Module-III

TESTING AND PERFORMANCE

Engine performance is an indication of the degree of success of the engine performs its assigned task, i.e. the conversion of the chemical energy contained in the fuel into the useful mechanical work. The performance of an engine is evaluated on the basis of the following;

(a) Specific Fuel Consumption.
(b) Brake Mean Effective Pressure.
(c) Specific Power Output.
(d) Specific Weight.
(e) Exhaust Smoke and Other Emissions.

Basic measurements:

The basic measurements to be undertaken to evaluate the performance of an engine on almost all tests are the following:

(a) Speed
(b) Fuel consumption
(c) Air consumption
(d) Smoke density
(e) Brake horse-power
(f) Indicated horse power and friction horse power
(g) Heat balance sheet or performance of SI and CI engine
(h) Exhaust gas analysis

1. Measurement of speed:

-One of the basic measurements is that of speed. A wide variety of speed measuring devices are available in the market. They range from a mechanical tachometer to digital and triggered electrical tachometers.

-The best method of measuring speed is to count the number of revolutions in a given time. This gives an accurate measurement of speed. Many engines are fitted with such revolution counters.

-A mechanical tachometer or an electrical tachometer can also be used for measuring the speed.

-The electrical tachometer has a three-phase permanent-magnet alternator to which a voltmeter is attached. -The output of the alternator is a linear function of the speed and is directly indicated on the voltmeter dial.

-Both electrical and mechanical types of tachometers are affected by the temperature variations and are not very accurate. For accurate and continuous measurement of speed a magnetic pick-up placed near a toothed wheel coupled to the engine shaft can be used.

-The magnetic pick-up will produce a pulse for every revolution and a pulse counter will accurately measure the speed.

2. Fuel consumption measurement:

Fuel consumption is measured in two ways:

(a) The fuel consumption of an engine is measured by determining the volume flow in a given time interval and multiplying it by the specific gravity of the fuel which should be measured occasionally to get an accurate value.

(b) Another method is to measure the time required for consumption of a given mass of fuel.

As already mentioned two basic types of fuel measurement methods are:
-Volumetric type
-Gravimetric type
Volumetric type flow meter includes Burette method, Automatic Burette flow meter and Turbine flow meter.

Gravimetric Fuel Flow Measurement
The efficiency of an engine is related to the kilograms of fuel which are consumed and not the number of litres. The method of measuring volume flow and then correcting it for specific gravity variations is quite inconvenient and inherently limited in accuracy. Instead if the weight of the fuel consumed is directly measured a great improvement in accuracy and cost can be obtained. There are three types of gravimetric type systems which are commercially available include Actual weighing of fuel consumed, Four Orifice Flow meter, etc.

3. Measurement of air consumption:
In IC engines, the satisfactory measurement of air consumption is quite difficult because the flow is pulsating, due to the cyclic nature of the engine and because the air a compressible fluid. Therefore, the simple method of using an orifice in the induction pipe is not satisfactory since the reading will be pulsating and unreliable.
All kinetic flow-inferring systems such as nozzles, orifices and venturies have a square law relationship between flow rate and differential pressure which gives rise to severe errors on unsteady flow. Pulsation produced errors are roughly inversely proportional to the pressure across the orifice for a given set of flow conditions. The various methods and meters used for air flow measurement include,
(a) Air box method, and
(b) Viscous-flow air meter

4. Measurement of brake power:
The brake power measurement involves the determination of the torque and the angular speed of the engine output shaft. The torque measuring device is called a dynamometer.
Dynamometers can be broadly classified into two main types, power absorption dynamometers and transmission dynamometer.
Absorption Dynamometers
These dynamometers measure and absorb the power output of the engine to which they are coupled. The power absorbed is usually dissipated as heat by some means. Example of such dynamometers is prony brake, rope brake, hydraulic dynamometer, etc.
Transmission Dynamometers
In transmission dynamometers, the power is transmitted to the load coupled to the engine after it is indicated on some type of scale. These are also called torque-meters.

(a) Prony brake dynamometer
One of the simplest methods of measuring brake power (output) is to attempt to stop the engine by means of a brake on the flywheel and measure the weight which an arm attached to the brake will support, as it tries to rotate with the flywheel.
It consists of wooden block mounted on a flexible rope or band the wooden block when pressed into contact with the rotating drum takes the engine torque and the power is dissipated in frictional resistance. Spring-loaded bolts are provided to tighten the wooden block and hence increase the friction.

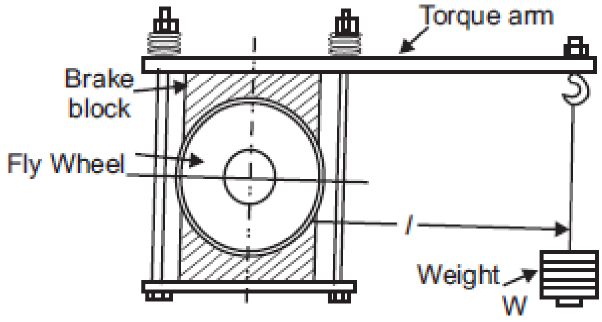

Fig. 29. Prony brake

The whole of the power absorbed is converted into heat and hence this type of dynamometer must the cooled. The brake horsepower is given by

$$BP = 2p\,NT$$

$$\text{where, } T = W \times l$$

W being the weight applied at a radius *l*.

(b) Rope brake

It consists of a number of turns of rope wound around the rotating drum attached to the output shaft. One side of the rope is connected to a spring balance and the other to a loading device. The power is absorbed in friction between the rope and the drum. The drum therefore requires cooling.

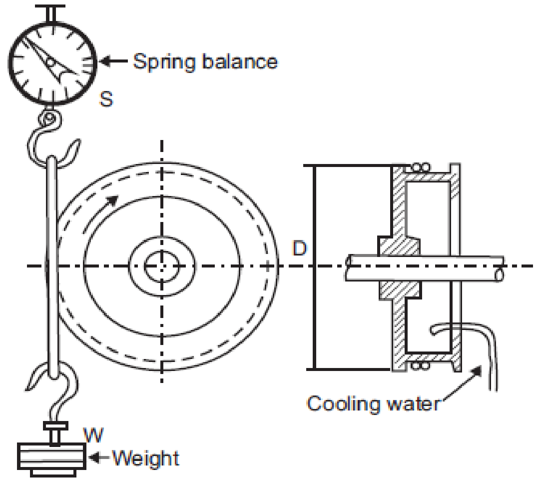

Fig. 30. Rope brake

Rope brake is cheap and easily constructed but not a very accurate method because of changes in the friction coefficient of the rope with temperature.

The *bp* is given by

$$bp = p\,DN\,(W - S)$$

where, *D* is the brake drum diameter, *W* is the weight in Newton and *S* is the spring scale reading.

(c) Hydraulic Dynamometer

Hydraulic dynamometer works on the principle of dissipating the power in fluid friction rather than in dry friction.

-In principle its construction is similar to that of a fluid flywheel.

-It consists of an inner rotating member or impeller coupled to the output shaft of the engine.

-This impeller rotates in a casing filled with fluid.

