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**SCHOOL OF MECHANICAL ENGINEERING**

**DEPARTMENT OF AUTOMOBILE ENGINEERING**

# SAUA1302 AUTOMOTIVE PETROL ENGINE

# UNIT I ENGINE CONSTRUCTION & OPERATION

# UNIT 1 ENGINE CONSTRUCTION AND OPERATION

Constructional details of four stroke petrol engine, working principle, air standard Otto cycle, actual indicator diagram, fuel air analysis, two stroke engine construction and operation, comparison of four stroke and two stroke engines operation, firing order and its significance. Theoretical and actual Port Timing, Valve Timing of petrol engines.

**Heat engine:**

A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. It is classified into two types-

(a) External combustion engine

(b) Internal combustion engine

**External combustion engine:**

In this engine, the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle.

Examples:

- In the steam engine or a steam turbine plant, the heat of combustion is employed to generate steam which is used in a piston engine (reciprocating type engine) or a turbine (rotary type engine) for useful work.
- In a closed cycle gas turbine, the heat of combustion in an external furnace is transferred to gas, usually air which the working fluid of the cycle.

**Internal combustion engine:**

In this engine, the combustion of air and fuels take place inside the cylinder and are used as the direct motive force. It can be classified into the following types:

1. ***According to the basic engine design***- (a) Reciprocating engine (Use of cylinder piston arrangement), (b) Rotary engine (Use of turbine)

2. ***According to the type of fuel used***- (a) Petrol engine, (b) diesel engine, (c) gas engine (CNG, LPG), (d) Alcohol engine (ethanol, methanol etc)

3. ***According to the number of strokes per cycle***- (a) Four stroke and (b) Two stroke engine

4. ***According to the method of igniting the fuel***- (a) Spark ignition engine, (b) compression ignition engine and (c) hot spot ignition engine

5. ***According to the working cycle***- (a) Otto cycle (constant volume cycle) engine, (b) diesel cycle (constant pressure cycle) engine, (c) dual combustion cycle (semi diesel cycle) engine.

6. ***According to the fuel supply and mixture preparation***- (a) Carburetted type (fuel supplied through the carburettor), (b) Injection type (fuel injected into inlet ports or inlet manifold, fuel injected into the cylinder just before ignition).

7. ***According to the number of cylinder***- (a) Single cylinder and (b) multi-cylinder engine

8. ***Method of cooling***- water cooled or air cooled

9. ***Speed of the engine***- Slow speed, medium speed and high speed engine

10. ***Cylinder arrangement***-Vertical, horizontal, inline, V-type, radial, opposed cylinder or piston engines.

11. ***Valve or port design and location***- Overhead (I head), side valve (L head); in two stroke engines: cross scavenging, loop scavenging, uniflow scavenging.

12. ***Method governing***- Hit and miss governed engines, quantitatively governed engines and qualitatively governed engine

13. ***Application***- Automotive engines for land transport, marine engines for propulsion of ships, aircraft engines for aircraft propulsion, industrial engines, prime movers for electrical generators.

**<u>Comparison between external combustion engine and internal combustion engine:</u>**

| External combustion engine | Internal combustion engine |
|---|---|
| ➢ Combustion of air-fuel is outside the engine cylinder (in a boiler) | ➢ Combustion of air-fuel is inside the engine cylinder (in a boiler) |
| ➢ The engines are running smoothly and silently due to outside combustion | ➢ Very noisy operated engine |
| ➢ Higher ratio of weight and bulk to output due to presence of auxiliary apparatus like boiler and condenser. Hence it is heavy and cumbersome. | ➢ It is light and compact due to lower ratio of weight and bulk to output. |
| ➢ Working pressure and temperature inside the engine cylinder is low; hence ordinary alloys are used for the manufacture of engine cylinder and its parts. | ➢ Working pressure and temperature inside the engine cylinder is very much high; hence special alloys are used |
| ➢ It can use cheaper fuels including solid fuels | ➢ High grade fuels are used with proper filtration |
| ➢ Lower efficiency about 15-20% | ➢ Higher efficiency about 35-40% |
| ➢ Higher requirement of water for dissipation of energy through cooling system | ➢ Lesser requirement of water |

| | |
|---|---|
| ➢ High starting torque | ➢ IC engines are not self-starting |

## IC ENGINE COMPONENTS

Internal combustion engine consists of a number of parts which are given below

**Cylinder:**

It is a part of the engine which confines the expanding gases and forms the combustion space. It is the basic part of the engine. It provides space in which piston operates to suck the air or air-fuel mixture. The piston compresses the charge and the gas is allowed to expand in the cylinder, transmitting power for useful work. Cylinders are usually made of high grade cast iron.

**Cylinder block:**

It is the solid casting body which includes the cylinder and water jackets (cooling fins in the air cooled engines).

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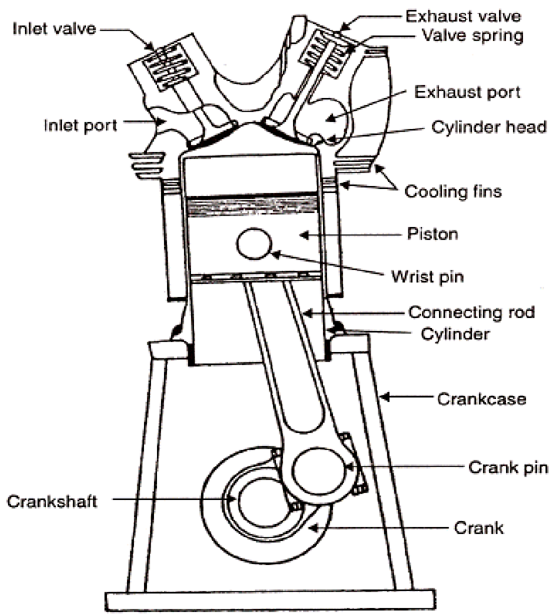


Figure 1: Constructional view of a single cylinder SI engine

**Cylinder head:**

It is a detachable portion of an engine which covers the cylinder and includes the combustion chamber, spark plugs or injector and valves.

**Cylinder liner or sleeve:**

It is a cylindrical lining either wet or dry type which is inserted in the cylinder block in which the piston slides. Liners are classified as: (1) Dry liner and (2) Wet liner. Dry liner makes metal to metal contact with the cylinder block casing. wet liners come in contact with the cooling water, whereas dry liners do not come in contact with the cooling water.

**Piston:**

It is a cylindrical part closed at one end which maintains a close sliding fit in the engine cylinder. It is connected to the connecting rod by a piston pin. The force of the expanding gases against the closed end of the piston, forces the piston down in the cylinder. This causes the connecting rod to rotate the crankshaft. Cast iron is chosen due to its high compressive strength. Aluminum and its alloys preferred mainly due to it lightness.

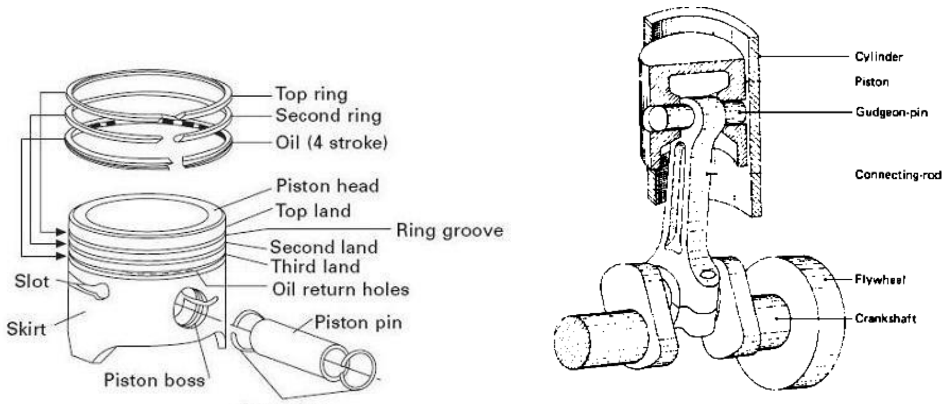

Fig. 1.1-1 Pictorial view of the basic engine.

Figure 2: Piston and piston ring assembly

**Head (Crown) of piston**: It is the top of the piston.

**Skirt**: It is that portion of the piston below the piston pin which is designed to adsorb the side movements of the piston.

**Piston ring:**

It is a split expansion ring, placed in the groove of the piston. They are usually made of cast iron or pressed steel alloy. The function of the ring are as follows :

a) It forms a gas tight combustion chamber for all positions of piston.
b) It reduces contact area between cylinder wall and piston wall preventing friction losses and excessive wear.
c) It controls the cylinder lubrication.
d) It transmits the heat away from the piston to the cylinder walls. Piston rings are of two types: (1) Compression ring and (2) Oil ring

**Compression ring:**

Compression rings are usually plain, single piece and are always placed in the grooves of the piston nearest to the piston head. They prevent leakage of gases from the cylinder and helps increasing compression pressure inside the cylinder.

**Oil ring:**

Oil rings are grooved or slotted and are located either in lowest groove above the piston pin or in a groove above the piston skirt. They control the distribution of lubrication oil in the cylinder and the piston.

**Piston Pin:**

It is also called wrist pin or gudgeon pin. Piston pin is used to join the connecting rod to the piston.

**Connecting rod:**

It is special type of rod, one end of which is attached to the piston and the other end to the crankshaft. It transmits the power of combustion to the crankshaft and makes it rotate continuously. It is usually made of drop forged steel.

**Crankshaft:**

It is the main shaft of an engine which converts the reciprocating motion of the piston into rotary motion of the flywheel. Usually the crankshaft is made of drop forged steel or cast steel. The space that supports the crankshaft in the cylinder block is called *main journal*, whereas the part to which connecting rod is attached is known as *crank journal*. Crankshaft is provided with counter weights throughout its length to have counter balance of the unit.

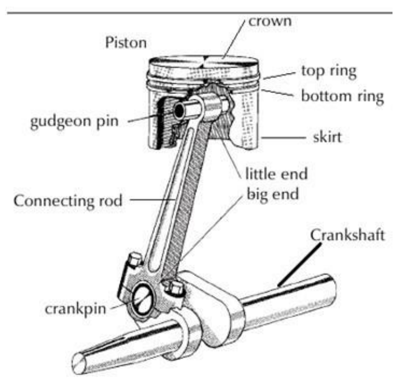


Figure 3: Connecting rod assembly

**Flywheel:**

Flywheel is made of cast iron. Its main functions are as follows :

a) It stores energy during power stroke and returns back the energy during the idle strokes, providing a uniform rotary motion of flywheel.
b) The rear surface of the flywheel serves as one of the pressure surfaces for the clutch plate.
c) Engine timing marks are usually stamped on the flywheel, which helps in adjusting the timing of the engine.
d) Sometime the flywheel serves the purpose of a pulley for transmitting power.

**Crankcase:**

The crankcase is that part of the engine which supports and encloses the crankshaft and camshaft. It provides a reservoir for the lubricating oil. It also serves as a mounting unit for such accessories as the oil pump, oil filter, starting motor and ignition components. The upper portion of the crankcase is usually integral with cylinder block. The lower part of the crankcase is commonly called oil pan and is usually made of cast iron or cast aluminum.

**Camshaft:**

It is a shaft which raises and lowers the inlet and exhaust valves at proper times. Camshaft is driven by crankshaft by means of gears, chains or sprockets. The speed of the camshaft is exactly half the speed of the crankshaft in four stroke engine. Camshaft operates the ignition timing mechanism, lubricating oil pump and fuel pump. It is mounted in the crankcase, parallel to the crankshaft.

**Timing gear:**

Timing gear is a combination of gears, one gear of which is mounted at one end of the camshaft and the other gear at the crankshaft. Camshaft gear is bigger in size than that of the crankshaft gear and it has twice as many teeth as that of the crankshaft gear. For this reason, this gear is commonly called half time gear. Timing gear controls the timing of ignition, timing of opening and closing of valve as well as fuel injection timing.

**Inlet manifold:** It is that part of the engine through which air or air-fuel mixture enters into the engine cylinder. It is fitted by the side of the cylinder head.

**Exhaust manifold:** It is that part of the engine through which exhaust gases go out of the engine cylinder. It is capable of withstanding high temperature of burnt gases. It is fitted by the side of the cylinder head.

**Fuel injector:**

A pressurized nozzle that sprays fuel into the incoming air on SI engines or into the cylinder on CI engines. On SI engines, fuel injectors are located at the intake valve ports on multipoint port injector systems and upstream at the intake manifold inlet on throttle body injector systems. In a few SI engines, injectors spray directly into the combustion chamber.

**Fuel pump:**

Electrically or mechanically driven pump to supply fuel from the fuel tank (reservoir) to the engine. Many modern automobiles have an electric fuel pump mounted submerged in the fuel tank. Some small engines and early automobiles had no fuel pump, relying on gravity feed.

**TERMINOLOGIES IN IC ENGINES**

**Bore-** Bore is the diameter of the engine cylinder.

**Stroke** - It is the linear distance traveled by the piston from Top dead centre (TDC) to Bottom dead centre (BDC).

**Stroke-bore ratio** -The ratio of length of stroke (L) and diameter of bore (D) of the cylinder is called stroke-bore ratio (L/D). In general, this ratio varies between 1 to 1.45 and for tractor engines, this ratio is about 1.25.

**Swept volume** - It is the volume (A x L) displaced by one stroke of the piston where A is the cross sectional area of piston and L is the length of stroke

**Top dead centre** - When the piston is at the top of its stroke, it is said to be at the *top dead centre* (TDC),

**Bottom dead centre** - when the piston is at the bottom of its stroke, it is said to be at its bottom dead centre (BDC).

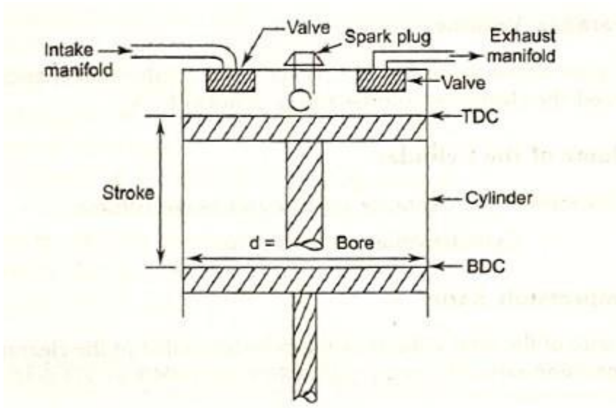


Figure 4: Location of dead centre in the cylinder area

**Compression ratio** - It is the ratio of the volume of the cylinder at the beginning of the compression stroke to that at the end of compression stroke, i.e. ratio of total cylinder volume to clearance volume. The Compression ratio of diesel engine varies from 14:1 to 22:1 and that of carburetor type engine (spark ignition engine) varies from 4:1 to 8:1.

**Power** - It is the rate of doing work. S.I. unit of power is watt.

Watt = Joule/sec. (4.2 Joules = 1 Calorie).

In metric unit the power can be expressed in kg.m/sec.

**Horse power (HP)** - It is the rate of doing work. Expressed in horse power Conversion factors from work to power

4500 kg m of work /minute = 1.0 hp 75

kg. m of work /second = 1.0 hp.

**Indicated horse power (IHP)** - It is the power generated in the engine cylinder and received by the piston. It is the power developed in a cylinder without accounting frictional losses.

**Brake horse power (BHP)** - It is the power delivered by the engine at the end of the crankshaft. It is measured by a dynamometer.

Ignition Delay(ID) - Time interval between ignition initiation and the actual start of combustion.

**Air-Fuel Ratio** (AF) Ratio of mass of air to mass of fuel input into engine.

**Fuel-Air Ratio** (FA) Ratio of mass of fuel to mass of air input into engine.

## BASIC ENGINE CYCLES

Most internal combustion engines, both spark ignition and compression ignition, operate on either a four-stroke cycle or a two-stroke cycle. These basic cycles are fairly standard for all engines, with only slight variations found in individual designs

### Four-Stroke SI Engine Cycle

1. *First Stroke: Intake Stroke or Induction*

The piston travels from TDC to BDC with the intake valve open and exhaust valve closed. This creates an increasing volume in the combustion chamber, which in turn creates a vacuum. The resulting pressure differential through the intake system from atmospheric pressure on the outside to the vacuum on the inside causes air to be pushed into the cylinder. As the air passes through the intake system, fuel is added to it in the desired amount by means of fuel injectors or a carburetor.

2. *Second Stroke: Compression Stroke*

When the piston reaches BDC, the intake valve closes and the piston travels back to TDC with all valves closed. This compresses the air-fuel mixture, raising both the pressure and temperature in the cylinder. The finite time required to close the intake valve means that actual compression doesn't start until sometime at BDC. Near the end of the compression stroke, the spark plug is fired and combustion is initiated.

3. *Combustion:*

Combustion of the air-fuel mixture occurs in a very short but finite length of time with the piston near TDC (i.e., nearly constant-volume combustion). It starts near the end of the compression stroke slightly by TDC and lasts into the power stroke slightly at TDC. Combustion changes the composition of the gas mixture to that of exhaust products and increases the temperature in the cylinder to a very high peak value. This, in turn, raises the pressure in the cylinder to a very high peak value.

4. Third Stroke: Expansion Stroke or Power Stroke

With all valves closed, the high pressure created by the combustion process pushes the piston away from TDC. This is the stroke which produces the work output of the engine cycle. As the piston travels from TDC to BDC, cylinder volume is increased, causing pressure and temperature to drop.

5. Exhaust Blowdown

Late in the power stroke, the exhaust valve is opened and exhaust blow down occurs. Pressure and temperature in the cylinder are still high relative to the surroundings at this point, and a pressure differential is created through the exhaust system which is open to atmospheric pressure. This pressure differential causes much of the hot exhaust gas to be pushed out of the cylinder and through the exhaust system when the piston is near BDC. This exhaust gas carries away a high amount of enthalpy, which lowers the cycle thermal efficiency. Opening the exhaust valve before BDC reduces the work obtained during the power stroke but is required because of the finite time needed for exhaust blow down.

6. *Exhaust Stroke:*

*Exhaust Stroke* By the time the piston reaches BDC, exhaust blow down is complete, but the cylinder is still full of exhaust gases at approximately atmospheric pressure. With the exhaust valve remaining open, the piston now travels from BDC to TDC in the exhaust stroke. This pushes most of the remaining exhaust gases out of the cylinder into the exhaust system at about atmospheric pressure, leaving only that trapped in the clearance volume when the piston reaches TDC. Near the end of the exhaust stroke by TDC, the intake valve starts to open, so that it is fully open by TDC when the new intake stroke starts the next cycle. Near TDC the exhaust valve starts to close and finally is fully closed sometime at TDC. This period when both the intake valve and exhaust valve are open is called valve overlap.

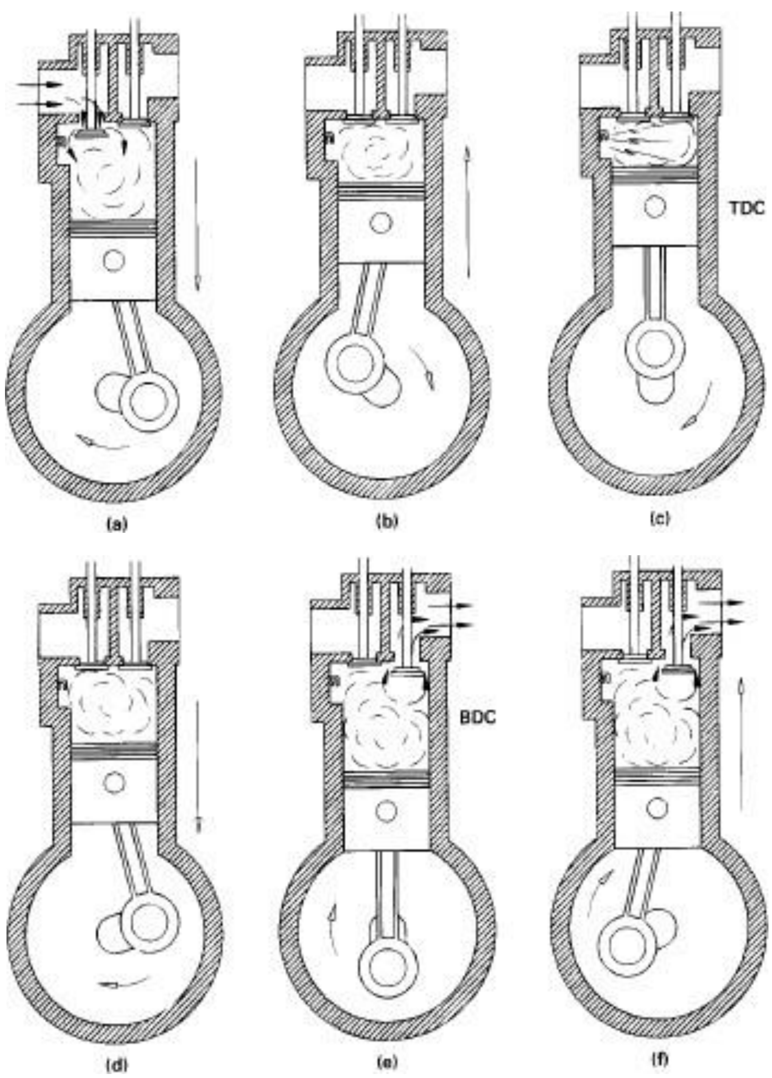


Figure 5: Four stroke SI engine operating cycle.

## Two-Stroke SI Engine Cycle

1. *Combustion*

With the piston at TDC combustion occurs very quickly, raising the temperature and pressure to peak values, almost at constant volume.

2. *First Stroke: Expansion Stroke or Power Stroke*

Very high pressure created by the combustion process forces the piston down in the power stroke. The expanding volume of the combustion chamber causes pressure and temperature to decrease as the piston travels towards BDC.

3. *Exhaust Blow down*

At about 75° by BDC, the exhaust valve opens and blow down occurs. The exhaust valve may be a poppet valve in the cylinder head, or it may be a slot in the side of the cylinder which is uncovered as the piston approaches BDC. After blow down the cylinder remains filled with exhaust gas at lower pressure.

