CONTENTS

KME101T / KME201T : FUNDAMENTAL OF MECHANICAL ENGINEERING AND MECHATRONICS

1 UNIT

Introduction to Mechanics of Solid

CONTENTS

PART-1

Normal and Shear Stress, Strain, Hooke's Law, Poisson's Ratio.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. **Define stress and also classify it.**

Answer

A. Stress :

1. The force of resistance per unit area, offered by a body against deformation is known as stress. The external force acting on the body is called the load or force. Mathematically

Stress, $\sigma = \dfrac{P}{A}$

Where, P = External force or load,
A = Cross-sectional area.

2. It is expressed in N/m^2.

B. Types of Stress : Types of stress are as follows :

i. Normal Stress :

1. It is the stress, which acts in a direction perpendicular to the area. It is represented by σ.
2. The normal stress is further divided into tensile stress and compressive stress.

a. Tensile Stress :

1. The stress induced in a body, when subjected to two equal and opposite pulls as a result of which there is an increase in length, is known as tensile stress (Fig. 1.1.1(*a*)).
2. The tensile stress acts normal to the area and it pulls on the area.

b. Compressive Stress :

1. The stress induced in a body, when subjected to two equal and opposite pushes as a result of which there is a decrease in length of the body, is known as compressive stress (Fig. 1.1.1(*b*)).
2. The compressive stress acts normal to the area and it pushes on the area.

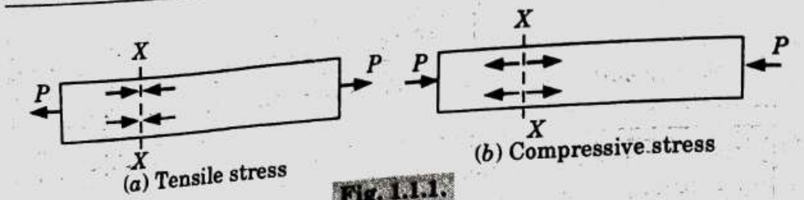


Fig. 1.1.1.

ii. **Shear Stress :**

1. The stress induced in a body, when subjected to two equal and opposite forces which are acting tangentially across the resisting section as a result of which the body tends to shear off across the section, is known as shear stress (Fig. 1.1.2).
2. It is given by, $\tau = \dfrac{\text{Shear resistance}}{\text{Shear area}} = \dfrac{P}{A}$

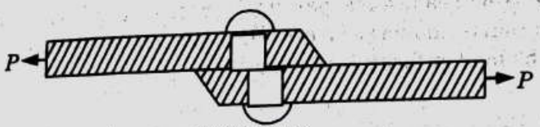


Fig. 1.1.2.

Que 1.2. **Define strain. What are different types of strain ?**

Answer

A. **Strain :**

1. The ratio of change in dimension of the body to the original dimension is known as strain.
2. These changes in the dimension of the body occur due to external load subjected on the body

$$\text{Strain} = \frac{\text{Change in dimension}}{\text{Original dimension}}$$

B. **Types of Strain :** Types of strain are as follows :

i. **Tensile Strain :** If there is some increase in length of a body due to external force, then the ratio of increase in length to the original length of the body is known as tensile strain.

ii. **Compressive Strain :** If there is some decrease in length of the body due to external force, then the ratio of decrease in length of the body to the original length is known as compressive strain.

iii. **Volumetric Strain :** The ratio of change in volume of the body to the original volume is known as volumetric strain.

iv. **Shear Strain :** The strain produced by shear stress is known as shear strain.

Que 1.3. **Write short notes on :**

i. **Hooke's law,**
ii. **Longitudinal strain,**
iii. **Lateral strain, and**
iv. **Poisson's ratio.**

Answer

i. **Hooke's Law :**

1. It states that, when a material is loaded, within its elastic limit, the stress is proportional to the strain. Mathematically,

$$\sigma \propto \varepsilon$$
$$\sigma = E\,\varepsilon$$

2. It may be noted that Hooke's law equally holds good for tension as well as compression.

ii. **Longitudinal Strain :**

1. The ratio of change in length to the original length of the body is known as longitudinal (or linear) strain.
2. The longitudinal strain in also defined as the deformation of the body per unit length in the direction of the applied load.

Let, L = Length of the body,
P = Tensile force acting on the body.
δL = Increase in the length of the body in the direction of P.

Then, longitudinal strain $= \dfrac{\delta L}{L}$

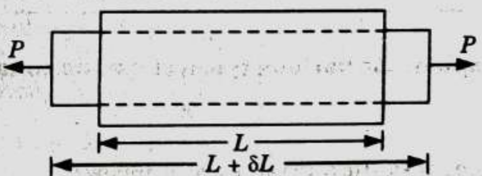


Fig. 1.3.1.

iii. **Lateral Strain :**

1. The strain at right angles to the direction of applied load is known as lateral strain.
2. Let a rectangular bar of length, L, breadth, b and depth, d is subjected to an axial tensile load, P as shown in Fig. 1.3.2. The length of the bar will increase while the breadth and depth will decrease.

Let, δL = Increase in length.

δb = Decrease in breadth.