-This outer casing, due to the centrifugal force developed, tends to revolve with the impeller, but is resisted by a torque arm supporting the balance weight.

-The frictional forces between the impeller and the fluid are measured by the spring-balance fitted on the casing.
-The heat developed due to dissipation of power is carried away by a continuous supply of the working fluid, usually water.
-The output can be controlled by regulating the sluice gates which can be moved in and out to partially or wholly obstruct the flow of water between impeller, and the casing.

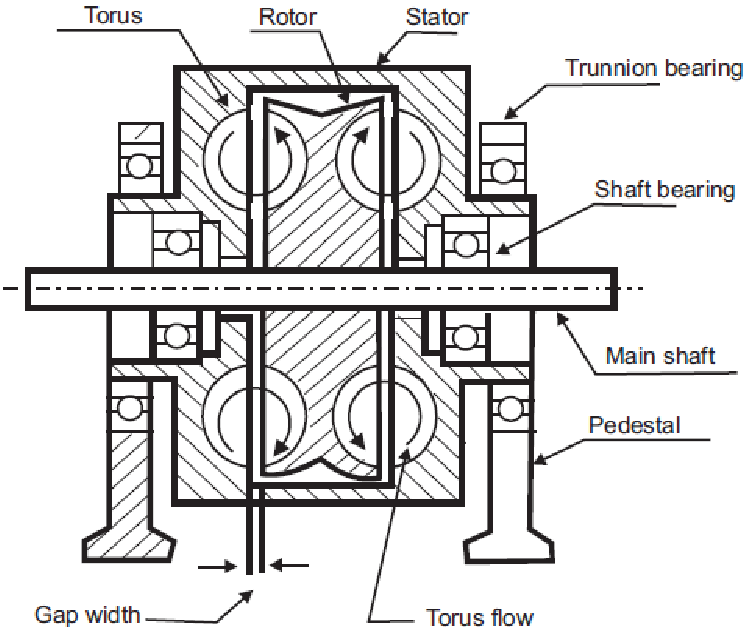

Fig. 31. Hydraulic dynamometer

(d) Eddy Current Dynamometer

It consists of a stator on which are fitted a number of electromagnets and a rotor disc made of copper or steel and coupled to the output shaft of the engine. When the rotor rotates eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets. These eddy currents are dissipated in producing heat so that this type of dynamometer also requires some cooling arrangement. The torque is measured exactly as in other types of absorption dynamometers, i.e. with the help of a moment arm. The load is controlled by regulating the current in the electromagnets.

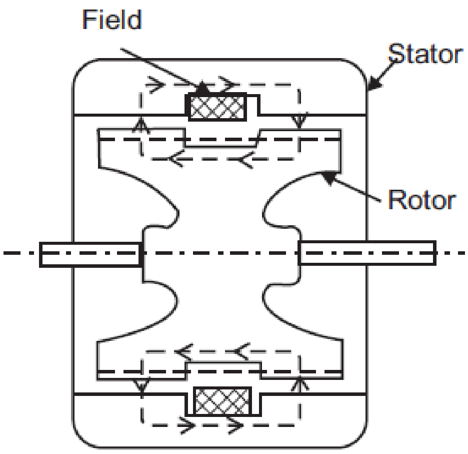

Fig. 32. Eddy current dynamometer

The following are the main advantages of eddy current dynamometer:
(a) High brake power per unit weight of dynamometer.

(b) They offer the highest ratio of constant power speed range (up to 5 : 1).
(c) Level of field excitation is below 1% of total power being handled by dynamometer, thus, easy to control and programme.
(d) Development of eddy current is smooth hence the torque is also smooth and continuous under all conditions.
(e) Relatively higher torque under low speed conditions.
(f) It has no intricate rotating parts except shaft bearing.
(g) No natural limit to size-either small or large.

(e) Swinging Field d.c. Dynamometer

Basically, a swinging field d.c. dynamometer is a d.c. shunt motor so supported on trunnion bearings to measure their action torque that the outer case and filed coils tend to rotate with the magnetic drag. Hence, the name swinging field. The torque is measured with an arm and weighing equipment in the usual manner.

Many dynamometers are provided with suitable electric connections to run as motor also. Then the dynamometer is reversible, i.e. works as motoring as well as power absorbing device.

-When used as an absorption dynamometer it works as a d.c. generator and converts mechanical energy into electric energy which is dissipated in an external resistor or fed back to the mains.

-When used as a motoring device an external source of d.c. voltage is needed to drive the motor.

The load is controlled by changing the field current.

Fan Dynamometer

It is also an absorption type of dynamometer in that when driven by the engine it absorbs the engine power. Such dynamometers are useful mainly for rough testing and running. The accuracy of the fan dynamometer is very poor. The power absorbed is determined by using previous calibration of the fan brake.

Transmission Dynamometers

Transmission dynamometers, also called torque meters, mostly consist of a set of strain-gauges fixed on the rotating shaft and the torque is measured by the angular deformation of the shaft which is indicated as strain of the strain gauge. Usually, a four arm bridge is used to reduce the effect of temperature to minimum and the gauges are arranged in pairs such that the effect of axial or transverse load on the strain gauges is avoided.

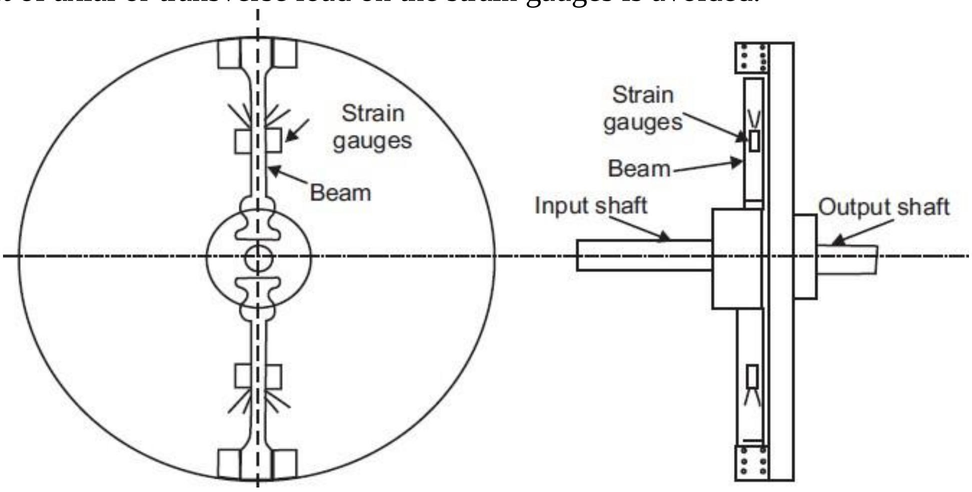

Fig. 33. Transmission dynamometer

Transmission dynamometers are very accurate and are used where continuous transmission of load is necessary. These are used mainly in automatic units.

5. Measurement of friction power:

-The difference between indicated power and the brake power output of an engine is the friction power.

-Almost invariably, the difference between a good engine and a bad engine is due to difference between their frictional losses.

