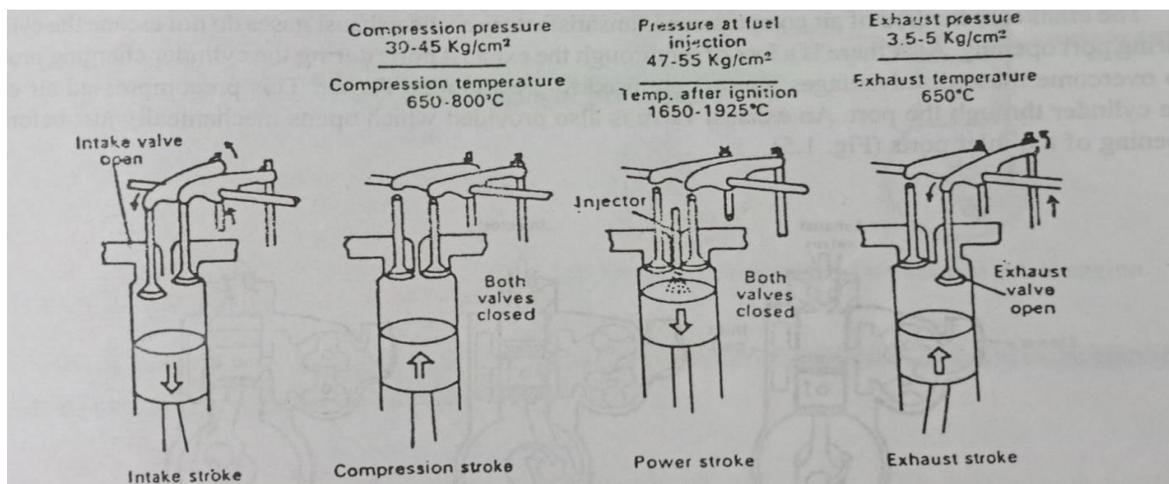


# PRINCIPLES OF OPERATION OF IC ENGINES

## Four-Stroke Cycle Diesel Engine

In four-stroke cycle engines there are four-strokes completing two revolutions of the crankshaft. These are respectively, the suction, compression, power and exhaust strokes. In Figure, the piston is shown descending on its suction stroke. Only pure air is drawn into the cylinder during this stroke through the inlet valve, whereas, the exhaust valve is closed. These valves can be operated by the cam, push rod and rocker arm. The next stroke is the compression stroke in which the piston moves up with both the valves remaining closed. The air which has been drawn into the cylinder during the suction stroke is progressively compressed as the piston ascends. The compression ratio usually varies from 14:1 to 22:1. The pressure at the end of the compression stroke ranges from 30 to 45 kg/cm<sup>2</sup>. As the air is progressively compressed in the cylinder, its temperature increases, until when near the end of the compression stroke, it becomes sufficiently high (650- 800°C) to instantly ignite any fuel that is injected into the cylinder. When the piston is near the top of its compression stroke, a liquid hydrocarbon fuel, such as diesel oil, is sprayed into the combustion chamber under high pressure (140-160 kg/cm<sup>2</sup>), higher than that existing in the cylinder itself. This fuel then ignites, being burnt with the oxygen of the highly compressed air.



During the fuel injection period, the piston reaches the end of its compression stroke and commences to return on its third consecutive stroke, viz., power stroke. During this stroke the hot products of combustion consisting chiefly of carbon dioxide, together with the nitrogen left from the compressed air

expand, thus forcing the piston downward. This is only the working stroke of the cylinder.