δd = Decrease in depth.

$$\text{Lateral strain} = \frac{\delta b}{b} \text{ or } \frac{\delta d}{d}$$

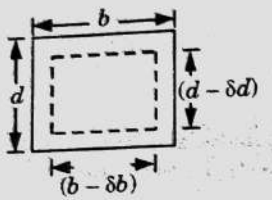


Fig. 1.3.2.

iv. **Poisson's Ratio :** The ratio of lateral strain to the longitudinal strain is a constant for a given material, when the material is stressed within the elastic limit. This ratio is called Poisson's ratio and it is generally denoted by μ.

$$\text{Poisson's ratio, } \mu = -\frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

PART-2

Elastic Constants and their Relationship.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.4. **Explain the various types of elastic constants.**

Answer

Various types of elastic constants are as follows :

i. **Young's Modulus :** It is the ratio between tensile stress and tensile strain or compressive stress and compressive strain. It is denoted by E. It is the same as modulus of elasticity. Hence, mathematically,

$$\text{Young's Modulus, } E = \frac{\sigma}{\varepsilon}$$

ii. **Modulus of Rigidity :** It is defined as the ratio of shear stress, τ to shear strain and is denoted by G. It is also called shear modulus of elasticity. It is given by, $G = \dfrac{\tau}{\varepsilon_s}$

iii. **Bulk or Volume Modulus of Elasticity :** It may be defined as the ratio of normal stress to volumetric strain and is denoted by K. Hence, mathematically,

$$K = \frac{\sigma}{\varepsilon_e}$$

Que 1.5. **Derive the following expression for the elastic constants :**

$$K = \frac{E}{3(1-2\mu)}$$

Answer

1. Bulk Modulus, $\quad K = \dfrac{\text{Normal stress}}{\text{Volumetric strain}} = \dfrac{\sigma}{\varepsilon_v}$ ...(1.5.1)

2. Consider a cubical element subjected to stress σ along X, Y and Z directions (as shown in Fig. 1.5.1).

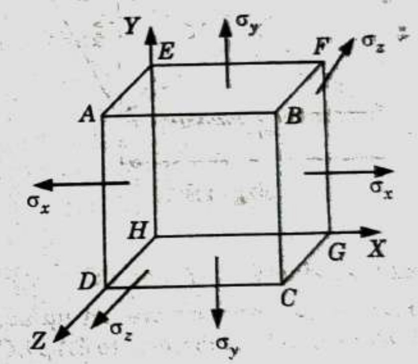


Fig. 1.5.1.

[Forces are same along each face $P_x = P_y = P_z = P$]

3. Strain in X-direction, $\varepsilon_x = \dfrac{\sigma_x}{E} - \dfrac{\mu\sigma_y}{E} - \dfrac{\mu\sigma_z}{E}$

$\because \quad \sigma_x = \sigma_y = \sigma_z = \sigma$

$\therefore \quad \varepsilon_x = \dfrac{\sigma}{E} - \mu\dfrac{\sigma}{E} - \mu\dfrac{\sigma}{E} = \dfrac{\sigma}{E}(1-2\mu)$

Similarly, $\quad \varepsilon_y = \varepsilon_z = \dfrac{\sigma}{E}(1-2\mu)$

4. Volumetric strain, $\quad \varepsilon_v = \varepsilon_x + \varepsilon_y + \varepsilon_z$

5. From eq. (1.5.1), we get

$$\varepsilon_v = 3\,\frac{\sigma}{E}(1-2\mu)$$

$$E = 3\frac{\sigma}{\varepsilon_v}(1-2\mu)$$
$$= 3K(1-2\mu)$$
$$K = \frac{E}{3(1-2\mu)}$$

Que 1.6. **Establish the relation between modulus of elasticity (*E*) and shear modulus (*G*).**

Answer

1. Consider a cubic element *ABCD* with fixed bottom (*BC*) and top face *AD* subjected to force *P* (tangential).

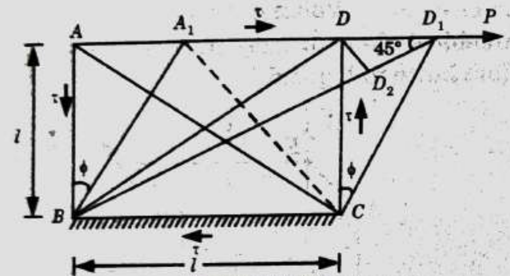


Fig. 1.6.1.

2. Due to load *P* :
   i. Shear stress τ is induced at *AD* and *BC*.
   ii. Complimentary shear stresses are set up at *AB* and *DC* due to which cubic element *ABCD* distorts to BA_1D_1C.
   $$AA_1 = DD_1$$
3. From ΔDCD_1, $\frac{DD_1}{l} = \tan\phi = \phi$ (Since ϕ is very small)
   $$\therefore \quad DD_1 = l\phi \quad ...(1.6.1)$$
   Diagonal *BD* elongates to BD_1.
   Diagonal *AC* shortens to A_1C.
4. Longitudinal strain in $BD = \frac{BD_1 - BD}{BD} = \frac{BD_1 - BD_2}{BD}$
   [DD_2 is perpendicular from *D* to BD_1]
5. DD_1 is small, therefore $\angle BDC \approx \angle BD_1C \approx 45°$
   $$\therefore \quad \angle DD_1D_2 \approx 45^0$$
6. Longitudinal strain in $BD = \frac{D_1D_2}{BD} = \frac{DD_1 \cos 45°}{BD}$
7. From eq. (1.6.1), we get