-The frictional losses are ultimately dissipated to the cooling system (and exhaust) as they appear in the form of frictional heat and this influences the cooling capacity required. Moreover, lower friction means availability of more brake power; hence brake specific fuel consumption is lower.

-The *bsfc* rises with an increase in speed. Thus, the level of friction decides the maximum output of the engine which can be obtained economically.

The friction force power of an engine is determined by the following methods :

(a) Willan‟s line method.
(b) Morse test.
(c) Motoring test.
(d) Difference between *ip* and *bp*.

(a) Willan's line method

-In this method, gross fuel consumption vs. *bp* at a constant speed is plotted and the graph is extrapolated back to zero fuel consumption.

-The point where this graph cuts the *bp* axis is an indication of the friction power of the engine at that speed. This negative work represents the combined loss due to mechanical friction, pumping and blow by.

-The main drawback of this method is the long distance to be extrapolated from data measured between 5 and 40% load towards the zero line of fuel input.

-The directional margin of error is rather wide because of the graph which may not be a straight line many times.

-The changing slope along the curve indicates part efficiencies of increments of fuel. The pronounced change in the slope of this line near full load reflects the limiting influence of the air-fuel ratio and of the quality of combustion.

-Similarly, there is a slight curvature at light loads. This is perhaps due to difficulty in injecting accurately and consistently very small quantities of fuel per cycle.

-Therefore, it is essential that great care should be taken at light loads to establish the true nature of the curve.

-The Willan‟s line for a swirl-chamber CI engine is straighter than that for a direct injection type engine.

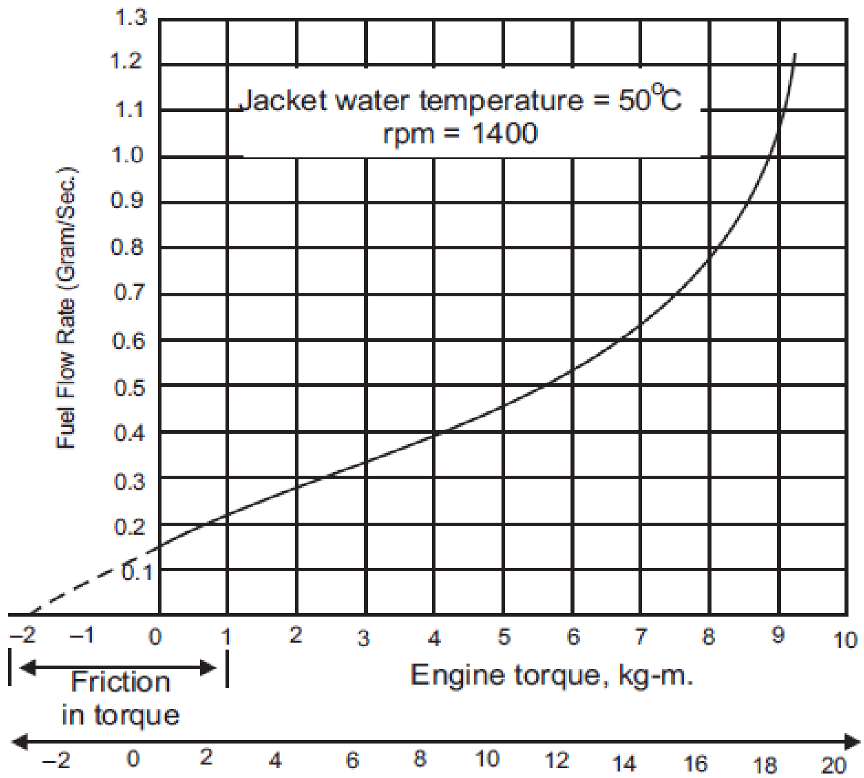

Fig. 34. Willian's line method

The accuracy obtained in this method is good and compares favourably with other methods if extrapolation is carefully done.

(b) Morse Test

-The Morse test is applicable only to multicylinder engines.
-In this test, the engine is first run at the required speed and the output is measured.
-Then, one cylinder is cut out by short circuiting the spark plug or by disconnecting the injector as the case may be.
-Under this condition all other cylinders „motor" this cut-out cylinder.
-The output is measured by keeping the speed constant at its original value.
-The difference in the outputs is a measure of the indicated horse power of the cut-out cylinder.
-Thus, for each cylinder the *ip* is obtained and is added together to find the total *ip* of the engine.
-This method though gives reasonably accurate results and is liable to errors due to changes in mixture distribution and other conditions by cutting-out one cylinder. In gasoline engines, where there is a common manifold for two or more cylinders the mixture distribution as well as the volumetric efficiency both change. Again, almost all engines have a common exhaust manifold for all cylinders and cutting out of one cylinder may greatly affect the pulsations in exhaust system which may significantly change the engine performance by imposing different back pressures.

(c) Motoring Test

-In the motoring test, the engine is first run up to the desired speed by its own power and allowed to remain at the given speed and load conditions for some time so that oil, water, and engine component temperatures reach stable conditions.
-The power of the engine during this period is absorbed by a swinging field type electric dynamometer, which is most suitable for this test.

-The fuel supply is then cut-off and by suitable electric-switching devices the dynamometer is converted to run as a motor to drive for „motor" the engine at the same speed at which it was previously running.
-The power supply to the motor is measured which is a measure of the *fhp* of the engine. During the motoring test the water supply is also cut-off so that the actual operating temperatures are maintained.
-This method, though determines the *fp* at temperature conditions very near to the actual operating temperatures at the test speed and load, does, not give the true losses occurring under firing conditions due to the following reasons.
(i) The temperatures in the motored engine are different from those in a firing engine because even if water circulation is stopped the incoming air cools the cylinder. This reduces the lubricating oil temperature and increases friction increasing the oil viscosity. This problem is much more severing in air-cooled engines.
(ii) The pressure on the bearings and piston rings is lower than the firing pressure. Load on main and connecting road bearings are lower.
(iii) The clearance between piston and cylinder wall is more (due to cooling). This reduces the piston friction.
(iv) The air is drawn at a temperature less than when the engine is firing because it does not get heat from the cylinder (rather loses heat to the cylinder). This makes the expansion line to be lower than the compression line on the p-v diagram. This loss is however counted in the indicator diagram.
(v) During exhaust the back pressure is more because under motoring conditions sufficient pressure difference is not available to impart gases the kinetic energy is necessary to expel them from exhaust.

Motoring method, however, gives reasonably good results and is very suitable for finding the losses due to various engine components. This insight into the losses caused by various components and other parameters is obtained by progressive stripping-off of the under progressive dismantling conditions keeping water and oil circulation intact. Then the cylinder head can be removed to evaluate, by difference, the compression loss. In this manner piston ring, piston etc. can be removed and evaluated for their effect on overall friction.

(d)* Difference between *ip* and *bp
(i) The method of finding the *fp* by computing the difference between *ip*, as obtained from an indicator diagram, and *bp*, as obtained by a dynamometer, is the ideal method.
(ii) In obtaining accurate indicator diagrams, especially at high engine speeds, this method is usually only used in research laboratories. Its use at commercial level is very limited.

