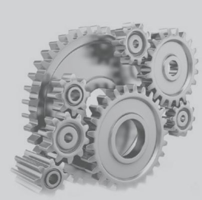
MECHANICAL ENGINEERING

Internal Combustion Engine



Comprehensive Theory
with Solved Examples *and* Practice Questions

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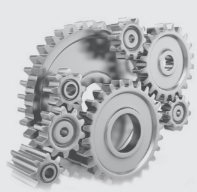

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CHAPTER

1

Basics and Air Standard Cycles

1.1 INTRODUCTION

Engine is a machine used for converting one form of energy into another form. Engine generally converts thermal energy into mechanical work and therefore they are called heat engines. When fuel burns in presence of air, a tremendous amount of heat energy is released. This energy is converted into useful work by means of heat engine. Heat engines are broadly classified into:

(a) **External Combustion Engine:** In external combustion engines, the combustion of fuel takes place outside the engine. For example in steam engine, heat generated due to combustion of fuel is used to generate high pressure steam which is used as working fluid in steam engine. A steam turbine is a good example of external combustion engine.

(b) **Internal Combustion Engine :** In internal combustion engine, combustion take place inside the engine. In this engine chemical energy of fuel is first converted to thermal energy by means of combustion of fuel with air inside the engine. This thermal energy raises the temperature and pressure of the gases inside the engine, and the high pressure gas then expands against the mechanical mechanism of the engine. This expansion of gas is converted by the mechanical linkage of the engine to a rotating crankshaft, which is the output of the engine.

1.2 CLASSIFICATION OF IC ENGINES

The internal combustion engines are usually of reciprocating type. The reciprocating internal combustion engines are classified on the basis of the thermodynamic cycle, mechanical method of operation, type of fuel used, type of ignition, type of cooling system and cylinder arrangement, etc. The detailed classification is given below :

1. **According to number of strokes in the working cycle :**
   (a) **Four Stroke Engine :** In this engine, the thermodynamic cycle is completed in four strokes of piston.
   (b) **Two Stroke Engine :** In this engine, thermodynamic cycle is completed in two strokes of piston.
2. **According to fuel used :**
   (a) **Petrol Engine :** It uses petrol and needs a spark plug to ignite petrol.
   (b) **Diesel Engine :** It uses diesel and self ignition occurs in the combustion chamber due to high temperature of air.

(c) **Gas Engine :** These engine use fuel like CNG, LPG, biogas. Gaseous fuels are better compared to liquid fuels because of reduced ignition delay.

(d) **Multi fuel Engine :** In these engines a gaseous fuel is supplied along with air during initial part of compression and other fuel is injected into combustion space at end of compression stroke.

3. **According to method of ignition :**

(a) **Spark Ignition Engines :** These engines requires an external source of energy for initiation of spark and thereby the combustion process starts.

(b) **Compression Ignition Engines :** In these engines there is no need for an external means to produce ignition. They have high compression ratio which results in high temperature at end of compression process which is sufficient to self ignite the fuel.

4. **According to charge feeding system :**

(a) **Naturally Aspirated Engines :** In these engines admission of air or air-fuel mixture is at atmospheric pressure.

(b) **Supercharged Engines :** In these engines admission of air or air-fuel mixture is at pressure that is above atmospheric pressure.

5. **According to cooling system :**

(a) **Air Cooled Engine :** These engines uses fins to dissipate heat to surrounding to keep the engine within operating temperature.

(b) **Water Cooled Engines :** In these engines water is circulated continuously by means of a external pump which absorbs the engine heat and rejects it to surrounding by using radiator.

6. **According to cylinder arrangements :** To classify engines according to cylinder arrangement two terms must be defined.

(i) **Cylinder Row :** In this arrangement centreline of crankshaft journal is perpendicular to plane containing centreline of engine cylinder.

(ii) **Cylinder Bank :** In this arrangement the centreline of crankshaft journal is parallel to plane containing centreline of engine cylinder.

(a) **In-Line Engine :** In these engines all cylinders are arranged linearly and transmit power to single crankshaft.