$$= \frac{l\phi(1/\sqrt{2})}{l\sqrt{2}}$$

8. Longitudinal strain in $BD = \frac{\phi}{2} = \frac{\tau}{2G}$ [$\because \tau = G\phi$] ...(1.6.2)
9. Strain in diagonal *BD* is also given by :
   (Strain due to tensile stress in diagonal *BD*) – (Strain due to complimentary stress in diagonal *AC*)
   $$= \frac{\tau}{E} - \left(-\mu\frac{\tau}{E}\right) = \frac{\tau}{E}(1+\mu) \quad ...(1.6.3)$$
10. From eq. (1.6.2) and eq. (1.6.3), we get
   $$\frac{\tau}{2G} = \frac{\tau}{E}(1+\mu)$$
   $$\Rightarrow \quad E = 2G(1+\mu)$$

Que 1.7. **Show that *E*, *G* and *K* are related by the following expression :**

$$E = \frac{9KG}{3K+G}$$

Answer

1. We know that, $E = 2G(1+\mu)$ ...(1.7.1)
   and, $E = 3K(1-2\mu)$ ...(1.7.2)
2. From eq. (1.7.1), $\mu = \frac{E}{2G} - 1$ and put it in eq. (1.7.2).
   $$E = 3K\left[1 - 2\left(\frac{E}{2G} - 1\right)\right] = 3K\left[1 - \frac{E}{G} + 2\right]$$
   $$E = 3K\left[3 - \frac{E}{G}\right] = 3K\left[\frac{3G - E}{G}\right] = \left[\frac{9KG - 3KE}{G}\right]$$
   $$GE = 9KG - 3KE$$
   $$GE + 3KE = 9KG$$
   $$E(3K+G) = 9KG$$
   $$E = \frac{9KG}{3K+G}$$

Que 1.8. **Determine the Poisson's ratio and bulk modulus of a material, for which Young's modulus is 120 GPa and modulus of rigidity 48 GPa.**

Answer

Given : $E = 120$ GPa $= 1.2 \times 10^5$ N/mm^2
$G = 48$ GPa $= 4.8 \times 10^4$ N/mm^2
To Find : Poisson's ratio and bulk modulus.

1. We know that, $E = 2G(1 + \mu)$
$$1.2 \times 10^5 = 2 \times 4.8 \times 10^4 (1 + \mu)$$
$$\mu = 1.25 - 1.0 = 0.25.$$
2. Bulk modulus is given by,
$$K = \frac{E}{3(1-2\mu)} = \frac{1.2 \times 10^5}{3(1 - 2 \times 0.25)}$$
$$= 8 \times 10^4 \text{ N/mm}^2.$$

PART-3

Stress-Strain Diagram for Ductile and Brittle materials.

Questions-Answers
Long Answer Type and Medium Answer Type Questions

Que 1.9. **Draw and explain the stress-strain diagram for mild steel under tensile load.**

Answer

Fig. 1.9.1 shows stress vs strain diagram for mild steel specimen. The following salient points are observed on stress-strain curve :

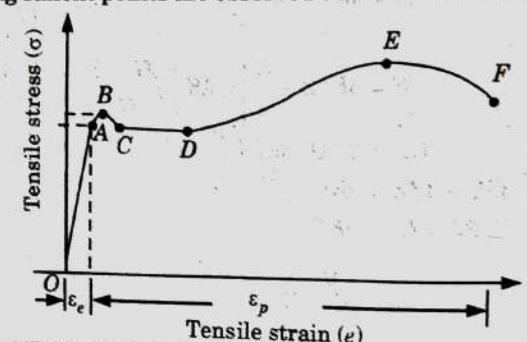


Fig. 1.9.1. Stress-strain diagram for mild steel.

i. **Limit of Proportionality (A) :** It is the limiting value of the stress upto which stress is proportional to strain.

ii. **Elastic Limit :** This is the limiting value of stress upto which if the material is stressed and then released (unloaded) strain disappears completely and the original length is regained. This point is slightly beyond the limit of proportionality.

iii. **Upper Yield Point (*B*) :** This is the stress at which, the load starts reducing and the extension increases. This phenomenon is called yielding of material.

iv. **Lower Yield Point (*C*) :** At this stage the stress remains same but strain increases for same time.

v. **Ultimate Stress (*E*) :** This is the maximum stress the material can resist. At this stage cross-sectional area at a particular section starts reducing very fast. This is called neck formation. After the stage load and hence the stress developed starts reducing.

vi. **Breaking Point (*F*) :** The stress at which finally the specimen fails is called breaking point. At this point strain is 20 to 25 per cent.

Que 1.10. **Define brittle material. Explain the stress-strain diagram for brittle material.**

Answer

A. **Brittle Material :**
1. The material which shows very small elongation before fracture is known as brittle material.
2. Cast iron, concrete and high carbon steel is brittle material.
3. Hence brittle materials break easily when subjected to shock.

B. **Stress-Strain Diagram for Brittle Material :**
1. Fig. 1.10.1 shows the stress-strain diagram for brittle material, in which strain is are plotted along x-axis and corresponding stress is plotted along y-axis.

