June : 2016 (CBCS)

Note : **Max. marks : 60**

(i) Attempt any five questions.

(ii) All questions carry equal marks.

Q.1 **(a)** Write brief description of lathe machine and its components.

Ans. **Introduction to lathe :** The lathe is a machine tool on which metal machining is done by combining the rotation of the job with a perpendicular feed of the tool. It is the oldest and the most common type of machine tools.

Though primarily designed to produce cylindrical surfaces with a single point cutting tool, a lathe can be used for most other operations done on general purpose machine tools directly or with attachments. Now a days, large number of modern machine tools are found, still the lathe machines are used in all modern tool rooms, repair shops and training workshops.

Construction : The figure shows the general layout of lathe, its major parts are :

1. **Headstock :** It houses the power source, all the power transmission, gear box and the spindle. It is fixed at the left hand side of the bed.
2. **Tailstock :** It is situated towards the right hand side of the bed and houses the tailstock spindle for the purpose of locating the long components by the use of centres.
3. **Carriage :** It provides the necessary longitudinal motion to the cutting tool, to generate the surfaces.
4. **Bed :** It provides a supports for all the elements present in a machine tool. Beds are generally constructed using cast iron or alloy cast iron which consists of alloying elements such as nickel, chromium and molybdenum.
5. **Columns :** The columns are those in which the bed is fixed.
6. **Work-holding devices :** They are normally used for suitable location, effective clamping and support when required. e.g. chuck, mandrel etc.
7. **Lead screw :** The lead screw is used for thread cutting. It could be used for feeding the cutting tool in a direction parallel to the axis of rotation, many a times a separate feed rod is provided for this function.
8. **Backgear :** A backgear is the gear which is mounted at the back of the headstock that allows the chuck to rotate slowly with greatly increased power.

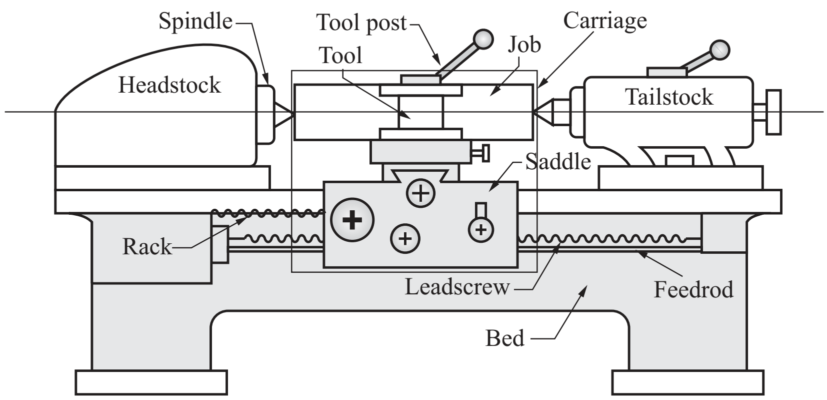

Fig. Lathe machine tool

Working principle :

- Lathe is a machine tool which holds the workpiece securely between the two rigid and strong supports called as centers or in a chuck or face plate, while the workpiece revolves.

- The cutting tool is rigidly held and supported in a tool post and is fed against the revolving workpiece. While the workpiece revolves about its own axis, the tool is made to move in parallel or at an inclination with the axis of a material to be cut.
- Hence the main function of a lathe is to remove metal from a workpiece and to give it a desired shape and size.
- The material from the workpiece is removed in the form of chips. Also, to cut the material properly, the tool material should be harder than the workpiece material.

Q.1 (b) What are the different types of welding methods employed in engineering?

Ans. **Based on the method of heat generation and application, welding process can be divided into seven main categories :**

1. Gas welding :
(a) Oxy-acetylene gas welding
(b) Air-acetylene gas welding
(c) Oxy-hydrogen gas welding.

2. Arc welding :
(a) Shielded metal arc welding (SMAW)
(b) Inert gas shielded metal arc welding (TIG/MIG)
(c) Atomic hydrogen welding
(d) Submerged arc welding
(e) Plasma arc welding
(f) Electro slag welding.

3. Resistance welding :
(a) Spot welding
(b) Seam welding
(c) Projection welding
(d) Percussion welding
(e) Flash butt welding.

4. Solid-state welding :
(a) Friction welding
(b) Explosive welding
(c) Roll welding
(d) Ultrasonic welding
(e) Forge welding
(f) Diffusion welding
(g) Hot pressure welding.

5. Radiant energy welding :
(a) Electron beam welding
(b) Laser beam welding.

6. Exothermic welding :
(a) Thermite welding
(b) Cad welding.

7. Related welding process :
(a) Soldering
(b) Brazing.

Q.2 (a) With the help of *p-V* diagram explain Diesel cycle.

Ans. **Diesel cycle :** This is the ideal cycle for the Diesel engine, which is also called the *compression ignition engine*. Diesel cycle is modified form of Otto cycle. Here heat addition process is replaced from constant volume type to constant pressure type.

This cycle comprises of the following operations :

Process (1-2) : Reversible adiabatic compression, (–ve work, W_c)
Process (2-3) : Reversible heat addition at constant pressure (+ve heat, Q_{add})
Process (3-4) : Reversible adiabatic expansion, (+ve work, W_e)
Process (4-1) : Reversible heat rejection at constant volume (–ve heat, Q_{rej})

Note

Negative sign indicates work done on the system.
Positive sign indicates work done by the system.

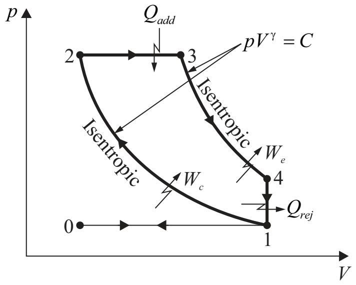

Fig.(a) Diesel cycle on *p-V* diagram

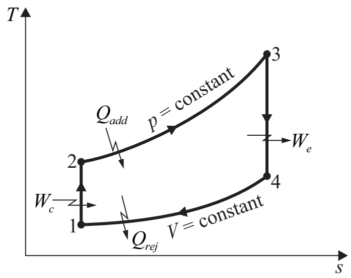

Fig.(b) Diesel cycle on *T-s* diagram

Working :

- **Process (0-1) suction :** It is a constant pressure suction process in which only air is introduced into the cylinder.
- **Process (1-2) compression :** It is a reversible adiabatic compression process where air is compressed up to the clearance volume V_2 .

