shaft speed.

It is the ***reduction gearbox*** that is most commonly found on ship propulsion systems.

The reduction gear box can have two common forms:

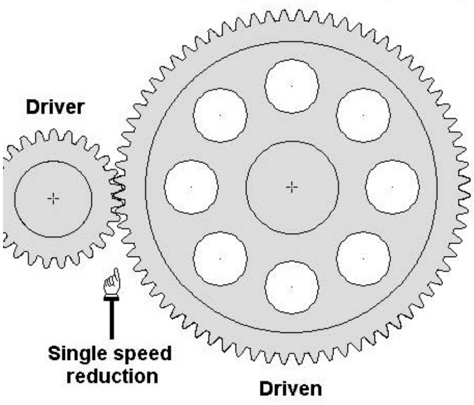
1 ***Single reduction***;

The speed reduction is carried out using one pair of gears.

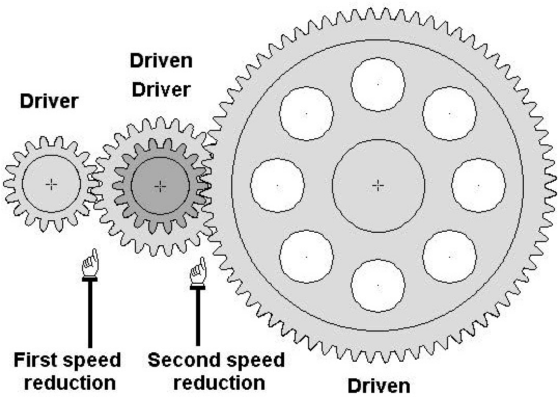
2 ***Double reduction***.

The speed reduction is carried out using two pairs of gears.

The type of gearbox reduction used depends upon the magnitude of the speed reduction required.



Single reduction gearbox



Double reduction gearbox

With a **single reduction gearbox** the speed reduction is achieved using a pair of parallel gears, i.e. there is one, or a single speed reduction. The arrangement shown above is with a simple gear train.

With a **double reduction gearbox** the speed reduction is made twice, using four parallel gears. There is one speed reduction between each pair of gears. The arrangement shown above is with a compound gear train.

Gear boxes

Introduction

There are many variations of marine propulsion gearing for medium and high speed diesel engine installations. Gearing must be adaptable to meet a variety of requirements for different powers and speeds to be transmitted, and location of shafts to be connected on individual vessels. Gearing is also influenced by the specific background and experience of the individual gear manufacturer.

A gearbox unit is commonly found on medium speed and high speed engines. The gearbox transmits the output torque from the engine, whilst adjusting the rotational speed from the higher engine speed to the lower and more efficient propeller speeds. The **ideal propeller speed** is considered to be about 70 revs/min, but this may not be achieved with high speed engines.

Reduction ratios range from about 2:1 to 6:1 on modern installations and will be commonly single helical or epicyclic.

There are three main types of gearbox:

1 Axial or helical gears with clutch.

2 Epicyclic gearbox.

3 Cone clutch gearbox.

Cone clutch gearbox

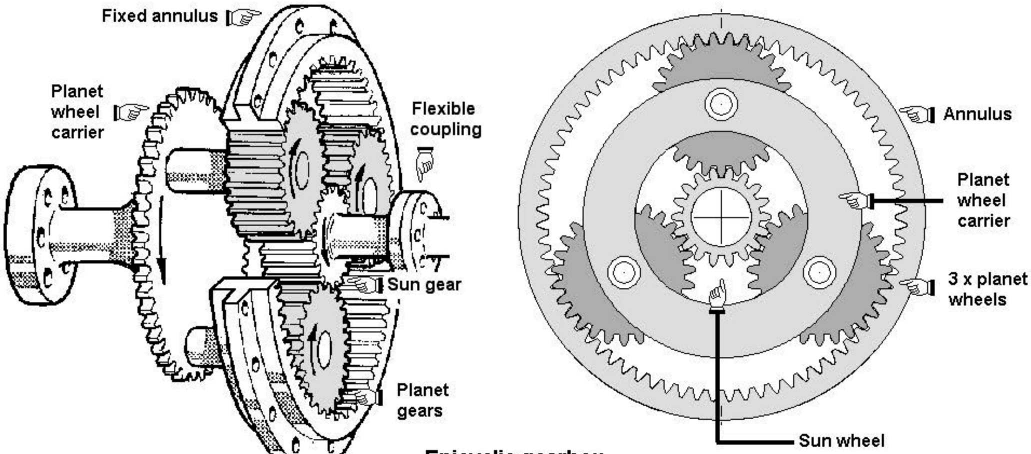
Cone clutch-type gearboxes incorporate two gear trains, similar to the helical gearbox. The cones work as clutches when the male and female parts are forced together. The gear trains provide a fixed ratio of propeller shaft speed to engine speed.

In most cases lubrication is with engine oil but in some gear oil is specified. In all cases only use the oil recommended by the engine or gearbox manufacturer.

Epicyclic gearbox

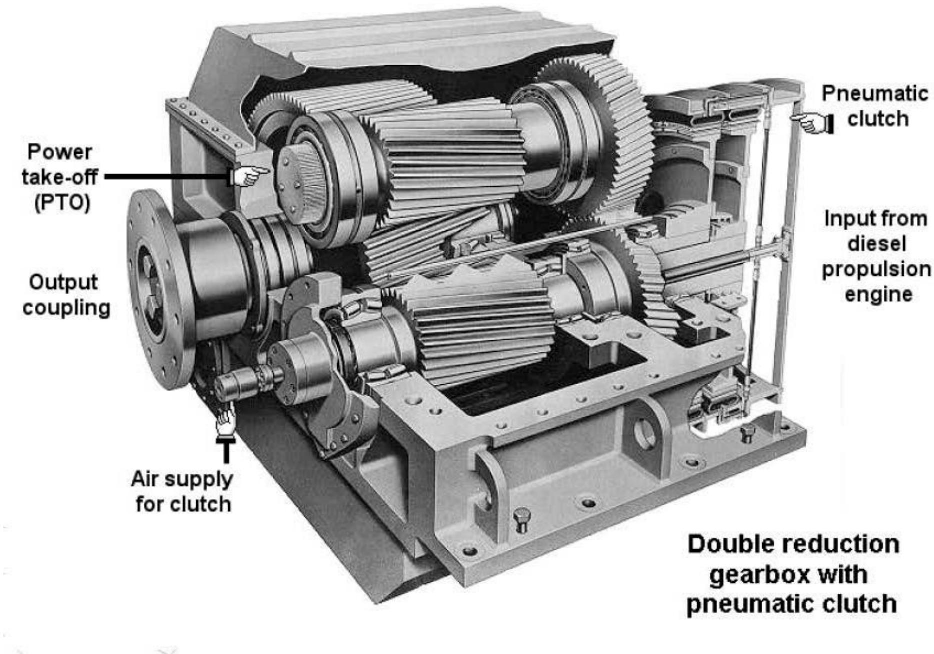
The main advantage of the epicyclic gearbox is it is small and compact compared to other arrangements. It is however more complex.

Epicyclic gearboxes use a sun and planet gear train, which reverses when the outer gear is restrained. The engagement adjustment needs to be positive to avoid slippage and the manufacturers recommendations regarding lubrication must be followed closely.



Epicyclic gearbox

Helical gearbox



Double reduction gearbox with pneumatic clutch

Because of the action of the gears rotating in the lubricating oil helical gearboxes tend to run hot. Large gearboxes or those working in unusual circumstances therefore need oil coolers.

A helical gearbox incorporates two multi-disc clutches and two gear trains terminating in the output shaft. One clutch is engaged for forward, the other for reverse.