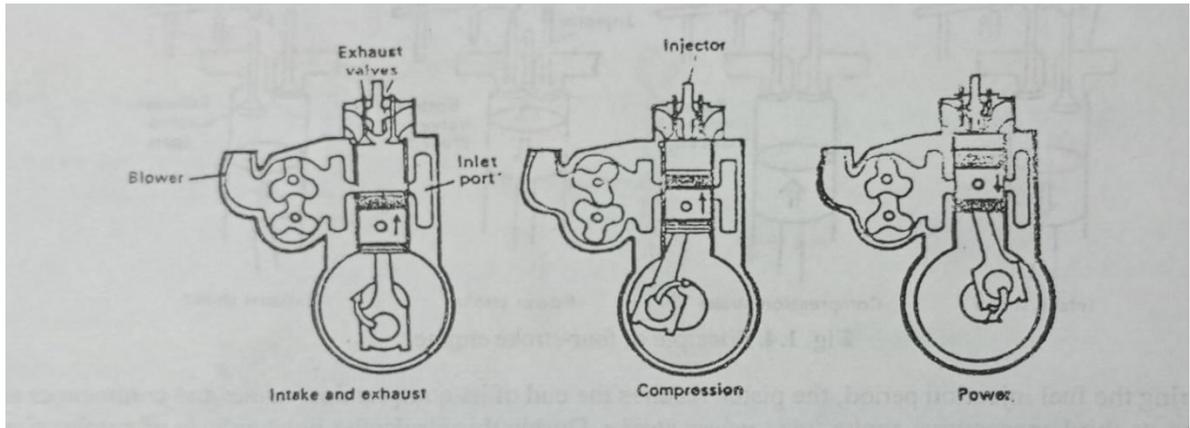
During the power stroke the pressure falls from its maximum combustion value (47-55 kg/cm<sup>2</sup>), which is usually higher than the greater value of the compression pressure (45 kg/cm<sup>2</sup>) to about 3.5-5 kg/cm<sup>2</sup> near the end of the stroke. The exhaust valve then opens, usually a little earlier than when the piston reaches its lowest point of travel. The exhaust gases are swept out on the following upward stroke of the piston. The exhaust valve remains open throughout the whole stroke and closes at the top of the stroke.

The reciprocating motion of the piston is converted into the rotary motion of the crankshaft by means of a connecting rod and crankshaft. The crankshaft rotates in the main bearings which are set in the crankcase. The flywheel is fitted on the crankshaft in order to smoothen out the uneven torque that is generated in the reciprocating engine.

### **Two-Stroke Cycle Diesel Engine:**

The cycle of the four-stroke of the piston, i.e., the suction, compression, power and exhaust strokes of a four-stroke cycle engine is completed only in two strokes in the case of a two-stroke engine. The air is drawn into the crankcase due to the suction created by the upward stroke of the piston. On the down-stroke of the piston it is compressed in the crankcase. The compression pressure is usually very low, being just sufficient to enable the air to flow into the cylinder through the transfer port when the piston reaches near the bottom of its down stroke.

The air thus flows into the cylinder, where it is compressed by the piston as it ascends, till the piston is nearly at the top of its stroke. The compression pressure is increased sufficiently high to raise the temperature of the air above the self-ignition point of the fuel used. The fuel is injected into the cylinder head just before the completion of the compression stroke and only for a short period. The burnt gases expand during the next downward stroke of the piston. These gases escape into the exhaust pipe to the atmosphere through the piston uncovering the exhaust port.