4. *Intake and Scavenging*

When blow down is nearly complete, at about 50° by BDC, the intake slot on the side of the cylinder is uncovered and intake air-fuel enters under pressure. Fuel is added to the air with either a carburetor or fuel injection. This incoming mixture pushes much of the remaining exhaust gases out the open exhaust valve and fills the cylinder with a combustible air-fuel mixture, a process called scavenging. The piston passes BDC and very quickly covers the intake port and then the exhaust port (or the exhaust valve closes). The higher pressure at which the air enters the cylinder is established in one of two ways. Large two stroke cycle engines generally have a supercharger, while small engines will intake the air through the crankcase. On these engines the crankcase is designed to serve as a compressor in addition to serving its normal function.

5. *Second Stroke:*

*Compression Stroke* With all valves (or ports) closed, the piston travels towards TDC and compresses the air-fuel mixture to a higher pressure and temperature. Near the end of the compression stroke, the spark plug is fired; by the time the piston gets to IDC, combustion occurs and the next engine cycle begins.

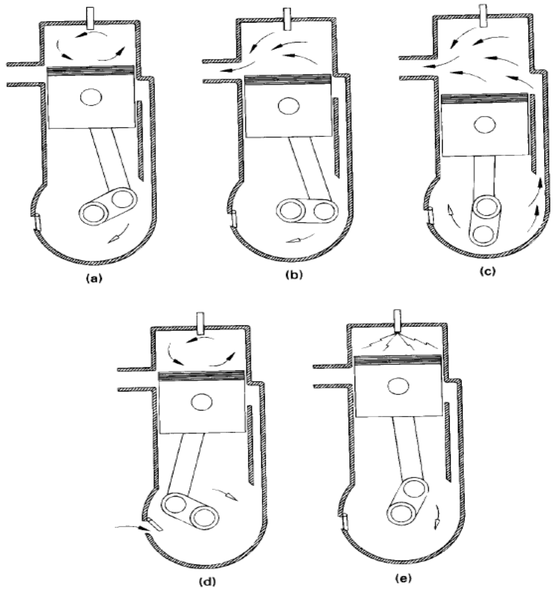

Figure 6: Two stroke engine operating cycle

**Comparison of Four-stroke and two-stroke engine:**

| **Four-stroke engine** | | **Two-stroke engine** |
|---|---|---|
| 1. | Four stroke of the piston and two revolution of crankshaft | Two stroke of the piston and one revolution of crankshaft |
| 2. | One power stroke in every two revolution of crankshaft | One power stroke in each revolution of crankshaft |
| 3. | Heavier flywheel due to non-uniform turning movement | Lighter flywheel due to more uniform turning movement |
| 4. | Power produce is less | Theoretically power produce is twice than the four stroke engine for same size |
| 5. | Heavy and bulky | Light and compact |
| 6. | Lesser cooling and lubrication requirements | Greater cooling and lubrication requirements |
| 7. | Lesser rate of wear and tear | Higher rate of wear and tear |
| 8. | Contains valve and valve mechanism | Contains ports arrangement |
| 9. | Higher initial cost | Cheaper initial cost |

| | | |
|---|---|---|
| 10. | Volumetric efficiency is more due to greater time of induction | Volumetric efficiency less due to lesser time of induction |
| 11. | Thermal efficiency is high and also part load efficiency better | Thermal efficiency is low, part load efficiency lesser |
| 12. | It is used where efficiency is important.<br><br>Ex-cars, buses, trucks, tractors, industrial engines, aero planes, power generation etc. | It is used where low cost, compactness and light weight are important.<br><br>Ex-lawn mowers, scooters, motor cycles, mopeds, propulsion ship etc. |

**Comparison of SI and CI engine:**

| **SI engine** | **CI engine** |
|---|---|
| Working cycle is Otto cycle. | Working cycle is diesel cycle. |
| Petrol or gasoline or high octane fuel is used. | Diesel or high cetane fuel is used. |
| High self-ignition temperature. | Low self-ignition temperature. |
| Fuel and air introduced as a gaseous mixture in the suction stroke. | Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke. |
| Carburettor used to provide the mixture. Throttle controls the quantity of mixture introduced. | Injector and high pressure pump used to supply of fuel. Quantity of fuel regulated in pump. |
| Use of spark plug for ignition system | Self-ignition by the compression of air which increased the temperature required for combustion |
| Compression ratio is 6 to 10.5 | Compression ratio is 14 to 22 |
| Higher maximum RPM due to lower weight | Lower maximum RPM |
| Maximum efficiency lower due to lower compression ratio | Higher maximum efficiency due to higher compression ratio |
| Lighter | Heavier due to higher pressures |

**Valve timing diagram:**

The exact moment at which the inlet and outlet valve opens and closes with reference to the position of the piston and crank shown diagrammatically is known as valve timing diagram. It is expressed in terms of degree crank angle. The theoretical valve timing diagram is shown in Figure below

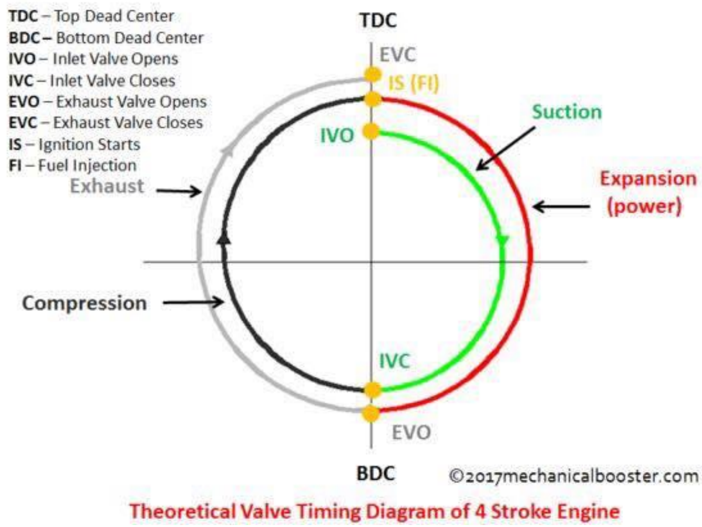


Figure 7: Theoretical valve timing diagram

But actual valve timing diagram is different from theoretical due to two factors-mechanical and dynamic factors. Figure 4 shows the actual valve timing diagram for four stroke low speed or high speed engine.

***Opening and closing of inlet valve***

-Inlet valve opens 12 to 30$^{o}$ CA before TDC to facilitate silent operation of the engine under high speed. It increases the volumetric efficiency.

-Inlet valve closes 10-60$^{o}$ CA after TDC due to inertia movement of fresh charge into cylinder i.e. ram effect.

Figure below represents the actual valve timing diagram for low and high speed engine.

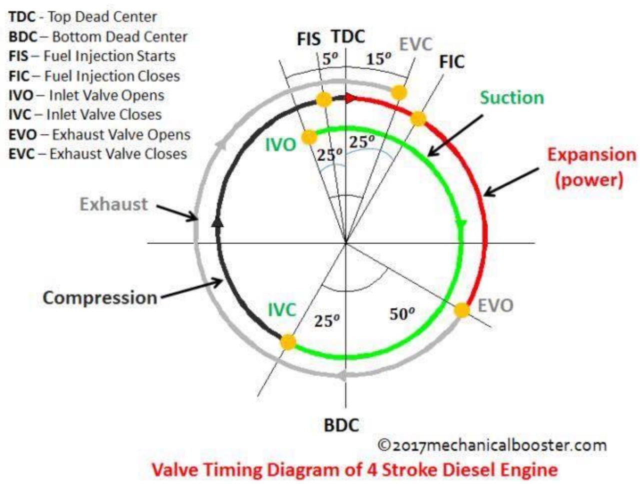


Figure 8: Actual valve timing diagram for low and high speed engine

### *Opening and closing of exhaust valve*

Exhaust valve opens 25 to 55$^o$ CA before BDC to reduce the work required to expel out the burnt gases from the cylinder. At the end of expansion stroke, the pressure inside the chamber is high, hence work to expel out the gases increases.

Exhaust valve closes 10 to 30$^o$ CA after TDC to avoid the compression of burnt gases in next cycle. Kinetic energy of the burnt gas can assist maximum exhausting of the gas. It also increases the volumetric efficiency.

Note: For low and high speed engine, the lower and upper values are used respectively

### *Valve overlap*

During this time both the intake and exhaust valves are open. The intake valve is opened before the exhaust gases have completely left the cylinder, and their considerable velocity assists in drawing in the fresh charge. Engine designers aim to close the exhaust valve just as the fresh charge from the intake valve reaches it, to prevent either loss of fresh charge or unscavenged exhaust gas.

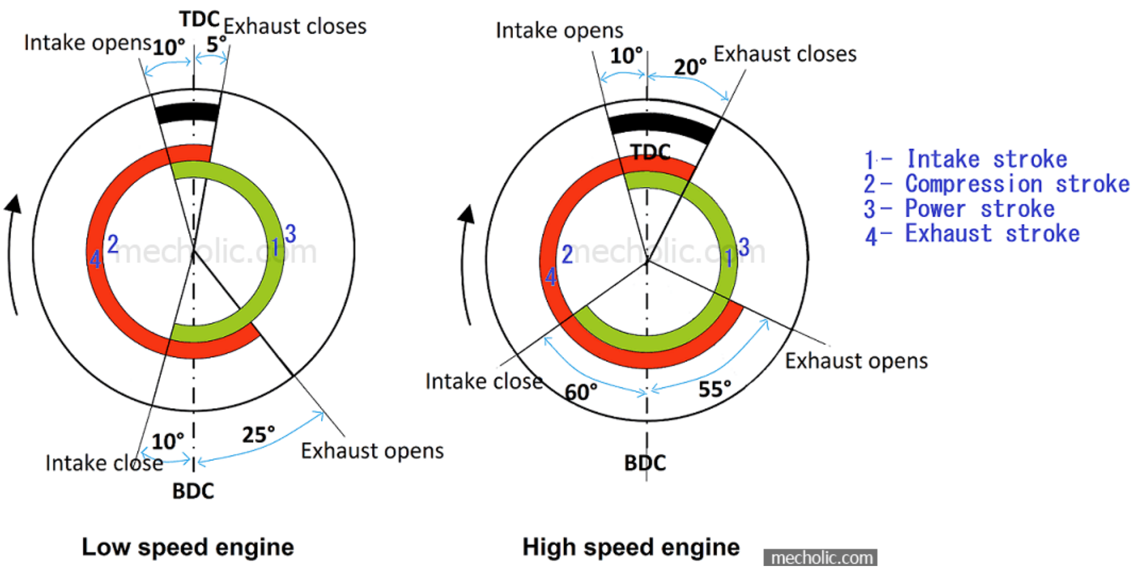


Figure 10: Actual valve timing diagram for low speed and high speed engines.

**Port timing diagram:**

-Drawn for 2-stroke engine
-No valve arrangement
-3 ports- inlet, transfer and exhaust

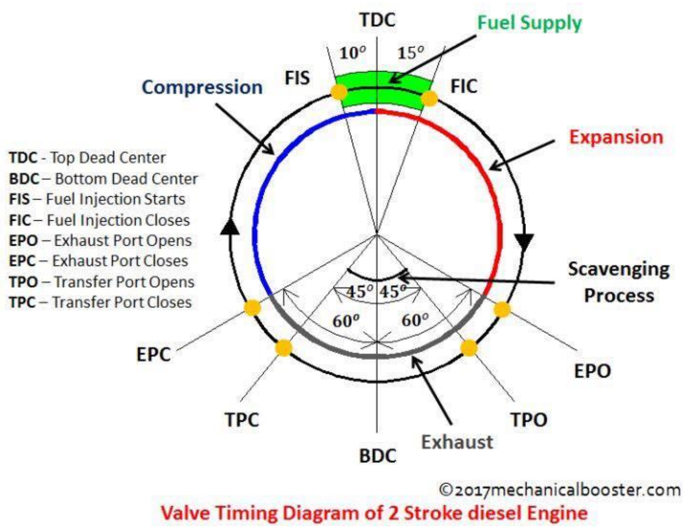


Figure11: port timing diagram for 2-stroke engine

***Otto cycle-*** thermodynamic cycle for SI/petrol engine

-Reversible adiabatic compression and expansion process

-Constant volume heat addition (combustion) and heat rejection process (exhaust)

Figure below depicts the Otto cycle

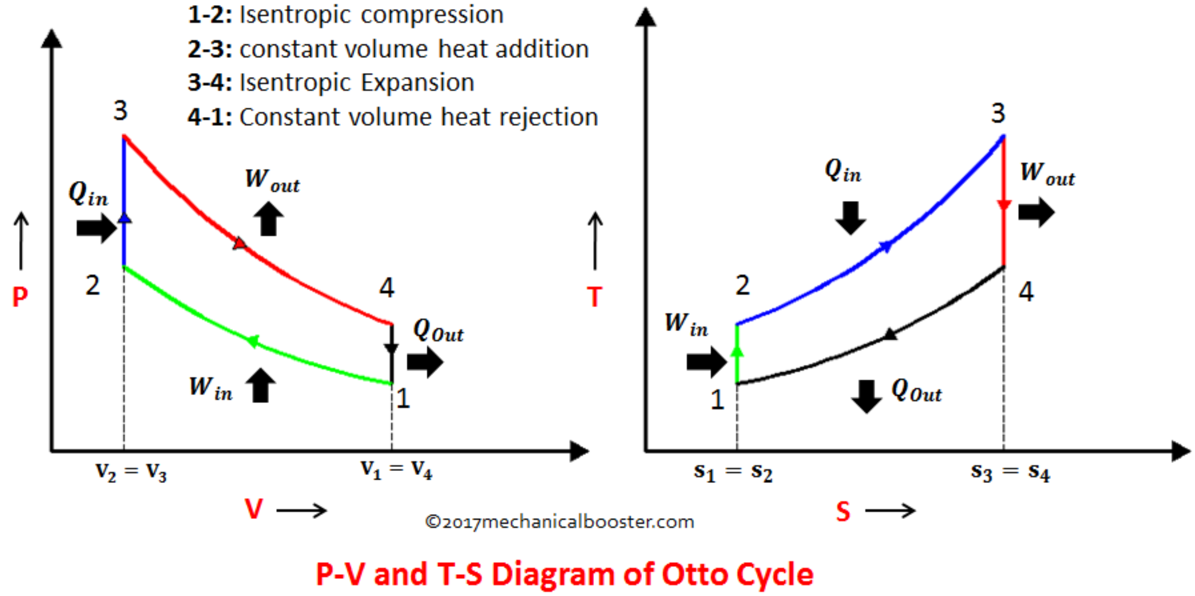


Figure 12: P-V and T-S diagram of Otto cycle.

To find the air standard efficiency

Heat supplied, $q_s = C_v(T_3 - T_2)$

Heat rejection, $q_R = C_v(T_4 - T_1)$

Compression ratio, $r_k = \frac{V_1}{V_2}$

Thermal efficiency, $\eta_{th} = \frac{q_s - q_R}{q_s} = \frac{Cv(T3-T2) - Cv(T4-T1)}{Cv(T3-T2)} = 1 - \frac{T4-T1}{T3-T2}$

In process 1-2, adiabatic compression process,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$=> T_2 = T_1.(r_k)^{\gamma-1}$$

In adiabatic expansion process, i.e. 3-4,

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

$$=> T_3 = T_4.(r_k)^{\gamma-1}$$

$$\eta_{th} = 1 - \frac{T_4 - T_1}{T_4.(r_k)^{\gamma-1} - T_1.(r_k)^{\gamma-1}}$$

$$= 1 - \frac{1}{(r_k)^{\gamma-1}}$$

*Work done (W)*

Pressure ratio, $r_p = \frac{P_3}{P_2} = \frac{P_4}{P_1}$

$\frac{P_2}{P_1} = \frac{P_3}{P_4} = \left(\frac{V_1}{V_2}\right)^{\gamma} = (r_k)^{\gamma}$

$$W = \frac{P_3V_3 - P_4V_4}{\gamma - 1} - \frac{P_2V_2 - P_1V_1}{\gamma - 1}$$

$$= \frac{1}{\gamma - 1}\left[P_4V_4\left(\frac{P_3V_3}{P_4V_4} - 1\right) - P_1V_1\left(\frac{P_2V_2}{P_1V_1} - 1\right)\right]$$

$$= \frac{1}{\gamma - 1}[P_4V_1({r_k}^{\gamma-1} - 1) - P_1V_1({r_k}^{\gamma-1} - 1)]$$

$$= \frac{P_1V_1}{\gamma - 1}[r_p({r_k}^{\gamma-1} - 1) - ({r_k}^{\gamma-1} - 1)]$$

$$= \frac{P_1V_1}{\gamma - 1}[({r_k}^{\gamma-1} - 1)(r_p - 1)]$$

Mean effective pressure, $P_m = \frac{work\ done}{Swept\ volume} = \frac{work\ done}{V_1 - V_2}$

$$P_m = \frac{\frac{P_1V_1}{\gamma - 1}[({r_k}^{\gamma-1} - 1)(r_p - 1)]}{V_1 - V_2} = \frac{P_1r_k[({r_k}^{\gamma-1} - 1)(r_p - 1)]}{(\gamma - 1)(r_k - 1)}$$

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# UNIT II SI ENGINE FUEL SYSTEM

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Carburetor working principle, requirements of an automotive carburetor, Solex, S.U, Carter carburetor. starting, idling, acceleration and normal circuits of carburetors. Compensation, maximum power devices, constant choke and constant vacuum carburetors, fuel feed systems; mechanical and electrical fuel feed pumps. Petrol injection, GDI, MPFI.

## CARBURETION

### Introduction

Spark-ignition engines normally use volatile liquid fuels. Preparation of fuel-air mixture is done outside the engine cylinder and formation of a homogeneous mixture is normally not completed in the inlet manifold. Fuel droplets, which remain in suspension, continue to evaporate and mix with air even during suction and compression processes. The process of mixture preparation is extremely important for spark-ignition engines. The purpose of carburetion is to provide a combustible mixture of fuel and air in the required quantity and quality for efficient operation of the engine under all conditions.

### Definition of Carburetion

The process of formation of a combustible fuel-air mixture by mixing the proper amount of fuel with air before admission to engine cylinder is called carburetion and the device which does this job is called a carburetor.

### Factors Affecting Carburetion

Of the various factors, the process of carburetion is influenced by

i. The engine speed
ii. The vaporization characteristics of the fuel
iii. The temperature of the incoming air and
iv. The design of the carburetor

### Principle of Carburetion

Both air and gasoline are drawn through the carburetor and into the engine cylinders by the suction created by the downward movement of the piston. This suction is due to an increase in the volume of the cylinder and a consequent decrease in the gas pressure in this chamber. It is the difference in pressure between the atmosphere and cylinder that causes the air to flow into the chamber. In the carburetor, air passing into the combustion chamber picks up discharged from a tube. This tube has a fine orifice called carburetor jet that is exposed to the air path. The rate at which fuel is discharged into the air depends on the pressure difference or pressure head between the float chamber and the throat of the venturi and on the area of the outlet of the tube.

In order that the fuel drawn from the nozzle may be thoroughly atomized, the suction effect must be strong and the nozzle outlet comparatively small. In order to produce a strong suction, the pipe in the carburetor carrying air to the engine is made to have a restriction. At this restriction called throat due to increase in velocity of flow, a suction effect is created. The restriction is made in the form of a venturi to minimize throttling losses. The end of the fuel jet is located at the venturi or throat of the carburetor. The geometry of venturi tube is as shown in Fig.3. It has a narrower path at the center so that the flow area through which the air must pass is considerably reduced. As the same amount of air must pass through every point in the tube, its velocity will be greatest at the narrowest point. The smaller the area, the greater will be the velocity of the air, and thereby the suction is proportionately increased

As mentioned earlier, the opening of the fuel discharge jet is usually loped where the suction is maximum. Normally, this is just below the narrowest section of the venturi tube. The spray of gasoline from the nozzle and the air entering through the venturi tube are mixed together in this region and a combustible mixture is formed which passes through the intake manifold into the cylinders. Most of the fuel gets atomized and simultaneously a small part will be vaporized. Increased air velocity at the throat of the venturi helps he rate of evaporation of fuel. The difficulty of obtaining a mixture of sufficiently high fuel vapour-air ratio for efficient starting of the engine and for uniform fuel-air ratio indifferent cylinders (in case of multi cylinder engine) cannot be fully met by the increased air velocity alone at the venturi throat.

**The Simple Carburetor**

Carburetors are highly complex. Let us first understand the working principle bf a simple or elementary carburetor that provides an air fuel mixture for cruising or normal range at a single speed. Later, other mechanisms to provide for the various special requirements like starting, idling, variable load and speed operation and acceleration will be included. Figure 3. shows the details of a simple carburetor.

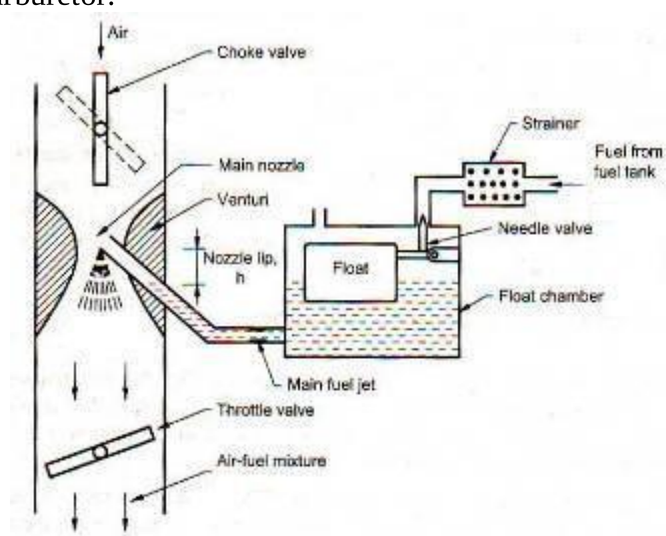



**Figure 1: Schematic diagram of Simple Carburetor**

The simple carburetor mainly consists of a float chamber, fuel discharge nozzle and a metering orifice, a venturi, a throttle valve and a choke. The float and a needle valve system maintain a constant level of gasoline in the float chamber. If the amount of fuel in the float chamber falls below the designed level, the float goes down, thereby opening the fuel supply valve and admitting fuel. When the designed level has been reached, the float closes the fuel supply valve thus stopping additional fuel flow from the supply system. Float chamber is vented either to the atmosphere or to the" upstream side of the venturi. During suction stroke air is drawn through the venturi.