Installation

Two most important requirements during installation are:

- the attainment of good static gear alignment with the least possible constraint of the gear case, and
- the optimum alignment of engines and shafting to the gear set.

Thermal effects have the greatest influence on the gear/engine/shaft alignment, which should be optimised for full load running when hot. Flexible couplings can absorb a certain amount of misalignment, but premature coupling wear will occur if misalignment is excessive.

Methods used by manufacturers to verify shop alignment differ widely but the object is to ensure correct gear-meshing with the gear case fastened down. The use of transfer marking, preferably red and blue on pinion and wheel respectively.

Gearbox mounting

Sometimes the main engines are flexibly mounted to reduce noise in parts of the ship outside the engine room, especially in passenger vessels. Flexible mounting of the gearbox, however, appears to be expensive if a substantial improvement has to be obtained. One problem is the occurrence of sound leaks through the propeller shafting. Applying acoustic treatments to the gearbox, such as acoustic hoods etc., has only some effect inside and not outside the engine room. Even if the engines are flexibly mounted the vessel would nevertheless still suffer from gear noise in locations outside the engine room.

Ship machinery foundations structures often are anything but stable and rigid platforms and the adverse effects of their deflections must be kept far from the gearbox. In view of this, the conventional design of many holding down bolts, more or less equally distributed all around the gearbox supporting base plate edge, may in a number of cases be not acceptable. The gearbox would be forced to follow any foundation deflection. This has led to the use of a four point support, the four points being located under each of both gearwheel bearings and half way under the port and starboard sides of the gearbox.

The four points will provide their function adequately when the four supporting structures on the double bottom are of small size. This implies that they are unable to transmit the propeller thrust from the gearbox to the hull structure and therefore the thrust block cannot be incorporated in a gearbox with four point support. Moreover, a built-in propeller thrust block would severely destroy the required symmetry.

Gearbox inspection

Inspection frequency is normally not less than 6 months, too frequent inspection may introduce contamination into the gearbox.

The first signs of trouble can easily be missed if the inspection is too infrequent or not systematic. This is particularly true of the main wheel teeth to which access is sometimes limited.

In order to examine all the gear teeth, it may be necessary to rotate the input gear, but even so a complete inspection of the main wheel is difficult. Thus the area of inspection must be assumed to be representative of the whole gear wheel.

Should damage be seen, then photographic evidence or replicas (prints) of the damage should be taken. These replicas can be either marking blue onto paper, or using silica rubber that can show the depth of defects such as pitting. Non- destructive testing (NDT) of deep pits may be necessary to inspect for cracks. Monitoring of defects is important, so that the size and rate of growth can be recorded.

In the cases of fatigue damage, it is often desirable to monitor the progress of pitting. From carefully prepared prints, it is possible to plot the area lost through pitting against running hours.

For examining debris associated with damage to the gears, magnetic plugs correctly positioned in way of the lubricant flow are a simple means of obtaining samples. Examination of such debris can often identify the wear process e.g. abrasive, pitting etc.

Gearbox pre-departure checks

Assuming that normal maintenance has been carried out on the gearbox the following checks carried out pre departure should be sufficient to ensure the gearbox will operate effectively:

- Check the oil level in the gearbox sump.
- Run the engine with the gearbox in the neutral position and check for leaks and check pressure gauges if fitted.
- Operate the gearbox ahead and astern to ensure satisfactory operation. Note:
- Before doing this, check that the mooring lines holding the vessel are secure, arrange for someone to stand by during testing.

Gearbox lubrication

A manual gearbox will usually use a simple lubrication system consisting of oil stored in the gearbox sump and the gears dipping into this oil and spraying or splashing the oil around the inside of the gearbox. This method is referred to as ***splash lubrication***, generally no cooling is used with this system.