6. Heat balance sheet:
The performance of an engine is usually studied by heat balance-sheet. The main components of the heat balance are:
-Heat equivalent to the effective (brake) work of the engine,
-Heat rejected to the cooling medium,
-Heat carried away from the engine with the exhaust gases, and
-Unaccounted losses.
The unaccounted losses include the radiation losses from the various parts of the engine and heat lost due to incomplete combustion. The friction loss is not shown as a separate item to the heat balance-sheet as the friction loss ultimately reappears as heat in cooling water, exhaust and radiation.

(i) Performance of SI engine:
-At full throttle the brake thermal efficiency at various speeds varies from 20 to 27 percent, maximum efficiency being at the middle speed range.

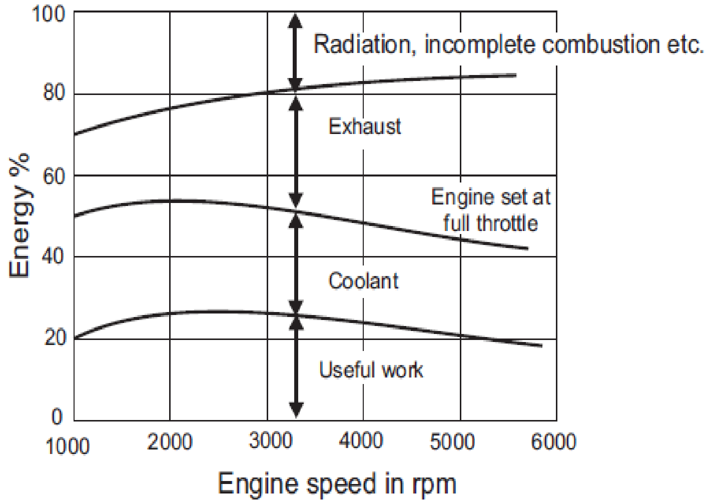

Fig. 35. Heat balance sheet for SI engine

-The percentage heat rejected to coolant is more at lower speed (» 35%) and reduces at higher speeds (» 25%). Considerably more heat is carried by exhaust at higher speeds.
-Torque and mean effective pressure do not strongly depend on the speed of the engine, but depend on the volumetric efficiency and friction losses. Maximum torque position corresponds with the maximum air charge or minimum volumetric efficiency position.
-High power arises from the high speed. In the speed range before the maximum power is obtained, doubling the speed doubles the power.
-At low engine speed the friction power is relatively low and *bhp* is nearly as large as *ip*. As engine speed increases, however, *fp* increases at continuously greater rate and therefore *bp* reaches a peak and starts reducing even though *ip* is rising. At engine speeds above the usual operating range, *fp* increases very rapidly. Also, at these higher speeds *ip* will reach a maximum and then fall off. At some point, *ip* and *fp* will be equal, and *bp* will then drop to zero.

(ii) Performance of CI engine:
The performance of a CI engine at constant speed and variable load is given as,
As the efficiency of CI engine is more than the SI engine the total losses are less. The coolant loss is more at low loads and radiation, etc. losses are more at high loads.
-The *bmep*, *bp* and torque directly increase with load
-The lowest brake specific fuel consumption and hence the maximum efficiency occurs at about 80% of the full load.

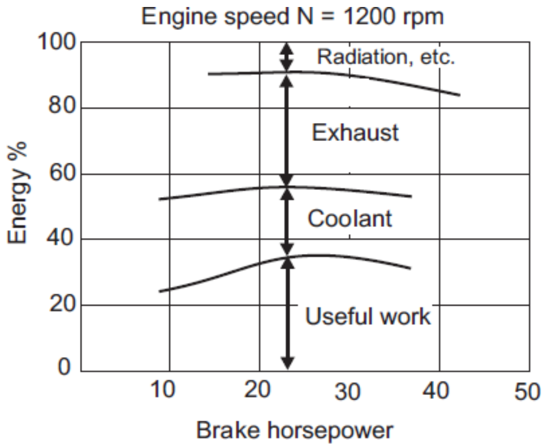

Fig. 36. Heat balance sheet of CI engine at constant speed

ENGINE COOLING

In a SI engine, cooling must be satisfactory to avoid pre-ignition and knock. In a compression ignition engine, since a normal combustion is aided, cooling must be sufficient to allow the parts to operate properly. In short, cooling is a matter of equalization of internal temperature to prevent local overheating as well as to remove sufficient heat energy to maintain a practical overall working temperature.

***Requirements of cooling system in the IC engine**

The cooling system is provided in the IC engine for the following reasons:

-The temperature of the burning gases in the engine cylinder reaches up to 1500 to 2000°C, which is above the melting point of the material of the cylinder body and head of the engine. (Platinum, a metal which has one of the highest melting points, melts at 1750 °C, iron at 1530°C and aluminium at 657°C.) Therefore, if the heat is not dissipated, it would result in the failure of the cylinder material.

-Due to very high temperatures, the film of the lubricating oil will get oxidized, thus producing carbon deposits on the surface. This will result in piston seizure.

-Due to overheating, large temperature differences may lead to a distortion of the engine components due to the thermal stresses set up. This makes it necessary for, the temperature variation to be kept to a minimum.

-Higher temperatures also lower the volumetric efficiency of the engine.

Effect of overcooling:

-Thermal efficiency is decreased due to more loss of heat carried by the coolant
-The vaporization of the fuel is less resulting in lower combustion efficiency
-Low temperature increases the viscosity of lubricant causing more loss due to friction

There are mainly two types of cooling systems:
(a) Air cooled system, and
(b) Water cooled system

Air Cooled System:

-Air cooled system is generally used in small engines say up to 15-20 kW and in aero plane engines.
-In this system fins or extended surfaces are provided on the cylinder walls, cylinder head, etc. Heat generated due to combustion in the engine cylinder will be conducted to the fins and when the air flows over the fins, heat will be dissipated to air.

-The amount of heat dissipated to air depends upon:
(a) Amount of air flowing through the fins
(b) Fin surface area
(c) Thermal conductivity of metal used for fins

-For efficient cooling the length of the fins and the spacing between them is quite important
-Larger inter spacing between the fins offers larger area for cooling air but the heating of the air is less, so more cooling air is required
-Smaller inter spacing between the fins results in smaller flow area of cooling air and hence input cooling air is less
-Usually fin height varies from 15 to 25 mm

Advantages of air cooled engines

Air cooled engines have the following advantages:
1. Its design of air-cooled engine is simple.
2. It is lighter in weight than water-cooled engines due to the absence of water jackets, radiator, circulating pump and the weight of the cooling water.
3. It is cheaper to manufacture.
4. It needs less care and maintenance.
5. This system of cooling is particularly advantageous where there are extreme climatic conditions in the arctic or where there is scarcity of water as in deserts.
6. No risk of damage from frost, such as cracking of cylinder jackets or radiator water tubes.

Disadvantages of air cooled engines

-Relatively large amount of power is used to drive the cooling fan.™
-Engines give low power output.™
-Cooling fins under certain conditions may vibrate and amplify the noise level.
-Cooling is not uniform.™
-Engines are subjected to high working temperature.