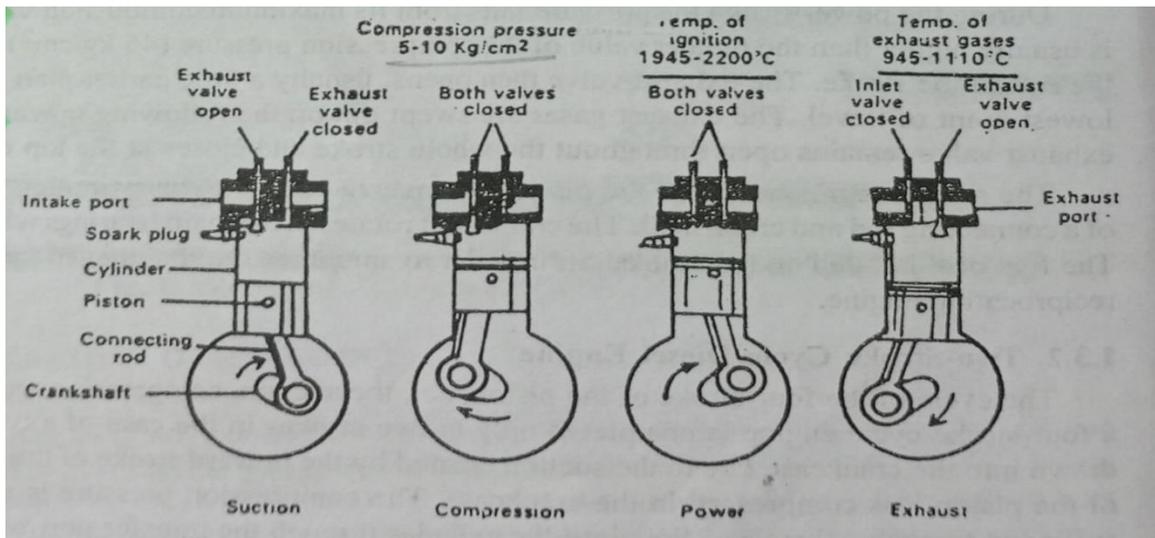


### **Modern Two-Stroke Cycle Diesel Engine:**

The crankcase method of air compression is unsatisfactory as the exhaust gases do not escape the cylinder during port opening. Also there is a loss of air through the exhaust ports during the cylinder charging process. To overcome these disadvantages blowers are used to pre-compress the air. This pre-compressed air enters the cylinder through the port. An exhaust valve is also provided which opens mechanically just before the opening of the inlet ports.

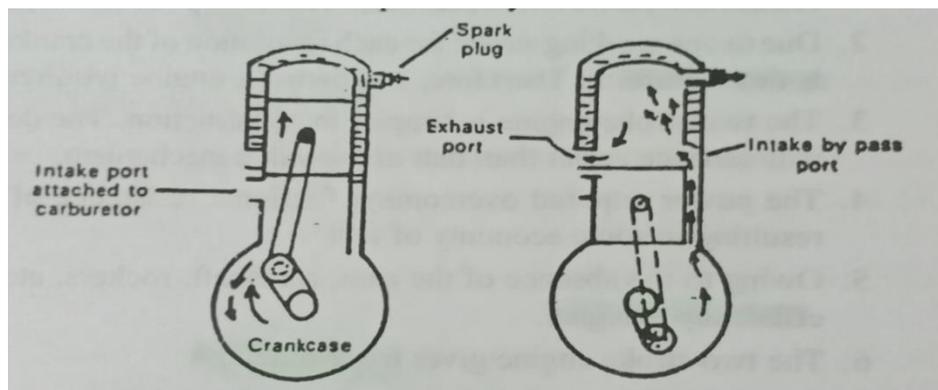
### **Four-Stroke Spark Ignition Engine:**

In this gasoline is mixed with air, broken up into a mist and partially vaporized in a carburetor. The mixture is then, sucked into the cylinder. There it is compressed by the upward movement of the piston and is ignited by an electric spark. When the mixture is burned, the resulting heat causes the gases to expand. The expanding gases exert a pressure on the piston (power stroke). The exhaust gases escape in the next upward movement of the piston. The strokes are similar to those discussed under four-stroke diesel engines. The various temperatures and pressures are shown in Fig. 1.6. The compression ratio varies from 4:1 to 0.8:1 and the air-fuel mixture from 10:1 to 20:1.



### Two-Stroke Spark Ignition Engine:

The two-cycle carburetor type engine makes use of an air tight crankcase for partially compressing the air-fuel mixture. As the piston travels down, the mixture previously drawn into the crankcase is partially compressed. As the piston nears the bottom of the stroke, it uncovers the exhaust and intake ports. The exhaust flows out, reducing the pressure in the cylinder. When the pressure in the combustion chamber is lower than the pressure in the crankcase through the port openings to the combustion chamber, the incoming mixture is deflected upward by a baffle on the piston. As the piston moves up, it compresses the mixture above and draws into the crankcase below a new air-fuel mixture.



The two-stroke cycle engine can be easily identified by the air-fuel mixture valve attached to the crankcase and the exhaust port located at the bottom of the cylinder.

### COMPARISON OF CI AND SI ENGINES:

The CI engine has the following advantages over the SI engine:

1. Reliability of the CI engine is much higher than that of the SI engine. This is because in case of the failure of the battery, ignition or carburetor system, the SI engine cannot operate, whereas the CI engine, with a separate fuel injector for each cylinder, has less risk of failure.