A hydraulic gearbox will store the oil in a similar way but will have an in-built lubrication system including:

- An input shaft driven oil pump
- A pressure relief valve
- An oil cooler
- A direction control valve
- Oil filter(s)

The oil pump provides oil pressure for both lubrication and the operation of the clutches. Oil pressure can be quite low when in neutral and quite high when the clutch is applied, typically around 20 to 25 bar.

It is very important to use the correct type of oil in hydraulic gearboxes as the incorrect oil can cause operation problems, always follow the manufacturer's recommendations.

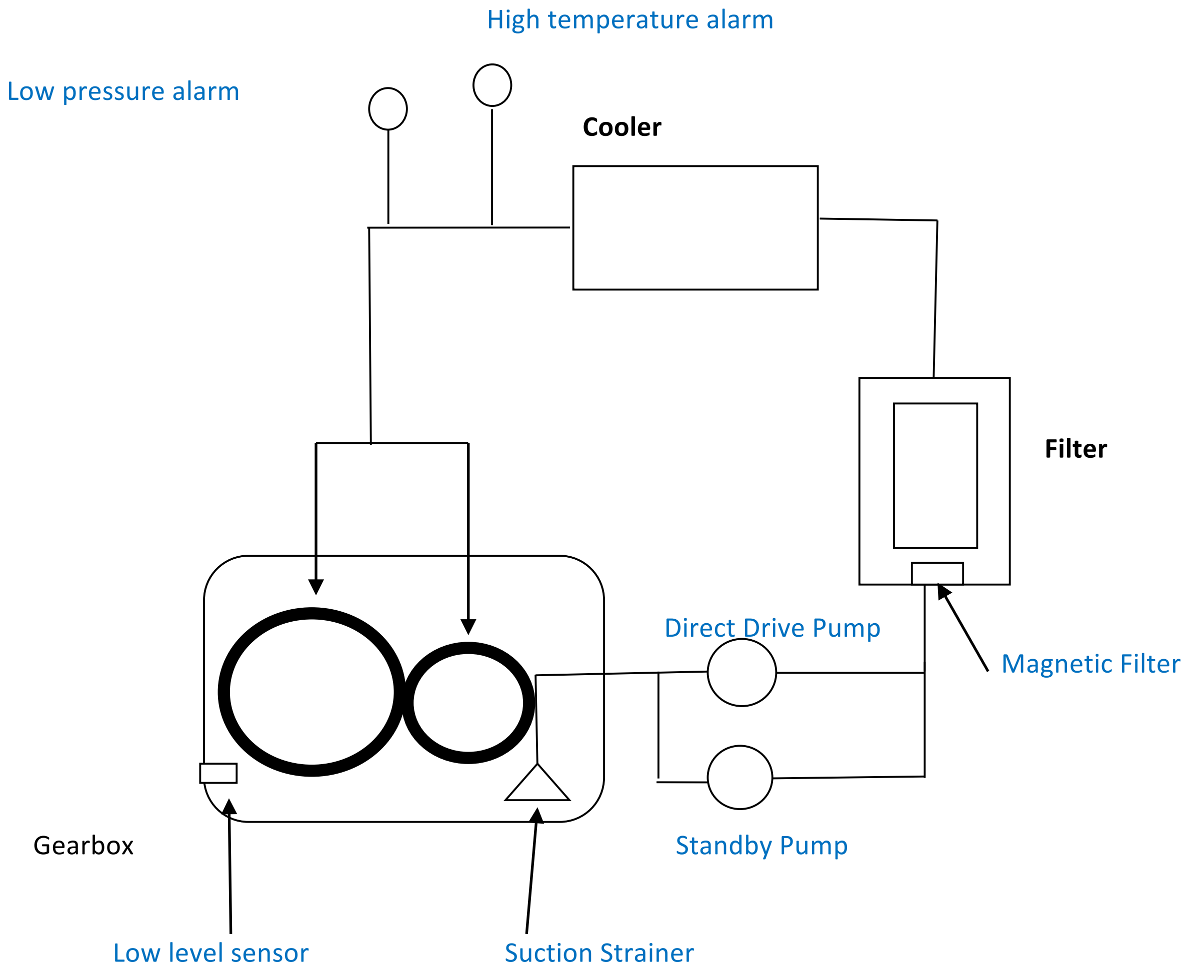
Lubrication of the gearing unit is carried out by a gearbox driven pump during normal operation, with an electric driven pump used for priming and emergency conditions. A pressure switch usually controls the electric pump. Oil is commonly distributed over the gears using spray nozzles.

