Lecture No – 2 and 3 Principle of operation of I.C. engine

I.C. engine types, Components of I.C. engine, working principles, Two and Four stroke engine, Engine terminology and examples (MKS system)

Heat engine:-**Heat engine is a machine used for converting heat, developed by burning fuel into useful work (or) it is equipment which generates thermal energy and transforms it into mechanical energy.**

Heat engine is of two types *(based on combustion of fuel)*

(i) External combustion engine, and

(ii) Internal combustion engine.

External combustion engine: It is the engine designed to derive its power from the fuel, burnt outside the engine cylinder. Here combustion process uses heat in the form of steam, which is generated in a boiler, placed entirely separate from the working cylinder.

Internal combustion engine (I. C. Engine): It is the engine designed to derive its power from the fuel, burnt within the engine cylinder. Here combustion of fuel and generation of heat takes place within the cylinder of the engine.

Engine types: The three distinct types of internal combustion which are used either for mobile or stationery works are as follows:

1. Carburetor type: In which liquid fuel is atomized, vaporized and mixed with air in correct proportion before being taken to the engine through intake manifolds. Ignition of mixture reaching the cylinders is caused by an electric spark.

2. Diesel type: In which liquid fuel alone is injected under high pressure of 105kg/cm^2 or above at right moment directly into the combustion chamber which contains highly compressed air. Compressing the air makes it very hot so that when fine fuel spray hits the highly heated air, burning takes place immediately and no spark is required for ignition.

3. Duel fuel type: In which both diesel and gases like methane, biogas etc are used to develop power. About 75% of the diesel replacement can be achieved by application of these gases. Gases produced in biogas plants and gasifiers are most commonly used.

Classification of internal combustion engines in different ways

The internal combustion engines may be classified in the following ways:

1. According to the type of fuel used

a) Petrol engines

b) Diesel engines and

c) Gas engines.

2. According to the method of igniting the fuel

a) Spark ignition (S.I.) engines and

b) Compression ignition (C.I.) engines.

3. According to the number of strokes per cycle

a) Four stroke cycle engines and

b) Two stroke cycle engines.

4. According to the cycle of operation

a) Otto cycle engines and

b) Diesel cycle engines.

5. According to the speed of the engine

a) Slow speed engines- Engine speed below 350 rpm

b) Medium speed engines- Engine speed between 350 rpm to 1000 rpm

c) High speed engines- Engine speed over 1000 rpm

6. According to the cooling system

a) Air-cooled engines - used on motor cycles, scooters and small cars and

b) Water-cooled engines - used on trucks, tractors and heavy vehicles.

7. According to the number of cylinders

a) Single cylinder engines, and

b) Multi-cylinder engines.

8. According to arrangement of cylinders

a) Horizontal engines, and

b) Vertical engines.

9. According to valve arrangement

a) Overhead valve engines, and

b) Side valve engines.

10. According to piston movement

a) Reciprocating-piston moves in linear motion to produce power

b) Rotary engines- uses rotary design to convert pressure into rotational motion.

Tractors are mostly equipped with high speed engines running at about 2000 rpm. Low and medium speed engines are usually employed for stationery jobs. Engine used on plant protection equipment operate at extremely high speed over 3500 rpm.

ENGINE TERMINOLOGY:

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

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

3. 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.

4. 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.