As already described, venturi is a tube of decreasing cross-section with a minimum area at the throat, Venturi tube is also known as the choke tube and is so shaped that it offers minimum resistance to the air flow. As the air passes through the venturi the velocity increases reaching a maximum at the venturi throat. Correspondingly, the pressure decreases reaching a minimum. From the float chamber, the fuel is fed to a discharge jet, the tip of which is located in the throat of the venturi. Because of the differential pressure between the float chamber and the throat of the venturi, known as carburetor depression, fuel is discharged into the air stream. The fuel discharge is affected by the size of the discharge jet and it is chosen to give the required air-fuel ratio. The pressure at the throat at the fully open throttle condition lies between 4 to 5 cm of Hg, below atmospheric and seldom exceeds8 cm Hg below atmospheric. To avoid overflow of fuel through the jet, the level of the liquid in the float chamber is maintained at a level slightly below the tip of the discharge jet. This is called the tip of the nozzle. The difference in the height between the top of the nozzle and the float chamber level is marked h in Fig.3.

The gasoline engine is quantity governed, which means that when power output is to be varied at a particular speed, the amount of charge delivered to the cylinder is varied. This is achieved by means of a throttle valve usually of the butterfly type that is situated after the venturi tube. As the throttle is closed less air flows through the venturi tube and less is the quantity of air-fuel mixture delivered to the cylinder and hence power output is reduced. As the" throttle is opened, more air flows through the choke tube resulting in increased quantity of mixture being delivered to the engine. This increases the engine power output. A simple carburetor of the type described above suffers from a fundamental drawback in that it provides the required A/F ratio only at one throttle position. At the other throttle positions the mixture is either leaner or richer depending on whether the throttle is opened less or more. As the throttle opening is varied, the air flow varies and creates a certain pressure differential between the float chamber and the venturi throat. The same pressure differential regulates the flow of fuel through the nozzle. Therefore, the velocity of flow of air II and fuel vary in a similar manner. At the same time, the density I of air decrease as the pressure at the venturi throat decrease with increasing air flow whereas that of the fuel remains unchanged. This results in a simple carburetor producing a progressively rich mixture with increasing throttle opening.

## The Choke and the Throttle

When the vehicle is kept stationary for a long period during cool winter seasons, may be overnight, starting becomes more difficult. *As* already explained, at low cranking speeds and intake temperatures a very rich mixture is required to initiate combustion. Some times air-fuel ratio as rich as 9:1 is required. The main reason is that very large fraction of the fuel may remain as liquid suspended in air even in the cylinder. For initiating combustion, fuel-vapour and air in the form of mixture at a ratio that can sustain combustion is required. It may be noted that at very low temperature vapour fraction of the fuel is also very small and this forms combustible mixture to initiate combustion. Hence, a very rich mixture must be supplied. The most popular method of providing such mixture is by the use of choke valve. This is simple butterfly valve located between the entrance to the carburetor and the venturi throat as shown in Fig.3.

When the choke is partly closed, large pressure drop occurs at the venturi throat that would normally result from the quantity of air passing through the venturi throat. The very large depression at the throat inducts large amount of fuel from the main nozzle and provides a very rich mixture so that the ratio of the evaporated fuel to air in the cylinder is within the combustible limits. Sometimes, the choke valves are spring loaded to ensure that large carburetor depression and excessive choking does not persist after the engine has started, and reached a desired speed. This choke can be made to operate automatically by means of a thermostat so that the choke is closed when engine is cold and goes out of operation when engine warms up after starting. The speed and the output of an engine is controlled by the use of the throttle valve, which is located on the downstream side of the venturi.

The more the throttle is closed the greater is the obstruction to the flow *of* the mixture placed in the passage and the less is the quantity *of* mixture delivered to .the cylinders. The decreased quantity *of* mixture gives a less powerful impulse to the pistons and the output *of* the engine is reduced accordingly. As the throttle is opened, the output *of* the engine increases. Opening the throttle usually increases the speed *of* the engine. But this is not always the case as the load on the engine is also a factor. For example, opening the throttle when the motor vehicle is starting to climb a hill may or may not increase the vehicle speed, depending upon the steepness *of* the hill and the extent *of* throttle opening. In short, the throttle is simply a means to regulate the output *of* the engine by varying the quantity *of* charge going into the cylinder.

**Compensating Devices**

An automobile on road has to run on different loads and speeds. The road conditions play a vital role. Especially on city roads, one may be able to operate the vehicle between 25 to 60% of the throttle only. During such conditions the carburetor must be able to supply nearly constant air-fuel ratio mixture that is economical (16:1).However, the tendency of a simple carburetor is to progressively richen the mixture as the throttle starts opening. The main metering system alone will not be sufficient to take care of the needs of the engine. Therefore, certain compensating devices are usually added in the carburetor along with the main metering system so as to supply a mixture with the required air- fuel ratio. A number of compensating devices are in use. The important ones are

i. Air-bleed jet
ii. Compensating jet
iii. Emulsion tube
iv. Back suction control mechanism
v. Auxiliary air valve
vi. Auxiliary air port

As already mentioned, in modern carburetors automatic compensating devices are provided to maintain the desired mixture proportions at the higher speeds. The type of compensation mechanism used determines the metering system of the carburetor. The principle of operation of various compensating devices are discussed briefly in the following sections.

**Air-bleed jet**

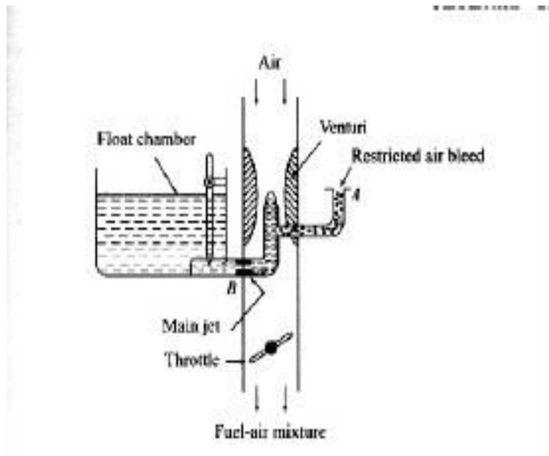



**Figure 2: Air bleed principle in a typical carburetor**

Figure 2. illustrates a principle of an air-bleed system in atypical modern downdraught carburetor. As could be seen it contains an air-bleed into the main nozzle. An orifice restricts the flow of air through this bleed and therefore it is called restricted air-bleed jet that is very popular. When the engine is not operating the main jet and the air bleed jet will be filled with fuel. When the engine starts, initially the fuel starts coming through the main as well as the air bleed jet (A). As the engine picks up, only air starts coming through the air bleed and mixes with fuel at B making a air fuel emulsion. Thus the fluid stream that has become an emulsion of air and liquid has negligible viscosity and surface tension. Thus the flow rate of fuel is augmented and more fuel is sucked at low suctions. ‘By proper design of hole size at B compatible with the entry hole at A, it is possible to maintain a fairly uniform mixture ratio for the entire power range of the operation of an engine. If the fuel flow nozzle of the air-bleed system is placed in the centre of the venturi, both the air-bleed nozzle and the venturi are subjected to same engine suction resulting approximately same fuel-air mixture for the entire power range of operation.

**Compensating Jet**

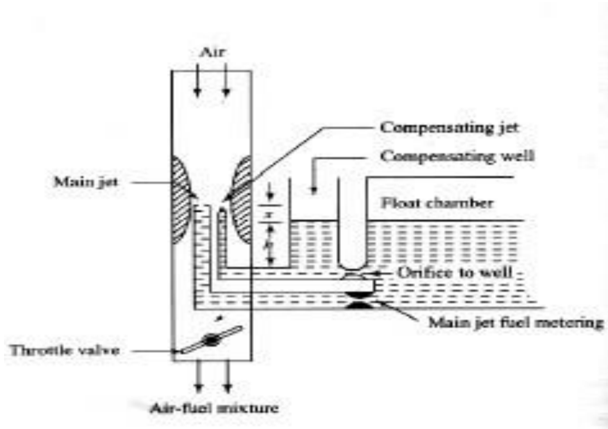



**Figure 3: Compensating Jet device**

The principle of compensating jet device is to make the mixture leaner as the throttle opens progressively. In this method, as can be seen from Fig.5 in addition to the main jet, a compensating jet is incorporated. The compensating jet is connected to the compensation well. The compensating well is also vented to atmosphere like the main float chamber. The compensating well is supplied with fuel from the main float chamber through a restricting orifice. With the increase in airflow rate, there is decrease of fuel level in the compensating well, with the result that fuel supply through the compensating jet decreases. The compensating jet thus progressively makes the mixture leaner as the main jet progressively makes the mixture richer. The main jet curve and the compensating jet curve are more or less reciprocals of each other.

**Emulsion Tube**

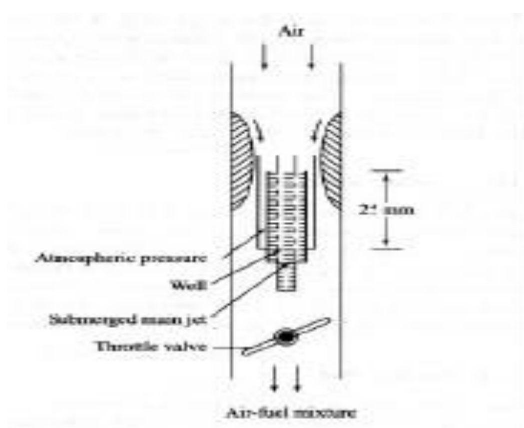



**Figure 4: Emulsion Tube**

The mixture correction is attempted by air bleeding in modern carburetor. In one such arrangement as shown in Fig.6, the main metering jet is kept at a level of about 25 mm below the fuel level in the float chamber. Therefore, it is also called submerged jet. The jet is located at the bottom of a well. The sides of the well have holes. As can be seen from the figure these holes are in communication with the atmosphere. In the beginning the level of petrol in the float chamber and the well is the same. When the throttle is opened the pressure at the venturi throat decreases and petrol is drawn into the air stream. This results in progressively uncovering the holes in the central tube leading to increasing air-fuel ratios or decreasing richness of mixture when all holes have been uncovered. Normal flow takes place from the main jet. The air is drawn through these holes in the well, and the fuel is emulsified and the pressure differential across the column of fuel is not as high as that in simple carburetor.

**Acceleration Pump System**

Acceleration is a transient phenomenon. In order to accelerate the vehicle and consequently its engine, the mixture required is very rich and the richness of the mixture has to be obtained quickly and very rapidly. In automobile engines situations arise when it is necessary to accelerate the vehicle. This requires an increased output from the engine in a very short time. If the throttle is suddenly opened there is a corresponding increase in the air flow. However, because of the inertia of the liquid fuel, the fuel flow does not increase in proportion to the increase in air flow. This results in a temporary lean mixture ca11singtheengine to misfire and a temporary reduction in power output.

To prevent this condition, all modern carburetors are equipped with an accelerating system. Figure 7. illustrates simplified sketch of one such device. The pump comprises of a spring loaded plunger that takes care of the situation with the rapid opening of the throttle valve. The plunger moves into the cylinder and forces an additional jet of fuel at the venturi throat. When the throttle is partly open, the spring sets the plunger back. There is also an arrangement which ensures that fuel in the pump cylinder is not forced through the jet when valve is slowly opened or leaks past the plunger or some holes into the float chamber.

Mechanical linkage system, in some carburetor, is substituted by an arrangement where by the pump plunger is held up by manifold vacuum. When this vacuum is decreased by rapid opening of the throttle, a spring forces the plunger down pumping the fuel through the jet.

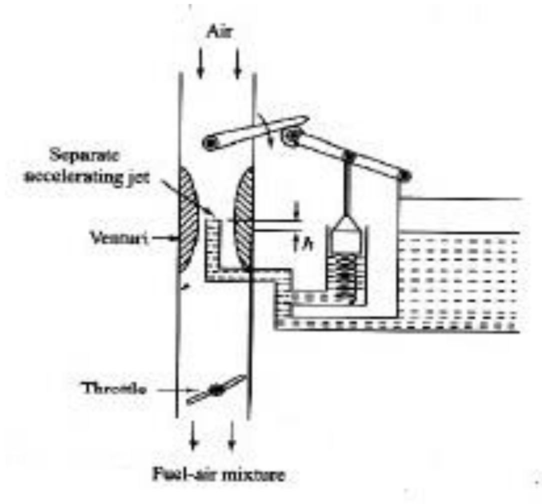



**Figure 5: Acceleration pump system**

## AUTOMOBILE CARBURETORS

Following three types of automobile carburetors are available.

1. Solex carburetor
2. Carter carburetor
3. S.U carburetor

### 1. Solex carburetor

Solex Carburetor is one of the famous Carburetor for the ease of starting the engine and the best performance of the engine. Solex Carburetor is a downdraught Carburetor. This is used mostly in the automobile engines. As we already discussed the main drawback of the simple Carburetor is the maintaining one air-fuel ratio at one throttle position. This Solex Carburetor can provide the rich mixture when the engine needs to start and supply the lean mixture when the cruising (Travelling with smoothly with economical speed) the vehicle.

This Carburetor has different fuel discharge circuits so that it can deliver different mixtures for the different operating conditions such as the *Engine Starting, Engine Idling, Low-speed Operation, Normal Operating and Acceleration*

### Construction of Solex Carburetor

A float with a tapered valve at the top face of the float is arranged in the float chamber to take care of the fuel level in it as shown in the below schematic representation. (Figure 6)

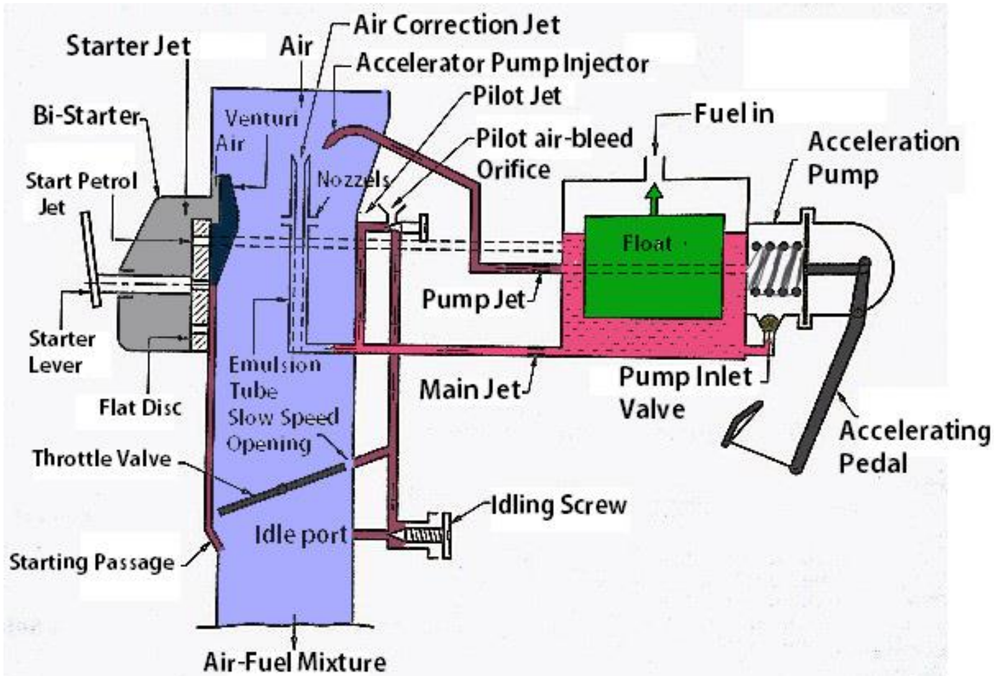



**Figure 8 : Cross sectional view of solex carburetor**

- The Main metering Jet will discharge the fuel into the venturi throat tube.
- The fuel from the main metering jet will go into the air-bleed emulsion system, this has the lateral holes as shown in the schematic diagram.
- Air correction jet calibrates the air entering through it and ensures the air-fuel balance.
- The metered emulsion of fuel and air is supplied through the spraying orifice or nozzles. These nozzles are drilled horizontally on the vertical pipe in the choke tube as shown in the schematic diagram.
- There is a throttle valve provided at the end of the tube to control the air-fuel mixture quantity supply into the engine. This valve also knows as the conventional butterfly valve.

With this circuit, the engine can run at the normal running with this Solex Carburetor. But for the other operating conditions of the engine, we will use different fuel circuits for different operating conditions.

***Cold starting and warming***

The main advantage with the Solex Carburetor is that it has the Bi-Starter also known as the progressive starter. Initially, the engine needs a richer mixture and the after starting of the engine, the mixture supposed to be lean. So this progressive starter will do the job for the engine.

- This starter is in the form of a flat disc with the holes of different sizes.
- The starter petrol jet and the starter jet (Air) are connected together by the holes present in the starter disc and open into the passage arranged to below the throttle valve.
- There is a starter lever that used to adjust the hole sizes so that the amount of the fuel and the air will be passed to the engine cylinder in the suction stroke.

- When we starting the engine we will close the throttle and provide the air-fuel mixture from the starting passage which is having a richer mixture from this Bi-Starter setup.

Once the engine started, we have to warm it up by accelerating a couple of times and then release the throttle valve and pass the lean/normal mixture thru the venturi throat.

***Idling and Slow Running of the Engine (Cruising)***

Idling of the engine is at where the engine will not deliver any work it only delivers enough power for its auxiliaries. During this idling or slow running of the engine needs to have a rich mixture and because of the cylinder pressure is less and then there is a chance of re sucking of the exhaust gases and cause the poor combustion to make the engine stumble. So this rich mixture helps in making it happen smooth.

- During the Idling, the throttle valve is closed completely.
- The suction created by the suction stroke is acted on the pilot jet directly.
- The fuel will be inducted from the pilot jet and mixed with the less amount of air sucked from the pilot air-bleed orifice from the outside atmosphere.
- This rich mixture will be directly sent to the cylinder by a tube directly opened right below the throttle valve as shown in the schematic diagram.
- There is an idle speed adjustment screw is arranged so that we can set the idle speed of the engine by controlling the amount of mixture injected.
- For the smooth running adjustment, we will have an additional by-pass adjustment. (Not shown in the schematic representation) Which will make the less rich mixture and the throttle will also open a little bit. so that engine can run smoothly with the full movement of the air-fuel mixture.

***Acceleration of Engine***

For the Engine acceleration, and additional acceleration pump injector equipment is arranged right side of the floating chamber as you can see from the schematic diagram. This acceleration pump will supply the additional fuel for the engine with the help of the Acceleration pump injector directly on top of the venture. The operating of the Carburetor is the same as the normal running but with the additional fuel drops the engine get excited when we press the accelerator pedal. When you release the pedal the accelerator pump will suck the fuel from the float chamber and stores for the next pedal movement.

2. **Carter Carburetor**
   - Carter Carburetor is an automobile Carburetor used mostly in jeeps
   - It was first founded by William Carter for the jeeps run by four-cylinder engines.
   - Carter Carburetor is a downdraught type Carburetor. It is having multiple jets, a plain tube with only one adjustment for the idling or low speed running of the engine.

**Construction of Carter carburetor**

The schematic diagram of carter carburetor has been shown in figure 9.

A float with a tapered valve at the top face of the float is arranged in the float chamber to take care of the fuel level in it

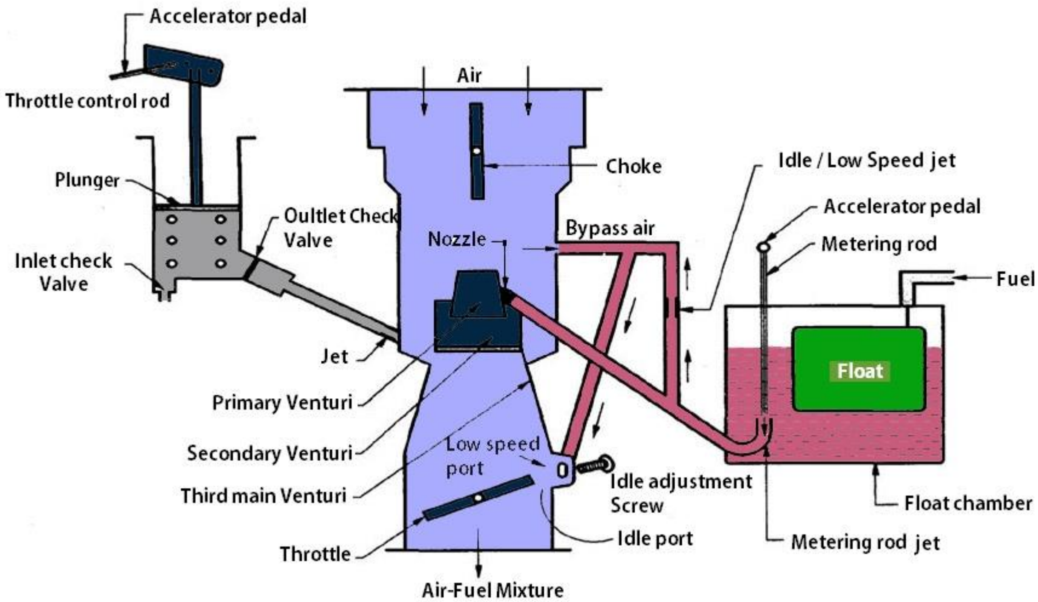



Figure 9: schematic diagram of carter carburetor

The air enters at the top of the tube operated by the choke valve. During normal operation, the choke valve will be fully opened. This Carburetor is comprised of 3 venturi tubes. Among these, the smallest one is maintained a little bit above to the level of fuel in the float chamber. The other two will be below the level of the fuel in the float chamber.

The fuel nozzle injects the fuel at the primary venturi and throws the fuel against the air flow coming from the top. The air and the fuel mixed at the primary venturi and flow thru the secondary venturi and exposed to some more air steam and further flow thru the third venturi as well. After this, the fuel mixture enters into the engine during the suction stroke.There is a metering rod provided at the float chamber, which controls the quantity of fuel supply to the engine.

***Engine starting circuit***

During the engine starting a richer mixture need to be provided. The suction created by the piston during the engine starting is exerted on to the nozzle to provide the correct quantity of the fuel. The choke valve also provides less air. So that correct quantity of the richer mixture is prepared and inducted into the engine cylinder to start the engine smoothly.