  Work done in compression is given by,

  $$W_c = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$$

- **Process (2-3) :** It is a constant pressure heat addition process where the Diesel fuel is injected through fuel injector and the mixture of Diesel and air is self-ignited.

  Heat addition is given by,

  $$Q_{add} = Q_{2\text{-}3} = mC_p(T_3 - T_2)$$

  where, C_p is specific heat at constant pressure.

- **Process (3-4) :** It is a reversible adiabatic expansion process in which the useful work output is obtained.

  Work done in expansion is given by,

  $$W_e = \frac{p_3V_3 - p_4V_4}{\gamma - 1}$$

- **Process (4-1) :** It is a reversible constant volume heat rejection process.

  Heat rejection is given by,

  $$Q_{rej} = Q_{4\text{-}1} = mC_v(T_4 - T_1)$$

  where, C_v is specific heat at constant volume.

Air standard efficiency of Diesel cycle :

Let pressure at various state points = p_1, p_2, p_3, p_4 respectively.

Temperature at various state points = T_1, T_2, T_3, T_4 respectively.

Volume at various state points = V_1, V_2, V_3, V_4 respectively.

Air standard efficiency is given as,

$$\eta_{Diesel} = \frac{W_{net}}{Q_{add}}$$

From first law of thermodynamics,

$$\Sigma W_{net} = \Sigma Q_{net}$$

so $$\eta_{Diesel} = \frac{\Sigma Q_{net}}{Q_{add}} = \frac{Q_{add} - Q_{rej}}{Q_{add}} = 1 - \frac{Q_{rej}}{Q_{add}} = 1 - \frac{mC_v(T_4 - T_1)}{mC_p(T_3 - T_2)}$$

$\therefore$ $$\eta_{Diesel} = 1 - \frac{T_4 - T_1}{\gamma(T_3 - T_2)}$$

The efficiency may be expressed in terms of any two of the following three ratios.

Compression ratio :

$$r_k = \frac{V_1}{V_2}$$

Expansion ratio : It is the ratio of volume after expansion to the volume before expansion. It is denoted by (r_e).

$$r_e = \frac{V_4}{V_3} \quad \ldots\text{(i)}$$

Cut off ratio : It is the ratio of volume after combustion to the volume before combustion. It is denoted by (r_c).

$$r_c = \frac{V_3}{V_2} \quad \ldots\text{(ii)}$$

Note

The air standard efficiency of an Otto cycle depends only upon the compression ratio, and cut off ratio is usually 1 in case of an Otto cycle. In this cycle heat addition takes place at constant volume, so there will be no effect on the air standard efficiency of Otto cycle due to cut off ratio.

From equation (i) and (ii),

$$r_k = r_e \cdot r_c$$

For process 3-4 : $\dfrac{T_4}{T_3} = \left(\dfrac{V_3}{V_4}\right)^{\gamma-1} = \dfrac{1}{r_e^{\gamma-1}}$

$$T_4 = T_3 \times \frac{r_c^{\gamma-1}}{r_k^{\gamma-1}}$$

For process 2-3 : $\dfrac{T_2}{T_3} = \dfrac{p_2V_2}{P_3V_3} = \dfrac{V_2}{V_3} = \dfrac{1}{r_c}$

$$T_2 = T_3 \times \frac{1}{r_c}$$

For process 1-2 : $\dfrac{T_1}{T_2} = \left(\dfrac{V_2}{V_1}\right)^{\gamma-1} = \dfrac{1}{r_k^{\gamma-1}}$

$$T_1 = T_2 \times \frac{1}{r_k^{\gamma-1}} = \frac{T_3}{r_c} \cdot \frac{1}{r_k^{\gamma-1}} \qquad \left[\because T_2 = \frac{T_3}{r_c}\right]$$

Substituting the value of T_1, T_2 and T_3 in the expression of efficiency

$$\eta_{Diesel} = 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)} = 1 - \frac{\left(T_3 \dfrac{r_c^{\gamma-1}}{r_k^{\gamma-1}}\right) - \left(\dfrac{T_3}{r_c} \cdot \dfrac{1}{r_k^{\gamma-1}}\right)}{\gamma\left(T_3 - T_3 \dfrac{1}{r_c}\right)}$$

$$\therefore \qquad \eta_{Diesel} = 1 - \frac{1}{\gamma} \cdot \frac{1}{r_k^{\gamma-1}} \cdot \frac{r_c^{\gamma} - 1}{r_c - 1}$$

Note

As $r_c > 1$ *therefore* $\dfrac{1}{\gamma} \cdot \left(\dfrac{r_c^{\gamma} - 1}{r_c - 1}\right)$ *is also greater than unity. Therefore for same compression ratio the efficiency of Diesel cycle is less than that of Otto cycle.*

Q.2 **(b)** Draw neat sketch of thermal power plant, showing its components and proper layout. Also write function of each component.

Ans.

- Electrical power is produced in a steam power plant with the help of coal. It is commonly used in India. These plants are by capacity range of 10 MW to higher.
- These plants are located where fuel transportation facility is available and availability of water also must be there.
- Steam power plants using steam basically works on Rankine cycle. However, in actual power plant, there are lot of improvements and modifications has been done on the Rankine cycle for better fuel economy and improvements in thermal efficiency.