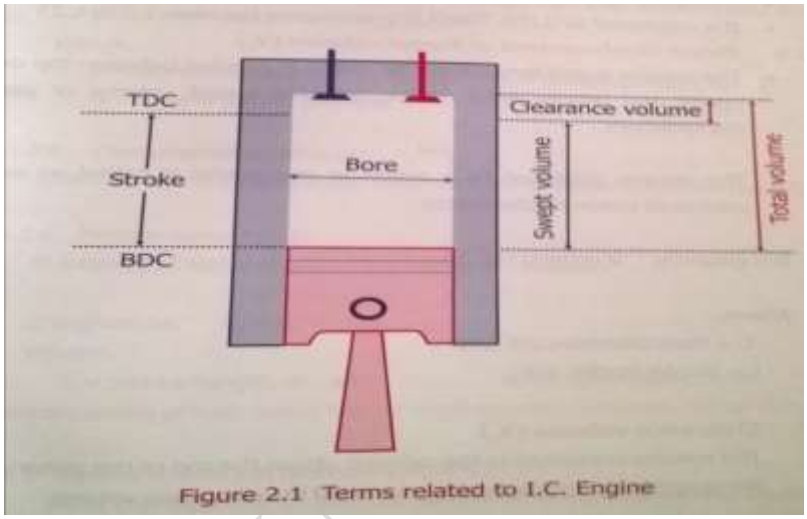


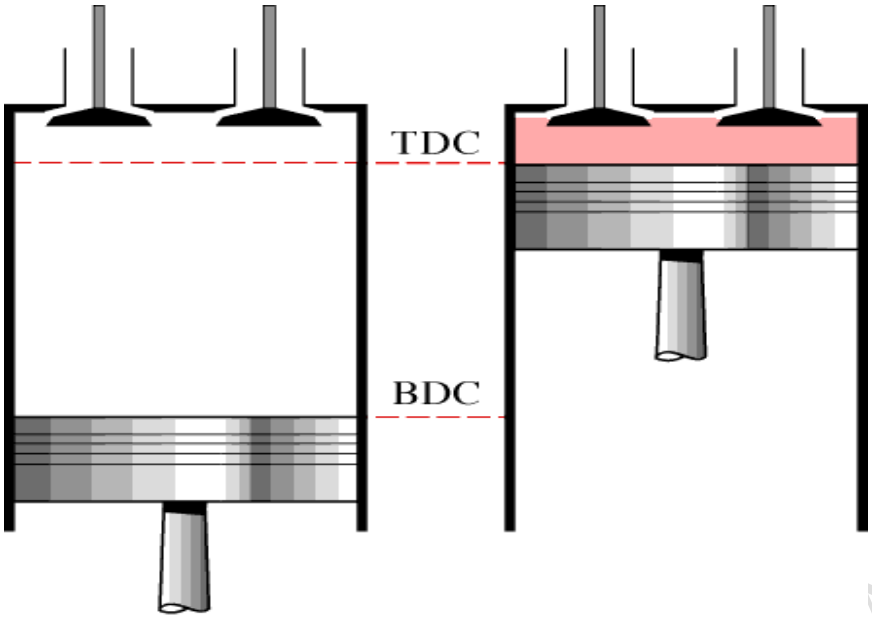
Figure 2.1 Terms related to I.C. Engine

5. Total volume (V_1) : The volume contained in the cylinder above the top of the piston, when the piston is at bottom dead centre, is called the total volume.

Total volume = swept volume + clearance volume.

6. Clearance volume (V_2) : The volume contained in the cylinder above the top of the piston, when the piston is at top dead centre, is called the clearance volume.

7. Compression ratio (r): 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.**



(*a*) Displacement volume (*b*) Clearance volume

8. **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 expressed in kg.m/sec.

9.Horse power(HP) –It is the rate of doing work. Expressed in horse power
Conversion factors from work to power
4500kgm of work /minute=1.0hp
75 kg. m of work /second = 1.0 hp.

10. **Indicated Horse Power (IHP):** It is the total horse power developed by all the cylinders and received by pistons, without friction and losses within the engine.

$$IHP = \frac{PLAN}{4500} \times \frac{n}{2} \cdots (\textit{for 4 stroke engine})$$

$$IHP = \frac{PLAN}{4500} \times n \cdots (\textit{for 2 stroke engine})$$

Where ,

P - Mean effective pressure in Kg/cm^2

L- Length of the piston stroke in meters

A -Cross sectional area of piston in cm^2

N- Engine revolution per minute.

n - Number of cylinders in the engine.

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

$$BHP = \frac{2\Pi NT}{4500} \quad hp$$

where , T = Torque in kg.m
N = speed, RPM

12. Belt power: It is the power of the engine measured at the end of suitable belt, receiving from pto shaft.

13. Power take-off horse power (PTO HP) – It is the power delivered by a tractor through its PTO shaft. In general, the belt and PTO horse power of a tractor will approximately be the same. The PTO hp is around 80-85% 0f tractor engine power.

14. Drawbar horse power (DBHP) – It is the power of a tractor measured at the drawbar of a tractor. It is that power which is available for pulling loads. It is around 50-55 % of engine power.

15. **Frictional horse power (FHP)** – It is the power required to run the engine at a given speed without producing any useful work. It represents the friction and pumping losses of an engine.

IHP = BHP + FHP

F.H.P= I.H.P - B.H.P

16. **Mean effective pressure**: It is the average pressure during the power strokes minus the average pressure during other strokes. This pressure actually forces the piston down during the power stroke.