After the engine starts, the spring controlled choke valve is open to allow the correct quantity of the air during the period of warm up.

***Idle and Low-speed(Cruising) circuit***

For the idle speed, the richer mixture is required in small quantity. In this operating condition, the throttle valve is slightly open. So that the suction created by the piston downward movement is

exerted on to the ideal port. This is how the rich mixture is provided by the idle/slow speed jet. The air-fuel ratio can be controlled by the idle adjustment screw.
For the low-speed operation, the throttle can be further open to run the engine smoothly above the idle speed operation.

***Acceleration of Engine***

There is an acceleration pump arrangement as shown in the above diagram. This will helps to accelerate the engine by supplying the additional amount of fuel with the help of jet at the direct throat.
This acceleration pump consists of non-return inlet check valve and the outlet check valve, plunger and a spring operated accelerator pedal. When we push the accelerator pedal, this will push a small amount of petrol to the throat by means of non-return inlet check valve to the outlet check valve and to the jet as shown in the above diagram. Now when you release the pedal, it will suck some amount of fuel from the float chamber.

### 3. SU Carburetor

S.U Carburetor is a constant vacuum with an automatic variable choke. There are three different types of Carburetors available in the market. the H-type, HD-type(Diaphragm-jet), HS-type and the DU6-type (dual choke) is in limited quantity. Out of these, the H-type is the most familiar type Carburetor.

**S.U Carburetor Construction**

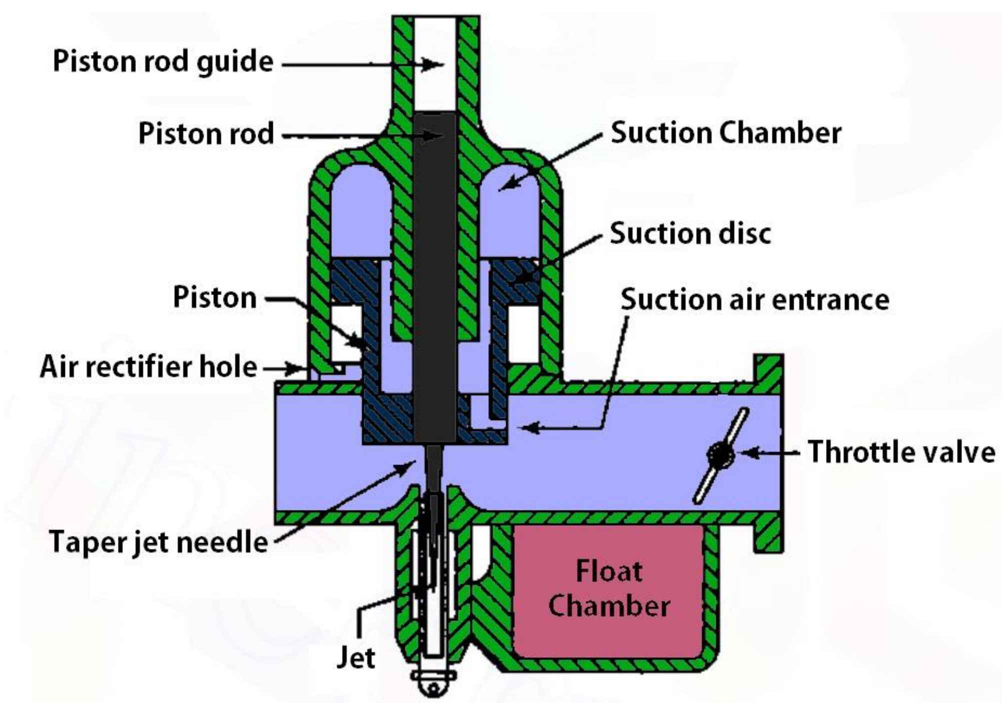



Figure 10: Cross sectional view of SU carburetor

- S.U Carburetor consists of a sliding piston and the tapered needle inserted into the main jet.
- Along with the piston upward and downward movement, the needle and the main jet also moves.
- There is a suction disc attached to the upper end of the piston.
- Piston rod and the piston rod guide help to guide the piston and the suction disc as shown in the schematic diagram.
- The piston is loaded with the helical spring.
- There is this portion above the suction disc is called the suction chamber which will be connected by the air passage by means of a slot provided in the piston.
- And there is an ordinary butterfly throttle valve as shown in the above fig.
- There is an air rectifier hole provided at the lower portion of the suction disc and the upper portion of this disc will be connected to the throttle air passage.

**S.U Carburetor working principle**

This Carburetor does not have different engine operating condition such as the idling and the slow running (cruising), normal running, accelerating.
As the piston is loaded with the helical spring and the weight of the piston will be also supported by the vacuum in the suction chamber. The position of the piston will be balanced by maintaining the constant vacuum in the suction chamber. If any deviation occurred, the piston gets moved up/down.
There will be a lever attached to the main jet to control the fuel flow while the engine needs to start. Because the engine starting needs a richer mixture.

The throttle is opened more the more air is allowed to pass thru through the inlet due to the upward movement of the piston. the upward movement of the tapered needle also ensures the more fuel flow from the main jet. This is how the air and the fuel passages are varied with the different engine speeds and velocities of the fuel and the air remains constant. in this system.

**Types of Carburetors**

There are three general types of carburetors depending on the direction of flow of air. The first is the up draught type shown in Fig.11 in which the air enters at the bottom and leaves at the top so that the direction of its flow is upwards. The disadvantage of the up draught carburetor is that it must lift the sprayed fuel droplet by air friction. Hence, it must be designed for relatively small mixing tube and throat so that even at low engine speeds the air velocity is sufficient to lift and carry the fuel particles along. Otherwise, the fuel droplets tend to separate out providing only a lean mixture to the engine. On the other hand, the mixing tube is finite and small then it cannot supply mixture to the engine at a sufficiently rapid rate at high speeds.

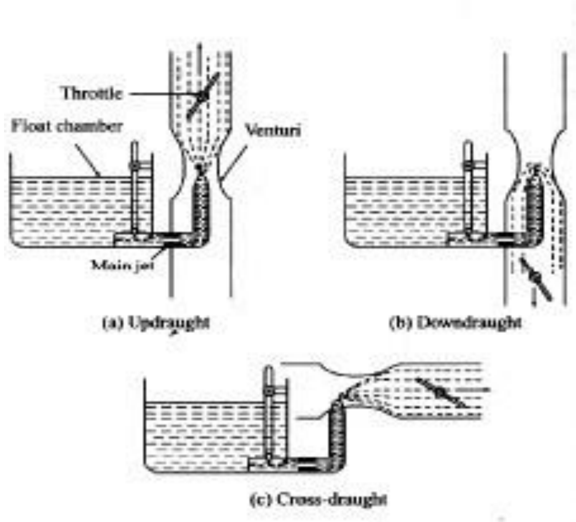



Figure: 11 Types of Carburetors

In order to overcome this drawback the downdraught carburetor [Fig.11 (b)] is adopted. It is placed at a level higher than the inlet manifold and in which the air and mixture generally follow a downward course. Here the fuel does not have to be lifted by air friction as in the up draught carburetors but move into the cylinders by gravity even if the air velocity is low. Hence, the mixing tube and throat can be made large which makes high engine speeds and high specific outputs possible.

A cross-draught carburetor consists of a horizontal mixing tube with a float chamber on one side of it [Fig.11(c)]. By using across-draught carburetor in engines, one right-angled turn in the inlet passage is eliminated and the resistance to flow is reduced.

**Constant Choke Carburetor:**

In the constant choke carburetor, the air and fuel flow areas are always maintained to be constant. But the pressure difference or depression, which causes the flow of fuel and air, is being varied as per the demand on the engine. Solex and Zenith carburetors belong to this class.

**Constant Vacuum Carburetor:**

In the constant vacuum carburetor, (sometimes called variable choke carburetor) air and fuel flow areas are being varied as per the demand on the engine, while the vacuum is maintained to be always same. The S.U. and Carter carburetors belong to tills class.

**Multiple Venturi Carburetor:**

Multiple venturi system uses double or triple venturi. The boost venturi is located concentrically within the main venturi. The discharge edge of the boost venturi is located at the throat of the main venturi. The boost venturi is positioned upstream of the throat of the larger main venturi. Only a fraction of the total air flows though the boost venturi. Now the pressure at the boost venturi exit equals the pressure at the main venturi throat. The fuel nozzle is located at the throat of the boost venturi.

**Electronic Unit Injectors**

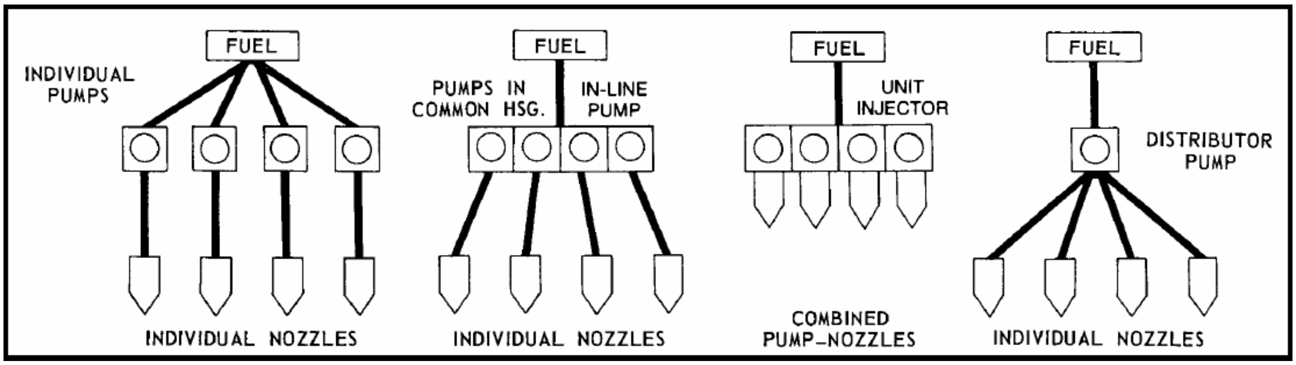



Figure 12: Electronic Fuel injectors

**Unit Injectors** are less commonly also called ***Combined Pump and Nozzle***

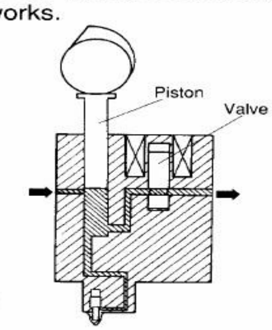
Acronyms are: **MUI,** (**M**echanical **U**nit **I**njectors) **EUI**, (**E**lectronic **U**nit **I**njectors) and **HEUI**. (**H**ydraulically actuated **E**lectronic **U**nit **I**njector)
The pumping plunger and nozzle are located in the same body and a camshaft actuates the injector. A common fuel manifold will supply all the injectors.

**Functions**

Electronic unit injectors are *mechanically pressurized* and electronically controlled. This means injection timing, duration, and metering are controlled by the ECM or electronic governor.
Unit injection systems functions are incorporated into one unit the following functions:

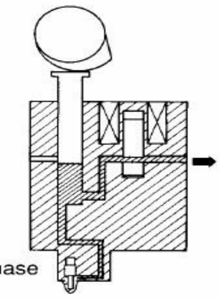
- Time fuel delivery
- Pressurize the fuel for combustion
- Atomize and distribute fuel in the combustion chamber

Shown here is the unit injector in extremely simplified form. However, it is easy to understand how the injector works.



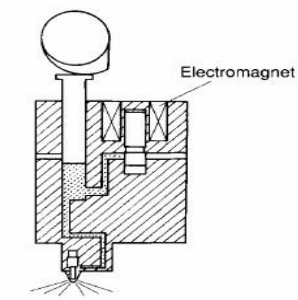

Flushing

In this position, the piston is at its highest and the valve is open. Fuel flows through the injector and all of the spaces are filled with fuel.



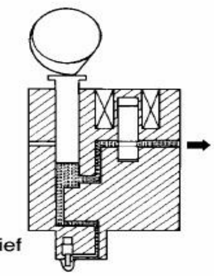
Overflow phase

The camshaft has pushed down the piston and the inlet is plugged. No injection will take place due to the fact that the valve is open. Fuel is forced out only through the piston outlet.




Injection

The solenoid is energized and the valve closes rapidly. The piston is still traveling downwards and the fuel pressure is rising rapidly. The injector needle opens at 4,350 psi, then the pressure increases still further to more than 22,000 psi. The fuel is injected in the form of tiny droplets or mist.



Pressure relief

The injector must be relieved from the pressure of the fuel so that injection is discontinued very quickly and definitely. This is what happens when the solenoid is not energized and the valve opens again.

**Trigger pulses**

As you can see, the position of the valve determines whether injection will take place or not.
Open valve - no injection. Closed valve - injection.
The position of the valve is determined in turn by whether or not the solenoid is energized. The valve is opened and held open by the solenoid. Power is supplied to the solenoid for only a few milli-seconds. This short power feed is known as the trigger pulse.

The pulses determine two things:

- When injection should start (how many degrees BTDC).
- How long injection lasts, and how much fuel should be injected.

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# UNIT III IGNITION SYSTEM

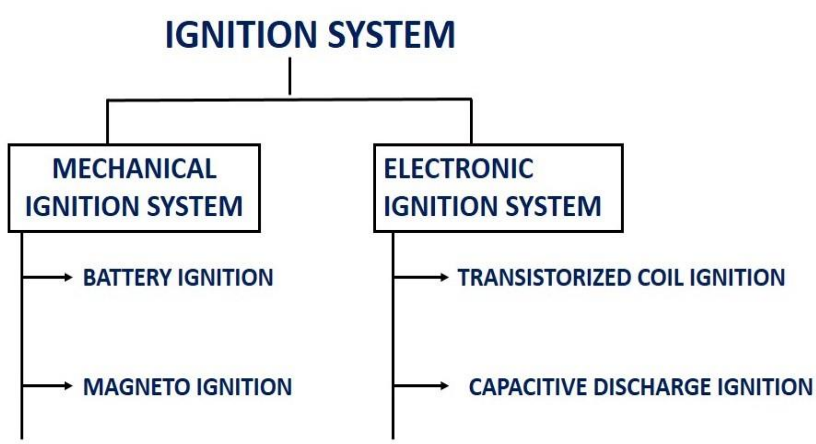
## UNIT 3 IGNITION SYSTEM

Types and working of battery coil and magneto ignition systems, relative merits and demerits, centrifugal and vacuum advance mechanisms. Types and construction of spark plugs, electronic ignition systems- Transistorized coil ignition system Capacitive discharge ignition system.

IGNITION SYSTEM

- ❖ The ignition system takes electricity from the vehicle's battery, increases the battery voltage to a much higher voltage, and then sends this high voltage to the spark plugs.
- ❖ The high voltage causes the spark plugs to produce a powerful, hot spark.
- ❖ Each spark plug is threaded into a hole that leads directly into a cylinder's combustion chamber.
- ❖ In simple terms, a spark plug is a device that electricity flows through. At the very end of the spark plug are a pair of metal contacts called *electrodes*. These contacts are separated from one another by a small air space.
- ❖ When electricity flows through a spark plug, it jumps across this air space from one electrode to the other.
- ❖ As the electricity jumps across the space, a powerful spark is produced. This spark ignites the air-and-fuel mixture that surrounds it inside the cylinder. The resulting "explosion" in the combustion chamber forces the piston down and gets the crankshaft turning.
- ❖ An ignition system must produce a very high voltage in order to force electric current—moving electrons—across the spark.
- ❖ The spark that's produced must be very powerful so that it can quickly ignite the air-and-fuel mixture in the cylinder.
- ❖ The more completely the fuel is burned, the more power that's produced. The spark must plug gap also occur near the end of each cylinder's compression stage in order to properly ignite and burn the air-and-fuel mixture.
- ❖ Also, an engine requires many sparks per minute in order to keep running at the proper speed
- ❖ if a typical six-cylinder engine is operating at a speed of 3,000 rpms, a spark occurs 1,500 times per minute in each cylinder. Since the engine has six cylinders, this is a total of 9,000 spark occurrences for all of the cylinders

TYPES OF IGNITION SYSTEM



**BATTERY IGNITION SYSTEM**
This basic battery ignition system contains a battery, an ignition switch, an ignition coil, a distributor, a triggering device, a spark plug wire, and a spark plug.

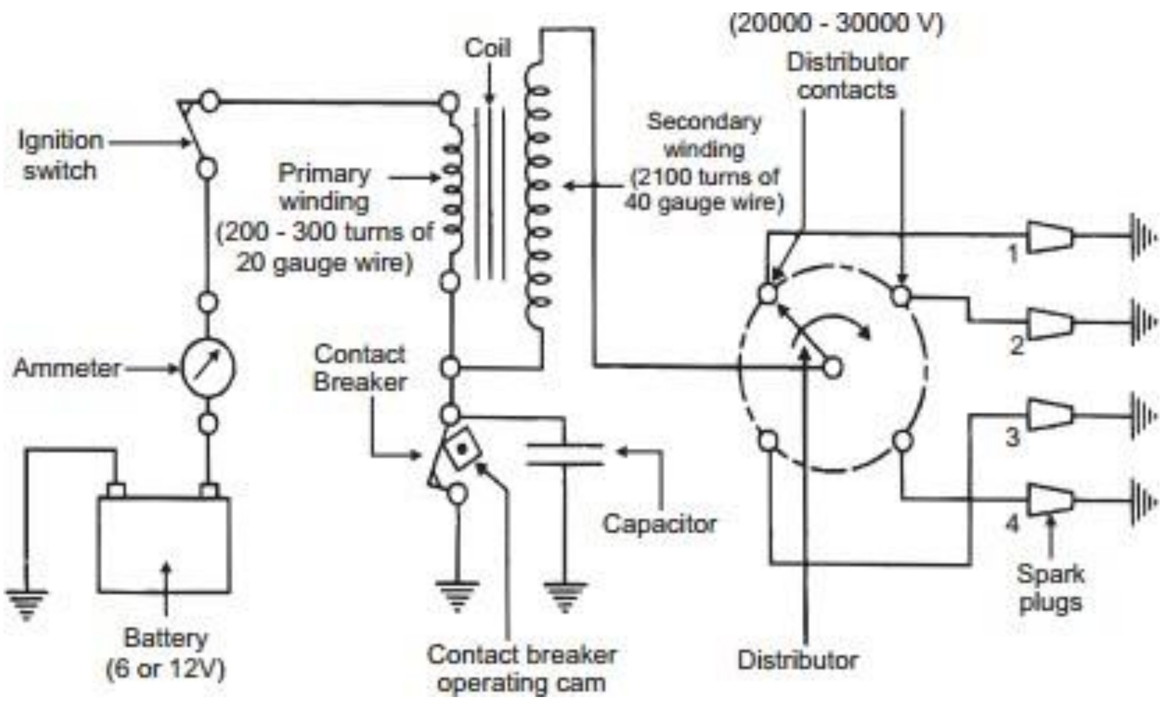



Figure 1: schematic diagram of battery ignition system

**Functions of each components**

- The battery supplies electricity to the system.
- The ignition switch turns the system on and off.
- The ignition coil strengthens the electricity from the battery.
- The distributor directs the electricity to the spark plug.
- The triggering device controls when the spark occurs.
- The spark plug wire carries the electricity to the spark plug.
- The spark plug produces the spark in the cylinder that ignites the air-and-fuel mixture

## Battery

- In most automobiles, the power source for the ignition is a battery and an alternator. In a battery ignition system, the battery provides power to the ignition coil.
- The battery used in this type of system is a lead acid storage battery. In addition to providing electricity to the ignition coil, the battery may also be used to power lights, horns, and other accessory circuits.
- A typical lead-acid storage battery is made up of several individual compartments called *cells*.

- Each cell is made up of a series of lead plates. Small spaces between the plates are filled with an electrolyte solution.
- This solution is usually made from sulphuric acid diluted with water.
- Each cell produces approximately 2 V when the battery is fully charged, so a 12 V battery contains six cells
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- Normally, a battery has a total output voltage of 12 volts of direct current, or 12 DC.
- The current produced by the battery is often measured in units called *ampere/hours (Ah)*.
- In a battery ignition system, the alternator is used to recharge the battery as the engine operates.

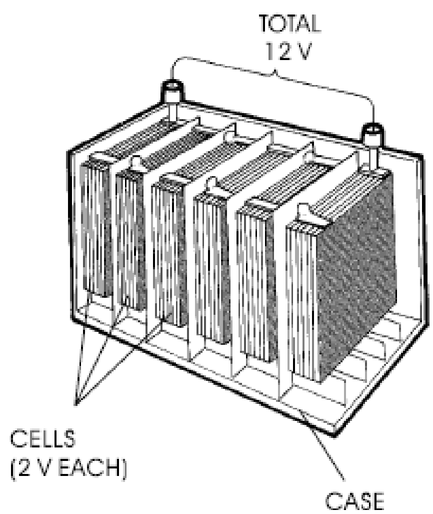


Figure 2. Cut section of a battery

**The Ignition Switch**

- The switch assembly is usually mounted a short distance down the steering column from the key lock cylinder assembly. The two assemblies are then connected by an ignition switch actuator rod.
- Turning the key moves a gear-and-rack assembly. The gear-and-rack assembly, in turn, moves the ignition switch actuator rod and plunger to the various positions required for performing ignition switch functions.

- ❑ Several different types of ignition switches are commonly used.
- ❑ The most common is the *five-position switch*.