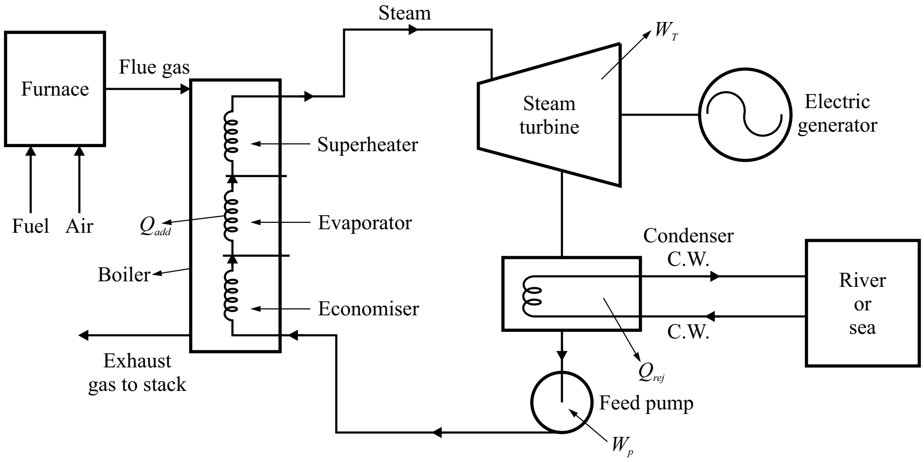

Fig. A simple thermal (steam) power plant

The function of main components of thermal power plant are explain below :

1. **Boiler :** A boiler is a closed vessel in which water or other fluid is heated. The heated or vaporized fluid exits the boiler for use in various processes or heating application including boiler based power generation.

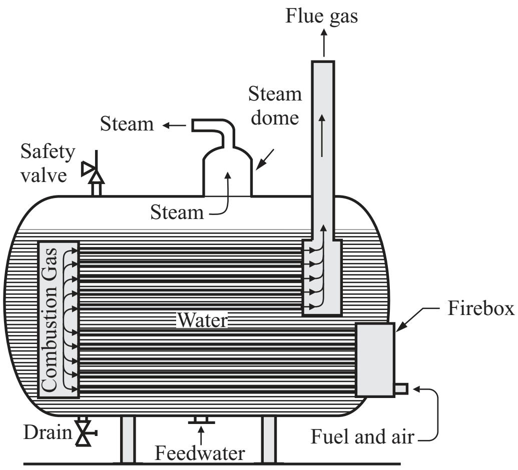

Fig. Boiler

2. **Turbine :** A turbine is a rotary mechanical device that extracts energy from fluid flow and converts it into useful work. A turbine is a turbo machine with at least one moving part called a rotor or shaft assembly, which is a shaft or drum with blades attached. Moving fluid act on the blades so that they move and impart rotational energy to the rotor.

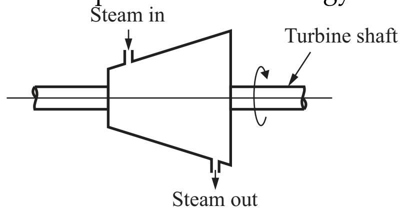

Fig. Turbine

3. **Condenser :** A condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. Condensers are typically heat exchanger which have various designs and come in many sizes ranging from rather small to very large industrial scale units used in plant processes.

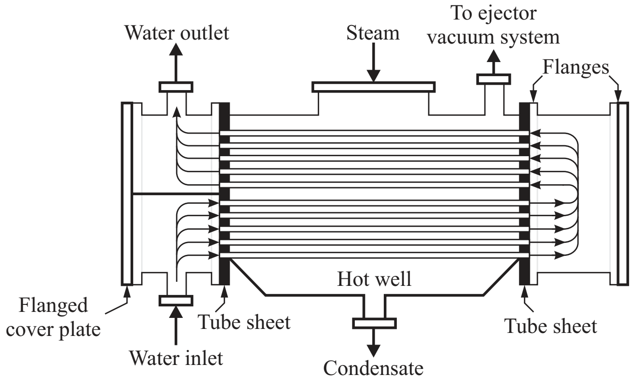

Fig. Condenser

4. **Feed pump :** The feed pump is a pump which is used to deliver feed water to the boiler. It is desirable that the quantity of water supplied should be at least equal to that evaporated and supplied to the engine.

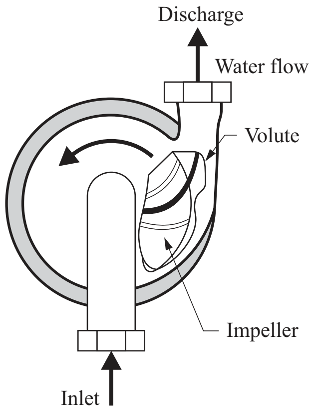

Fig. Feed pump

5. **Economiser :** In boilers, economisers are heat exchanging devices that heat fluids, usually water, up to but not normally beyond the boiling point of that fluid. Economizers are so named because they can make use of the enthalpy in fluid streams that are hot, but not hot enough to be used in a boiler, thereby recovering more useful enthalpy and improving the boiler's efficiency.
6. **Air preheater :** An air preheater is a general term to describe any device designed to heat the air before process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process.

The applications of steam power plant are as follows :

1. Condenser is used in refrigerator and air conditioner.
2. Boiler are used for steam generation like in power plant.
3. Economiser is used at power plant to increase the efficiency.
4. Turbine is used for power generation.
5. Air preheater is used to raise the temperature of air by the hot flue gases.

Q.3 **(a)** Explain following gear terminology

(i) Module (ii) Pitch circle

(iii) Pressure angle

Ans. **The important definitions related to gears are as mention below :**

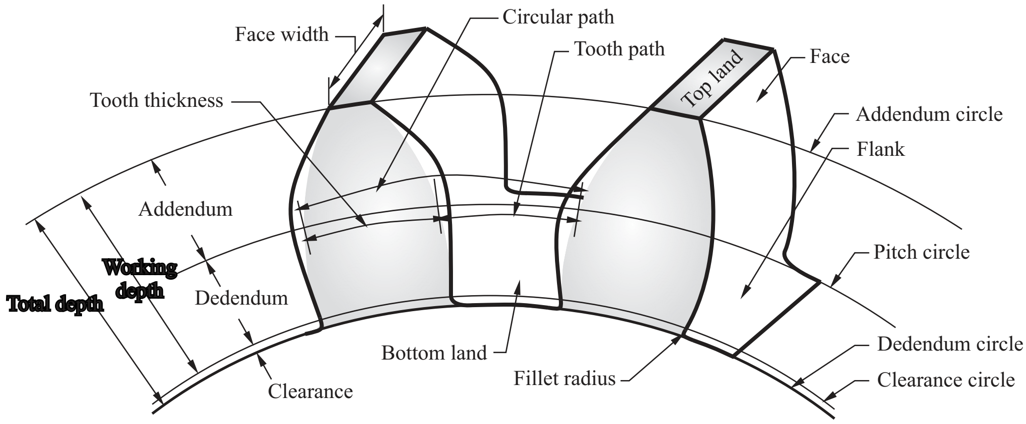

Fig. Gear terminology of a tooth profile

1. **Pinion :** It is usually the smaller or driving gear of a pair of mated gear.
2. **Pitch point :** The point of contact of two pitch circle is known as the pitch point.
3. **Pitch line :** It is the part of pitch circle of a rack and is a straight line as shown in figure.
4. **Pitch :** Pitch of two mating gears must be same. It is defined as follows :