17. **Brake mean effective pressure (BMEP):** It is the average pressure acting throughout the entire power strokes which are necessary to produce BHP of the engine.

$$BMEP = \frac{BHP \times 75 \times 60}{L \times A \times N \times \frac{n}{2}} \cdots (for\ 4 stroke\ engine)$$

$$BMEP = \frac{BHP \times 75 \times 60}{L \times A \times N \times n} \cdots (for\ 2 stroke\ engine)$$

18. Volumetric efficiency (η_v): It is the ratio of actual weight of air introduced by the engine on the suction stroke to the theoretical weight of air that should have been introduced by the filling the piston displacement volume with air at atmospheric pressure and temperature. **Or**

It is the ratio of actual weight of air taken into cylinder to the swept volume.

19. Torque: A turning effect due to force applied on some point is called torque (T).

T= F x r

F= force, r= distance of the force from the centre of the shaft.

20. Piston displacement: It is volume displaced by one stroke (L) of the piston. It is also known as swept volume.

Piston displacement = A x L

A= cross-sectional area of piston

L=length of stroke

21. Displacement Volume: It is the total swept volume of all pistons during power stroke occurring in one minute.

Displacement volume= A x L x N x (n/2)……. *For 4 stroke engine*

Displacement volume= A x L x N x (n/1)……. For 2 stroke engine

Where,

A -Cross sectional area of piston

L- Length of the piston stroke

N- speed, revolutions per minute.

n - Number of cylinders in the engine.

22. Piston Speed: It is the total l travel of the piston in a cylinder in one minute.

Sp= 2 x L x N

Sp= Piston Speed (meter/minute)

L= Piston stroke (meter)

N= Engine rpm

23. Specific Fuel Consumption: It is the quantity of fuel consumed per kW-hr or IHP-hr or BHP-hr.

24. Mechanical efficiency: (η_{mech}) : It is the ratio of BHP to IHP.

Mech. Efficiency=(BHP/IHP) x 100

25. Thermal efficiency: (η_{them}): It is the ratio of the output in form of useful mechanical power (bhp) to the power value of fuel consumed.

$$\text{Thermal efficiency} = \frac{\text{Brake power X 100}}{\text{Power value of fuel}}$$

26. TDC and BDC- The upper most position of piston is called TDC and Lower most position of piston is called BDC.

27. Frictional power: It is the power required to run the engine at a given speed without producing any useful power.

28. Firing order: The sequence in which power strokes occurs in each cylinder is called firing order.

Firing order- 4 cylinder engine-1-3-4-2, 1-2-4-3

Firing order- 6 cylinder engine-1-5-3-6-2-4, 1-4-2-6-3-5

Engine components:

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

1. 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 such the air or air-fuel mixture. The piston compresses the charge and the gas is allowed to expend in the cylinder, transmitting power for useful work. Cylinders are usually made of high-grade cast iron.

i. Cylinder Block:

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

ii. Cylinder Head:

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

iii. Cylinder Liner or Sleeve:

It is a cylindrical lining either wet or dry, which is inserted in the cylinder block in which the piston slides. Cylinder liners are fitted in the cylinder bore and they are easily replaceable. The overhauling and repairing of the engines, fitted with liners is easy and economical. 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 cooling water.

2. Piston:

It is a cylindrical part closed at one and 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 expending 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, low coefficient of expansion, resistance to high temperature ease of casting and low cost. Aluminum and its alloys are preferred mainly due to it lightness.

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

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

iii. **Piston Ring:** It is a split expansion ring, placed in the groove of the piston, piston rings are fitted in the grooves, made in the piston. They are usually made of cost iron or pressed steel alloy. The functions 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 for 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.

a) Compression Ring: Compression rings are usually plain, single piece and are always placed in the grooves, nearest to the piston head.

b) 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. They prevent excessive oil consumption also. Oil ring is provided with small holes through which excess oil returns back to the crankcase chamber. Ring clearance is the gap at the joint of the ring, measured when the ring is inside the cylinder. The gap is usually 1 mm per 200 mm diameter of the piston. This clearance is necessary for expansion of the ring in heated condition, without which the ring can break or buckle.

3. Piston Pin:

It is also called wrist pin or gudgeon pin. Piston pin is used to join the connecting rod to the piston. It provided a flexible or hinge like connection between the piston and the connecting rod. It is usually made of case hardened alloy steel.

4. 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. Its small end in fitted with bronze bushing and big and is provided with bearings split into two shells.

5 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. Split shell bearings are mostly used as main bearings as well as twisting from the connecting rod end

6 Flywheel:

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

(a) It stores energy during power stroke and returns back the same energy during the idle strokes, providing a uniform rotary motion by virtue of its inertia.

(b) It also carries ring gear that meshes with the pinion of starting motor.
(c) The rear surface of the flywheel serves as one of the pressure surface for the clutch plate.
(d) Engine timing marks are usually stamped on the flywheel, which helps in adjusting the timing of the engine.
(e) Sometime the flywheel serves the purpose of a pulley for transmitting power.