Water cooling system:

Cooling water jackets are provided around the cylinder, cylinder head, valve seats etc. The water when circulated through the jackets, it absorbs heat of combustion. This hot water will then be cooling in the radiator partially by a fan and partially by the flow developed by the forward motion of the vehicle. The cooled water is again recirculated through the water jackets.

Antifreeze mixture

In western countries if the water used in the radiator freezes because of cold climates, then ice formed has more volume and produces cracks in the cylinder blocks, pipes, and radiator. So, to prevent freezing antifreeze mixtures or solutions are added in the cooling water.

Normally following are used as antifreeze solutions:
(i) Methyl, ethyl and isopropyl alcohols
(ii) A solution of alcohol and water
(iii) Ethylene Glycol raises the boiling temperature substantially and hence more heat dissipation
(iv) A solution of water and Ethylene Glycol
(v) Glycerin along with water, etc.
(vi) Chromates are used to prevents deposit

Water cooling system mainly consists of:
-Radiator
-Thermostat valve
-Water pump
-Fan
-Water Jackets
-Antifreeze mixtures

Various types of water cooling systems are given as;

(a) Thermo-syphon cooling
(b) Forced or pump cooling
(c) Cooling with thermostatic regulator
(d) Pressurised water cooling system
(e) Evaporative cooling

(a) Thermo-syphon cooling:
This system works on the principle that hot water being lighter rises up and the cold water being heavier goes down. In this system the radiator is placed at a higher level than the engine for the easy flow of water towards the engine. Heat is conducted to the water jackets from where it is taken away due to convection by the circulating water. As the water jacket becomes hot, it rises to the top of the radiator. Cold water from the radiator takes the place of the rising hot water and in this way a circulation of water is set up m the system. This helps in keeping the engine at working temperature.

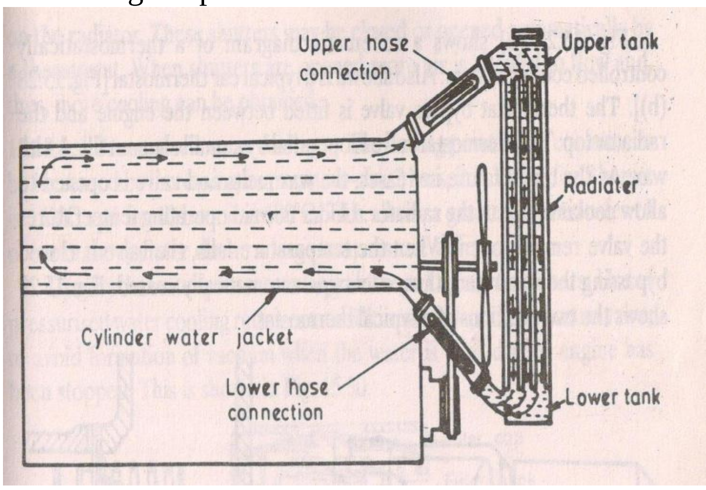

Fig. 37. Thermo-syphon cooling

Disadvantages of Thermo-syphon system,
-Rate of circulation is too slow.

-Circulation commences only when there is a marked difference in temperature.
-Circulation stops as the level of water falls below the top of the delivery pipe of the radiator.
For these reasons this system has become obsolete and is no more in use.

(b) Forced or pump cooling:
-This system is used in large number of vehicles like car, buses, trucks and other heavy vehicles. Here circulation of water takes place with convection currents help by a pump.

-The water or coolant is circulated through jackets around the parts of the engine to be cooled, and is kept in motion by a centrifugal pump, driven from the engine through V-belt.

Limitation
-Cooling is independent of temp.
-Engine is overcooled (when range of temp.=75-90^0C)
-Can be overcome by using thermostat

(c) Cooling with thermostatic regulator:
-Whenever the engine is started from cold, the coolant temperature has to be brought to the desired warm up time to avoid corrosion damage due to condensation of acids as well as help in easy starting of the engine. This can be done by the use of thermostatic device or thermostat.
-It is a kind of check valve which opens and closes with the effect of temperature. It is fitted in the water outlet of the engine. During the warm-up period, the thermostat is closed and the water pump circulates the water only throughout the cylinder block and cylinder head. When the normal operating temperature is reached, the thermostat valve opens and allows hot water to flow towards the radiator. Standard thermostats are designed to start opening at 70 to 75°C and they fully open at 82°C. High temperature thermostats, with permanent anti-freeze solutions (Prestine, Zerex, etc.), start opening at 80 to 90°C and fully open at 92°C.
- There are three types of thermostats: (i) bellow type, (ii) bimetallic type and (iii) wax type.

Bellow type valve: Flexible bellows are filled with alcohol or ether. When the bellows is heated, the liquid vaporises, creating enough pressure to expand the bellows. When the unit is cooled, the gas condenses. The pressure reduces and the bellows collapse to close the valve.

Bimetallic type valve: This consists of a bimetallic strip. The unequal expansion of two metallic strips causes the valve to open and allows the water to flow in the radiator.

Wax type valve:
-Can operate reliably within the specified temperature range
- Heat is transmitted to wax, which has high coefficient of thermal expansion
-Upon being heated, wax expands and the rubber plug presses the plunger forcing it to move vertically upwards

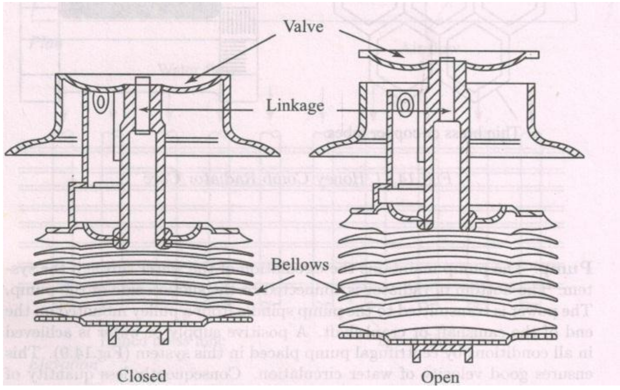

Fig. 38. Bellow type thermostat

(d) Pressurised water cooling system:

In the case of the ordinary water-cooling system where the cooling water is subjected to atmospheric pressure, the water boils at 212°F. But, when water is heated in a closed radiator under high pressure, the boiling temperature of water increases. The higher water temperature gives more efficient engine performance and affords additional protection under high altitude and tropical conditions for long hard driving periods. Therefore, a pressure-type radiator cap is used with the forced circulation cooling system. The cap is fitted on the radiator neck with an air tight seal. The pressure-release valve or safety valve is set to open at a pressure between 4 and 13 psi. With this increase in pressure, the boiling temperature of water increases to 243°F (at 4 psi boiling tap 225°F and 13 psi boiling temperature 243°F). Any increase in pressure is released by the pressure release valve or safety valve to the atmosphere. On cooling, the vapours will condense and a partial vacuum will be created which will result in the collapse of the hoses and tubes. To overcome this problem the pressure release valve is associated with a vacuum valve which opens the radiator to the atmosphere.