(b) **V-Engine :** In these engines there are two banks of cylinders inclined at an angle to each other with one crankshaft.

(c) **Opposed Cylinder Engine :** These engines has two cylinder banks located in same plane on opposite side of crankshaft.

(d) **Radial Engine :** These engines has more than two cylinders in each row and are equally spaced around crankshaft.

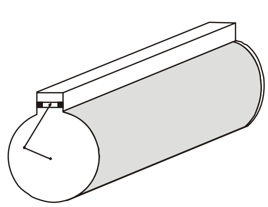


Figure: Inline cylinder Engine

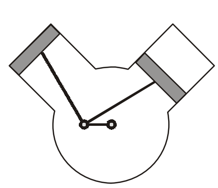


Figure: V engine

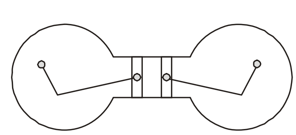


Figure: Opposed cylinder engine

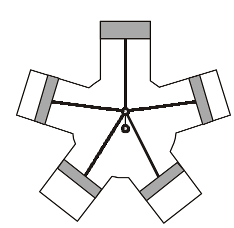


Figure: Radial engine

1.3 COMPONENTS OF ENGINES

An internal combustion engine consists of a large number of parts and each part has its own function. A few of them are shown in figure and listed below.

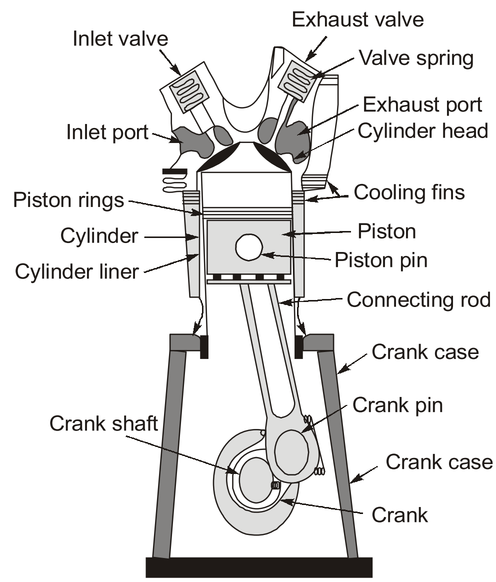


Figure : Components of an internal combustion engine

1. **Cylinder :** It is the heart of the engine. The piston reciprocates in the cylinder. It has to withstand high pressure and temperature, and thus it is made strong. Generally, it is made from cast iron. It is provided with a cylinder liner on the inner side and a cooling arrangement on its outer side. For two-stroke engines, it houses exhaust and transfer port.
2. **Cylinder Head :** The top cover of the cylinder, towards TDC, is called cylinder head. It houses the spark plug in petrol engines and fuel injector in Diesel engines. For four stroke cycle engines, the cylinder head is the housing of inlet and exhaust valves.
3. **Piston :** It is the reciprocating member of the engine. It reciprocates in the cylinder. Its top surface is called piston crown and bottom surface is called piston skirt. Its top surface is made flat for four-stroke engines and deflected for two-stroke engines.
4. **Piston Rings :** Two or three piston rings are provided on the piston. The piston rings seal the space between the cylinder liner and piston in order to prevent leakage (blow by losses) of high-pressure gases, from cylinder to crank case.
5. **Crank :** It is a rotating member. It makes circular motion in the crank case (its housing). Its one end is connected with a shaft called crank-shaft and the other end is connected with a connecting rod.
6. **Crank Case :** It is the housing of the crank and body of the engine to which cylinder and other engine parts are fastened. It also acts as a ground for lubricating oil.
7. **Connecting Rod :** It is a link between the piston and crank. Its one end is connected with a crank while other end with a piston. It transmits power developed on the piston to a crank shaft through crank. It is usually made of medium carbon steel.
8. **Crank Shaft :** It is the shaft, a rotating member, which connects the crank. The power developed by the engine is transmitted outside through this shaft. It is made of medium carbon or alloy steels.
9. **Cooling Fins or Cooling Water Jackets :** During combustion, the engine releases a large amount of heat. Thus the engine parts may be subjected to a temperature at which engine parts may not sustain their properties such as hardness, etc. In order to keep the engine parts within safe temperature limits, the cylinder and the cylinder head are provided with a cooling arrangement. The cooling fins are provided on light duty engines, while a cooling water jacket is provided on medium and heavy duty engines.
10. **Cam Shaft :** It is provided on four-stroke engines. It carries two cams, for controlling the opening and closing of inlet and exhaust valves.
11. **Inlet Valve :** This valve controls the admission of charge into the engine during a suction stroke.
12. **Exhaust Valve :** The removal of exhausted gases after doing work on the piston is controlled by exhaust valve.