7. 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 of the engine. It also serves as a mounting unit for such accessories as the oil pump, oil filter, generator, 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.

8. Camshaft:

It is a shaft which raise and lowers the inlet and exhaust valves at proper time. 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.

9. 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 on the end of the crankshaft. Camshaft gear is bigger in size than 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 valves as well as fuel injection timing.

10. 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 side of the cylinder head.

11. Exhaust Manifold:

It is that part of the engines through which exhaust gases go out of the engine cylinder. It is capable of withstanding high temperature of burn gases. It is fitted by the side of the cylinder head.

12. Spark Plug:-

This device is <u>used in petrol engine only</u> to ignite the charge of fuel for combustion.

13. Tappet:

It is also called **Valve lifter**. Tappet raises/ lowers the valves. It recives motion from the cams mounted on camshaft. It opens or closes valves at proper time. It is usually made of hardened steel.

14. Rocker arm:

It is an arm used to change upward motion of push rod to downward motion for opening an engine valve. It is a small rod, one end of which touches the end of the valve stem and the other end touches the upper end of tappet rod.

15. Valve spring:

A strong spring with the help of retainer and a key holds the valve tightly against the seat and thus prevents leakage on the compression stroke and power stroke.

16. A valve:

It is small mechanical device used for opening and closing the passage leading to engine cylinder. Inlet valve of I.C. engine allows air or air –fuel mixture to an into combustion chamber. The exhaust valve allows burnt gases to go out of engine cylinder.

17. Tappet clearance:

It is the clearance between rocker arm and valve stem to enable the valve to sit properly.

Materials of construction of engine parts

	Engine parts	Materials used
1.	Cylinder head	Cast iron, Cast Aluminum
2.	Cylinder liner	Cast iron, Cast steel
3.	Engine block	Cast iron, Cast Aluminum
4.	Piston	Cast iron, Aluminum alloy
5.	Piston pin	Forged steel, Aluminum alloy
6.	Piston ring	Forged steel alloy, Cast Aluminum
7.	Connecting rod	Forged steel, Aluminum alloy
8.	Main bearing	White metal
9.	Connecting rod bearing	Bronze
10.	Crank shaft	Cast steel, forged steel
11.	Cam shaft	Forged steel, cast iron
12.	Timing gear	Cast iron
13.	Manifolds	Cast iron
14.	Fly wheel	Cast iron
15.	Gasket	Cork, copper, asbestos
16.	Crankcase	Cast iron, Cast Aluminum

Two and Four stroke engine

Two Stroke Cycle Engine

Two Stroke Cycle Engine:

In such engines, the whole sequence of events i.e. suction, compression, power and exhaust are completed in two strokes of the piston and one complete revolution of the crankshaft. There is no valve in this type of engine. Gas movement takes place through holes called ports in the cylinder. The crankcase of the engine is gas tight in which the crankshaft rotate-s.

First Stroke (Suction + Compression):

When the piston moves up the cylinder it covers two of the ports, the exhaust port and the transfer port, which are normally almost opposite to each other. This traps a charge of fresh mixture in the cylinder and further upward movement of the piston compresses this charge. Further upward movement of the piston also uncovers a third port in the cylinder called suction port. More fresh mixture is drawn through this port into the crankcase. Just before the end of this stroke, the mixture in the cylinder is ignited as in the four-stroke cycle.

Second Stroke (Power + Exhaust):

The rise in pressure in the cylinder caused by the burning gas forces the piston to move down the cylinder. When the piston goes down, it covers and closes the suction port, trapping the mixture drawn into the crankcase during the previous stroke then a compressing it. Further downward movement of the piston uncovers first the exhaust port and then transfers port. This allows the burnt gases to flow out through exhaust port. Also the fresh mixture under pressure in the crankcase is transferred into the cylinder through transfer port during this stroke. Special shaped piston crown deflects the incoming mixture up around the cylinder so that it can help in driving out the exhaust gases.

When the piston is at the top of its stroke, it is said to be at the top dead centre (TDC). When the piston is at the bottom of its stroke, it is said to be at its bottom dead centre (BDC). In two-stroke cycle engine, both the sides of the piston are effective which not the case in four stroke cycle engine is.

Scavenging:

The process of removal of burnt or exhaust gases from the engine cylinder is known as scavenging. Entire burnt gases do not go out in normal stroke, hence some type of blower or compressor is used to remove the exhaust gases in two-stroke cycle engine.