(i) **Circular pitch (P_c) :** It is the circular distance measured along the circumference of the circular pitch from a point on one teeth to the corresponding point on the adjacent tooth.

$$P_c = \frac{\pi D}{T} = \pi m \qquad \left[\because \text{ Module } (m) = \frac{D}{T}\right]$$

where, P_c = Circular pitch, D = Pitch circle diameter.

T = Number of teeth.

(ii) **Diametral pitch (P_d) :** It is the ratio of number of teeth per unit length of the pitch circle diameter in inches. i.e.

$$P_d = \frac{T}{D} = \frac{\pi}{P_c} = \frac{1}{m} \qquad \left[P_c = \frac{\pi D}{T}\right]$$

(iii) **Module (m) :** It is the ratio of pitch circle diameter in mm to the number of teeth on gear.

$$m = \frac{D}{T}$$

5. (i) **Gear ratio (i) :** It is the ratio of number of teeth on the gear to that of the pinion.

$$i = \frac{T}{t}$$

where, T = Number of teeth on gear.

t = Number of teeth on pinion.

Or

$$\text{Gear ratio } (i) = \frac{n_p}{n_g}$$

where, n_p = Speed of pinion.

n_g = Speed of gear.

(ii) **Velocity ratio ($V.R$) :** It is defined as the ratio of angular velocity of driven gear (follower) to the angular velocity of driver gear.

Let, subscript 1 = Driver

subscript 2 = Driven (follower)

$$V.R = \frac{\text{Angular velocity of driven}}{\text{Angular velocity of driver}}$$

$$V.R = \frac{\omega_2}{\omega_1}$$

$$V.R = \frac{2\pi N_2}{2\pi N_1} \qquad [\because \omega = 2\pi N]$$

$$\therefore \quad V.R = \frac{N_2}{N_1}$$

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \qquad [\because \pi D_1 N_1 = \pi D_2 N_2]$$

$$\therefore \quad V.R = \frac{D_1}{D_2}$$

$$V.R = \frac{D_1}{D_2} = \frac{T_1}{T_2} \qquad \left[\because \ m = \frac{D_1}{T_1} = \frac{D_2}{T_2}\right]$$

$$\therefore \quad V.R = \frac{T_1}{T_2}$$

(ii) Pitch line velocity : It is given by,

$$v_p = r \times \omega = r \times \frac{2\pi N}{60} \qquad \text{where, } v_p \text{ is in m/s.}$$

6. **Addendum circle :** It is a circle passing through the tips of teeth.
7. **Dedendum circle :** It is a circle passing through the roots of teeth.
8. **Addendum :** It is the radial height of the teeth above the pitch circle. Its standard value is one module.
9. **Dedendum :** It is the radial depth of the tooth below the pitch circle. Its standard value is 1.157 module.
10. **Clearance :** Radial difference between addendum and dedendum of a tooth i.e.
    Its standard value is 0.175 m.
11. **(i) Top land :** It is the surface on the top of the tooth.
    (ii) Bottom land : The surface of the bottom of the tooth between adjacent fillets.
    (iii) Face : The surface between the pitch circle and top land.
    (iv) Flank : Tooth surface between pitch circle and bottom land including fillet.
12. **Line of action or pressure line :** The force which the driving (driver) tooth exerts on the driven tooth, in a long a line form the pitch point to the point of contact of the two teeth. The line is also the common normal at the point of contact of the mating gears and is known as the line of action or the pressure line.
13. **Pressure angle or angle of obliquity (ϕ) :** The angle between the pressure line and the common tangent to the pitch circle is known as pressure angle.
14. **Angle of action (S) :** It is the angle turned by a gear from the beginning of engagement to the end of engagement of a pair of teeth.

$$S = \alpha + \beta$$

Q.3 (b) How can profile helps to achieve definite follower motion explain with suitable example?

Ans. The cam profile :

- The profile of the contact surface of the follower is drawn in the correct position for each successive angular position of the line of stroke and the profile of the working surface of the cam is drawn so as to touch the successive positions of the follower.
- When the displacement time diagram has been drawn to correspond with the desired motion of the followers, the shapes of the cam profile may be set out.
- ` This is most conveniently done by reversing the actual conditions and imagining the cam to remain fixed while the line of stroke of the followers revolves round the cam in the opposite sense to that in which the cam actually turns on its own axis.

The following steps involved to achieve a definite follower motion are :

1. Initially it is required to select a displacement diagram for the follower motion.
   For example : Considering follower moves with simple harmonic motion.
2. Finally it is required to select a type of follower used in cam profile.
   For example : Considering in a knife edge follower.

The following steps involved in drawing displacement diagram of simple harmonic motion are as follows :

1. Draw a semi-circle on the follower stroke equal to its diameter.
2. Divide the semi-circle into any number of even equal parts (say six).
3. Divide the angular displacement of the cam during out stroke and return stroke into the same number of equal parts.
4. The displacement diagram is obtained by projecting the points as shown in figure below.