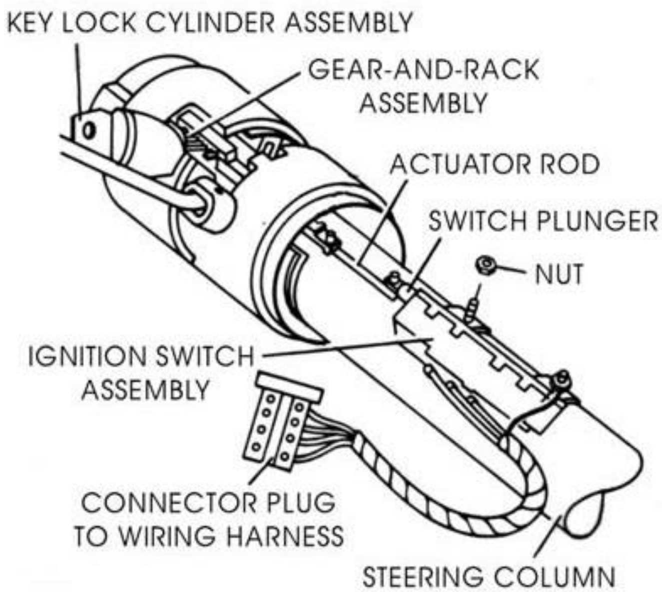


Figure 3 : Ignition switch circuit diagram

- ➢ In the accessory or ACT position, the engine is shut off and a connection is made from the battery terminal to the accessory terminal of the switch. This allows accessories such as the radio, heater, blower, and windshield wiper to be operated when the ignition, fuel gage, and indicator light circuits are off.
- ➢ In the OFF and LOCK positions, accessories that are supplied with power through the ignition switch can't be operated. Also, it's general practice to ground the resistance wire circuit to the ignition coil when the switch is in the LOCK position.
- ➢ This prevents the engine from being operated with a jumper to the coil.
- ➢ Generally, in the START position, all accessories that are supplied with power through the switch are temporarily disconnected.
- ➢ One connection is made to the starter solenoid, and a second connection is made directly to the ignition coil.
- ➢ Because the battery voltage lowers when an engine is started, the ballast resistor, which supplies the switch with power, is bypassed to provide a higher secondary winding voltage to start the engine.
- ➢ When the ignition switch is released from the START position, a spring returns the switch to the ON position.

**Ignition Coil**

- All ignition systems contain an ignition coil. The ignition coil is actually a type of electric transformer that changes low-voltage electricity to high-voltage electricity.
- Ignition coils work on the principles of magnetic induction.
- An ignition coil contains two coils of wire called the *primary winding* and the *secondary winding*.
- The primary winding is made of turns of heavy-gage wire; in contrast, the secondary winding is made of many turns of very fine-gage wire wrapped around a soft iron core.
- The secondary winding has many more turns of wire than the primary winding.
- The difference in the number of turns of wire between the two is what allows the ignition coil to increase voltage.
- In an ignition system, a triggering device is attached to the primary winding of the ignition coil.
- The triggering device is used to turn the current flow in the primary winding on and off at the proper time.
- The secondary coil winding is connected to the spark plug wire.
- The spark plug wire is a heavily insulated wire that leads directly to the spark plug

**All ignition coils contain the following basic components:**

1. A small number of turns of heavy wire

2. A large number of turns of fine wire

3. A central core of soft iron

4. Insulation between each turn of wire, and between the turns and the iron core

5. External electrical connections

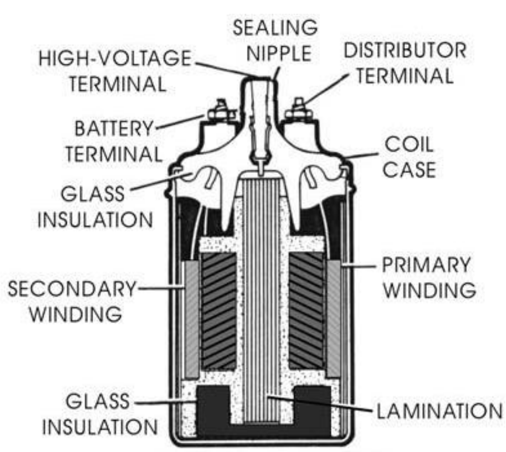


Figure 4: Cross sectional view of Ignition coil

**Spark Plug wire**

- Ignition system wires can be classified into two general types: *primary wires* and *secondary wires*.
- Primary wires carry high-current loads at low voltages from the battery to the ignition components. These wires are made of large-diameter conductors that are covered with light insulation.
- In contrast, secondary wires are used to carry small amounts of current, but at very high voltages. Therefore, secondary wires are made of small-diameter conductors that are covered with thick coatings of rubber, plastic, or neoprene insulation.
- Both ends of a spark plug wire have metal connectors called *terminals* attached to them.

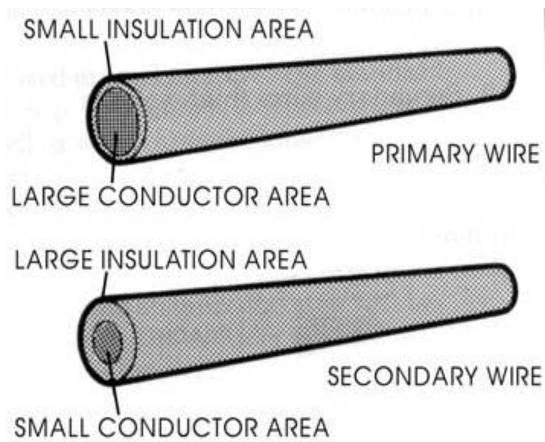


Figure 6: spark plug wire

**Spark Plugs**

- A spark plug is designed to allow a voltage to jump across a gap, producing a spark that ignites the engine's fuel. Four stroke engines contain one spark plug for each cylinder.
- A spark plug has two metal electrodes or terminals. The metal electrodes are conductors through which current flows. One electrode runs through the entire length of the spark plug. This is called the *center electrode*.
- The second electrode is connected to the threaded part of the spark plug. This electrode is sometimes called the *side electrode* or the *grounding electrode*.
- The grounding electrode bends around so that it's very close to the end of the center electrode. The small air space between the two electrodes is called the *gap*.

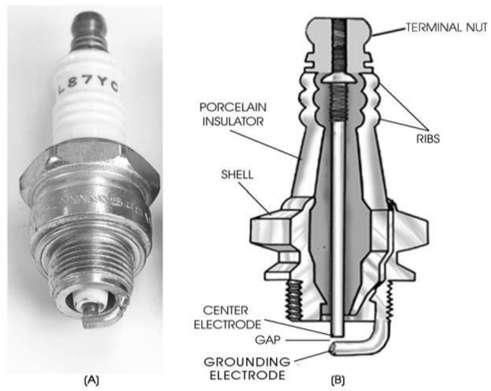


Figure 7: sectional view of spark plug

- ❖ Each spark plug has a heat range. A spark plug's heat range determines, to a large extent, engine performance under different conditions and speeds.
- ❖ A heat range classifies a spark plug according to its ability to transfer heat from the gap end of the plug to the engine's cooling system.
- ❖ A spark plug is called a *cold plug* if it can easily transfer combustion heat from the firing end of the plug out to the cylinder head. In a *hot plug,* the center electrode is more isolated from the shell and the cylinder head. Therefore, a hot plug tends to retain its heat.
- ❖ Cold plugs have shorter insulator tips than hot plugs.

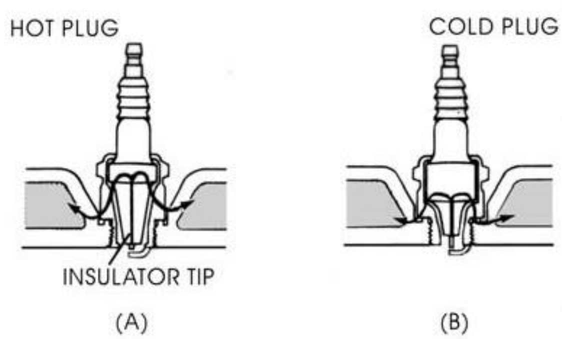


Figure 8: sectional view of hot & cold spark plug.

**Distributor**

- ➢ A device called a *distributor* is used to direct the high voltage from the ignition coil to the spark plugs.
- ➢ The distributor directs the high voltage to the cylinder that's currently on its compression stroke and ready to have the air-and-fuel mixture ignited to produce power.
- ➢ The distributor is usually mounted to an engine with its housing placed in a hole in the engine block or cylinder head.

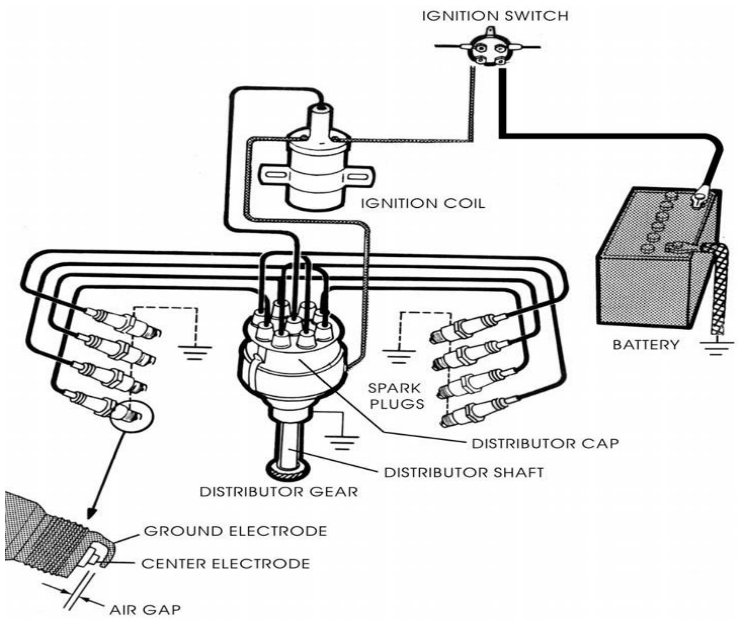


Figure 9: schematic view of distributor

- When a distributor is installed in an engine, the gear on the end of the distributor shaft is driven by a similar gear that's attached to the engine's camshaft.
- Therefore, whenever the engine is running, the distributor shaft turns with the camshaft at the same speed. Therefore, one camshaft rotation results in one distributor rotation.

**Dwell period**

An ignition system's *dwell* is the number of degrees that the distributor cam rotates during the time that the contact points are closed. When the rubbing block reaches the lobe or corner of the distributor cam, the points open and the dwell period ends. After the rubbing block passes a cam lobe, the block returns to the flat side of the cam, and the next dwell period begins.
The dwell setting is very important to the proper operation of an ignition system.
There are 360 degrees in a circle, so the maximum dwell for any engine is 360 degrees divided by the number of engine cylinders. One complete rotation of the distributor cam equals 360 degrees. An 8-cylinder engine has 8 cam lobes, so 45 degrees of rotation is between each cam lobe (360 _ 8 = 45). A 6-cylinder engine has 60 degrees between each cam lobe (360 _ 6 = 60). A 4-cylinder engine has 90 degrees between each cam lobe (360 _ 4 = 90).

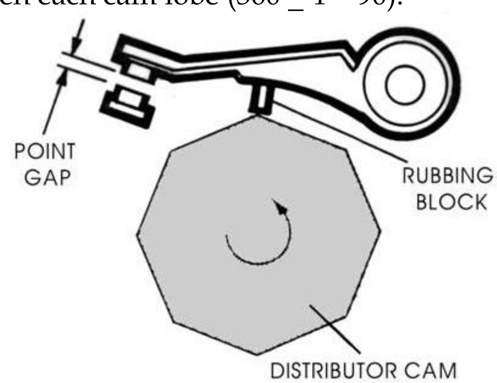


Figure 10: sectional view of contact breaker.

## MAGNETO IGNITION SYSTEM

- ➢ The source that generates energy in the Magneto Ignition System is the Magneto.
- ➢ Generally, a magneto is a small generator that works on electricity.
- ➢ When magneto is rotated by the engine, it produces the voltage.
- ➢ The higher the rotation, the greater will be the amount of voltage produced by the system.
- ➢ The magneto does not need any external power source such as a battery to kick start it as it itself is a source for generating energy.
- ➢ There are two types of winding in it. It has a primary binding and a secondary binding.
- ➢ In addition to this, magneto has 3 types based on its engine rotation
- ❖ **Armature rotating type**
- ❖ **Magnet rotating type**
- ❖ **Polar inductor type**
- ➢ In the armature rotating type, armature rotates between the stationary magnet whereas in the magnet rotating type, the armature is stationary and the magnets are rotating around the armature.
- ➢ In the polar inductor type, both the magnet and the windings remain stationary but the voltage is generated by reversing the flux field with the help of soft iron polar projections, called inductors.

### WORKING PRINCIPLE

The working principle of this ignition system is similar to the working principle of coil or battery ignition system except that in it magneto is used to produce energy but not the battery. Here are the following scenarios that occur in it.

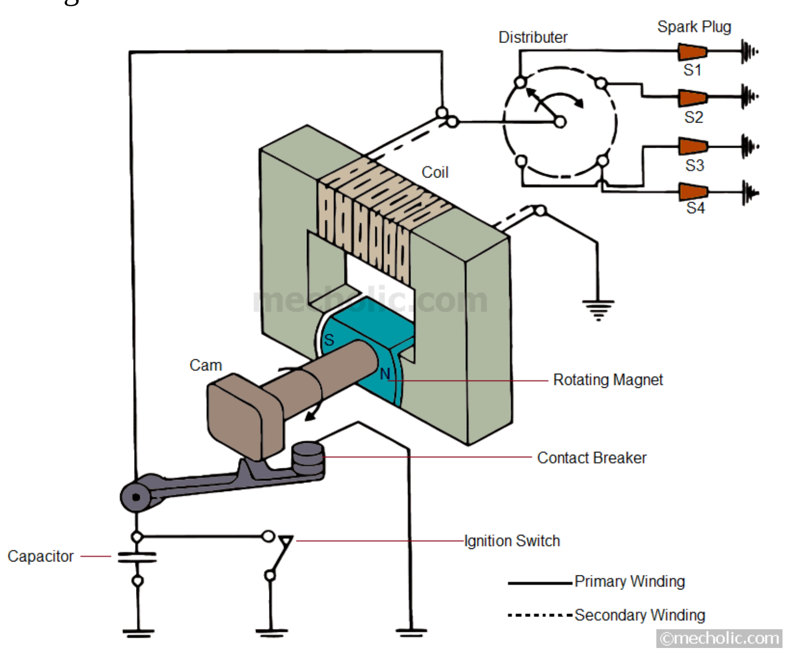


Figure 11: Schematic diagram of magneto ignition system

- When engine in the system starts it help magneto to rotate and thereby producing the energy in the form of high voltage.
- The one end of the magneto is grounded through contact breaker and the ignition capacitor is connected to it parallel.
- The contact breaker is regulated by the cam and when the breaker is open, current flows through the condenser and charges it.
- As the condenser is acting like a charger now, the primary current flow is reduced thereby reducing the overall magnetic field generated in the system. This increases the voltage in the condenser.
- This increased high voltage in the condenser will act as an EMF thereby producing the spark at the right spark plug through the distributor.
- At the initial stage, the speed of the engine is low and hence the voltage generated by the magneto is low but as the rotating speed of the engine increases, it also increases the voltage generated by the magneto and flow of the current is also increased. To kick start the engine, we can use an external source such as the battery to avoid the slow start of the engine.

**Advantages**

- It is a self-energizing type ignition system, so there is no need for an external energy source/ heavy battery, and it is compact.
- More reliable as there is no battery.
- It gives good quality spark at high speed.
- Since there no battery, it does not require high maintenance.

**Disadvantages**

- It has a starting problem due to the low rotating speed at the starting of the engine.
- It is more expensive when compared to a battery ignition system.
- There is a possibility of misfire due to leakage because the variation of voltage in the wiring can occur.

**Application**

- Here is the partial list of the applications of engines equipped with a magneto ignition system.
- Tractors, Oil Burners, and Outboard Motors
- Trucks and Cement Mixers
- Buses
- Airplane Engines
- Power Units, Marine Engines and Natural Gas Engines

## Difference between Battery Ignition System and Magneto Ignition System

| Battery Ignition System | Magneto Ignition System |
|---|---|
| Current required for spark or primary is circuit is obtained from a battery. | It produces the electricity required for spark plug or primary with its own electric generator. |

| | |
|---|---|
| This type of ignition system Battery is a necessary component. | Magneto ignition system does not need a battery. |
| The problem of discharged battery. | Since it does not require a battery there is no problem of discharged battery. |
| It is heavy and requires more space than a Magneto type. | It occupies less space when compared to battery type. |
| Quality of spark does not depend on the engine speed. | The quality of spark depends on the engine speed. |
| Good quality spark is obtained at low speed. | At low speed or at starting the quality of spark is poor because the generator produces less energy than required. |
| At high speed, the spark intensity reduces, and hence the efficiency of system decreases. | As speed increases the spark intensity also increases. It improves the efficiency of the system. |
| Since this system contains battery it requires high maintenance. | Less maintenance is required when compared to battery type. |
| It finds application in SI engines of cars and light commercial vehicle. | They are mainly used in racing cars and two-wheelers. |

## Drawbacks of Mechanical Ignition system

- Following are the drawbacks of conventional ignition system
- Because of arcing, pitting of contact breaker point and which will lead to regular maintenance problems.
- Poor starting : After few thousands of kilometers of running, the timing becomes inaccurate, which results into poor starting (Starting trouble).
- At very high engine speed, performance is poor because of inertia effects of the moving parts in the system.
- Some times it is not possible to produce spark properly in fouled spark plugs

## Advantages of Electronics Ignition system

- Moving parts are absent so less maintenance
- Contact breaker points are absent so no arcing
- Spark plug life increases by 50% and they can be used for about 60000 km without any problem
- Better combustion in combustion chamber, about 90-95% of air fuel mixture is burnt compared with 70-75% with conventional ignition system
- More power output.
- More fuel efficiency

## TYPES OF ELECTRONIC IGNITION SYSTEM

Electronic Ignition System is as follow :

(a) Capacitance Discharge Ignition system

(b) Transistorized system

(c) Piezo-electric Ignition system

(d) The Texaco Ignition system

## Capacitive Discharge Ignition system

- It mainly consists of 6-12 V battery, ignition switch, DC to DC convertor, charging resistance, tank capacitor, Silicon Controlled Rectifier (SCR), SCR-triggering device, step up transformer, spark plugs
- A 6-12 volt battery is connected to DC to DC converter i.e. power circuit through the ignition switch, which is designed to give or increase the voltage to 250-350 volts. This high voltage is used to charge the tank capacitor (or condenser) to this voltage through the charging resistance. The charging resistance is also so designed that it controls the required current in the SCR

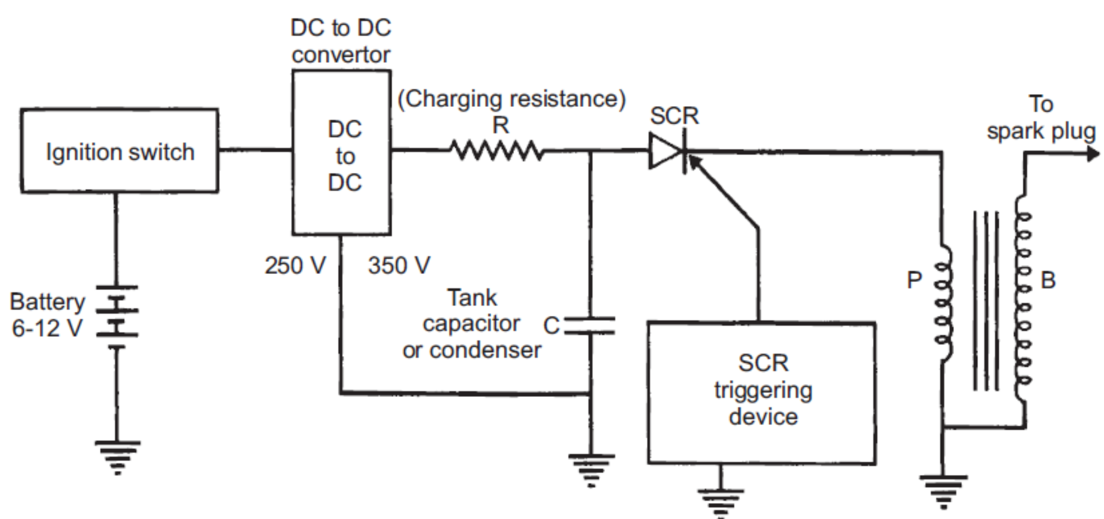


Figure 12: Capacitive ignition system

### Charging Coil

The charging coil is one coil in the stator, which is used to produce 6 volts to charge the capacitor C1. Based on the flywheel's movement the single pulsed power is produced and is supplied to the sparking plug by the charging coil to ensure the maximum spark.

**Hall Sensor**

The Hall Sensor measures the Hall effect, the instantaneous point where the flywheel's magnet changes from a north to a south pole. When the pole change occurs, the device sends a single, tiny pulse to the CDI box which triggers it to dump the energy from the charging capacitor into the high voltage transformer.

**Timing Mark**

The timing mark is an arbitrary alignment point shared by the engine case and stator plate. It indicates the point at which the top of the piston's travel is equivalent to the trigger point on the flywheel and stator.

By rotating the stator plate left and right, you effectively change the trigger point of the CDI, thus advancing or retarding your timing, respectively. As the flywheel turns fast, the charging coil produces an AC current from +6V to -6V.
The CDI box has a collection of semiconductor rectifiers that connected to G1 on the box allows only the positive pulse to enter the capacitor (C1). While the wave entering into the CDI, the rectifier allows only the positive wave.

**Trigger Circuit**

- The trigger circuit is a switch, probably using a Transistor, Thyristor or SCR. This triggered by a pulse from the Hall Sensor on the stator. They only allow current from one side of the circuit until they are triggered.
- Once the Capacitor C1 is fully charged, the circuit can be triggered again. This is why there is timing involved with the motor. If the capacitor and stator coil were perfect, they would charge instantaneously and we can trigger them as fast as our wish. However, they require a fraction of a second to full charge.

- If the circuit triggers too fast, then the spark from the spark plug will be enormously weak. Certainly, with the higher accelerating motors, we may have the triggering faster than the capacitor full charge, which will affect performance. Whenever the capacitor is discharged, then the switch turns itself off and the capacitor charges again.

- The trigger pulse from the Hall sensor feeds into the gate latch and allows all the stored charge to rush through the primary side of the high-voltage transformer. The transformer has a common ground between the primary and secondary windings, known as an auto step-up transformer.
- Therefore, as if we increase the windings on the secondary side, you will multiply the voltage. Since a spark plug needs a good 30,000 volts to sparks, there must be many thousands of wraps of wire around the high voltage or secondary side.

- When the gate opens and dumps all the current into the primary side, it saturates the low-voltage side of the transformer and sets up a short but immensely magnetic field. As the field reduces gradually, a large current in the primary windings forces the secondary windings to produce extremely high voltage.