Comparison between two stroke and four stroke engine

	Four Stroke Engine		Two Stroke Engine
1.	One power stroke for every two revolution of the crankshaft	:	One power stroke for each revolution of the crankshaft
2.	There are inlet and exhaust valves in the engine	:	There are inlet and exhaust ports instead of valves
3.	Crankcase is not fully closed and air tight	:	Crankcase is fully closed and air tight.
4.	Top of the piston compresses the charge	:	Both sides of piston compresses the charge
5.	Size of the flywheel is comparatively larger	:	Size of the flywheel is comparatively smaller
6.	Fuel is fully consumed	:	Fuel is not fully consumed
7.	Weight of engine per hp is high	:	Weight of engine per hp is comparatively low
8.	Thermal efficiency is high	:	Comparatively low
9.	Removal of exhaust gases easy	:	Removal of exhaust gases comparatively difficult
10.	Torque produced is even	:	Torque produced is less even
11.	All types of speed are possible	:	Mostly high speed engines are there
12.	It can be operated in one direction only	:	It can be operated in both direction

Comparison of Diesel Engine and Petrol Engine

	Diesel Engine		Spark Ignition (Petrol) Engine
1.	It has got no carburetor, ignition coil and spark plug	:	It has got carburetor, ignition coil and spark plug.
2.	It's compression ratio varies from 14 : 1 to 22 : 1	:	It's compression ratio varies from 5 : 1 to 8 : 1
3.	It uses diesel oil as fuel	:	It uses petrol or power kerosene
4.	Only air is sucked in cylinder in suction stroke	:	Mixture of air and fuel sucked in cylinder in suction stroke.
5.	It has got fuel injection pump	:	It has got no fuel injection pump
6.	Fuel is injected in combustion chamber and ignited due to heat of compression	:	Air fuel mixture is compressed in the combustion chamber where ignited by an electric spark.
7.	Thermal efficiency 32 to 38 %	:	Thermal efficiency 25 to 32 %
8.	Engine weight per hp is high	:	Engine weight per hp is low
9.	Operating cost is low	:	Operating cost is high
10.	Compression pressure inside the cylinder varies from 35 to 45 kg/cm^2 and temp. is about 500^OC	:	Compression pressure varies from 6 to 10 $kg.cm^2$ and temp. is about 260^OC

Problems

1. Calculate the BHP of a 4 stroke, 4 cylinder I.C. engine which has cylinder bore = 12.5 cm, stroke length = 15 cm., Crank shaft Speed - 1000 rpm, frictional HP = 30, mean effective pressure = 7 kg/cm^2

2. A four cylinder four stroke gas engine has cylinder diameter of 25 cm, stroke bore ratio is 1.8, clearance volume 4500 cm^3, engine speed 240 rev/min, mean effective pressure 6.8 kg/cm^2 and mechanical efficiency is 75 per cent, calculate (1) IHP, (2) BHP, (3) Comp. ratio, (4) Swept volume.

3. A four stroke engine has a mean effective pressure of 7 kg/cm^2, area of piston is 730 cm^2, stroke length 45 cm, torque due to break load is 110 kg-meter, fuel consumed per hr. is 4.5 kg and working speed 120 r.p.m. find IHP, BHP, mech. Efficiency and specific fuel consumption.

Four Stroke Cycle Engine

Principle of operation of Internal Combustion Engine

All internal combustion engines used expansive forces of gases by burning fuel within a cylinder. There are two ways in which combustion takes place in the cylinder.

i. By rapid explosion of air fuel mixture when it is ignited by spark called as constant volume combustion e.g. petrol engine.
ii. Explosion takes place by slow combustion of injected fuel in the hot compressed air called as constant pressure combustion e.g. Diesel engine.

Working of Four Stroke Cycle Engine

In four stroke cycle engine all events takes place inside the cylinder are completed in four strokes of piston. Valves are provided for inlet and exhaust gases. The cycle is completed in two revolution of the crankshaft or four strokes of piston.

Four Strokes are as follows

1. Suction or Intake Stroke
2. Compression Stroke
3. Power Stroke
4. Exhaust Stroke

1. Suction Stroke

During suction stroke air or mixture of air and fuel is taken in the cylinder through inlet valve opening, which remains open during suction stroke. A sort of vacuums is created in the cylinder due to movement of piston. Exhaust valve remains closed during this stroke.