13. **Inlet Manifold :** It is the passage which connects intake system to inlet valve.
14. **Exhaust Manifold :** It is the passage which carries the exhaust gases from the exhaust valve to the atmosphere.
15. (a) **Spark Plug :** It is provided on petrol engines. It produces a high-intensity spark which initiates the combustion process of the charge.

    (b) **Fuel Injector :** It is provided on diesel engines. The diesel fuel is injected in the cylinder at the end of the compression through a fuel injector under very high pressure.
16. (a) **Carburettor :** It is provided with a petrol engine for preparation of a homogeneous mixture of air and fuel (petrol). This mixture, as a charge, is supplied to engine cylinder through suction valve or port.

    (b) **Fuel Pump :** It is provided with a diesel engine. The diesel is taken from the fuel tank, its pressure is raised in the fuel pump and then it is delivered to fuel injector.
17. **Flywheel :** It is mounted on the crank shaft and is made of cast iron. It stores energy in the form of inertia, when energy is in excess and it gives back energy when it is in deficit. In other words, it minimizes the speed fluctuations on the engine.

EXAMPLE : 1.1

The gudgeon pin of an IC engine is made hollow

(a) To save material in order to decrease cost.

(b) To have more section modulus for same volume.

(c) To have more polar modulus for same volume.

(d) To reduce weight for having low inertia effect.

Solution: (d)

Less the inertia effects, more the net force on piston.

1.4 BASIC TERMINOLOGY

The basic terminology used for volumes and measurements in the cylinder region is presented and shown in figure.

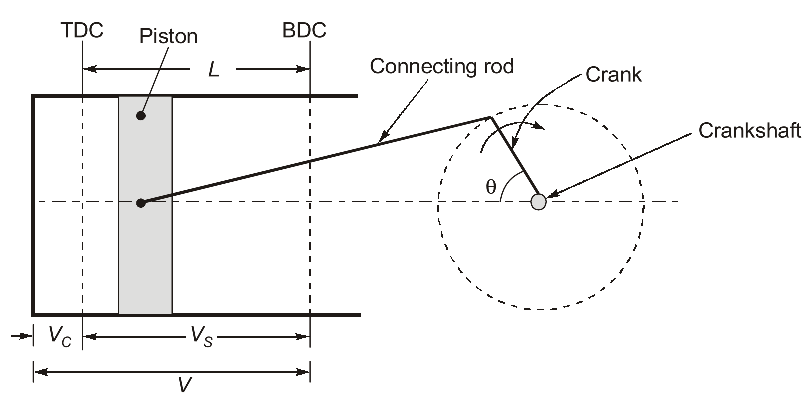


Figure : Basic Terminology

1. **Bore (d) :** It is the inside diameter of the engine cylinder. It is called the bore as it is made through a boring process.