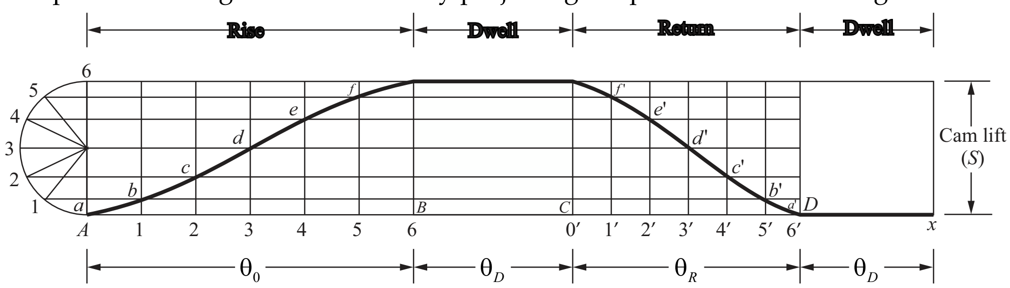

Fig.(a) Displacement diagram of simple harmonic motion

Terminology used in displacement diagram of simple harmonic motion :

1. **Stroke of the follower or cam lift :** It is the maximum lift obtained by the follower, it is denoted by (S).
2. **Angle of rise :** It is the angular displacement of cam during out stroke. It is denoted by (θ_0).
3. **Angle of return :** It is the angular displacement of cam during return stroke. It is denoted by (θ_R).
4. **Angle of dwell :** It is a period of dwell in which no follower displacement (movement) occur. It is denoted by (θ_D).

Mathematical expression for simple harmonic motion of follower are :

1. Maximum velocity of the follower on the out stroke (v_0) :

$$v_0 = \frac{\pi \omega S}{2\theta_0}$$

where, ω = Angular velocity (rad/sec)
S = Stroke of follower (mm)
θ_0 = Angle of rise (radian)

2. Maximum velocity of the follower on the return stroke (v_R) :

$$v_R = \frac{\pi\omega S}{2\theta_R}$$

where, θ_R = Angle of return (radian)

3. Maximum acceleration of the follower on the return stroke (a_R) :

$$a_R = \frac{\pi^2\omega^2 \cdot S}{2(\theta_R)^2}$$

Cam with knife-edge reciprocating follower :

A cam rotating clock wise at a uniform speed is required to give a knife-edge follower the motion defined below :

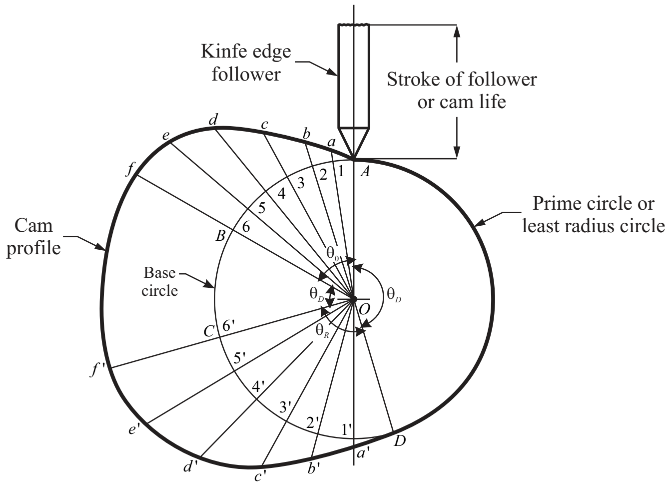

Fig. Cam profile

Q.4 (a) Explain function of boiler mountings.

Ans. The following table gives function of various boiler mountings :

S. No.	Boiler mounting	Location	Function
1.	Water level indicator	Normally two water level indicators are fitted at the front end of every boiler.	The function of a water level indicator is to indicate the level of water in the boiler constantly. It is also called water gauge.
2.	Pressure gauge	It is usually mounted on the front top of the shell or the drum.	The function of a pressure gauge is to measure the pressure exerted inside the vessel.
3.	Safety valves	A safety valve is generally fitted on the top of the shell. As per boiler regulation every boiler must be fitted at least with two safety valves.	The function of a safety valve is to release the excess steam when the pressure of steam inside the boiler exceeds the rated pressure.
4.	Fusible plug	It is fitted on the fire box crown plate or over the combustion chamber at its appropriate place.	The function of a fusible plug is to protect the boiler against damage due to overheating for low water level.

S. No.	Boiler mounting	Location	Function
5.	Blow off cock	It is fitted on the boiler shell directly or to a short branch pipe at the lowest part of the water space.	It may discharge a portion of water when the boiler is in operation to blow out mud, scale or sediment periodically. It may empty the boiler when necessary for cleaning, inspection and repair.
6.	Feed check valve	It is fitted in the water space of the boiler slightly below the normal level of the water.	The function of a feed check valve is to control the supply of water to the boiler and to prevent the escaping of water from the boiler when the pump pressure is less or pump is stopped.
7.	Junction or stop valve	A junction valve is a valve which is placed directly over a boiler and connected to a steam pipe which carries steam to the engine.	The function of the stop valve or junction valve is to regulate the flow of steam from one steam pipe to the other or from the boiler to the steam pipe.

Q.4 (b) Explain working of domestic refrigerator considering all thermodynamic processes involved and function of all components.

Ans. Figure below shows the schematic diagram of a simple vapour compression refrigeration system. It consists of the following four essential parts :

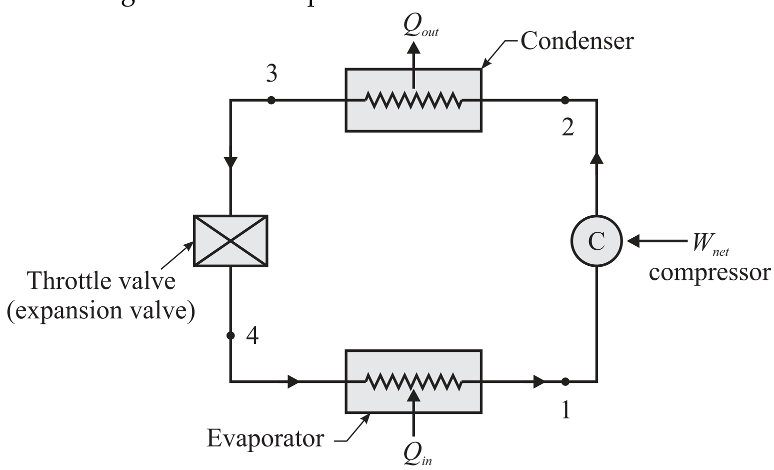

Fig. Block diagram of vapour compression refrigeration system

1. **Compressor :** The low pressure and temperature vapour refrigerant from evaporator is drawn into the compressor through the inlet or suction valve, where it is compressed to a high pressure and temperature. This high pressure and temperature vapour refrigerant is discharged into the condenser through the delivery or discharge valve.
2. **Condenser :** The condenser or cooler consists of coils of pipe in which the high pressure and high temperature vapour refrigerant is cooled and condensed. The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.