2. The distribution of fuel to each cylinder is uniform as each of them has a separate injector, whereas in the SI engine the distribution of fuel mixture is not uniform, owing to the design of the single carburetor and the intake manifold.

3. Since the servicing period of the fuel injection system of CI engine is longer, its maintenance cost is less than that of the SI engine.

4. The expansion ratio of the CI engine is higher than that of the SI engine, therefore, the heat loss to the cylinder walls is less in the CI engine than that of the SI engine. Consequently, the cooling system of the CI engine can be of smaller dimensions.

5. The torque characteristics of the CI engine are more uniform which results in better top gear performance.

6. The CI engine can be switched over from part load to full load soon after starting from cold, whereas the SI engine requires warming up.

7. The fuel (diesel) for the CI engine is cheaper than the fuel (petrol) for SI engine.

8. The fire risk in the CI engine is minimised due to the absence of the ignition system.

9. Due part load, the specific fuel consumption of the CI engine is low.

## **ADVANTAGES AND DISADVANTAGES OF TWO-STROKE CYCLE OVER FOUR-STROKE CYCLE ENGINES**

### **Advantages:**

1. The two-stroke cycle engine gives one working stroke for each revolution of the crankshaft. Hence, theoretically the power developed for the same engine speed and cylinder volume is twice that of the four-stroke cycle

engine which gives only one working stroke for every two revolutions of the crankshaft. However, in practice, because of poor scavenging, only 50-60% extra power is developed.

2. Due to one working stroke for each revolution of the crankshaft, the turning moment on the crankshaft is more uniform. Therefore, a two-stroke engine requires a lighter flywheel.

3. The two-stroke engine is simpler in construction. The design of its parts is much simpler and their maintenance easier than that of the valve mechanism.

4. The power required overcoming frictional resistance of the suction and exhaust strokes is saved resulting in some economy of fuel.

5. Owing to the absence of the cam, camshaft, rockers, etc. of the valve mechanism, the mechanical efficiency is higher.

6. The two-stroke engine gives less oscillation.

7. For the same power, a two-stroke engine is more compact and requires less space than a four-stroke cycle engine. This makes it more suitable for use in small machines and motorcycles.

8. A two-stroke engine is lighter in weight for the same power and speed especially when the crankcase compression is used.

9. Due to its simpler design, it requires fewer spare parts. 10. A two-stroke cycle engine can be easily reversed if it is of the valve less type.

### **Disadvantages:**

1. The scavenging being not very efficient in a two-stroke engine, the dilution of the charges takes place which results in poor thermal efficiency.

2. The two-stroke spark ignition engine does not have a separate lubrication system and normally, lubricating oil is mixed with the fuel. This is not as effective as the lubrication of a four-stroke engine. Therefore, the parts of the two-stroke engine are subjected to greater wear and tear.

3. In a spark ignition two-stroke engine, some of the fuel passes directly to the exhaust. Hence, the fuel consumption per horse-power is comparatively higher.

4. With heavy loads a two-stroke engine gets heated up due to the excessive heat produced. At the same time the running of the engine is not very smooth at light loads.

5. It consumes more lubricating oil because of the greater amount of heat generated.

6. Since the ports remain open during the upward stroke, the actual compression starts only after both the inlet and exhaust ports have been closed. Hence, the compression ratio of this engine is lower than that of a four-stroke engine of the same dimensions. As the efficiency of an engine is directly proportional to its compression ratio, the efficiency of a two-stroke cycle engine is lower than that of a four-stroke cycle engine of the same size.

### **FIRING ORDER:**

The sequence in which the power stroke cylinder occurs is called firing order. The arrangement of the crankpin on the crankshaft and design of the camshaft both determine the firing order.