2. Compression Stroke

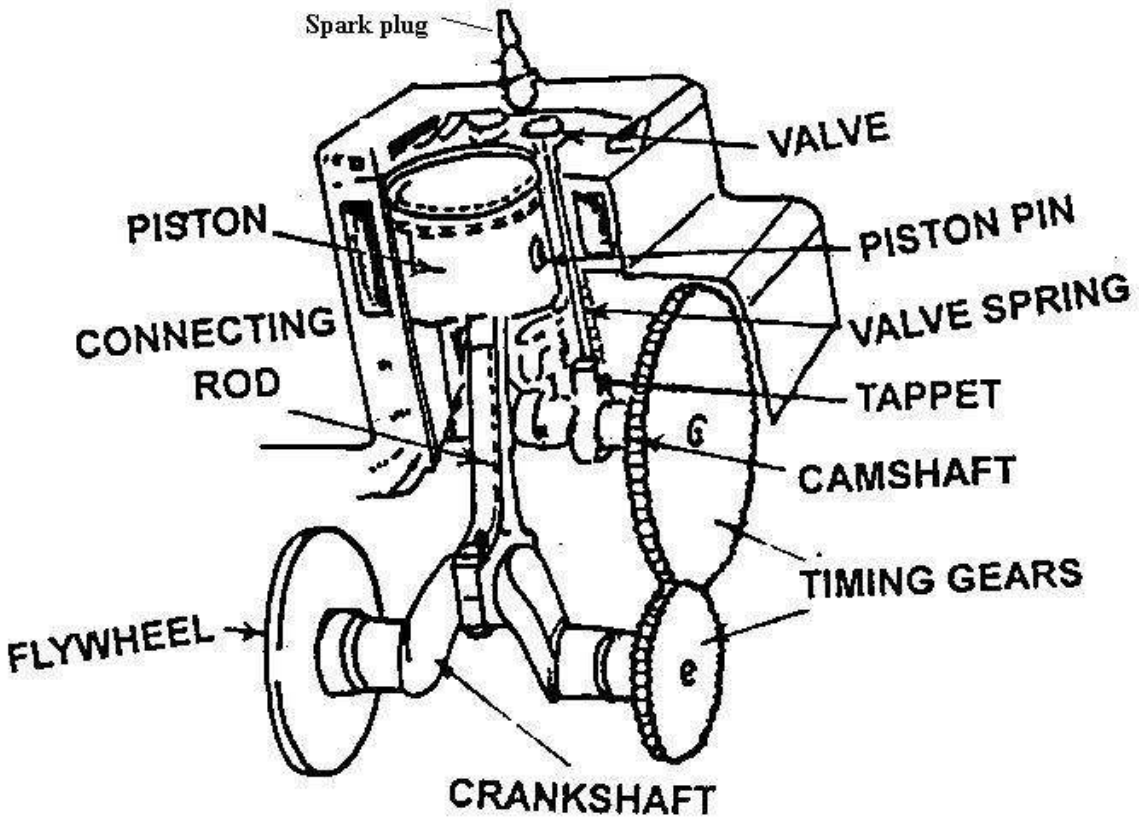
The charge taken in the cylinder is compressed to a small volume during this stroke. Both the valves remains closed during this stroke. At the end of the stroke the charge is ignited. Air fuel mixture is ignited by spark plug. If only air is compressed, fuel is injected and it is ignited due to high temperature and pressure at the end of the stroke.