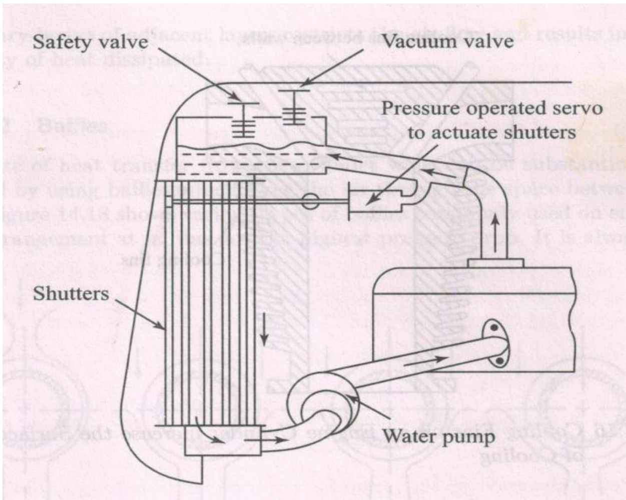

Fig. 39. Pressurised system

(e) Evaporative cooling system:

-In this system, the engine will be cooled because of the evaporation of the water in the cylinder jackets into steams.

-The advantage is being taken from the high latent heat of vaporization of water by allowing it to evaporate in the cylinder jackets. This system is used for cooling of many types of industrial engines

Descriptions of different parts of water cooling systems

Radiator: The purpose of the radiator is to cool down the water received from the engine. The radiator consists of three main parts: (i) upper tank, (ii) lower tank and (iii) tubes.
Hot water from the upper tank, which comes from the engine, flows downwards through the tubes. The heat contained in the hot water is conducted to the copper fins provided around the tubes. An overflow pipe, connected to the upper1 tank, permits excess water or steam to escape.
There are three types of radiators: (i) gilled tube radiator, (ii) tubular radiator and (iii) honey comb or cellular radiator

Gilled tube radiator:
This is perhaps the oldest type of radiator, although it is still in use. In this, water flows inside the tubes. Each tube has a large number of annular rings or fins pressed firmly over its outside surface.
Tubular radiator: The only difference between a gilled tubes radiator and a tubular one is that in this case there are no separate fins for individual tubes. The radiator vertical tubes pass through thin fine copper sheets which run horizontally.
Honey comb or cellular radiator: The cellular radiator consists of a large number of individual air cells which are surrounded by water. In this, the clogging of any passage affects only a small part of the cooling surface. However, in the tubular radiator, if one tube becomes clogged, the cooling effect of the entire tube is lost.

Water Pump:
This is a centrifugal type pump. It is centrally mounted at the front of the cylinder block and is usually driven by means of a belt. This type of pump consists of the following parts: (i) body or casing, (ii) impeller (rotor), (iii) shaft, (iv) bearings, or bush, (v) water pump seal and (vi) pulley.
The bottom of the radiator is connected to the suction side of the pump. The power is transmitted to the pump spindle from a pulley mounted at the end of the crankshaft. Seals of various designs are incorporated in the pump to prevent loss of coolant from the system.

Fan:
The fan is generally mounted on the water pump pulley, although on some engines it is attached directly to the crankshaft. It serves two purposes in the cooling system of a engine.
(i) It draws atmospheric air through the radiator and thus increases the efficiency of the radiator in cooling hot water.
(ii) It throws fresh air over the outer surface of the engine, which takes away the heat conducted by the engine parts and thus increases the efficiency of the entire cooling system.

***Advantages of water cooling system**
-Because of even cooling of cylinder barrel and head (due to jacketing) makes it possible to reduce the cylinder head and valve seat temperatures.
-The volumetric efficiency of water cooled engines is higher than that of air-cooled engines.
-Compact design of engines with appreciably smaller frontal area is possible.
-In case of water cooled engines, installation is not necessarily at the front of the mobile vehicles, aircraft etc. as the cooling system can be conveniently located.

***Disadvantages of water cooling system**
-The system requires more maintenance.
-The engine performance becomes sensitive to climatic conditions. ™
-The power absorbed by the pump is considerable and affects the power output of the engine.™
-In the event of failure of the cooling system serious damage may be caused to the engine.

LUBRICATION SYSTEM

IC engine is made of many moving parts. Due to continuous movement of two metallic surfaces over each other, there is wearing moving parts, generation of heat and loss of power in the engine. Hence, lubrication of moving parts is essential to prevent all these harmful effects.

In engine the frictional losses is attributed due to the following mechanical losses;

(i) Direct frictional losses:
-power absorbed due to the relative motion of different bearing surfaces such as piston rings, main bearings, cam shaft bearings etc.

(ii) Pumping loss:
-net power spent by the piston on the gas during intake and exhaust stroke
-more in case of four stroke engine compared to two stroke engine

(iii) Power loss to drive components to charge and scavenge:
-In four stroke supercharged engine, compressor used to provide high pressure air which is mechanically driven by the engine. This is counted as negative frictional loss.
-In two-stroke engine scavenging pump is used which is also driven by the engine

(iv) Power loss to drive the auxiliaries:
-Some power is used to drive auxiliaries such as water pump, lubricating oil pump, fuel pump, cooling fan, generator etc.

Function of lubrication:
Lubrication produces the following effects: (a) Reducing friction effect (b) Cooling effect (c) Sealing effect and (d) Cleaning effect.

(a) Reducing frictional effect: The primary purpose of the lubrication is to reduce friction and wear between two rubbing surfaces. Two rubbing surfaces always produce friction. The continuous friction produce heat which causes wearing of parts and loss of power. In order to avoid friction, the contact of two sliding surfaces must be reduced as far as possible. This can be done by proper lubrication only. Lubrication forms an oil film between two moving surfaces. Lubrication also reduces noise produced by the movement of two metal surfaces over each other.
(b) Cooling effect: The heat, generated by piston, cylinder, and bearings is removed by lubrication to a great extent. Lubrication creates cooling effect on the engine parts.
(c) Sealing effect: The lubricant enters into the gap between the cylinder liner, piston and piston rings. Thus, it prevents leakage of gases from the engine cylinder.
(d) Cleaning effect: Lubrication keeps the engine clean by removing dirt or carbon from inside of the engine along with the oil.

Lubrication theory: There are two theories in existence regarding the application of lubricants on a surface: (i) Fluid film theory and (ii) Boundary layer theory.

(i) Fluid film theory: According to this theory, the lubricant is, supposed to act like mass of globules, rolling in between two surfaces. It produces a rolling effect, which reduces friction.

(ii) Boundary layer theory: According to this theory, the lubricant is soaked in rubbing surfaces and forms oily surface over it. Thus the sliding surfaces are kept apart from each other, thereby reducing friction.