### **FIRING INTERVAL:**

The interval between successive power strokes in different cylinders is called firing interval (FI) and is determined in a four-stroke engine as follows:

$$\text{FI} = 1 \text{ cycle or } 2 \text{ revolutions of crankshaft } (720^\circ) / \text{No. of cylinders}$$

For a two-stroke engine, the formula for firing interval is:

$$\text{FI} = 360^\circ / \text{No. of cylinders}$$

### **BALANCE AND FIRING ORDER OF ENGINES**

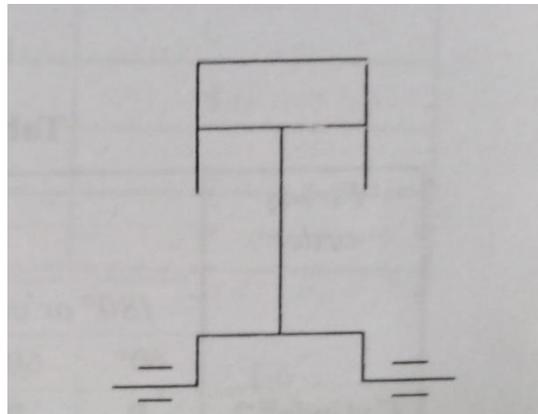
For a single cylinder engine, there is one power stroke in two revolutions of the flywheel. The movement of the flywheel, therefore, cannot be smooth and quiet. To compensate for this unevenness in the revolution of the flywheel, it is normally made heavy and large. For a four-cylinder engine, the power impulses are available twice in every revolution of the flywheel, i.e., every time there is a power stroke in one of the cylinders. As a result, the movement of the flywheel is smooth and free from noise.

From the above description it is apparent that the larger the number of cylinders, smoother rotation and lesser the vibration and problems of balancing.

The flywheel has to store and release less energy. Therefore, it can be lighter than those used in engines with fewer cylinders

### **Single-Cylinder Engines:**

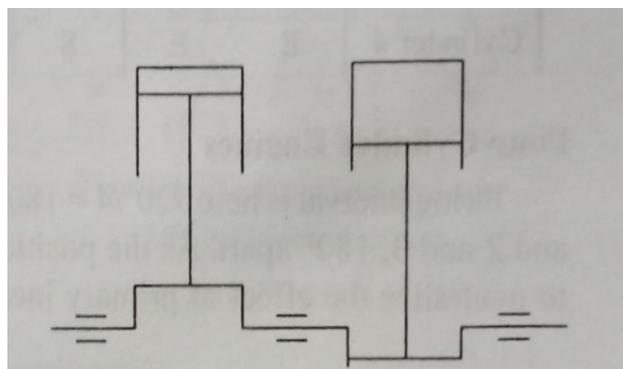
The reciprocating parts such as the piston and connecting rod are one each in single cylinder engines and there is no provision to counter-balance their weight. Therefore, the mechanical balance in single-cylinder engines is poor. However, by providing counter-weights to the crankshaft and heavy flywheel, single-cylinder engines can be balanced to some extent. However, fluctuations in the speed of the engines will cause vibration even in the best designed single-cylinder engines.



**Crank pin arrangement of single cylinder engine**

### **Two-Cylinder Engine:**

The crankshaft pins in this case are 180° apart and thus when one piston is going down the other goes up.



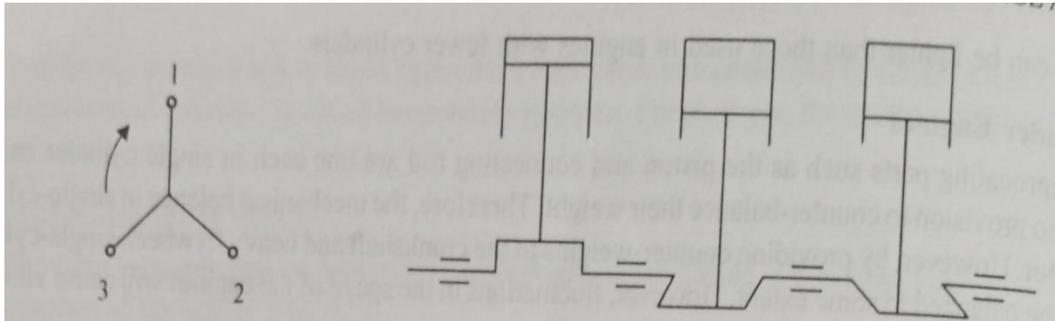
**Crank pin arrangement of two cylinder engine**