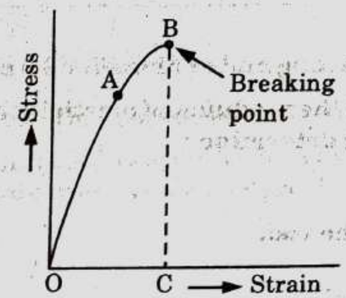


Fig. 1.10.1. Stress-strain diagram for brittle materials.

2. This diagram is obtained by performing a tensile test on the specimen.
3. The end of the test piece is fixed into grips connected to a straining device and load measuring device. The load on the test piece is increased slowly and corresponding extension is measured.

4. From these readings, the curve *OAB* is obtained.
5. In this curve, from *O* to *A* the stress is proportional to the strain and this is known as elastic stage.
6. Upto point *A*, Hook's law is applicable. The stress at *A* represents the proportional limit.
7. If the load is increased further the elongation becomes more rapid and diagram becomes curved. The stress will not be proportional to the strain.
8. At point *B*, suddenly the specimen breaks into pieces.
9. The total elongation *OC* before fracture is very small as compared to total elongation of ductile material.

PART-4

Factor of Safety, Basic Numerical Problems.

CONCEPT OUTLINE

Factor of Safety : It is defined as the ratio of ultimate tensile stress to the working (or permissible) stress.

$$\text{FOS} = \frac{\text{Ultimate stress}}{\text{Permissible stress}}$$

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.11. A rod 150 cm long and of diameter 2.0 cm is subjected to an axial pull of 20 kN. If the modulus of elasticity of the material of the rod is 2×10^5 N/mm²; determine :
i. The stress,
ii. The strain, and
iii. The elongation of the rod.

Answer

Given : $L = 150$ cm $= 1500$ mm, $D = 2$ cm $= 20$ mm,

$A = \frac{\pi}{4}(20)^2 = 100\pi$ mm², $P = 20$ kN $= 20{,}000$ N, $E = 2.0 \times 10^5$ N/mm²

1. The stress (σ) is given as,

$$\sigma = \frac{P}{A} = \frac{20000}{100\pi} = 63.662 \text{ N/mm}^2.$$

2. Modulus of elasticity,

$$E = \frac{\sigma}{\varepsilon}$$

$\therefore$ Strain, $$\varepsilon = \frac{\sigma}{E} = \frac{63.662}{2 \times 10^5} = 0.000318$$

3. Strain,

$$\varepsilon = \frac{dL}{L}$$

$\therefore$ Elongation, $$dL = \varepsilon \times L$$
$$= 0.000318 \times 1500 = 0.477 \text{ mm.}$$

Que 1.12. Find the minimum diameter of a steel wire, which is used to raise a load of 4000 N if the stress in the rod is not to exceed 95 MN/m².

Answer

Given : $P = 4000$ N, $\sigma = 95$ MN/m² $= 95$ N/mm²
To Find : Diameter of wire in mm

1. We know that, Stress $= \frac{\text{Load}}{\text{Area}} = \frac{P}{A}$

$$95 = \frac{4000}{\frac{\pi}{4}D^2} = \frac{4000 \times 4}{\pi D^2} \text{ or } D^2 = \frac{4000 \times 4}{\pi \times 95}$$

$$D = 7.32 \text{ mm}$$

Que 1.13. A steel bar 2 m long 20 mm wide, 10 mm thick is subjected to a pull of 20 kN in the direction of length. Find the changes in length, breadth, thickness of bar. Take $E = 2 \times 10^5$ N/mm² and Poisson's ratio 0.3.

Answer

Given : $L = 2$ m, $b = 20$ mm, $t = 10$ mm, $P = 20$ kN, $E = 2 \times 10^5$ N/mm², $\mu = 0.3$.
To Find : Changes in length, breadth and thickness of bar.

1. Longitudinal strain,

$$\frac{\delta l}{l} = \frac{\text{Stress}}{\text{Modulus of elasticity}}$$

$$= \frac{P/A}{E} = \frac{P}{AE} = \frac{20 \times 10^3}{(20 \times 10) \times 2 \times 10^5} \qquad (\because A = bt)$$

$$= 0.5 \times 10^{-3}$$

2. Change is length, δl = Longitudinal strain × Original length

$$= (0.5 \times 10^{-3}) \times (2 \times 10^3) = 1.0 \text{ mm (increase)}$$

3. Lateral strain = Poisson's ratio × Longitudinal strain

$$= 0.3 \times (0.5 \times 10^{-3}) = 0.15 \times 10^{-3}$$

4. Change in breadth,

$$\delta b = b \times \text{Lateral strain} = 20 \times (0.15 \times 10^{-3})$$

$$= 3 \times 10^{-3} \text{ mm (decrease)}$$

5. Change in thickness,

$$\delta t = t \times \text{Lateral strain} = 10 \times (0.15 \times 10^{-3})$$

$$= 1.5 \times 10^{-3} \text{ mm (decrease)}$$

Que 1.14. **The modulus of rigidity of material is 39 GPa. A 10 mm diameter rod of the material is subjected to an axial tensile force of 5 kN and the change in its diameter is 0.002 mm. Calculate the Poisson's ratio of the material.**

Answer

Given : $G = 39$ GPa, $d = 10$ mm, $F = 5$ kN, $\delta d = 0.002$ mm
To Find : Poisson's ratio of the material.