3. **Expansion valve :** It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as its passes through the expansion valve, but the greater portion is vaporized in the evaporator at the low pressure and temperature.
4. **Evaporator :** An evaporator consists of coils of pipe in which the liquid vapour refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which is to be cooled.

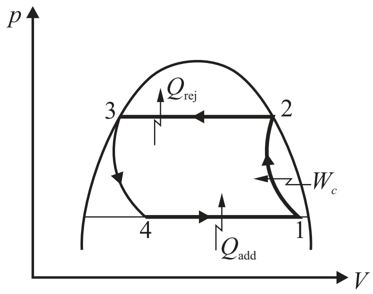

Fig. *p-V* diagram

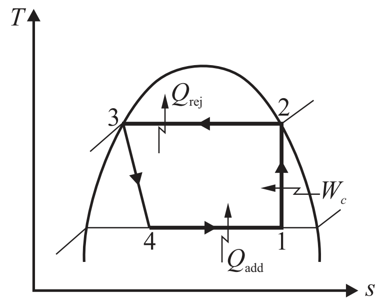

Fig. *T-s* diagram

Air conditioner : It is a device that removes heat from the air inside a building or vehicle, thus lowering the air temperature. The cooling is typically achieved through a refrigeration cycle, but sometimes evaporation or free cooling is used.

Q.5 **(a)** Explain two statements of second law of thermodynamics.

Ans. **Kelvin-Planck statement :** It is impossible to construct a heat engine or device which operates in a cycle produces no other effects than the production of work and the transfer of heat from a single body.

The efficiency of such an engine would be 100 %

$$\left[\eta = \left(\frac{W_{net}}{Q_{in}}\right)\times 100 = \left(\frac{W_{net}}{W_{net}}\right)\times 100 = \left(\frac{Q_{add}}{Q_{add}}\right)\times 100 = 100\%\right]$$

Such a device violates **Kelvin-Planck** statement even though it satisfies the first law of thermodynamics, i.e. **principle of conservation of energy**.

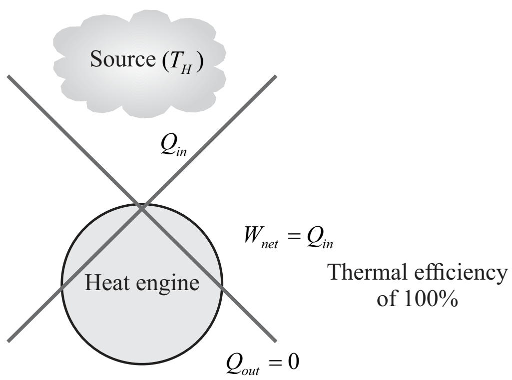

Fig. A heat engine that violates the Kelvin-Planck statement of the second law cannot be built

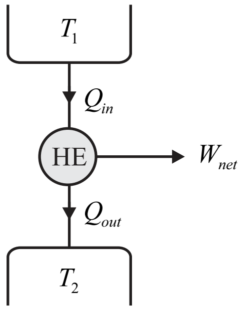

Fig. A heat engine that favors the Kelvin-Planck statement

Clausius Statement :

"It is impossible to construct a device that operates on a cycle whose main result is the transfer of heat from a cooler body to a hotter body without the assistance of external work.

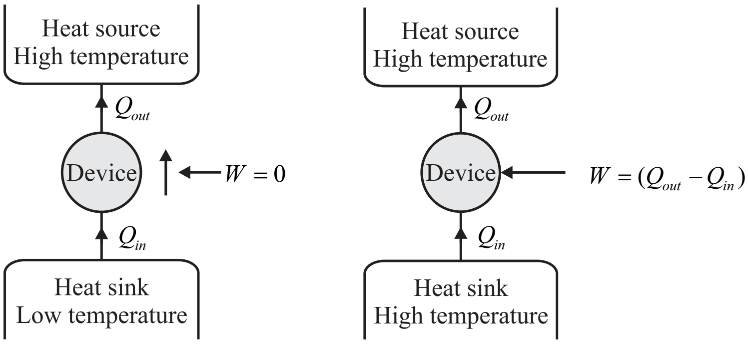

Fig. (a) Impossible **Fig. (b) Possible**

According to the above statement, it is clear that heat cannot flow itself from a lower temperature body to a higher temperature body without the assistance of an external work [Figure (a)]. This process is impossible and violates the **Clausius** statement of the second law of thermodynamics.

Alternatively, heat can transfer from a low temperature body to a high temperature body with the help of an external work (W) [Figure (b)]. This process is possible.

Q.5 **(b)** What are the different methods of heat transfer? Write Fourier's law of heat conduction.

Ans. **There are three distinct modes of heat transfer from a source to a receiver :**

1. **Conduction :** It is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance. It is found in solids.
2. **Convection :** When a fluid flows inside a duct or over a solid body and temperature of fluid and solid surfaces are different, heat transfer between fluid & solid surfaces will take place. This is due to motion of fluid relative to surface. This type of heat transfer is called *convection.*
3. **Radiation :** If two bodies at different temperature are placed in an evacuated adiabatic enclosure so that they are not in contact through a solid or fluid medium. The temperature of bodies tends to become equal & mode of this type of heat transfer is called *radiation.*

According to this law, "the rate of heat flow through a simple homogeneous solid is directly proportional to the area measured normal to direction of heat flow and the temperature gradient in the direction of heat flow".

$$Q \propto A \cdot \frac{dT}{dx}$$ [For one dimensional, steady state heat transfer]

$$Q = -kA.\frac{dT}{dx}$$

k is known as coefficient of the *thermal conductivity* in W/m K

where, Q = Rate of heat flow, kJ/sec

A = Area perpendicular to the direction of heat flow in m^2.

∂x = Thickness of material along the path of heat flow.

∂T = Temperature difference in kelvin.

$$q = \frac{Q}{A} = -k\frac{dT}{dx} \qquad \text{where, } q \text{ is a heat flux } kW/m^2.$$

Q.6 (a) What is fatigue failure? How does it happens?