- However, the voltage is now so high that it can arc through the air, so rather than being absorbed or retained by the transformer, the charge travels up the plug wire and jumps the plug gap.

- When we want to shut down the motor engine, we have two switches the key switch or the kill switch. The switches ground out the charging circuit so the entire charging pulse is sent to the ground. Since the CDI can no longer charge, it will cease to provide the spark and the engine will slow to a stop.

**Advantages of CDI**

- The major advantage of CDI is that the capacitor can be fully charged in a very short time (typically 1ms). So the CDI is suited to an application where the insufficient dwell time is available.
- The capacitor discharge ignition system has a short transient response, a fast voltage rise (between 3 to 10 kV/ µs) compared to inductive systems (300 to 500 V/ µs) and shorter spark duration (about 50-80 µs).
- The fast voltage rising makes CDI systems unaffected to shunt resistance.

**Disadvantages of CDI**

- The capacitor discharge ignition system generates huge electromagnetic noise and this is the main reason why CDIs are rarely used by automobile manufacturers.
- The short spark duration is not good for lighting relatively lean mixtures as used at low power levels. To solve this problem many CDI ignitions release multiple sparks at low engine speeds.

## Transistorized coil ignition system

- The breaker-point type of transistor ignition system was developed to replace the standard or conventional ignition system.
- To obtain the maximum power and speed that this engine can produce, you must install an ignition system that outperforms the conventional one.
- Electronic type of ignition systems provide a hotter, more uniform spark at a more precise interval.
- This promotes more efficient burning of the air/fuel mixture in the combustion chamber, producing less exhaust emissions, and resulting in better engine performance and increased mileage.
- The increased reliability of electronic ignition allows less frequent maintenance by increasing parts life. At high speeds, the breaker points of a conventional ignition system cannot handle the increased current flowing across them without pitting too much.

- Also, the dwell angle of the breaker points is too small for complete saturation of the ignition coil. The transistorized ignition system takes care of both drawbacks.

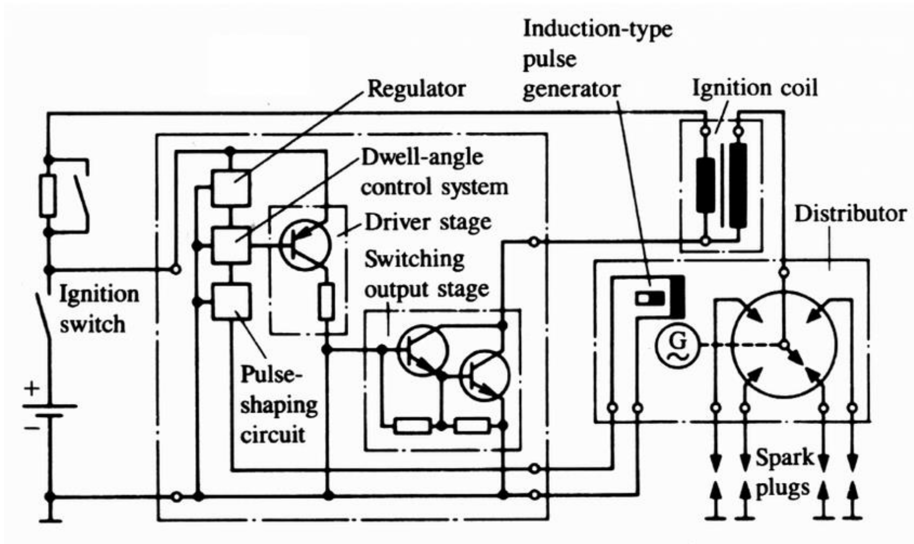


Figure 13: Transistorized coil ignition system

## Piezo-electric Ignition System

The development of synthetic piezo-electric materials producing about 22 kV by mechanical loading of a small crystal resulted in some ignition systems for single cylinder engines. But due to difficulties of high mechanical loading need of the order of 500 kg timely control and ability to produce sufficient voltage, these systems have not been able to come up.

## The Texaco Ignition System

Due to the increased emphasis on exhaust emission control, there has been a sudden interest in exhaust gas recirculation systems and lean fuel-air mixtures. To avoid the problems of burning of lean mixtures, the Texaco Ignition system has been developed. It provides a spark of controlled duration which means that the spark duration in crank angle degrees can be made constant at all engine speeds. It is a AC system. This system consists of three basic units, a power unit, a control unit and a distributor sensor. This system can give stable ignition up to A/F ratios as high as 24 : 1.

## Ignition Advance Mechanism

Ignition timing is very important, since the charge is to be ignited just before (few degrees before TDC) the end of compression, since when the charge is ignited, it will take some time to come to the required rate of burning.

**Ignition Advance**

The purpose of spark advance mechanism is to assure that under every condition of engine operation, ignition takes place at the most favorable instant in time i.e. most favorable from a standpoint of engine power, fuel economy and minimum exhaust dilution. By means of these mechanisms the advance angle is accurately set so that ignition occurs before TDC point of the piston. The engine speed and the engine load are the control quantities required for the automatic adjustment of the ignition timing. Most of the engines are fitted with mechanisms which are integral with the distributor and automatically regulate the optimum spark advance to account for change of speed and load. The two mechanisms used are :

- Centrifugal advance mechanism, and
- Vacuum advance mechanism

## Centrifugal Advance Mechanism

The centrifugal advance mechanism controls the ignition timing for full- load operation. The adjustment mechanism is designed so that its operation results in the desired advance of the spark. The cam is mounted, movably, on the distributor shaft so that as the speed increases, the flyweights which are swung farther and farther outward, shaft the cam in the direction of shaft rotation. As a result, the cam lobes make contact with the breaker lever rubbing block somewhat earlier, thus shifting the ignition point in the early or advance direction. Depending on the speed of the engine, and therefore of the shaft, the weights are swung outward a greater or a lesser distance from the center. They are then held in the extended
position, in a state of equilibrium corresponding to the shifted timing angle, by a retaining spring which exactly balances the centrifugal force. The weights shift the cam either or a rolling contact or sliding contact basis; for this reasons we distinguish between the rolling contact type and the sliding contact type of centrifugal advance mechanism.

The beginning of the timing adjustment in the range of low engine speeds and the continues adjustment based on the full load curve are determined by the size of the weights by the shape of the contact mechanisms (rolling or sliding contact type), and by the retaining springs, all of which can be widely differing designs. The centrifugal force controlled cam is fitted with a lower limit stop for purposes of setting the beginning of the adjustment, and also with an upper limit stop to restrict the greatest possible full load adjustment. A typical sliding contact type centrifugal advance mechanism is shown in Figures below

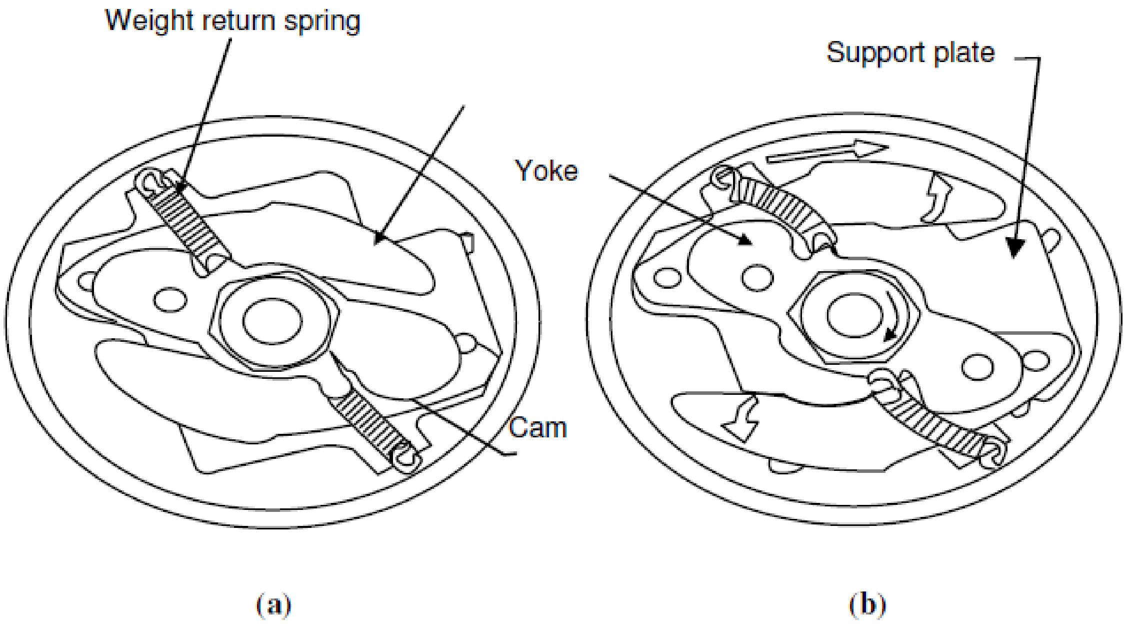

Figure 14: Sliding contact type centrifugal type advanced mechanism

**Vacuum Advance Mechanism**

Vacuum advance mechanism shifts the ignition point under partial load operation. The adjustment system is designed so that its operation results in the prescribed partial load advance curve. In this mechanism the adjustment control quantity is the static vacuum prevailing in the carburetor, a pressure which depends on the position of the throttle valve at any given time and which is at a maximum when this valve is about half open. This explains the vacuum maximum. The diaphragm of a vacuum unit is moved by changes in gas pressure. The position of this diaphragm is determined by the pressure differential at any given moment between the prevailing vacuum and atmospheric pressure. The beginning of adjustment is set by the pre-established tension on a compression spring. The diaphragm area, the spring force, and the spring rigidity are all selected in accordance with the partial –load advance curve which is to be followed and are all balanced with respect to each other. The diaphragm movement is transmitted through a vacuum advance arm connected to the movable breaker plate, and this movement shifts the breaker plate an additional amount under partial load condition in a direction opposite to the direction of rotation of the distributor shaft. Limit stops on the vacuum advance arm in the base of the vacuum unit restrict the range of adjustment.

The vacuum advance mechanism operates independent of the centrifugal advance mechanism. The mechanical interplay between the two advance mechanisms, however, permits the total adjustment angle at any given time to be the result of the addition of the shifts provided by the two individual mechanisms operates in conjunction with the engine is operating under partial load. A typical vacuum advance mechanism is shown in Figure below.

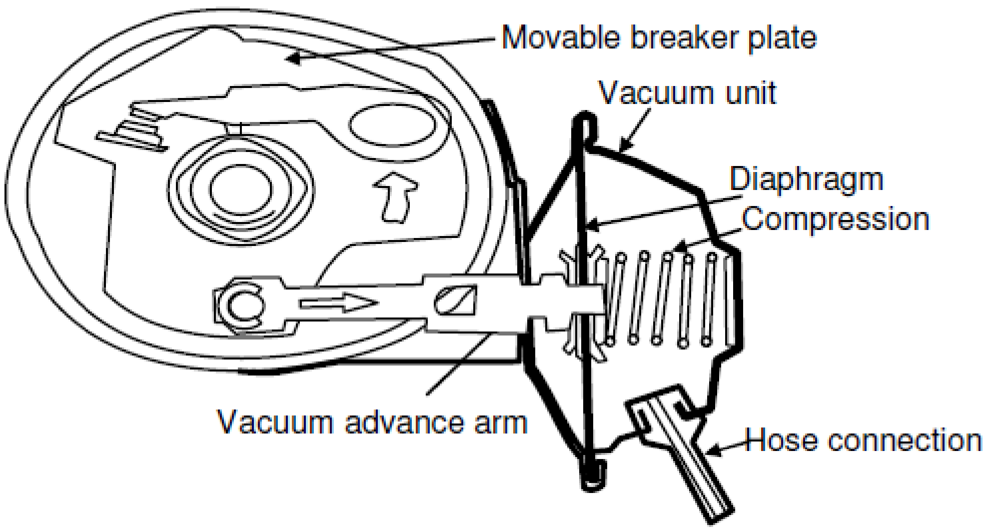


Figure 15 : Vacuum advanced mechanism

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# UNIT IV COOLING AND LUBRICATION SYSTEM

# UNIT 4 COOLING AND LUBRICATION SYSTEM

Need for cooling system, Types of cooling system: air cooling system, liquid cooling system, Comparison, forced circulation system, pressure cooling system. Lubrication system-Requirements, mist, wet sump lubrication system, properties of lubricants.

## 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.

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

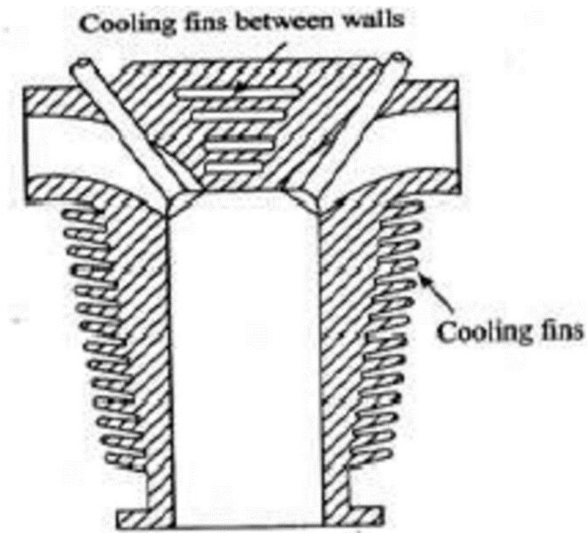

Figure 1 : Air cooling system

**Advantages of air cooled engines**

- ❖ Air cooled engines have the following advantages:
- ❖ Its design of air-cooled engine is simple.
- ❖ 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.
- ❖ It is cheaper to manufacture.
- ❖ It needs less care and maintenance.
- ❖ 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.
- ❖ 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.

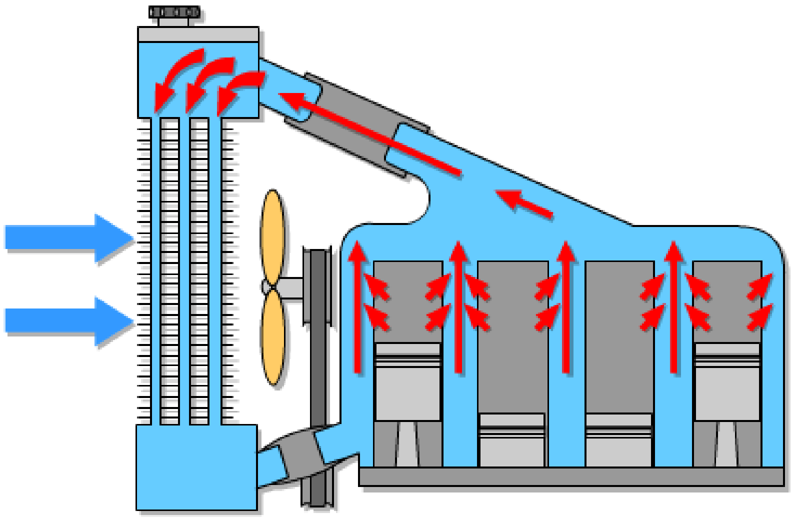

Figure 2: Water cooling system

**Types of Water Cooling System**

There are two types of water cooling system

1. Thermo siphon cooling system.

2, Pump circulation cooling system

**1. Thermo Siphon System**

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.

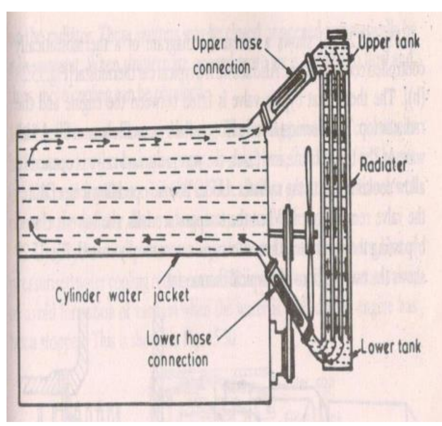


Figure 3: Thermo-syphon cooling

**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. Forthese reasons this system has become obsolete and is no more in use.

**2. Pump Circulation cooling System**

In this system circulation of water is obtained by a pump. This pump is driven by means of engine output shaft through V-belts.

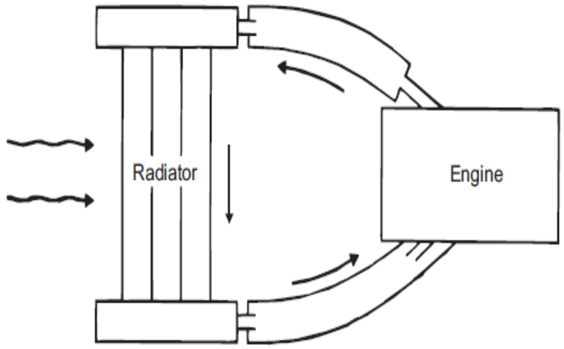


Figure 5.2 : Thermo Siphon System of Cooling

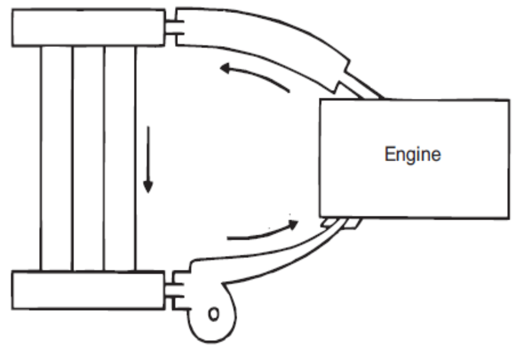


Figure 5.3 : Pump Circulation System

**Components of Water Cooling System**

Water cooling system mainly consists of :

(a) Radiator,
(b) Thermostat valve,
(c) Water pump,
(d) Fan,
(e) Water Jackets, and
(f) Antifreeze mixtures.

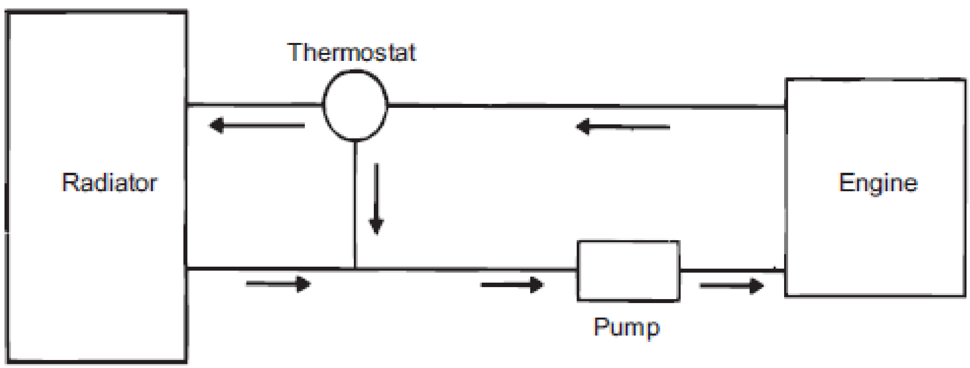


**Figure 5.4 : Water Cooling System using Thermostat Valve**

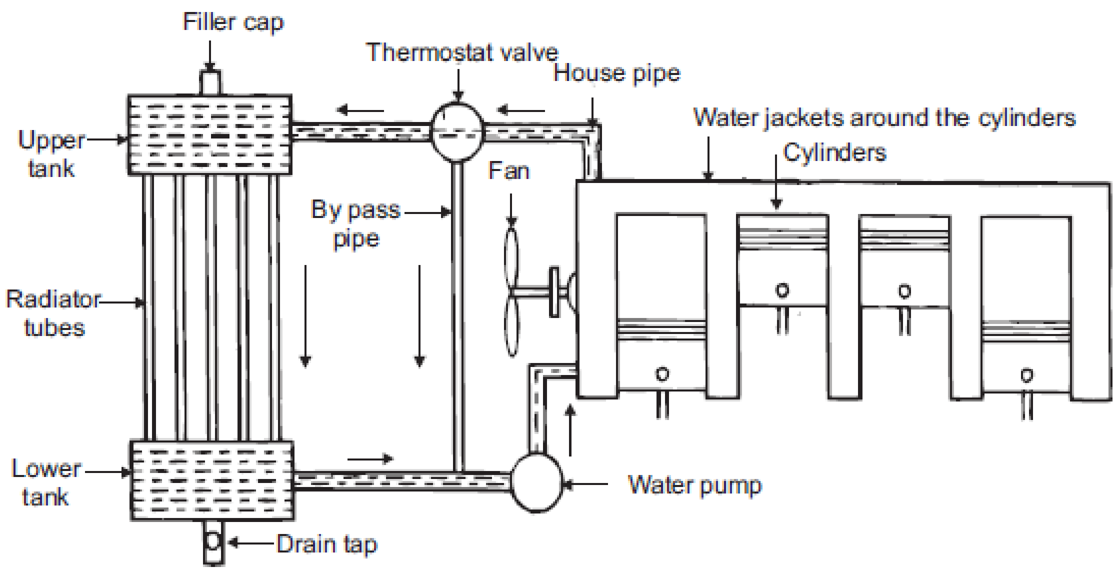


**Figure 5.5 : Water Cooling System of a 4-cylinder Engine**

**Water Pump**

- The water pump forces coolant through the engine cylinder block and head channels.
- Coolant is drawn into the centre of the water pump via the lower hose of the radiator.
- Centrifugal force, due to the rotation of the water pump impeller, throws the liquid out at the edge and into the cylinder block.
- If a mechanical cooling fan is used, it may often be attached to the water pump hub.

**Radiator**

- The function of the radiator is to transfer unwanted heat energy from the coolant to the outside air.
- Hoses connect the radiator to the engine cylinder block (water jacket) and passenger compartment heater.
- Fan(s) draw air through and over the radiator to increase the air flow and improve cooling efficiency.
- A thermostat controls the coolant flow during warm-up, so that the engine reaches operating temperature quickly.
- It mainly consists of an upper tank and lower tank and between them is a core. The upper tank is connected to the water outlets from the engines jackets by a hose pipe and the lover tank is connect to the jacket inlet through water pump by means of hose pipes.

There are 2-types of cores :

(a) Tubular

(b) Cellular.