Within the lube oil system, a fine filter and cooler must be provided. The filter should be inspected regularly and the source of any wear particles found identified, so that the next gear inspection will closely monitor this area of wear.

The cooler removes the heat absorbed due to friction within the gears and bearings. Operating the gearbox with too high an oil temperature will reduce oil viscosity and hence reduce oil film thickness causing increased wear.

The selection of lubrication oil is primarily for the gear contact area rather than the bearings. The level of viscosity, and the extreme pressure (EP) additives can dictate the wear rate of the gearing. However, for performance a straight mineral oil without additives is used, as there is a reduced friction loss within the bearings/gears.

A typical lubricating oil system for a gearbox showing safety devices is shown below:



Low pressure alarm. Gives warning that pumps are not operating correctly or that filters are blocked. This is to protect the teeth from metal to metal contact and subsequent damage by creating an oil pressure.

Low Level sensor. Warns of insufficient oil in gearbox which protects from metal to metal contact, overheating or loss of lubrication through frothing.

Suction Strainer. Prevents debris from entering the system and causing damage through abrasion or scoring.

Magnetic Filter. Traps ferrous particles from entering the system and causing damage as above.

Direct drive pump. This ensures a flow and maintains oil pressure at all times when the gearbox is rotating. Thus protecting the moving parts from metal to metal contact and maintaining required pressure for thick film or pressurized lubrication.

Standby pump. Electrically driven pump that provides pre-lubrication on first turn to prevent damage and can be used in an emergency as a back up to the shaft driven pump. Larger vessels may have two of these.

High Temperature Alarm. Gives warning of cooler malfunction or damage to prevent damage by changes in viscosity and hence loss of lubricating properties.

Lubricant testing

Regular examination of representative oil samples, drawn whilst the system is in operation, is useful as a general check on oil condition. Service hours and top-up quantities should always be supplied with the test sample which, in the case of ships is submitted to the laboratories for routine checking of viscosity, acidity and water content at six monthly intervals, or as advised by the gearbox manufacturer.

Ferrography

This is a monitoring technique of measuring the severity, and identifying the nature, of wear processes. The technique is based on the extraction of magnetically susceptible wear particles from a lubricant under the influence of a magnetic field.

Methods of propulsion reversal

Where a gearbox is used with a diesel engine, reversing gears may be incorporated so that the engine itself is not reversed. Where a controllable pitch propeller is in use there is no requirement to reverse the main engine.

Although some gearboxes will survive being put in reverse at full engine speed, it is far safer to reduce engine speed to tick over when changing gear either way. Helical gearboxes will withstand more punishment than metal-to-metal cone clutch types but sympathetic use will extend the life of the clutch.

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

- engine reversal of rotation;
- reversing rotation of the drive shafting by means of gears and clutches;
- controllable pitch propellers which can change the blade pitch from full ahead to full astern;
- azipod thrusters that can be steered by rotating the propeller through 360°.

Engine reversal of rotation

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

For a 4 stroke engine, this is usually done by providing ahead and astern cams side by side on the camshaft/s and the camshaft is designed to slide longitudinally.

In the normal position the ahead cams are in line with the cam followers. When astern rotation is required the camshaft is moved longitudinally and the astern cams are moved into line with the cam followers. In many engine designs the air start distributor is separate from the camshaft but a method of cam changeover from ahead to astern operation similar to moving the camshaft is adopted.