1. The stress induced in the rod by tensile force,

$$\sigma = \frac{F}{A} = \frac{5 \times 10^3}{\frac{\pi}{4} \times (10)^2} = 63.66 \text{ N/mm}^2$$

2. Longitudinal strain, $\varepsilon = \dfrac{\sigma}{E} = \dfrac{\sigma}{2G(1+\mu)}$ $\qquad [\because \; E = 2G(1+\mu)]$

$$\varepsilon = \frac{63.66}{2 \times 39 \times 10^3 (1+\mu)} = \frac{8.16 \times 10^{-4}}{(1+\mu)}$$

3. Poisson's ratio,

$$\mu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}} = \frac{(\delta d / d)}{(8.16 \times 10^{-4})/(1+\mu)}$$

$$\mu = \frac{(0.002/10)}{(8.16 \times 10^{-4})/(1+\mu)}$$

$$= 0.245098\,(1+\mu)$$

$$0.7594\,\mu = 0.245098$$

$$\mu = 0.322$$

PART-5

Types of Beams under Various Loads, Statically Determinate Beams.

CONCEPT OUTLINE

Beam : A beam may be defined as a structure element which has one dimension considerably larger than the other two dimensions, namely breadth and depth, and is supported at few points.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.15. **Describe the various types of beams.**

Answer

Types of beams are as follows :

i. **Cantilever Beam :** A beam which is fixed at one end and free at the other end is known as cantilever beam (Fig. 1.15.1).

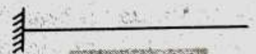


Fig. 1.15.1.

ii. **Simply Supported Beam :** A beam supported or resting freely on the supports at its both ends is known as simply supported beam (Fig. 1.15.2).

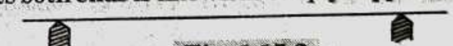


Fig. 1.15.2.

iii. **Overhanging Beam :** If the end portion of a beam is extended beyond the support, such beam is known as overhanging beam (Fig. 1.15.3).

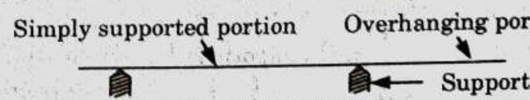


Fig. 1.15.3.

iv. **Fixed Beam :** A beam whose both ends are fixed or built-in walls, is known as fixed beam (Fig. 1.15.4). A fixed beam is also known as a built-in or encastre beam.

Fig. 1.15.4.

v. **Continuous Beam :** A beam which is provided more than two supports (Fig. 1.15.5) is known as continuous beam.

Fig. 1.15.5.

Que 1.16. **Describe statically determinate and indeterminate beam with examples.**

Answer

A. **Statically Determinate Beam :** A beam whose external support reaction can be calculated using the normal static equilibrium equations (*i.e.*, $\Sigma F_X = 0$, $\Sigma F_Y = 0$ and $\Sigma M = 0$) is known as statically determinate beam.
Examples : As simply supported beam, cantilever beam etc.

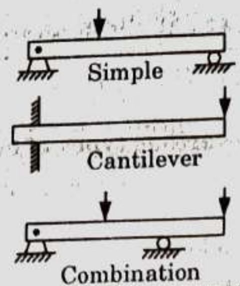


Fig. 1.16.1. Statically determinate beam.

B. **Statically Indeterminate Beam :** A beam having more supports than needed is known as statically indeterminate beam. To determine the support reaction in this kind of beam we must consider its load deformation equations in addition to normal static equilibrium equations.
Examples : Continuous beam, end supported beam and fixed beams etc.

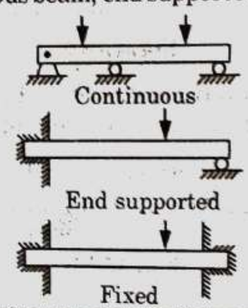


Fig. 1.16.1. Statically indeterminate beam.

PART-6

Shear Force and Bending Moment in Beams, Shear Force and Bending Moment Diagrams.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.17. **What do you mean by shear force ? Also define shear force diagram.**

Answer

A. **Shear Force (SF) :**
1. Shear is a strain produced by pressure in the structure of a beam when its layers are laterally shifted in relation to each other.
2. Shear force is the force that tries to shear off the section of a beam.
3. It is obtained as algebraic sum of all forces acting normal to axis of beam, either to the left or to the right of section.
4. If shear force (F) tries to push left portion upward with respect to right portion then shear force is taken as positive and vice versa.

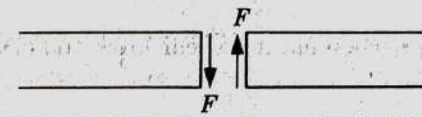


Fig. 1.17.1. Internal forces at section; positive shear force.

B. **Shear Force Diagram (SFD) :**
1. SFD represents the variation of shear force along the length of a beam.

Que 1.18. **What is bending moment and define bending moment diagram.**

Answer

A. **Bending Moment :** Bending moment is the moment that tries to bend the beam and is obtained as algebraic sum of moment of all forces about the section, acting either to left or to the right of section.
Sign Convention :

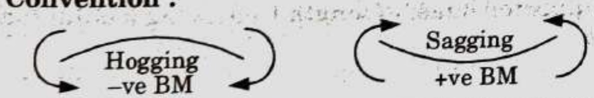


Fig. 1.18.1. External effect of bending moment.