- When the water is flowing down through the radiator core, it is cooled partially by the fan which blows air and partially by the air flow developed by the forward
- motion of the vehicle. As shown through water passages and air passages, wafer and air will be flowing for cooling purpose.
- It is to be noted that radiators are generally made out of copper and brass and their joints are made by soldering

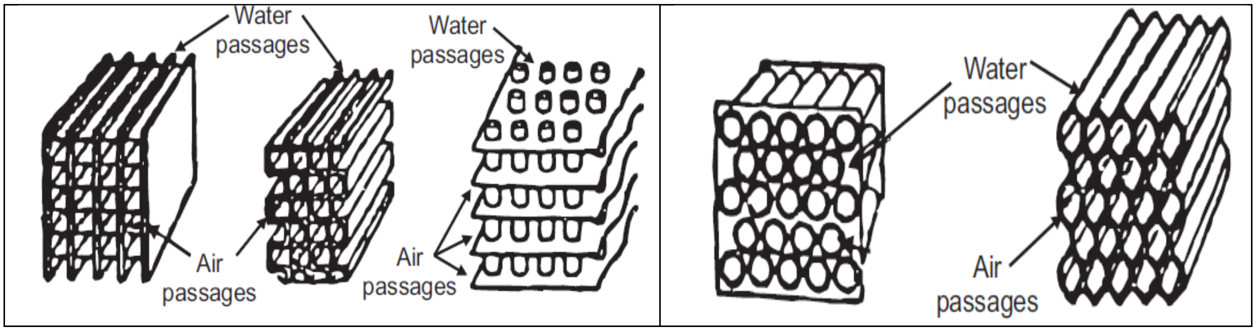


Figure 6: Cross sectional view of radiator tubes.

**Radiator Cap**

- The radiator pressure cap pressurizes the coolant system in order to raise the coolant's boiling point to about 125ºC (255ºF), this overcomes the production of steam.
- The pressure valve opens when the coolant system temperature rises significantly, to allow the escape of excess coolant to an expansion bottle.
- The surplus coolant is released and held in an expansion tank (in a closed system). Or in older vehicles, spills to the ground (in an open system).

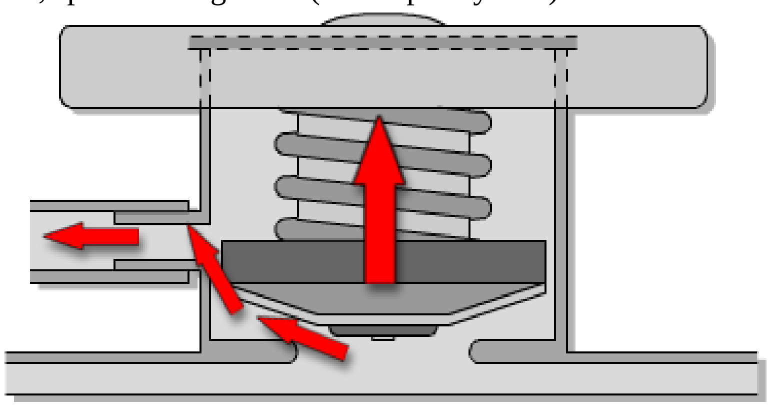

Figure 7: Radiator cap

**Thermostat Valve**

- It is a valve which prevents flow of water from the engine to radiator, so that engine readily reaches to its maximum efficient operating temperature.
- After attaining maximum efficient operating temperature, it automatically begins functioning. Generally, it prevents the water below 70°C.
- Figure shows the Bellow type thermostat valve which is generally used.
- It contains a bronze bellow containing liquid alcohol. Bellow is connected to the butterfly valve disc through the link.
- When the temperature of water increases, the liquid alcohol evaporates and the bellow expands and in turn opens the butterfly valve, and allows hot water to the radiator, where it is cooled.

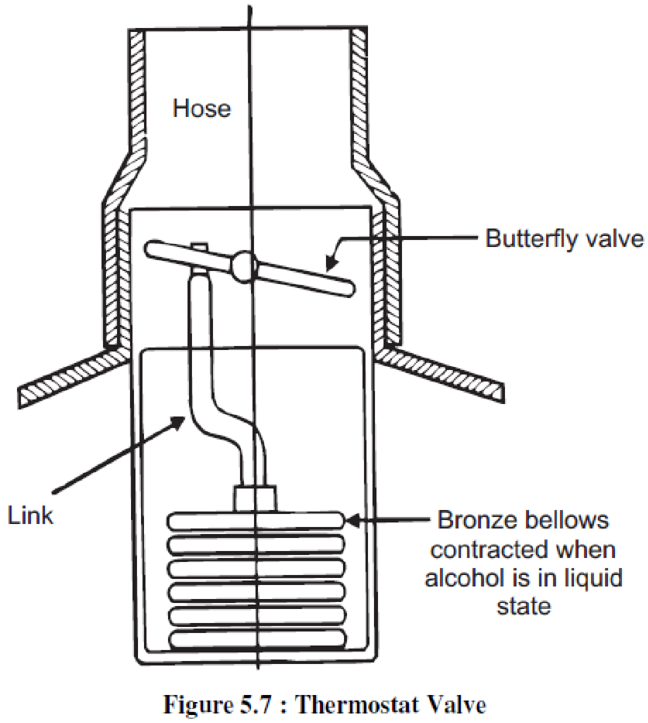


Figure 8: Thermostat valve

**Engine-Powered Cooling Fan**

- Mechanical fans provide air flow across the radiator core tubes and may be bolted to the water pump hub.
- A spacer may be needed in order to place the fan near to the radiator.
- The blades of the fan may be flexible or fixed.
- Fluid coupling fan clutches are arranged to slip at higher speeds when natural air flow is likely to be increased.
- Thermostatic fan clutches slip at cold temperatures, reducing air flow through the radiator and speed warm-up. When the
  coolant reaches the operating temperature, the clutch locks and the fan rotates in a fixed manner.

Figure 9: Cooling Fan

Fan
It is driven by the engine output shaft through same belt that drives the pump. It is provided behind the radiator and it blows air over the radiator for cooling purpose.

Water Jackets
Cooling water jackets are provided around the cylinder, cylinder head, valve seats and any hot parts which are to be cooled. Heat generated in the engine cylinder, conducted through the cylinder walls to the jackets. The water flowing through the jackets absorbs this heat and gets hot. This hot water will then be cooled in the radiator

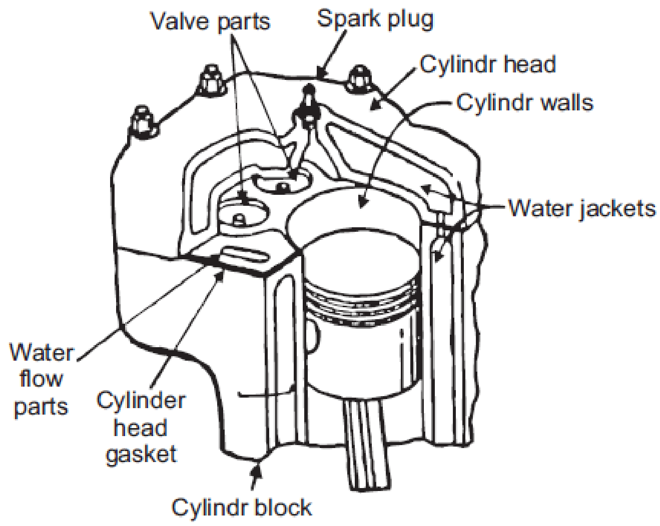


**Figure 5.9 : Water Jackets**

Figure 10: Water jacket in engine cylinder

**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.
The ideal antifreeze solutions should have the following properties :
(a) It should dissolve in water easily.
(b) It should not evaporate.
(c) It should not deposit any foreign matter in cooling system.
(d) It should not have any harmful effect on any part of cooling system.
(e) It should be cheap and easily available.
(f) It should not corrode the system.
No single antifreeze satisfies all the requirements. Normally following are used as antifreeze solutions :
(a) Methyl, ethyl and isopropyl alcohols.
(b) A solution of alcohol and water.
(c) Ethylene Glycol.
(d) A solution of water and Ethylene Glycol.

(e) Glycerin along with water, etc.

**Advantages and Disadvantages of Water Cooling System**

**Advantages**

(a) Uniform cooling of cylinder, cylinder head and valves.

(b) Specific fuel consumption of engine improves by using water cooling system.

(c) If we employ water cooling system, then engine need not be provided at the front end of moving vehicle.

(d) Engine is less noisy as compared with air cooled engines, as it has water for damping noise.

**Disadvantages**

(a) It depends upon the supply of water.

(b) The water pump which circulates water absorbs considerable power.

(c) If the water cooling system fails then it will result in severe damage of engine.

(d) The water cooling system is costlier as it has more number of parts. Also it

***(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.

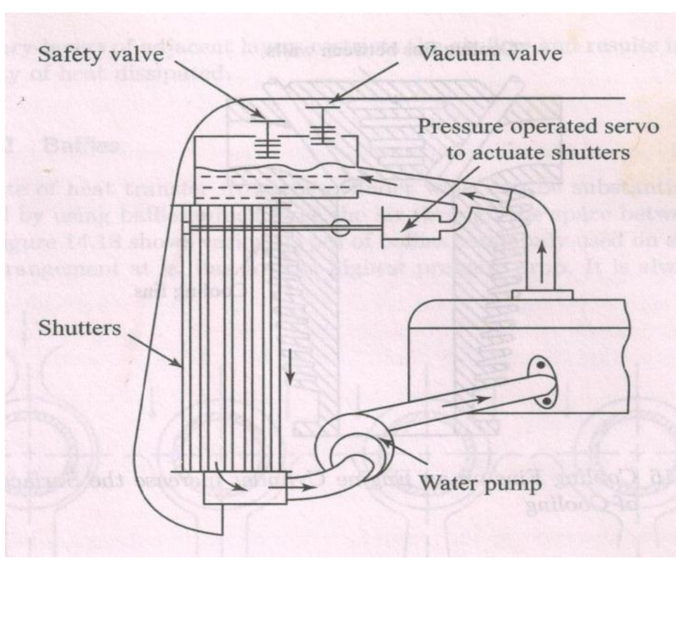

Figure 11: Pressurized cooling system

**Figure. Pressurised system**

***(e) Evaporative cooling system:***

- ❖ This is predominately used in stationary engine and in many types of industrial engines..
- ❖ In this system , the engine will be cooled because of the evaporation of the water in the cylinder jackets into steams.
- ❖ In this system, the water evaporates and becomes steam due high temperatures of the cylinder jackets. This steams is naturally Circulated into Radiator without pump

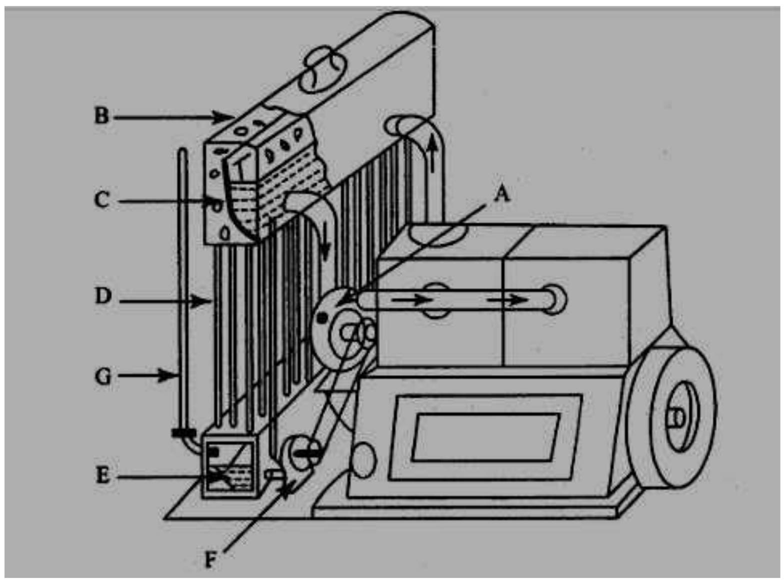


Figure 11: Evaporative cooling system.

- ❖ The figure shows the evaporative cooling with air cooled condenser.
- ❖ In this case water is circulated by the pump A and when delivered to the overhead tank B part of it boils out.
- ❖ The tank has portion C. The vapors rise above the portion C and because of the condensing action of the radiator tube D, condensate flow into the lower tank E from which it is picked up and return to the tank B by the small pump F.
- ❖ The vertical pipe G is in communication with the side atmosphere to prevent the collapsing of the tank B and E when the pressure inside them due to condensation fall below the atmosphere.

**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.

**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 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

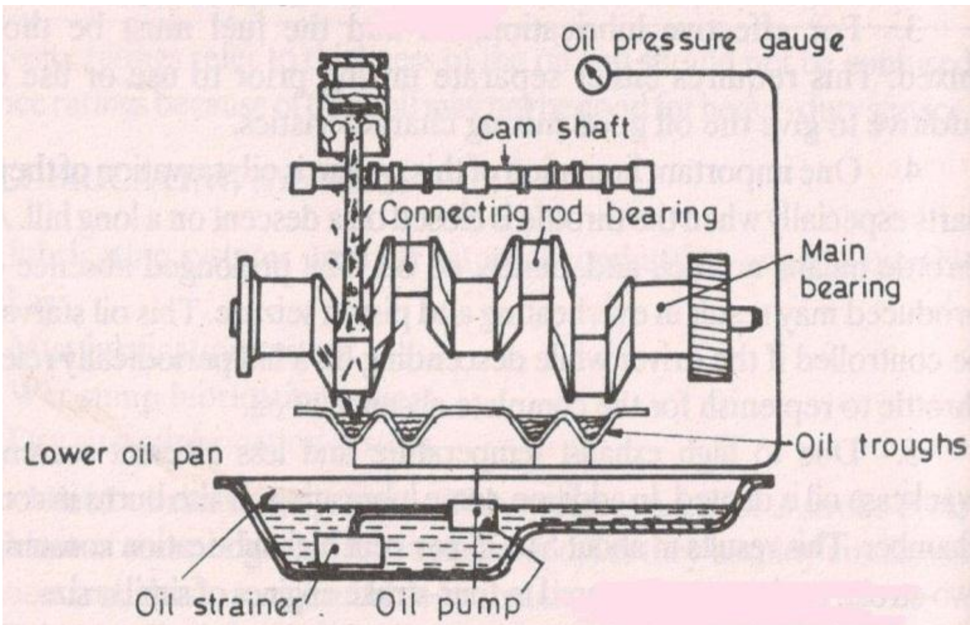


Figure 12: Splash lubricating system

(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.

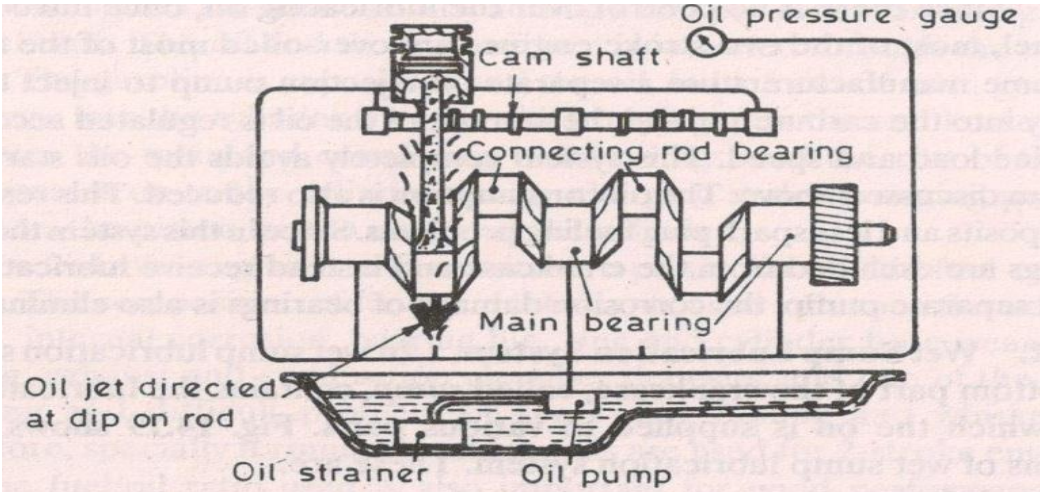


Figure 13: Splash and pressure lubricating system

(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/cm2 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.

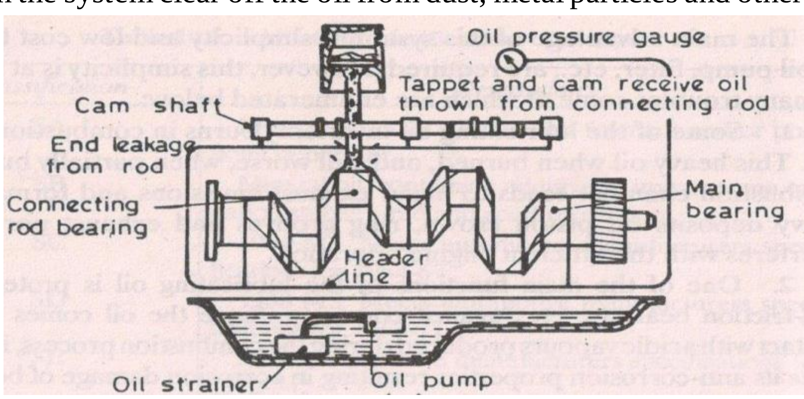


Figure 14: Pressure feed lubricating system

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# UNIT V COMBUSTION AND COMBUSTION CHAMBER

## UNIT 5 COMBUSTION AND COMBUSTION CHAMBERS

Combustion in SI engine; stages of combustion, flame propagation, rate of pressure rises, abnormal combustion, detonation, effect of engine variables on knock, knock rating. Combustion chambers; different types, factors controlling combustion chamber design.

### SI ENGINE COMBUSTION CHAMBER DESIGN

The design of the combustion chamber for an SI engine has an important influence on the engine performance and its knocking tendencies. The design involves

- The shape of the combustion chamber,
- The location of spark plug and
- The location of inlet and exhaust valves.

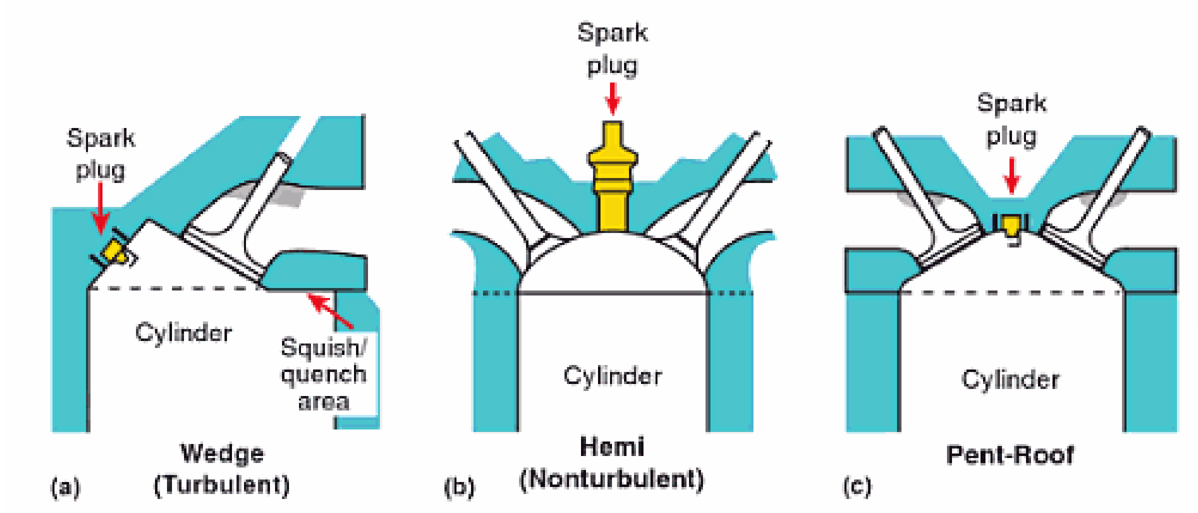



**Figure** Combustion chamber designs.

The important requirements of an SI engine combustion chamber are

- Smooth engine operation.
- High thermal efficiency and
- Provide high power output with minimum octane requirement

**I Smooth engine operation**

The aim of any engine design is to have a smooth operation and a good economy.

These can be achieved by the following:

a. **Moderate Rate of Pressure Rise**

Limiting the rate of pressure rise as well as the position of the peak pressure with respect to TDC affect smooth engine operation

**b. Reducing the Possibility of Knocking**

- Reducing the distance of the flame travel by centrally locating the spark plug and also by avoiding pockets of stagnant charge.
- Satisfactory cooling of the spark plug and of exhaust valve area which are the source of hot spots in the majority of the combustion chambers.

- Reducing the temperature of the last portion of the charge, through application of a high surface to volume ratio in that part where the last portion of the charge burns.

**II. High Power Output and Thermal Efficiency**

This can be achieved by considering the following factors:

- A high degree of turbulence is needed to achieve a high flame front velocity. Turbulence is induced by inlet flow configuration or squish
- Squish is the rapid radial movement of the gas trapped in between the piston and the cylinder head into the bowl or the dome.
- Squish can be induced in spark-ignition engines by having a bowl in piston or with a dome shaped cylinder head.
- High Volumetric Efficiency More charge during the suction stroke, results in an increased power output.
- This can be achieved by providing ample clearance around the valve heads, large diameter valves and straight passages with minimum pressure drop.