Ans. **Fatigue phenomenon :** It is the fracture of the material, when it is subjected to a cyclic load for a long period of time.

For example : Rotating shafts, aircraft wings, and connecting rods are some examples of the structural and machine components subjected to cyclic loading.

Fatigue test :

- A simple fatigue testing machine is shown in figure below.
- The specimen is connected to an electric motor through a shaft.
- The specimen is rotated with the help of electric motor.
- A revolution counter is used to measure the number of revolution made by the electric motor. A dead load is applied to the machine using ball bearings.
- The ball bearings relieve the machine from bending moment that is applied to the shaft.
- The specimen rotates due to the applied cyclic stress (sinusoidal stress).
- The number of cycles that the specimen can withstand without fracture is determined.
- The minimum stress at which a specimen can withstand without fracture, whatever may be the number of cyclic stress is known as *endurance limit*.
- Below the endurance limit, the specimen does not undergo fracture for repeated stresses.

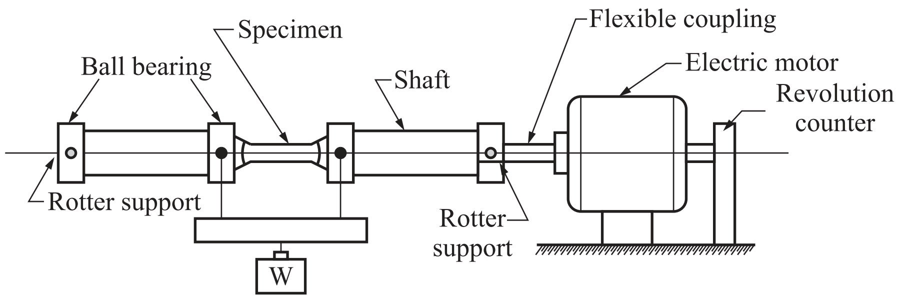

Fig. R.R. Moore fatigue testing machine

The following object can be obtained from performing fatigue testing operations are given below:

1. **Fatigue life :** It is the maximum value of number of cycles a material can withstand to a particular stress is known as *fatigue life*.
2. **Fatigue limit :** The stress below which no fatigue failures occur is known as *fatigue limit*.
3. **Fatigue strength :** The stress required to produce failure by fatigue is known as *fatigue strength*.

Q.6 (b) Define hardness and explain Rockwell hardness test.

Ans. **Hardness :** It is the ability of material to resist the permanent shape change due to external load. There are various measure of hardness : Scratch hardness, indentation hardness and rebound hardness.

Rockwell's hardness test : The Rockwell's hardness test is, generally performed when quick and direct reading is desirable. This test is also performed when the material have hardness, beyond the range of Brinell's hardness test. It differs from the Brinell's test in such a way that in this test the loads for making indent are smaller, and thus it makes smaller and shallower indents. It is because of this reason that the Rockwell's hardness test is widely used in the industry.

Q.7 (a) Explain sequence of operations take place during working of SI engine.

Ans. **Otto cycle :** The Otto cycle is the ideal cycle for spark-ignition reciprocating engines. A schematic of each stroke as well as a *p-V* diagram for an actual four stroke spark-ignition engine is given in figure below.

Thermodynamic processes under Otto cycle are as follows :

Process (1-2) : Reversible adiabatic compression process/Isentropic compression, (–ve work, W_c)

Process (2-3) : Reversible constant volume heat addition process (+ve heat, Q_{add})

Process (3-4) : Reversible adiabatic expansion process/Isentropic expansion, (+ve work, W_e)

Process (4-1) : Reversible constant volume heat rejection process (–ve heat, Q_{rej})

Note

Negative sign indicates work done on the system.

Positive sign indicates work done by the system.

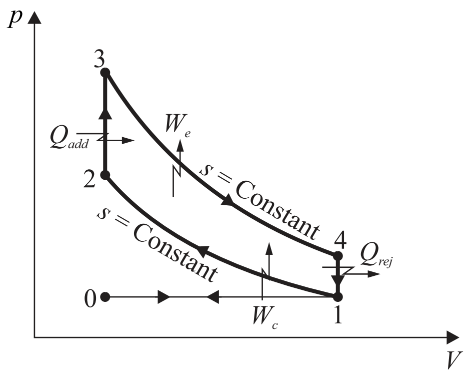

Fig. Otto cycle on *p-V* diagram

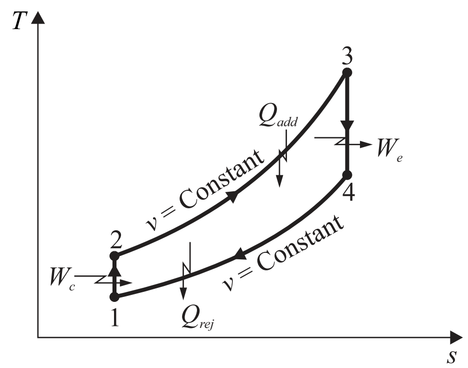

Fig. Otto cycle on *T-s* diagram

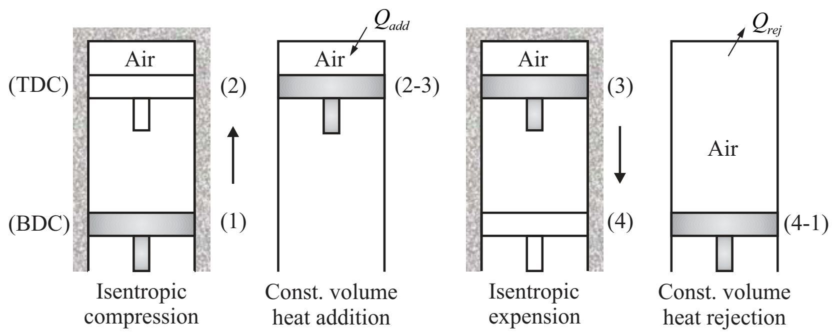

Fig. Ideal Otto cycle

Working :