B. Bending Moment Diagram (BMD) : BMD represents the variation of bending moment along the length of beam.

Que 1.19. **Write the steps involve in drawing SFD and BMD. Also define point of contraflexure.**

Answer

A. Steps Involve in Drawing SFD and BMD :

1. Obtain the values of all external support reactions on the beam by applying equilibrium equations.
2. Now cut the beam either to the right or to the left of an arbitrary transverse section with a free body diagram.
3. Assume that the shear force and bending moment acting on the cut section are in positive direction.
4. Now use the equilibrium equation to the section and get the expression for the shear force and bending moment acting at the cut section.
5. Following are some important points :
   i. Always choose that part of the beam which involves smaller number of forces either to the right or to the left of the arbitrary section.
   ii. Always avoid using a transverse section which coincides with the location of concentrated load or couple.

B. Sign Convention for Shear Force and Bending Moment :

1. For left side portion downward shear force and anticlockwise moment are positive.
2. And for right side portion upward shear force and clockwise moment are positive.

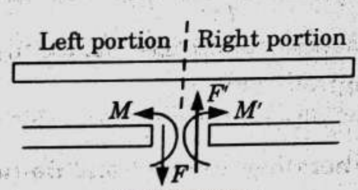


Fig. 1.19.1.

C. Point of Contraflexure : The point of contraflexure is a point which represents the section on the beam where bending moment is zero or bending moment changes its sign.

Que 1.20. **Draw the shear force and bending moment diagrams for simply supported beam of length L carrying a point load W at its middle point.**

Answer

A. Shear Force Diagram (SFD) :

1. Fig. 1.20.1 shows a beam AB of length L simply supported at the ends A and B and carrying a point load W at its middle point C.
2. The reactions at the support will be equal to $W/2$ as the load is acting at the middle point of the beam. Hence $R_A = R_B = W/2$.
3. Take a section X at a distance x from the end A between A and C.

   Let, F_x = Shear force at X,

   and M_x = Bending moment at X.
4. Here we have considered the left portion of the section. The shear force at X will be equal to the resultant force acting on the left portion of the section. But the resultant force on the left portion is $W/2$ acting upwards.
5. But according to the sign convention, the resultant force on the left portion acting upwards is considered positive. Hence shear force at X is positive and its magnitude is $W/2$.

$$\therefore \quad F_x = + W/2$$

Hence the shear force between A and C is constant and equal to $+ W/2$.

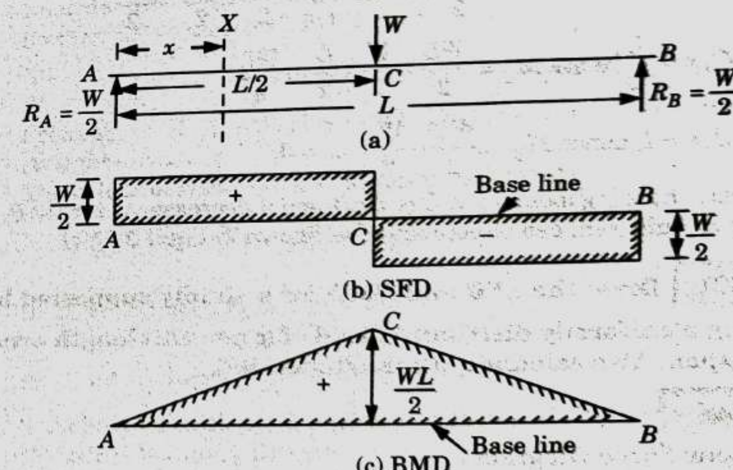


Fig. 1.20.1. SFD and BMD.

6. Now consider any section between C and B at distance x from end A. The resultant force on the left portion will be

   $(W/2 - W) = - W/2$.
7. This force will also remain constant between C and B. Hence shear force between C and B is equal to $- W/2$.
8. At the section C the shear force changes from $+ W/2$ to $- W/2$.

B. Bending Moment Diagram (BMD) :

1. The bending moment at any section between A and C at a distance of x from the end A is given by,

$$M_x = R_A x \quad \text{or} \quad M_x = +(W/2)\,x \qquad ...(1.20.1)$$

Bending moment will be positive as for the left portion of the section, the moment of all forces at X is clockwise.

2. Moreover, the bending of beam takes place in such a manner that concavity is at the top of the beam.

At A, $x = 0$ hence, $M_A = (W/2) \times 0 = 0$

At C, $= \dfrac{L}{2}$ hence, $M_C = \dfrac{W}{2} \times \dfrac{L}{2} = \dfrac{WL}{4}$.

From eq. (1.20.1), it is clear that BM varies according to straight line law between A and C. BM is zero at A and it increases to $WL/4$ at C.

3. The bending moment at any section between C and B at a distance x from the end A is given by,

$$M_x = R_A x - W \times \left(x - \frac{L}{2}\right)$$

$$= \frac{W}{2}x - Wx + W \times \frac{L}{2} = \frac{WL}{2} - \frac{Wx}{2}$$

At C, $x = \dfrac{L}{2}$ hence $M_C = \dfrac{WL}{2} - \dfrac{W}{2} \times \dfrac{L}{2} = \dfrac{WL}{4}$

At B, $x = L$ hence $M_B = \dfrac{WL}{2} - \dfrac{W}{2} \times L = 0$.