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

Reversal with gearbox

Gearboxes are classed as either a ***mechanical*** or ***hydraulic*** gearbox depending on the method used to operate the clutches within the gearbox.

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

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

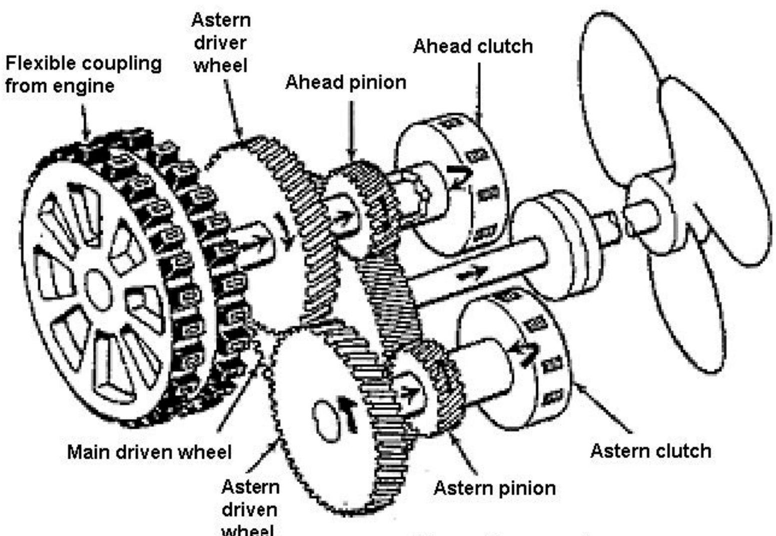
Mechanical gearboxes

As the name suggests the method of applying the clutches within the gearbox is purely mechanical where the operator applies the clutch force through the use of a lever or pivots. Once the lever is operated the clutch plates are compressed together thus enabling drive. When the lever is moved in the opposite direction the plates released from each other, thus not allowing the power to be transmitted to the drive shaft.

Hydraulic gearboxes

In a hydraulic gearbox the clutch is operated by the use of a hydraulic pressure system, generally the hydraulic pump is driven from the gearbox input shaft and the direction control is achieved by the use of a hydraulic control valve to apply oil pressure to the appropriate clutch pack.

Hydraulic gearbox operation



Reversing gearbox

In the hydraulic gearbox, the driving and reduction gears are in mesh all the time and the direction of propeller rotation is controlled by applying oil pressure to the appropriate clutch, this allows direction changes to be made quickly and smoothly.

It is however very important that to prevent excess wear on the clutches, manoeuvring is done with the minimum revs on the engine to reduce the load on the clutches, and when changing direction the clutch that was in use needs to be given time to fully release before the new clutch is engaged.

Gear and gearbox faults

Wear and failure

Failure modes

Generally gearing must be designed to avoid the occurrence of the following three failure modes:

1. Overstressing of the tooth flanks in the contact area, causing pitting.
2. Overstressing of the tooth roots, causing tooth fracture.
3. Thermal collapse of the lubricating oil film between the tooth flanks, causing scuffing.

Wear modes

Various wear modes can be found on the gear teeth, and a mixture of different faults cause of these faults.

Scuffing

In normal operation, gears should be separated by an oil film, which prevents the aspirates (surface peaks) of the gear teeth from touching. Should marginal contact occur, then a certain amount of protection is provided by the naturally occurring oxide films. If these are disrupted, metal-to-metal contact occurs with the possibility of scuffing. The latter is defined as **damage to the working surface caused by the formation and tearing of local welds**.

Hardened gears can be designed with a margin against scuffing by keeping the gear tooth loading at a modest level.