Properties of Lubricant:

1. *Viscosity:* Viscosity is a measure of the resistance to flow or the internal friction of the lubricant.
-usually measured by Saybolt universal seconds (SUS) and Redwood viscometer. Also it is expressed with centistoke (unit of kinematic viscosity) and centipoise (unit of absolute viscosity)
-expressed in two temperature i.e. -18^oC (0^oF) and 99^oC (210^oF)

2. *Viscosity Index:* It is used to grade lubricants. Viscosity is inversely proportional to temp.
-If temp. increases, the viscosity of the lubricant decreases and if temp. decreases, the viscosity of the lubricant increases.
-The variation of viscosity of oil with changes in temperature is measured by viscosity index
-oil to measure is compared with 2 reference oil having same viscosity at 99^oC. one is paraffinic base oil index of zero and another naphthenic base oil index of 100
-high viscosity index number indicates relatively smaller change in viscosity of the oil with temperature.
-low viscos oil is recommended for automobile engines in winter than summer. The viscosity of a lubricant should be just sufficient to ensure lubrication. If it is more than this value, power loss will be higher due to increased oil resistance.
-VI improver are added to improve viscosity index

3. *Oiliness:* It is the property of a lubricating oil to spread & attach itself firmly to the bearing surfaces as well as provide lubricity. Generally, the oiliness of the lubricating oil should be high particularly when it is to be used for mating surfaces subjected to a high intensity of pressure and smaller clearance portion to avoid the squeezing out of the oil. Such a way that the metal is protected by a thin layer of the oil and the wear is also considerably reduced. It is measured by co-efficient of friction at extreme operating condition.

4. *Flash Point:* Flash point of oil is the min. temp. at which the vapours of lubricating oil will flash when a small flame is passed across its surface. It is of two type open flash point and closed flash point. The flash point of the lubricating oil must be higher than the temp. likely to be developed in the bearings in order to avoid the possibility of fire hazards.

5. *Fire Point:* If the lubricating oil is further heated after the flash point has been reached, the lowest temp. at which the oil will burn continuously for 5 seconds is called fire point.
-usually 11^oC higher than open flash point and varies from 190^oC to 290^oC for the lubricants used for IC engines
-The fire point of a lubricant also must be high so that the oil does not burn in service.

6. *Cloud Point:* It is the temp. at which the lubricating oil changes its state from liquid to solid. Its temp. must high for the low temp. operability of the lubricating oil during winter.

7. *Pour Point:* It is the lowest temp. at which the lubricating oil will not flow or totally form wax or solidify. This property must be considered because of its effect on starting an engine in cold weather. Oil derived from paraffinic crudes tends to have higher pour points than those derived from naphthenic crudes. The pour points can be lower by the addition of pour point depressant usually a polymerised phenol or ester. Pour point must be at least 15^{o}F lower than the operating temperature to ensure maximum circulation.

8. *Corrosiveness:* The present of acid (mineral acid, petroleum acid) is harmful to the metal surfaces. The lubrication oil should not attack chemically the materials of the engine. The lubricant should not be corrosive, but it should give protection against corrosion. New oil has low neutralisation number i.e. it maintains the alkaline and acid solution to make the oil neutral.

9. *Oxidation stability:* It is resistance to oxidation. Due to oxidation the oil will form deposits on the piston rings and lose its lubricating property. Low temperature operation avoiding the hot-area contact and crankcase ventilation can help in preserving the stability of oil over longer periods. Oxidation inhibitors are used to improve oxidation stability. These are complex compounds of sulphur and phosphorus or amine and phenol derivatives.

10. *Cleanliness:* Lubricating oil must be clean. It should not contain dust and dirt particles as well as water content which promote corrosion.

11. *Carbon residue:* after evaporation of a mass sample of lubricating oil under specific condition may remain as carbonaceous residue. It indicates the deposit characteristics of oil. Paraffinic oil has higher carbon residues than the naphthenic base oil.

Types of lubricants:
Lubricants are at following three types.
1. Solid: graphic, mica etc
2. Semi solid: grease
3. Liquid: Lubricants are obtained from animal fat, vegetables and minerals. Lubricants made of animal fat, does not stand much heat. It becomes waxy and gummy which is not very suitable for machines. Vegetable lubricants are obtained from seeds, fruits and plants. Cottonseed oil, olive oil, linseed oil and castor oil are used as lubricant in small machines. Mineral lubricants are most popular for engines and machines. It is obtained from crude petroleum found in nature. Petroleum lubricants are less expensive and suitable for internal combustion engines.

-Graphite is often mixed with oil to lubricate automobile spring. Graphite is also used as a cylinder lubricant.
-Grease is used for chassis lubrication.

Grade of lubricants: Generally lubricating oils are graded by SAE (society of automotive engineers) method by assign a number to oil whose viscosity at given temperatures falls in certain range.
-Two temperatures -18^{o}C (0^{o}F) and 99^{o}C (210^{o}F) are used to assign the number
ex-*Single grade type:* (a) SAE 5w,10w and 20w grades are viscosity at -18^{o}C (0^{o}F) and for

winter use.
(b) SAE 20, 30, 40 and 50 grades lubricating oil are viscosity at 99°C (210°F) and for summer use.
Multi-grade type: ex- SAE 20W/50 oil has viscosity equal to that at SAE 20W at -18°C and viscosity equal to that at SAE 50 at 99°C

SAE grades of oil are based on viscosity but not quality based. API (American petroleum institute) used regular, premium and heavy duty type oil which are based upon properties of oil and operating conditions. Generally regular type oil is straight mineral oil, premium type contained oxidation inhibitors and heavy type contained oxidation inhibitors plus detergent-dispersant additives.
According to API,
For gasoline engine 5 service ratings oil are used: SA, SB, SC, SD and SE
For diesel engines 4 service ratings are use: CA, CB, CC and CD
Where S and C stands for SI and CI engines
Rating A is for light-duty service, the severity of service increasing towards rating D and E which is severe duty.

Lubrication system: various lubrication system used for IC engines are,
(a) Mist lubrication system
(b) Wet sump lubrication system
(c) Dry sump lubrication system

(a) Mist lubrication system:
-Used where crankcase lubrication is not suitable
- Generally adopted in two stroke petrol engine line scooter and motor cycle. It is the simplest form of lubricating system.
- It is the simplest form of lubricating system. It does not consist of any separate part like oil pump for the purpose of lubrication.
- In this system the lubricating oil is mixed into the fuel (petrol) while filling in the petrol tank of the vehicle in a specified ratio (ratio of fuel and lubricating oil is from 12:1 to 50:10 as per manufacturers specifications or recommendations.
- When the fuel goes into the crank chamber during the engine operation, the oil particles go deep into the bearing surfaces due to gravity and lubricate then. The piston rings, cylinder walls, piston pin etc. are lubricated in the same way.
-If the engine is allowed to remain unused for a considerable time, the lubricating oil separates oil from petrol & leads to clogging (blocking) of passages in the carburettor, results in the engine starting trouble. This is the main disadvantage of this system.
-It causes heavy exhaust smoke due to burning of lubricating oil partially or fully
-Increase deposits on piston crown and exhaust ports which affect engine efficiency
-Corrosion of bearing surfaces due to acids formation
-thorough mixing can fetch effective lubrication
-Engine suffers insufficient lubrication during closed throttle i.e. vehicle moving down the hill.