2. **Stroke (L) :** During the travel of the piston, there is an upper as well as a lower limiting position at which the direction of motion of the piston is reversed. The linear distance through which the piston travels between the extreme upper and lower positions of the piston is called the stroke. It is equal to two times the crank radius, $L = 2r$, where r is the crank radius.
3. **Top Dead Centre (TDC) :** When the piston is at the topmost position of the cylinder during its travel, that position is called the Top Dead Centre. At this position the piston velocity is zero and the piston reverses its direction of motion to travel downwards. It is the dead centre when the piston is farthest from the crankshaft.
4. **Bottom Dead Centre (BDC) :** When the piston is at the bottom-most position of the cylinder during its travel, that position is called the Bottom Dead Centre. At this position the piston velocity is zero and the piston reverses its direction of motion to travel upwards. It is the dead centre when the piston is nearest to the crankshaft.
5. **Clearance Volume (V_c) :** When the piston is at the TDC position, the volume contained in the cylinder above the top of the piston is called the clearance volume. The piston cannot occupy any part of this volume and always keeps this volume clear.
6. **Piston Displacement or Swept Volume (V_s) :** It is the volume swept through by the piston in moving between the TDC and the BDC, i.e.,

$$V_s = \frac{\pi}{4} d^2 L \quad \text{. . . (i)}$$

7. **Cylinder Volume (V) :** The cylinder volume includes both the clearance volume and the swept volume, i.e.,

$$V = V_c + V_s \quad \text{. . . (ii)}$$

8. **Compression Ratio (r) :** It is the ratio of the volume when the piston is at BDC to the volume when the piston is at TDC. Hence, it is the ratio of total cylinder volume to clearance volume.

$$r = \frac{V}{V_c} = \frac{V_c + V_s}{V_c} = 1 + \frac{V_s}{V_c} \quad \text{. . . (iii)}$$

9. **Mean Piston Speed :** As the piston moves inside the engine cylinder its speed changes continuously. It is zero at TDC and BDC and maximum nearly at the mid-position of TDC and BDC. The crank angle θ is zero at TDC, it is almost 90° when the piston speed is maximum and 180° at BDC. In the limit of infinitely long connecting rod, the motion is simple harmonic and maximum speed will be at 90° crank angle. Thus in a half rotation of the crank, the piston moves a distance equal to the length of the stroke, L. In full rotation, the distance travelled by piston will be $2L$. If N is the engine speed in revolutions per minute (rpm) and L is in metres, the mean piston speed will be $2LN/60$ m/s.

$$\text{Mean or Average piston speed, } \bar{u}_p = \frac{2LN}{60} \quad \text{. . . (iv)}$$

1.5 PETROL ENGINE

The ordinary Otto-cycle engine is a four stroke engine; that is, its piston makes four strokes, two toward the cylinder head and two away from the cylinder head (TDC). By suitable design, it is possible to operate an Otto-cycle as a two-stroke cycle engine with one power stroke in every revolution of the engine. Thus, the power of a two-stroke cycle engine is theoretically double that of a four-stroke cycle engine of comparable size. These engines are also called spark ignition engines.

OBJECTIVE BRAIN TEASERS

Q.1 With increasing temperature of intake air, IC engine efficiency
(a) decreases
(b) increases
(c) remains same
(d) depends on other factors

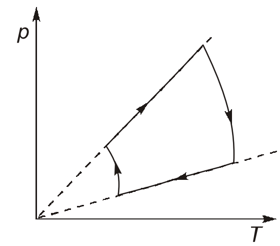
Q.2 The silencer of an internal combustion engine
(a) reduces noise
(b) decreases brake specific fuel consumption (*bsfc*)
(c) increases *bsfc*
(d) has no effect on its efficiency

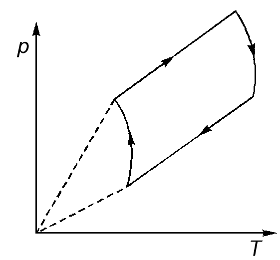
Q.3 A Diesel engine is usually more efficient than a spark ignition engine because
(a) diesel being a heavier hydrocarbon, releases more heat per kg than gasoline
(b) the air standard efficiency of diesel cycle is higher than the Otto cycle, at a fixed compression ratio
(c) the compression ratio of a diesel engine is higher than that of an SI engine
(d) self-ignition temperature of diesel is higher than that of gasoline

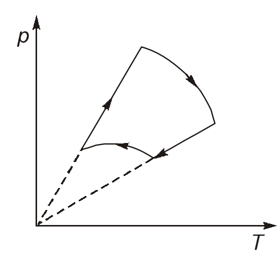
Q.4 Piston compression rings are made of
(a) Cast iron (b) Bronze
(c) Aluminum (d) White metal