This is achieved by

- using a good surface finish,
- designing the meshing of gears to achieve high rolling velocities (to produce oil film pressures), and
- low sliding velocity (to reduce heat generated)

Pitting

This mechanism occurs when the strength of the material is exceeded, usually by a repeated loading, which causes fatigue failure. Fatigue pitting has two main forms:

- incipient (or initial);
- progressive.

Incipient or initial pitting is caused by the presence of high spots on the tooth flank. The pits are small and shallow, randomly distributed, usually just below the pitch line. These pits may join into larger pits, especially if misalignment is present.

Progressive pitting is much larger and deeper than initial pitting, with branching cracks extending into the gear tooth. Cases of progressive pitting are almost always due to some form of overload, commonly misalignment. Most progressive pitting is larger and deeper than initial pitting, with branching fatigue cracks extending deep

into the metal. It can, however, take the form of a type of spalling or attrition of the dedendum surface, frequently leading to a distinct wear step at the pitch line.

Generally speaking, contact fatigue pitting is the result of a combination of several of the following features:

1 high surface loading due to dynamic overload misalignment;

2 rough surface finish;

3 profile with high spots;

4 susceptible surface layers or inclusions;

5 inadequate or unsuitable lubrication.

Another form of damage, associated with surface-hardened gears, is exfoliation of the hardened case. The cause may be inadequate case thickness or the presence of high residual stresses.

Abrasion

Abrasive wear is identified by scratches that run up and down the gear teeth. Hard particles in the lubricating oil cause these marks, as the particles are larger than the oil film thickness. The amount of wear is dependent upon the oil contamination, and the hardness of the particles.

Surface finish or texture

The measurement of surface texture is of fundamental importance in the production of high quality gears. The quality of the surface finish is important in reducing wear, as there will be a greater surface area of contact, and hence a reduced pressure of contact.

Two variables are considered:

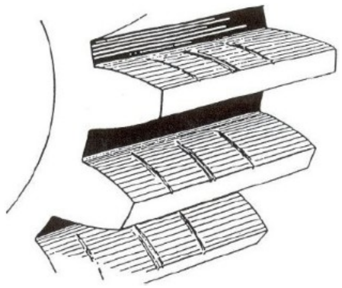
1 Roughness

2 Waviness

Roughness results from the irregularities of the machining process, and is the quality of surface finish, which can be felt by touch.

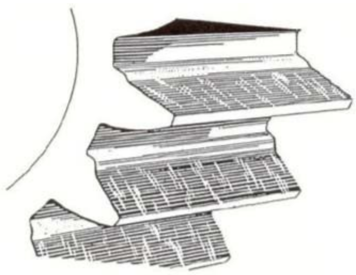
Waviness is a component upon which roughness is superimposed and is due to various factors associated with manufacture, such as chatter, vibration, machine cyclic errors, warping and so forth.

Surface texture is practically assessed by drawing a fine, pointed diamond stylus across the surface.



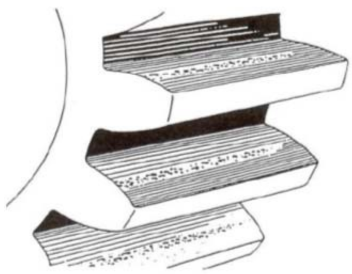
Scoring

When sharp projections on the surfaces of gear teeth pierce the oil film, they gouge or score the surface of the mating teeth. Rough finish, pitted surface or misalignment may be the cause.



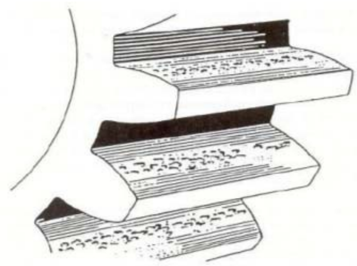
Abrasion

When foreign material of an abrasive nature enters between the meshing teeth, the resulting lapping or grinding action may either polish the surfaces or scratch them. In either case, there is abnormal wear.