(b) Wet sump lubrication system:
Bottom of the crankcase contains oil pan or sump from which the lubricating oil is pumped to various engine components by a pump. After lubrication, oil flows back to the sump by gravity. Three types of wet sump lubrication system,

(i) Splash system
(ii) Splash and pressure system
(iii) Pressure feed system

(i) Splash system:
-In this system of lubrication the lubricating oil is stored in an oil sump. A scoop or dipper is made in the lower part of the connecting rod. When the engine runs, the dipper dips in the oil once in every revolution of the crank shaft, the oil is splashed on the cylinder wall. Due to this action engine walls, piston ring, crank shaft bearings are lubricated.
-It is used for light duty engine

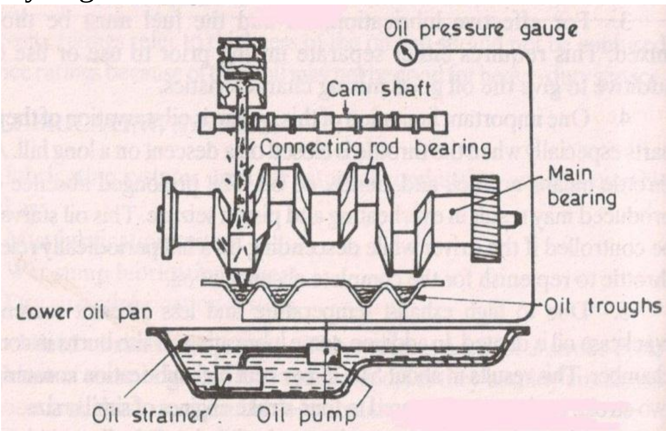

Fig. 40. Splash lubricating system

(ii) Splash and pressure system:
Lubricating oil is supplied under pressure to main, camshaft bearings and pipes which direct a stream of oil against the dippers on the big end of connecting rod bearing cup and thus crankpin bearings are lubricated by the splash or spray of oil thrown up by the dipper.

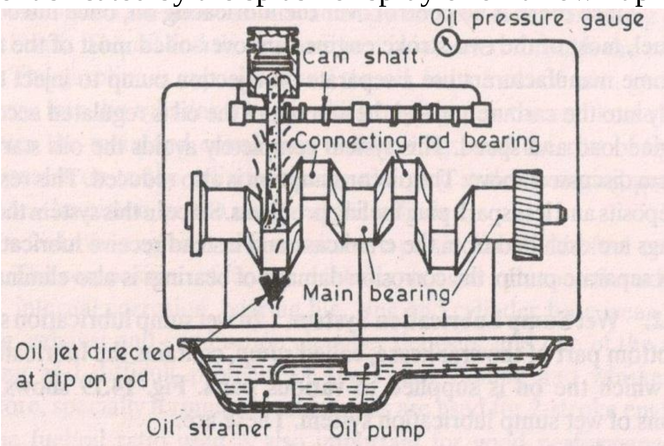

Fig. 41. Splash and pressure lubricating system

(iii) Pressure feed system:
In this system of lubrication, the engine parts are lubricated under pressure feed. The lubricating oil is stored in a separate tank (in case of dry sump system) or in the sump (in case of wet sump system), from where an oil pump (gear pump) delivers the oil to the main oil gallery at a pressure of 2-4 kg/cm^2 through an oil filter. The oil from the main gallery goes to main bearing, from where some of it falls back to the sump after lubricating the main bearing and some is splashed to lubricate the cylinder walls and remaining goes through a hole to the

crank pin. From the crank pin the lubricating oil goes to the piston pin through a hole in the connecting rod, where it lubricates the piston rings. For lubricating cam shaft and gears the oil is led through a separate oil line from the oil gallery. The oil pressure gauge used in the system indicates the oil pressure in the system. Oil filter & strainer in the system clear off the oil from dust, metal particles and other harmful particles.

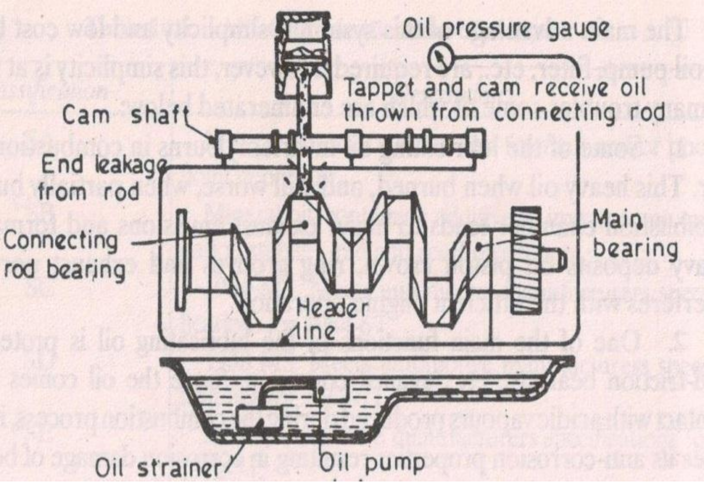

Fig. 42. Pressure lubricating system

Gear system:

-Used for a medium sized diesel engine

-It is a forced-feed system of lubrication and uses the oil contained in the bed plate as a reservoir. A gear type oil pump is driven from the crankshaft.

-The oil enters the pump and is carried around the pump casing by the gear teeth. It is then discharged. The oil is prevented from returning to the inlet by the meshing of the gear teeth. Oil is pumped from the bed plate through an oil filter and cooler into the lubricating oil manifold. A separate pipe supplies oil to the turbocharger. A supply of cooled oil is critical for the turbocharger to lubricate the high-speed bearings and to carry heat away from the rotor.

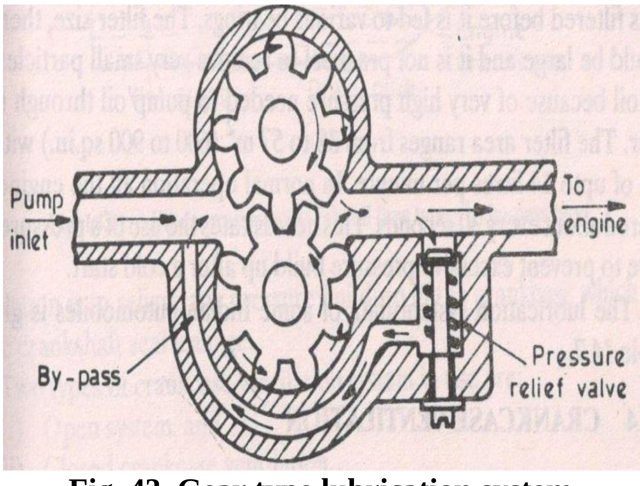

Fig. 43. Gear type lubrication system

<u>(c)</u> *<u>Dry sump lubrication system:</u>*

-Supply of oil is carried in external tank

-Oil pump draws oil from the supply tank and circulates it under pressure to various bearings of the engine

- Oil dripping from the cylinders and bearings into the sump is removed by a scavenging pump and again return to supply tank through the filter
-The capacity of scavenging pump is greater than the oil pump
-Separate oil cooler to remove heat from oil is used which is either cooled by air or water