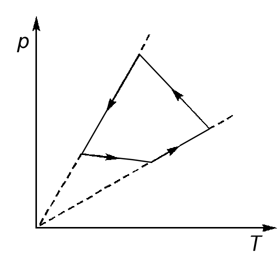
Q.5 **Statement (I):** For a given compression ratio, the thermal efficiency of the Diesel cycle will be higher than that of the Otto cycle.
Statement (II): In the Diesel cycle, work is also delivered during heat addition.
(a) Both Statement (I) and Statement (II) are true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are true but Statement (II) is not a correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

Q.6 Which one of the following p-T diagrams illustrates the Otto cycle of an ideal gas?

(a)


(b)


(c)


(d)


ANSWER KEY

1. (a) 2. (a) 3. (c) 4. (a) 5. (d)
6. (a)

CONVENTIONAL BRAIN TEASERS

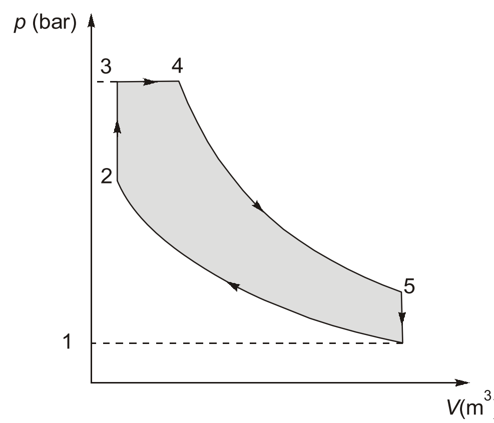
Q.1 In an engine working on Dual cycle, the temperature and pressure at the beginning of the cycle are 90°C and 1 bar respectively. The compression ratio is 9. The maximum pressure is limited to 68 bar and total heat supplied per kg of air is 1750 kJ.

Determine:

(i) Pressure and temperature at all salient points

(ii) Air standard efficiency

(iii) Mean effective pressure.



Solution:

Initial pressure, $p_1 = 1$ bar

Initial temperature, $T_1 = 90° = 363$ K

Compression ratio, $r = 9$

Maximum pressure, $p_3 = p_4 = 68$ bar

Total heat supplied = 1750 kJ kg

(i) Pressures and temperatures at salient points:

For the isentropic process 1-2,

$$p_1 V_1^\gamma = p_2 V_2^\gamma$$

$$p_2 = p_1 \times \left(\frac{V_1}{V_2}\right)^\gamma = 1 \times (r)^\gamma = 1 \times (9)^{1.4}$$

$$= \mathbf{21.67\ bar}$$

Also, $$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = (r)^{\gamma-1} = (9)^{1.4-1} = 2.408$$

$\therefore$ $$T_2 = T_1 \times 2.408 = 363 \times 2.408 = \mathbf{874.1\ K}$$

$$p_3 = p_4 = 68 \text{ bar}$$

For the constant volume process 2–3,

$$\frac{p_2}{T_2} = \frac{p_3}{T_3}$$

$\therefore$ $$T_3 = T_2 \times \frac{p_3}{p_2} = 874.1 \times \frac{68}{21.67} = \mathbf{2742.9\ K}$$

Heat added at constant volume $= c_v(T_3 - T_2) = 0.71(2742.9 - 874.1)$

$= 1326.8$ kJ/kg

$\therefore$ Heat added at constant pressure = Total heat added – Heat added at constant volume

$= 1750 - 1326.8 = 423.2$ kJ/kg

$\therefore$ $c_p(T_4 - T_3) = 423.2$

or $1.0(T_4 - 2742.9) = 423.2$

$\therefore$ $T_4 = \mathbf{3166\ K}$

For constant pressure process 3–4, $$\rho = \frac{V_4}{V_3} = \frac{T_4}{T_3} = \frac{3166}{2742.9} = 1.15$$