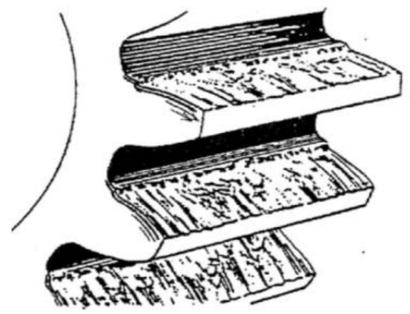
Incipient Pitting

Repeated stresses on the high or hard spots of gear teeth cause local fatigue failure of the metal. Small cones of metal break out at or slightly below the pitch line, leaving small craters or pits. After the high spots have broken out, further pitting may cease and normal wear may eventually polish out the pits.



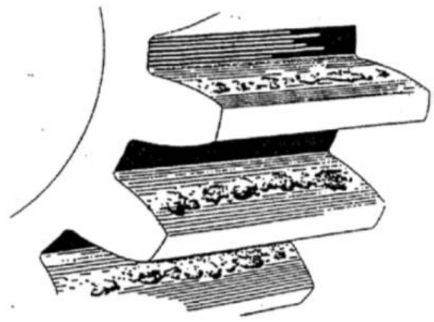
Destructive Pitting

Rough tooth surfaces may have many high spots or hard spots and may pit so badly that too much of the load-carrying surface is rendered ineffective. When this occurs, the increased loading of the remaining surface causes further pitting until the working areas are destroyed.



Advanced Scuffing or Galling

Consistent failure of the lubricating film may cause not only localised yielding and displacement of metal but also pressure welding or seizure between the engaged surfaces. When this occurs, chips and scales of metal tear from the teeth and the working surface becomes roughened. Scoring, abrasion and excessive wear then follow.



Flaking or Spalling

Abnormal tooth loading of tooth surface may overstress metal until large chips or flakes break away from the teeth.

Gear wheel surface defects

Fatigue tooth fracture

Due to high tooth loading, this creates cyclic stresses that may cause fatigue fracture. Stress raisers or pits in the surface of the teeth may aggravate the condition. Failure may occur at the root on smaller pitch gears and at the P.C.D. for larger teeth.

Ridging

A form of scratching under heavy load due to plastic flow caused by a high spot (usually on the pinion) ploughing through the surface of the mating tooth.

Rippling

Rippling is caused by plastic yielding under a heavy sliding action. This is characterised by a fish scale pattern that is caused by surface shearing stresses.

Gearbox overheating

Overheating of the gearbox lubricating oil is generally caused by one or more of the following:

- Blocked oil cooler
- Lack of cooling water
- Slipping clutches
- Binding clutches
- Low oil level
- Overfilled with oil
- Incorrect type of oil

If a gearbox is overheating the power should be reduced as much as is possible depending on the conditions and the cause found and remedied before continuing under load.

	Possible Causes	Remedial Measures
Possible causes for high gearbox temperature	Oil level in gearbox too high	Bring oil to level specified
	Cooler fouled	Clean cooler
	Rate of flow through cooler too low	Set correct rate of water flow
	Gearbox overloaded	Reduce input
	Anti-friction bearing damaged (chips in filter)	Replace anti-friction bearing
Possible causes for low operating pressure	Operating pressure too low on account of normal wear	Adjust operating pressure
	Filter blocked	Clean filter
	Oil level too low	Top up oil, locate cause for loss of oil
	Control valve defective	Replace or repair control valve
	Control valve not correctly switched on	Adjust remote controls
	Pump drive or pump damaged	Check pump drive and replace if necessary
	Oil inlet pipe leaks	Renew oil inlet pipe
	Section pipe blocked	Clean suction pipe
	Non-return valve defective	Check non-return valve
Possible causes for loss of oil	Oil drain screw not tight	Fit oil drain screw with new seal and tighten
	Shaft seals not tight	Renew shaft sealing rings and re-seal bearing