- **Process (0-1) suction :** It is a constant pressure suction process where inlet valve is open and the piston moves to the bottom dead centre (BDC).
- **Process (1-2) compression :** It is a reversible adiabatic compression process in which the air-fuel mixture is compressed into the cylinder.
  Work done in compression is given by,

$$W_c = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$$

- **Process (2-3) :** It is a constant volume heat addition where the air-fuel mixture is ignited with the help of spark plug.
  Heat addition is given by,
  $$Q_{add} = Q_{2\text{-}3} = mC_v(T_3 - T_2)$$
  where, C_v is specific heat at constant volume.
- **Process (3-4) :** It is a reversible adiabatic expansion process in which the useful work output is produced and it is also called *expansion* or *power stroke*.
  $$W_e = \frac{p_3V_3 - p_4V_4}{\gamma - 1}$$
- **Process (4-1) :** It is a reversible constant volume heat rejection where the exhaust gases are thrown out from the cylinder.
  Heat rejection is given by,
  $$Q_{rej} = Q_{4\text{-}1} = mC_v(T_4 - T_1)$$

Air standard efficiency of Otto cycle :

Let pressure at various state points = p_1, p_2, p_3, p_4 respectively.

Temperature at various state points = T_1, T_2, T_3, T_4 respectively.

Volume at various state points = V_1, V_2, V_3, V_4 respectively.

Air standard efficiency is given as,

$$\eta_{Otto} = \frac{W_{net}}{Q_{add}}$$

From first law of thermodynamics,

$$\Sigma W_{net} = \Sigma Q_{net}$$

So,
$$\eta_{Otto} = \frac{\Sigma Q_{net}}{Q_{add}} = \frac{Q_{add} - Q_{rej}}{Q_{add}} = 1 - \frac{Q_{rej}}{Q_{add}}$$

$$\eta_{Otto} = 1 - \frac{mC_v(T_4 - T_1)}{mC_v(T_3 - T_2)} = 1 - \left(\frac{T_4 - T_1}{T_3 - T_2}\right)$$

$$\eta_{Otto} = 1 - \frac{\left(\frac{T_4}{T_1} - 1\right)T_1}{\left(\frac{T_3}{T_2} - 1\right)T_2} \qquad \ldots\text{(i)}$$

For isentropic compression consider from processes (1-2 and 3-4) :

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \Rightarrow \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \frac{T_3}{T_4} \qquad [\because\ V_1 = V_4, V_3 = V_2]$$

Compression ratio :

$$\therefore \qquad \frac{V_1}{V_2} = \frac{V_4}{V_3} = r_k$$

So,
$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \qquad \Rightarrow \qquad \frac{T_3}{T_2} = \frac{T_4}{T_1}$$

Putting this value of $\frac{T_3}{T_2}$ in equation (i), we get

$$\eta_{Otto} = 1 - \frac{T_1}{T_2}\left(\frac{\frac{T_4}{T_1} - 1}{\frac{T_4}{T_1} - 1}\right) = 1 - \frac{T_1}{T_2} \qquad \ldots\text{(ii)}$$

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

$$\therefore \qquad \frac{T_1}{T_2} = \frac{1}{(r_k)^{\gamma-1}}$$

Air standard efficiency of Otto cycle is given by :

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

Mean effective pressure :

It is the ratio of net work output to the swept volume. It is denoted by (p_m).

Mathematically, Mean effective pressure, $p_m = \dfrac{\text{Net work output}\,(W_{net})}{\text{Swept volume}\,(V_1 - V_2)}$

Q.7 (b) Draw and explain stress strain diagram for ductile material.

Ans. **Stress-strain curve :** Stress-strain curve gives the relation between the stress and strain induced in a material due to externally applied force. This curve is different for ductile material (steel, rubber copper etc.) and brittle material (cast iron, glass etc.).

Stress-strain curve for ductile material :

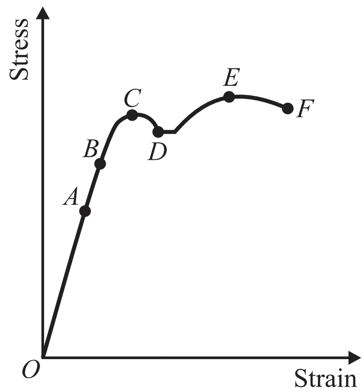

Fig. (a) Stress-strain curve for ductile material (mild steel)

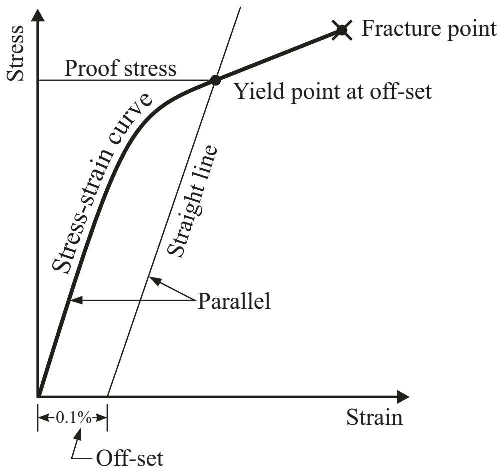

Fig. (b) Stress-strain curve for a brittle material (cast iron)

The important points on the stress-strain curve are as follows :

1. **Proportional limit :** It is also called *proportional stress*. It is the maximum value of the stress up to which stress is directly proportional to strain. In figure (a) point O to A is a straight line and beyond point A the curve slightly deviates from the straight line.

2. **Elastic limit :** It is the maximum value of stress up to which the deformation are elastic or temporary (after unloading, metal regains its original shape and size). Beyond elastic limit i.e. point *B* the deformation of metal is permanent.
3. **Yield point :** It is the stress at which material yields i.e. deformed plastically without any strain hardening. In this curve the stress corresponding to point *C* is called *upper yield* stress and for point *D* it is called *lower yield stress*.
4. **Ultimate stress :** It is the maximum value of stress on this curve without fracture. After this value i.e. point *E*, the failure of metal begins.
5. **Breaking point stress :** It is also called *failure stress* or *fracture stress*. Breaking stress point *F* is the fracture or failure point.
6. **Proof stress :** From figure (b) most of ductile materials such as *high strength deformed steel, brass, duralumin* etc., does not have position of yield point, so that the curve passes smoothly from elastic deformation to plastic deformation. For such materials a proof stress at a specified strain is calculated. It is generally calculated after test by an offset method.

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