4. Hence, bending moment at C is $WL/4$ and it decreases to zero at B. Now the BM diagram can be completed as shown in Fig. 1.20.1(c).

Que 1.21. **Draw the SFD and BMD for a simply supported beam carrying a uniformly distributed load of w per unit length over the entire span. Also calculate the maximum BM.**

Answer

A. Shear Force Diagram :

1. Fig. 1.21.1 shows a beam AB of length L simply supported at the ends A and B and carrying a uniformly distributed load of w per unit length over the entire length.

2. The reactions at the supports will be equal and their magnitude will be half the total load on the entire length.

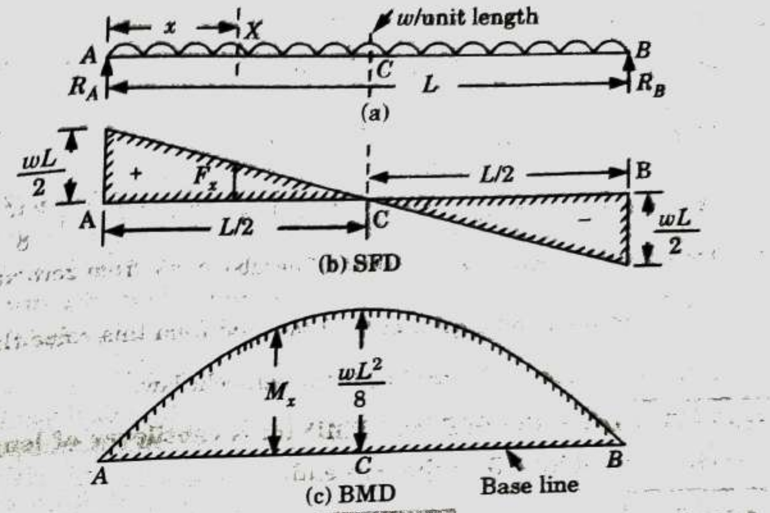


Fig. 1.21.1.

Let, R_A = Reaction at A, and R_B = Reaction at B

$$\therefore \quad R_A = R_B = \frac{wL}{2}$$

3. Consider any section X at a distance x from the left end A. The shear force at the section (*i.e.*, F_x) is given by,

$$F_x = +R_A - wx = +\frac{wL}{2} - wx \qquad ...(1.21.1)$$

From eq. (1.21.1), it is clear that the shear force varies according to straight line law.

4. The values of shear force at different points are :

At A, $x = 0$ hence $F_A = +\dfrac{wL}{2} - \dfrac{w0}{2} = +\dfrac{wL}{2}$

At B, $x = L$ hence $F_B = +\dfrac{wL}{2} - wL = -\dfrac{wL}{2}$

At C, $x = \dfrac{L}{2}$ hence $F_C = +\dfrac{wL}{2} - \dfrac{wL}{2} = 0$

The shear force diagram is drawn as shown in Fig. 1.21.1(b).

B. Bending Moment Diagram :

1. The bending moment at the section X at a distance x from left end A is given by,

$$M_x = +R_A x - wx\,\frac{x}{2}$$

$$= \frac{wL}{2}x - \frac{wx^2}{2} \qquad \left(\because R_A = \frac{wL}{2}\right) \qquad ...(1.21.2)$$

From eq. (1.21.2), it is clear that BM varies according to parabolic law.

2. The values of BM at different points are :

At A, $x = 0$ hence $M_A = \frac{wL}{2} 0 - \frac{w0}{2} = 0$

At B, $x = L$ hence $M_B = \frac{wL}{2} L - \frac{w}{2} L^2 = 0$

At C, $x = \frac{L}{2}$ hence $M_C = \frac{wL}{2}\frac{L}{2} - \frac{w}{2}\left(\frac{L}{2}\right)^2 = \frac{wL^2}{4} - \frac{wL^2}{8} = +\frac{wL^2}{8}$

3. Thus the BM increases according to parabolic law from zero at A to $+\frac{wL^2}{8}$ at the middle point of the beam and from this value the BM decreases to zero at B according to the parabolic law.

Que 1.22. **Draw the SFD and BMD for a cantilever of length L carrying a point load W at the free end.**

Answer

A. Shear Force Diagram :

1. Fig. 1.22.1 shows a cantilever AB of length L fixed at A and free at B and carrying a point load W at the free end B.

Let, F_x = Shear force at X.

M_x = Bending moment at X.

2. Take a section X at a distance x from the free end. Consider the right portion of the section.

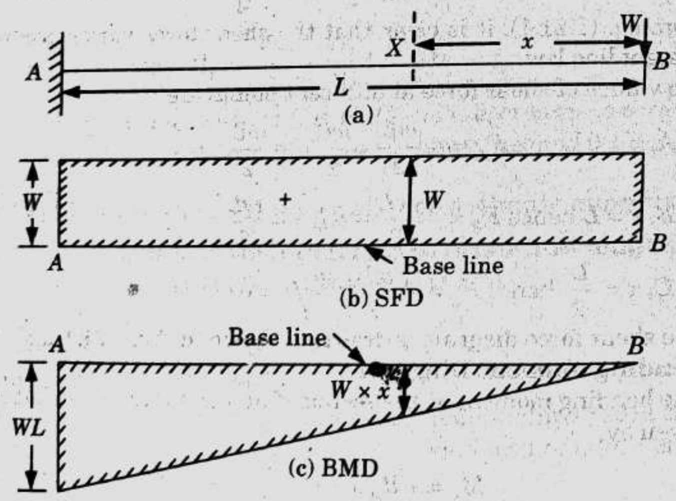


Fig. 1.22.1.