**TYPES OF COMBUSTION CHAMBER IN SI ENGINE**

(a) T-head combustion chamber
(b) L-Head Type
(c) I-head or side valve combustion chamber
(d) F-head combustion chamber

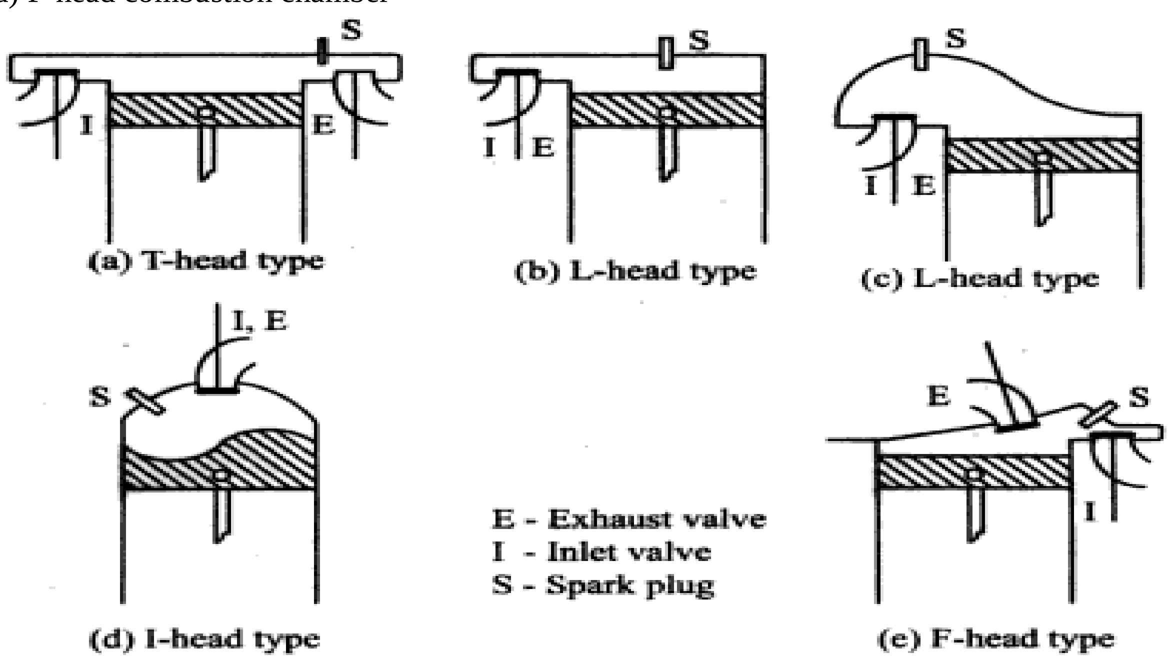



*Fig: Examples of Typical Combustion Chamber*

**(a)T-head combustion chamber.**

- The T-head combustion chambers were used in the early stage of engine development.
- Since the distance across the combustion chamber is very long, knocking tendency is high in this type of engines.
- This configuration provides two valves on either side of the cylinder, requiring two camshafts. From the manufacturing point of view, providing two camshafts is a disadvantage.

**(b) L-Head type combustion chamber.**

A modification of the T-head type of combustion chamber is the L-head type which provides the two valves on the same side of the cylinder and the valves are operated by a single camshaft. The main objectives of the Ricardo's turbulent head design, Fig (c), axle to obtain fast flame speed and reduced knock

**(c)I-head or side valve combustion chamber**

In this combustion chamber, both the valves are located on the cylinder head.

The overhead valve engine is superior to a side valve or an L-head engine at high compression ratios.

Some of the important characteristics of this type of valve arrangement are:

- less surface to volume ratio and therefore less heat loss
- less flame travel length and hence greater freedom from knock
- higher volumetric efficiency from larger valves or valve lifts

**(d) F-head combustion chamber**

The F-head type of valve arrangement is a compromise between L-head and I-head types.

Combustion chambers in which one valve is in the cylinder head and the other in the cylinder block are known as F-head combustion chambers

Modern F-head engines have exhaust valve in the head and inlet valve in the cylinder block.

The main disadvantage of this type is that the inlet valve and the exhaust valve are separately actuated by two cams mounted on to camshafts driven by the crankshaft through gears.

**Advantages and drawbacks of S I Engine combustion chambers**

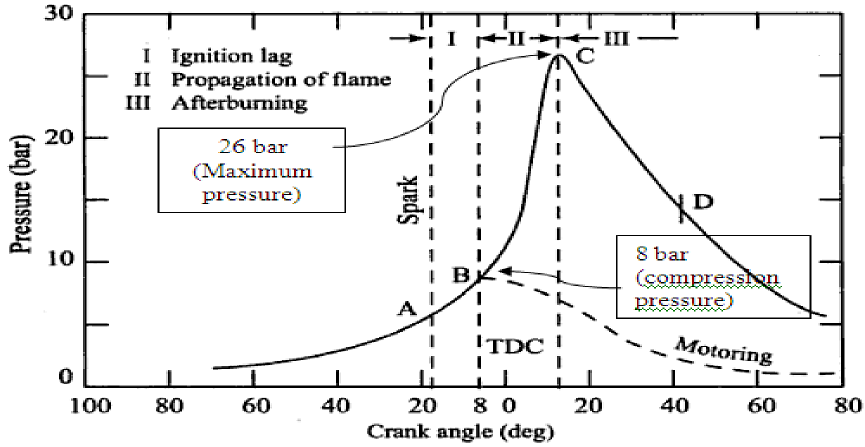
| **Sr. no.** | **Combustion Chamber Type** | **Advantages** | **Disadvantages** |
|---|---|---|---|
| 1 | T- head combustion chamber | 1. Easy to manufacture flat cylinder head,<br>2. Lower height of engine and front hood for better frontal visibility of vehicle. | 1. Longer length of flame travel.<br>2.Increased detonation tendency. |
| 2 | L- head or side head combustion chamber | 1. Neat and compact layout<br>2. Easy to lubricate valves, easy to decarbonize engine. | 1. Lack of turbulence<br>2. Extremely prone to detonation |

| | | | |
|---|---|---|---|
| | | | 3. Extremely sensitive to ignition timing slow combustion. |
| 3 | Ricardo Turbulent head side valve combustion chamber | 1. Faster flame speed,<br>2. Reduced detonation<br>3. Homogeneous air: fuel mixture formation. | 1. Inefficient operation as compared to latest engines with compression ratio of 10:1 |
| 4 | F- head combustion chamber | 1. Flat roof allows use of an inlet valve bigger than exhaust valve.<br>2. Valve and plug cooling is efficient. | Complex valve operating mechanism. |
| **5** | I – head combustion chamber (Wedge form and Bath tub form of combustion chamber) | 1. Lower pumping losses and higher volumetric efficiency.<br>2. Lesser distance of flame travel. Therefore low octane requirement.<br>3. More uniform cooling of cylinder and piston.<br>4. Lower surface to volume ratio and therefore less heat loss.<br>5. Easier to cast and hence lower casting cost. | 1. Large sized valves cannot be accommodated.<br>2. Valve operating mechanism gets disturbed while decarbonizing combustion chamber. |

**STAGES OF SI ENGINE COMBUSTION**

In SI engine homogeneous mixture of vaporised fuel, air and residual gases is ignited by a single intense and high temperature spark between the spark plug electrode (electrodes exceeds 10,000 $^{o}$C) and generate pre-flame which spreads to envelope of mixture for combustion.

The combustion in SI engine has divided into three stages.
1. Ignition lag or preparation phase (A-B)
II. Propagation of flame (B-C)
III. Period of after burning (C-D




*Stages of Combustion in an SI Engine*

**Stage I - Ignition lag or preparation phase (AB)**

- Growth and development of a semi propagating nucleus of flame.
- chemical process depending upon the nature of the fuel, upon both temperature and pressure, the proportion of the exhaust gas, and also upon the temperature coefficient of the fuel, that is, the relationship of oxidation or burning
- Point A shows the passage of spark and point B is the first rise of pressure
- Ignition lag is generally expressed in terms of crank angle
- Ignition lag is very small and lies between 0.00015 to 0.0002 seconds
- Ignition lag of 0.002 seconds corresponds to 35 degree crank rotation when the engine is running at 3000 RPM
- Angle of advance increase with the speed

**Stage II- Propagation of flame (BC)**

- Period from the point B where the line of combustion departs from the compression line to point C, the maximum rise of pressure in P-θ diagram
- Flame propagates at the constant velocity
- Heat transfer to the cylinder wall is low
- Rate of heat release depends upon the turbulence intensity and reaction rate
- During this second stage, the flame spreads throughout the combustion chamber. The second stage ends as maximum pressure (on indicator diagram) is reached.

**III-After burning (CD)**

- After point C, the heat release is due to the fuel injection in reduced flame front after the starts of expansion stroke.
- No pressure rise during this period.

- End of second stage means completion of flame travel. But it does not result in complete heat release (burning of fuel).
- Even after the passage of flame, some chemical adjustments continue throughout the expansion stroke- near the walls and behind the turbulent flame front. The rate of combustion reduces due to surface of the flame front becoming smaller and reduction in turbulence.

## Effect of engine variables on Ignition Lag

Ignition lag is a chemical process. The ignition lag in term of crank angle is $10^{o}$ to $20^{o}$& in terms of second, 0.0015 second. The duration of ignition lag depend on

**Fuel**- it is depend on chemical nature of fuel. The higher, the self ignition temp of fuel, the longer, the ignition lag

**Mixture Ratio**-The ignition lag is smallest for the mixture ratio which gives the maximum temperature this mixture ratio is some what richer than the stoichiometric ratio.

**Initial pressure and temperature** –increasing the intake temp, pressure, compression ratio and retarding spark, all reduce the ignition lag.

**Electrode gap-** It affects establishment of the nucleus of flame. If the gap is too small, quenching of the flame nucleus may occur & rang of fuel –air ratio for the development of a flame nucleus is reduced.

**Turbulence-** measured in degree of crank-rotation the ignition lag increases almost linearly with engine speed. For this reason. It becomes necessary to advance the spark timing at higher speed.

Excessive turbulence of the mixture in the area of the spark plug is harmful, since it increases the heat transfer from the combustion zone & leads to unstable development of the nucleus of flame. That is way the spark plug is usually arranged in a small recess in the wall of the combustion chamber.

## Effect of engine variables on Flame Propagation

Rate of flame propagation affects the combustion process in SI engines. Higher combustion efficiency and fuel economy can be achieved by higher flame propagation velocities. Unfortunately flame velocities for most of fuel range between 10 to 30 m/second.
The factors which affect the flame propagations are

1. Air fuel ratio
2. Compression ratio
3. Load on engine
4. Turbulence
5. engine speed
6. Engine size
7. Other factors

**1. Air-Fuel ratio:**

The mixture strength influences the rate of combustion and amount of heat generated. The maximum flame speed for all hydrocarbon fuels occurs at nearly 10% rich mixture. Flame speed is reduced both for lean and as well as for very rich mixture. Lean mixture releases less heat resulting lower flame temperature and lower flame speed. Very rich mixture results incomplete combustion and also results in production of less heat and flame speed remains low.

**2. Compression ratio:**

The higher compression ratio increases the pressure and temperature of the mixture and also decreases the concentration of residual gases. All these factors reduce the ignition lag and help to speed up the second phase of combustion. The maximum pressure of the cycle as well as mean effective pressure of the cycle with increase in compression ratio. Figure above shows the effect of compression ratio on pressure (indirectly on the speed of combustion) with respect to crank angle for same A: F ratio and same angle of advance. Higher compression ratio increases the surface to volume ratio and thereby increases the part of the mixture which after-burns in the third phase.

**3. Load on Engine:**

With increase in load, the cycle pressures increase and the flame speed also increases. In S.I. engine, the power developed by an engine is controlled by throttling. At lower load and higher throttle, the initial and final pressure of the mixture after compression decrease and mixture is also diluted by the more residual gases. This reduces the flame propagation and prolongs the ignition lag. This is the reason, the advance mechanism is also provided with change in load on the engine. This difficulty can be partly overcome by providing rich mixture at part loads but this definitely increases the chances of afterburning. The after burning is prolonged with richer mixture. In fact, poor combustion at part loads and necessity of providing richer mixture are the main disadvantages of SI engines which causes wastage of fuel and discharge of large amount of CO with exhaust gases.

**4. Turbulence:**

Turbulence plays very important role in combustion of fuel as the flame speed is directly proportional to the turbulence of the mixture. This is because, the turbulence increases the mixing and heat transfer coefficient or heat transfer rate between the burned and unburned mixture. The turbulence of the mixture can be increased at the end of compression by suitable design of the combustion chamber (geometry of cylinder head and piston crown). Insufficient turbulence provides low flame velocity and incomplete combustion and reduces the power output. But excessive turbulence is also not desirable as it increases the combustion rapidly and leads to detonation. Excessive turbulence causes to cool the flame generated and flame propagation is reduced. Moderate turbulence is always desirable as it accelerates the chemical reaction, reduces ignition lag, increases flame propagation and even allows weak mixture to burn efficiently.

**5. Engine Speed**

The turbulence of the mixture increases with an increase in engine speed. For this reason the flame speed almost increases linearly with engine speed. If the engine speed is doubled, flame to traverse the combustion chamber is halved. Double the original speed and half the original time give the same number of crank degrees for flame propagation. The crank angle required for the flame propagation, which is main phase of combustion will remain almost constant at all speeds. This is an important characteristic of all petrol engines.

**6. Engine Size**

Engines of similar design generally run at the same piston speed. This is achieved by using small engines having larger RPM and larger engines having smaller RPM. Due to same piston speed, the inlet velocity, degree of turbulence and flame speed are nearly same in similar engines regardless of the size. However, in small engines the flame travel is small and in large engines large. Therefore, if the engine size is doubled the time required for propagation of flame through combustion space is also doubled. But with lower RPM of large engines the time for flame propagation in terms of crank would be nearly same as in small engines. In other words, the number of crank degrees required for flame travel will be about the same irrespective of engine size provided the engines are similar.

**7. Other Factors:**

Among the other factors, the factors which increase the flame speed are supercharging of the engine, spark timing and residual gases left in the engine at the end of exhaust stroke. The air humidity also affects the flame velocity but its exact effect is not known. Anyhow, its effect is not large compared with A:F ratio and turbulence.

## DETONATION OR KNOCKING IN SI ENGINE

Knocking is due to auto ignition of end portion of unburned charge in combustion chamber. As the normal flame proceeds across the chamber, pressure and temperature of unburned charge increase due to compression by burned portion of charge. This unburned compressed charge may auto ignite under certain temperature condition and release the energy at a very rapid rate compared to normal combustion process in cylinder. This rapid release of energy during auto ignition causes a high pressure differential in combustion chamber and a high pressure wave is released from auto ignition region. The motion of high pressure compression waves inside the cylinder causes vibration of engine parts and pinging noise and it is known as knocking or detonation. This pressure frequency or vibration frequency in SI engine can be up to 5000 Cycles per second. Denotation is undesirable as it affects the engine performance and life, as it abruptly increases sudden large amount of heat energy. It also put a limit on compression ratio at which engine can be operated which directly affects the engine efficiency and output.

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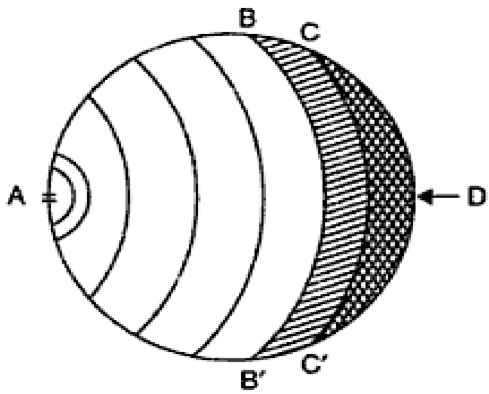
| <br><br>**Figure. Detonation in SI engine** | A= Source of ignition causing hollow nucleus to be formed and flame front to propagate further.<br>BB'*Type equation here.*= intermediate position of the flame front<br>CC' = intermediate position of flame front<br>CC'D = unburnt end charge reaching critical temperature<br>*In abnormal combustion, the end charge auto-ignites before the flame front reaches it.* |

**Detonation type of abnormal combustion**.

Figure shows combustion with detonation. The flame front has reached BB' and the unburnt charge BB'D has reached the critical conditions for auto-ignition. In this case there is a possibility of detonation. If the flame front can proceed from BB' to D and consume the unburnt charge in a normal manner, prior to completion of the Ignition delay period, there will be no detonation.

If, however, the flame front is able to proceed only as far as, say CC', during the ignition delay period, then the remaining portion of the unburnt charge CC'D will auto-ignite and cause extreme pressure fluctuations from about 50 bar to 150-200 bar.

**Effects of detonation**

- Noise and vibration: the presence of vibratory motion causes crankshaft vibrations and the engine runs rough.
- Mechanical damage: the cylinder head and valves may be pitted, increased rate of wear may occur.
- Carbon Deposits: detonation results in increased carbon deposits.
- Increase in heat transfer: occurs due to scouring away of protective layer of inactive stagnant gas on the cylinder walls due to pressure waves.
- Decrease in power output and efficiency: due to increase in the rate of heat transfer the power output as well as efficiency of a detonating engine decreases.
- Pre-ignition: The increased rate of heat transfer to walls causes local overheating of spark plug, which ignites charge before the spark, thus causing Pre- ignition.

**Control of detonation in SI engines**

Methods of controlling detonation:

By controlling following engine variables, detonation can be controlled.

- Increasing engine rpm.
- Retarding spark timing
- Reducing pressure in inlet manifold by throttling. In supercharged engines reducing supercharging pressures reduces detonation.
- Making the ratio too lean or too rich, preferably latter.
- Water injection.

By design features, detonation can be reduced.

- Use of low compression ratio.
- Increasing turbulence
- Relocating spark plugs or use of two or more spark plugs.
- Suitable combustion chamber design to reduce flame length and to reduce temperature of end gas.
- It can be eliminated by using High octane fuels, or by adding additives known as dopes to petrol.

**PRE-IGNITION COMBUSTION**

- The increase in the rate of heat transfer to the walls may cause local overheating specially of the spark plug, which may reach a temperature high enough to *ignite the charge before the passage of spark. This phenomenon is called Pre-ignition.*
- Pre-ignition may also be caused by *overheated exhaust valves or glowing carbon deposits in the combustion chamber.*
- Some part of the cylinder surface may be hot enough (nearly 1100°) to ignite the charge before the spark does so. This is equivalent to advancing the ignition, but since the hot spot surface is larger than the spark, the combustion rate would be faster than that of normal combustion.

  Creating very high cylinder pressures and temperatures and thus resulting in excessive negative compression work and increased heat loss to the walls. The overall effect will be the loss in power.
- Pre-ignition will also cause higher temperatures and pressures in the end-gas than those caused by normal ignition because of its earlier occurrence on the compression stroke. Thus pre-ignition leads to auto-ignition and hence knock. And auto-ignition encourages *pre-ignition.*

  *Knock and pre-ignition* are different phenomena. Knock is due to the rapid combustion of the last part of the mixture following the initiation of flame by the spark, whereas pre-ignition is the ignition of the charge by a hot body before the spark occurs.
- The result of pre-ignition are to increase the work of the compression stroke, decrease the net work of the cycle, increase the engine pressures, increase the heat loss from the engine and decrease the efficiency. Pre-ignition if not checked gets progressively worse, culminating in severe engine damage.

- Pre-ignition can be detected by switching off the ignition when irregular firing might occur for a few strokes before the engine speed drops. The sudden loss of power with no evidence of mechanical malfunctioning may also indicate pre-ignition.

## SURFACE IGNITION

- Under certain conditions, air-fuel mixture is ignited by a hot spot in the cylinder.
- Initiation of a flame front by a hot surface other than the spark is called *surface ignition*. The hot surface may be the spark plug insulator or electrode, the exhaust valve head, the combustion deposits on the combustion chamber surfaces etc.
- Surface ignition occurring before the spark is called ***pre-ignition*** and that occurring after the spark is called ***post-ignition.***
- Run-on, run-away, wild ping and rumble are caused by surface ignition which are harmful.

## EFFECT OF ENGINE OPERATING VARIABLES ON THE ENGINE KNOCKING DETONATION

The various engine variables affecting knocking can be classified as:

- Temperature factors
- Density factors
- Time factors
- Composition factors

### (a) Temperature factors:

- Increasing the temperature of the unburned mixture increase the possibility of knock in SI engine, the effect of following engine parameters on the temperature of the unburned mixture:
- Raising the compression ratio: Increasing the compression ratio increases both the temperature and pressure (density of the unburned mixture). Increase in temperature reduces the delay period of the end gas which in turn increases the tendency to knock.
- Supercharging: It also increases both temperature and density, which increase the knocking tendency of engine
- Coolant temperature: Delay period decreases with increase of coolant temperature, decreased delay period increase the tendency to knock
- Temperature of the cylinder and combustion chamber walls: The temperature of the end gas depends on the design of combustion chamber. Sparking plug and exhaust valve are two hottest parts in the combustion chamber and uneven temperature leads to pre-ignition and hence the knocking.

### (b) Density factors:

- Increasing the density of unburnt mixture will increase the possibility of knock in the engine. The engine parameters which affect the density are as follows:
- Increased compression ratio increase the density
- Increasing the load opens the throttle valve more and thus the density
- Supercharging increase the density of the mixture

- Increasing the inlet pressure increases the overall pressure during the cycle. The high pressure end gas decreases the delay period which increase the tendency of knocking.
- Advanced spark timing: quantity of fuel burnt per cycle before and after TDC position depends on spark timing. The temperature of charge increases by increasing the spark advance and it increases with rate of burning and does not allow sufficient time to the end mixture to dissipate the heat and increase the knocking tendency

**(c) Time factors**

- Increasing the time of exposure of the unburned mixture to auto-ignition conditions increase the possibility of knock in SI engines. Flame travel distance: If the distance of flame travel is more, then possibility of knocking is also more. This problem can be solved by combustion chamber design, spark plug location and engine size. Compact combustion chamber will have better anti-knock characteristics, since the flame travel and combustion time will be shorter. Further, if the combustion chamber is highly turbulent, the combustion rate is high and consequently combustion time is further reduced; this further reduces the tendency to knock.
- Location of sparkplug: A spark plug which is centrally located in the combustion chamber has minimum tendency to knock as the flame travel is minimum. The flame travel can be reduced by using two or more spark plugs.
- Location of exhaust valve: The exhaust valve should be located close to the spark plug so that it is not in the end gas region; otherwise there will be a tendency to knock.
- Engine size: Large engines have a greater knocking tendency because flame requires a longer time to travel across the combustion chamber. In SI engine therefore, generally limited to 100mm
- Turbulence of mixture: decreasing the turbulence of the mixture decreases the flame speed and hence increases the tendency to knock. Turbulence depends on the design of combustion chamber and one engine speed.

**(d) Composition factor**

The properties of fuel and A/F ratio are primary means to control knock:

- Molecular Structure: The knocking tendency is markedly affected by the type of the fuel used. Petroleum fuels usually consist of many hydro-carbons of different molecular structure. The structure of the fuel molecule has enormous effect on knocking tendency. Increasing the carbon-chain increases the knocking tendency and centralizing the carbon atoms decreases the knocking tendency. Unsaturated hydrocarbons have less knocking tendency than saturated hydrocarbons.

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