3. Power Stroke

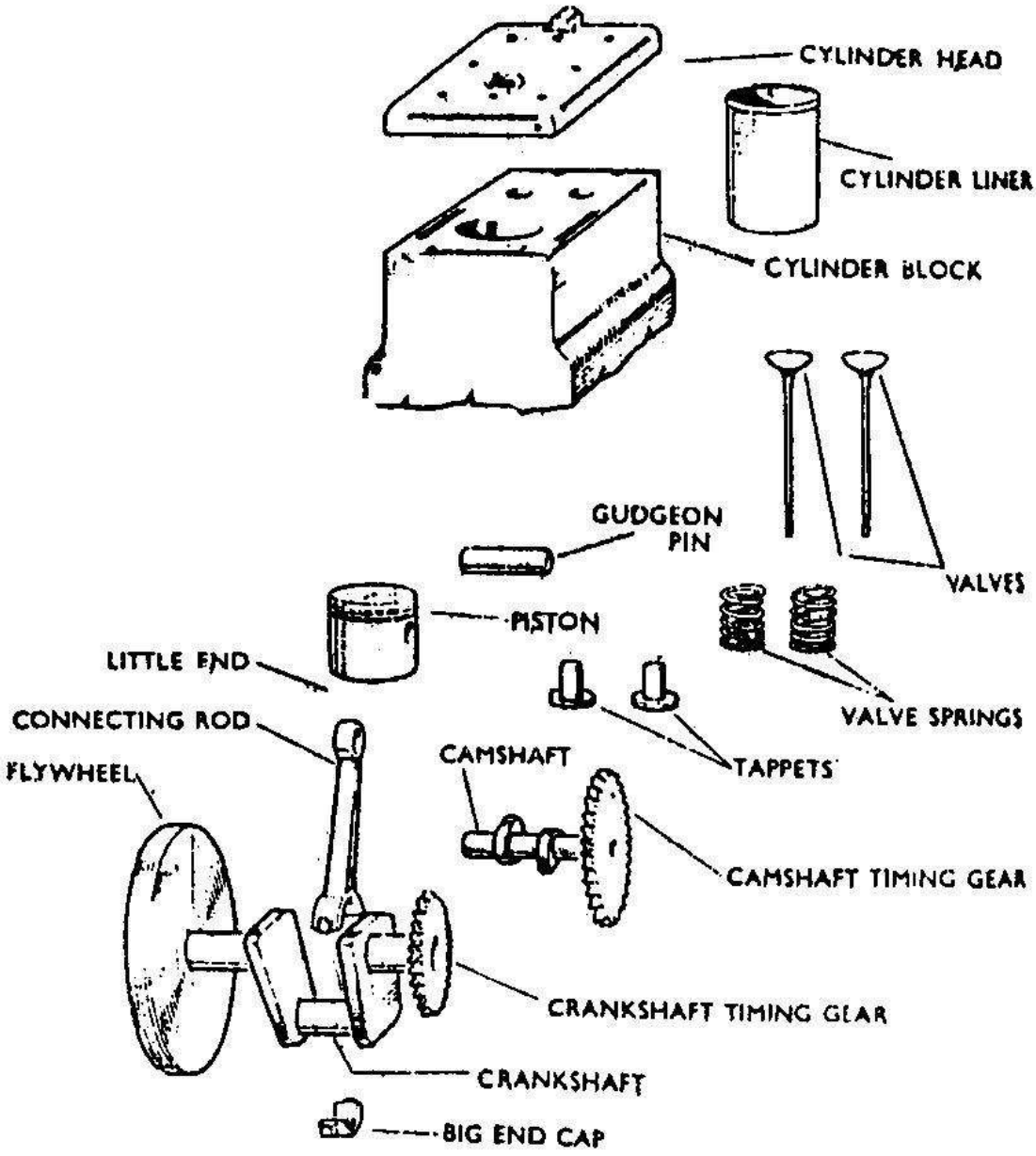
High pressure is developed due to combustion of fuel. It pushed the piston with tremendous amount of force in back ward direction. Power developed in this process is transmitted to crankshaft.

4. Exhaust Stroke

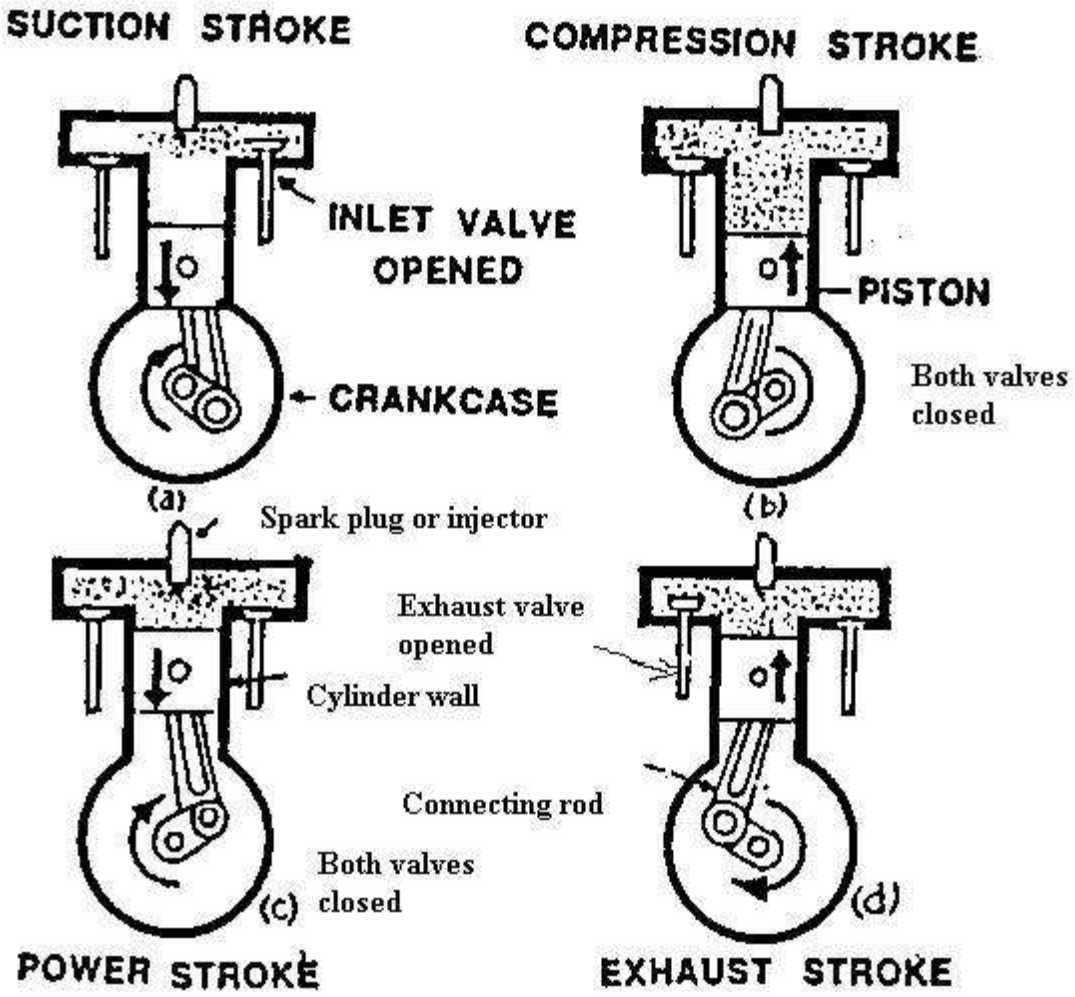
During this stroke exhaust value opens and exhaust gases are removed through valve opening out of the cylinder. Thus it is found that there is one power stroke in a cycle and other three strokes are idle strokes. Thus, the cycle is repeated during working of engine.