### Three-Cylinder Engines:

The firing interval in this case is

$$FI = 720^\circ / 3 = 240$$

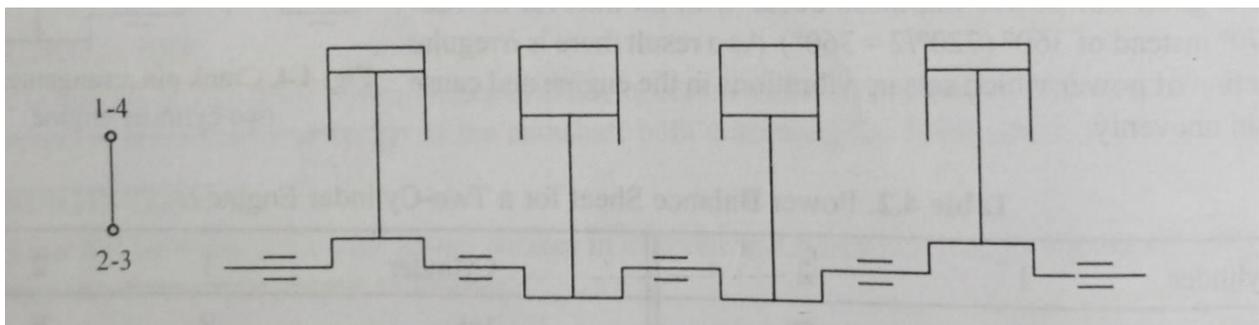
The crankshaft has been designed with crankpins  $120^\circ$  apart.



**Crank pin arrangement of three cylinder engine**

### Four Cylinder Engines:

Firing interval is here  $720^\circ / 4 = 180^\circ$  and the crankshaft is designed with crankpins 1 and 4 in one direction and 2 and 3,  $180^\circ$  apart. As the position of 1 and 4 is always moving opposite to that of 2 and 3, they tend to neutralize the effect of primary inertia forces.

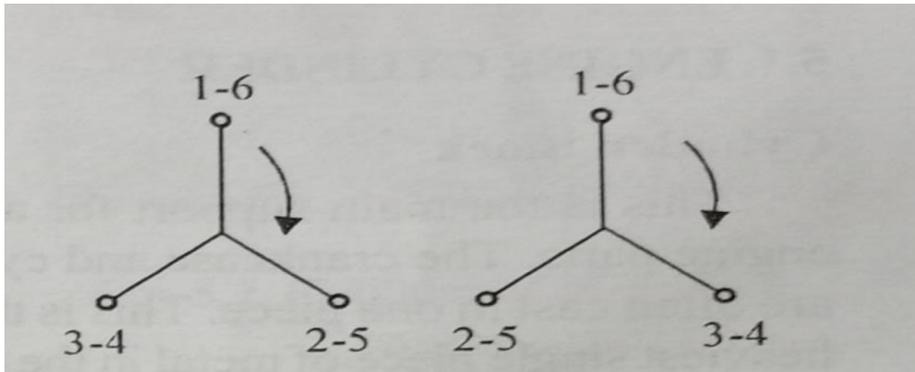


**Crank pin arrangement of four cylinder engine**

With the arrangement of cams, two types of firing order can be achieved. But the one most commonly used is 1-3-4-2. Hence, the crank revolution is smoother.

### Six-Cylinder Engines:

The crankshaft is arranged such that the crankpins 1 and 6, 2 and 5, and 3 and 4 are in the same radial plane,  $120^\circ$  apart. The firing interval is  $720^\circ/6=120^\circ$ . i.e., in two revolutions of the crankshaft six power strokes will be available with a firing interval of  $120^\circ$ . In other words, after every  $120^\circ$  there will be a power overlap for  $60^\circ$ . The crankshaft can be arranged in either of the two ways and the firing order will be 1-4-2-6-3-5 and 1-5-3-6-2-4 respectively.



**Crank pin arrangement of six cylinder engine**

The most common firing order in a six-cylinder engine is 1-5-3-6-2-4.