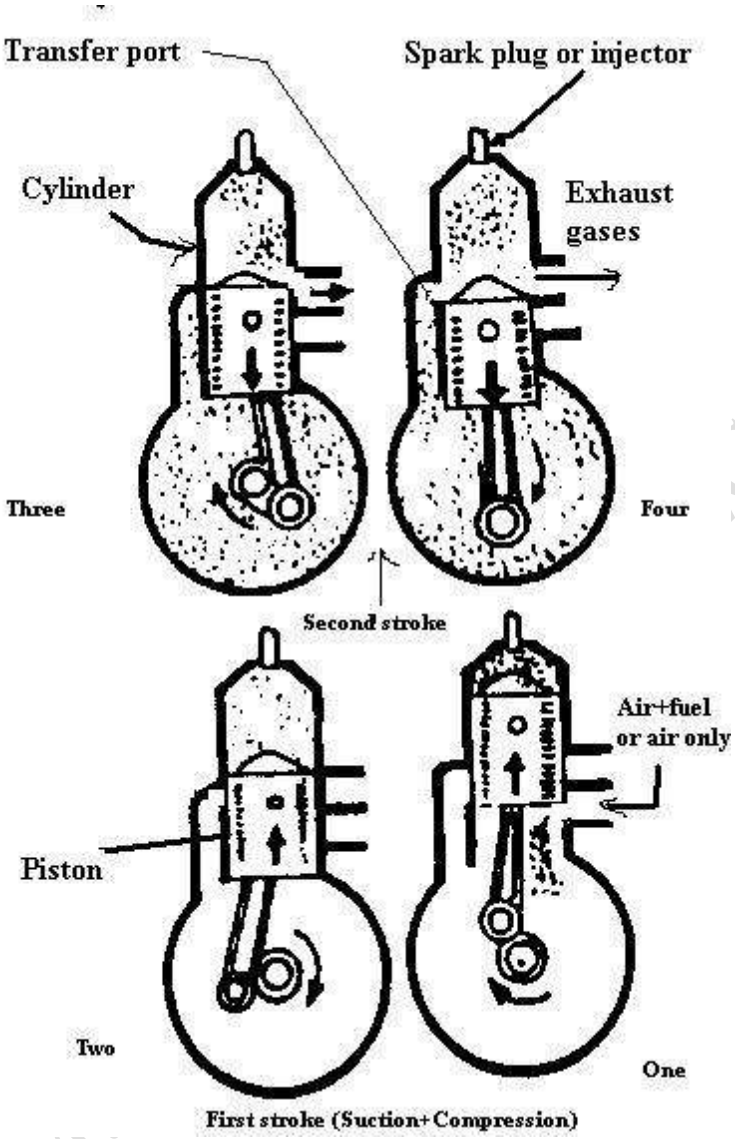
Components of Internal combustion engine



Components of Internal combustion engine



Working of four stroke cycle engine



Working of two stroke cycle engine