3. The shear force at this section is equal to the resultant force acting on the right portion at the given section.

4. But the resultant force acting on the right portion at the section X is W and acting in the downward direction.

5. But a force on the right portion acting downwards is considered positive. Hence shear force at X is positive.

$\therefore$ $F_x = + W$

6. The shear force will be constant at all sections of the cantilever between A and B as there is no other load between A and B. The shear force diagram is shown in Fig. 1.22.1(b).

B. Bending Moment Diagram :

1. The bending moment at the section X is given by,

$$M_x = - W \times x \quad ...(1.22.1)$$

2. From eq. (1.22.1), it is clear that BM at any section is proportional to the distance of the section from the free end.

At $x = 0$ *i.e.*, at B, BM = 0

At $x = L$ *i.e.*, at A, BM = WL

Hence BM follows the straight line law.

3. At point A, take $AC = WL$ in the downward direction. Joint B to C.

The BM diagram is shown in Fig. 1.22.1(c).

Que 1.23. **Draw the SFD and BMD for a cantilever of length L carrying a uniformly distributed load of unit per unit length over its entire length.**

Answer

A. Shear Force Diagram :

1. Fig. 1.23.1 shows a cantilever of length L fixed at A and carrying a uniformly distributed load of w per unit length over the entire length of the cantilever.

2. Take a section X at a distance of x from the free end B.

Let, F_x = Shear force at X.

M_x = Bending moment at X.

3. Here we have considered the right portion of the section. The shear force at the section X will be equal to the resultant force acting on the right portion of the section. But the resultant force on the right portion

$= w \times$ Length of right portion $= wx$.

4. This resultant force is acting downwards. But the resultant force on the right portion acting downwards is considered positive. Hence shear force at X is positive.

$\therefore$ $F_x = + wx$

5. The above equation shows that the shear force follows a straight line law.

At B, $x = 0$ and hence $F_x = 0$

At A, $x = L$ and hence $F_x = wL$

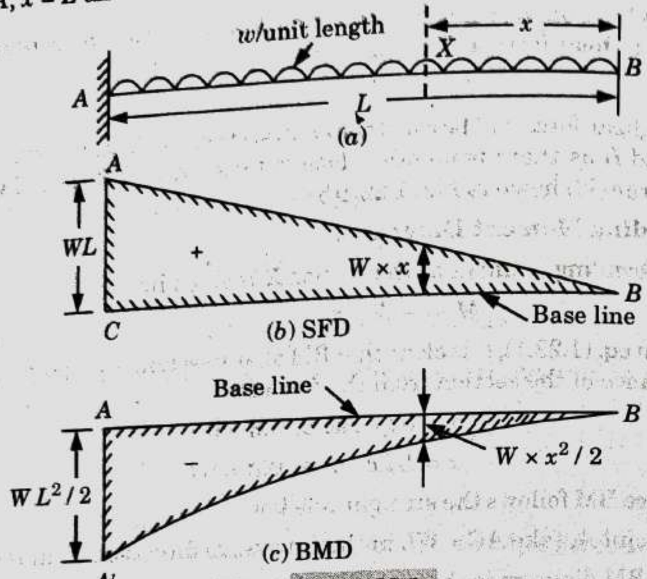


Fig. 1.23.1.

B. Bending Moment Diagram :

1. The bending moment at the section X is given by,

$$M_x = -(wx)\,\frac{x}{2} = -\,w\,\frac{x^2}{2} \quad \ldots(1.23.1)$$

2. From eq. (1.23.1), it is clear that BM at any section is proportional to the square of the distance of the section from the free end. This follows a parabolic law.

At B, $x = 0$, hence, $M_x = 0$

At A, $x = L$, hence, $M_x = -w\,(L^2/2)$

PART-7

Relationships between Load, Shear and Bending Moment, Basic Numerical Problems.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.24. **Derive the relation between load, shear force and bending moment.**

Answer

1. Consider a beam AB subjected to general loading.
2. Take a section $X - X'$ at a distance x from A.
3. Let intensity of load on beam is w/unit length.

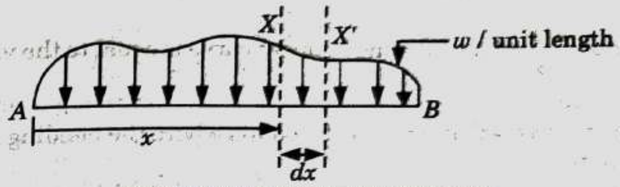


Fig. 1.24.1. Position of element.

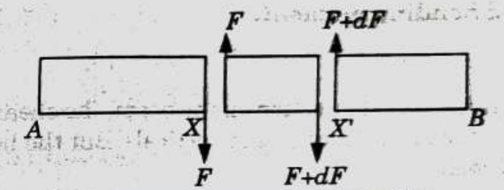


Fig. 1.24.2. FBD of elements.

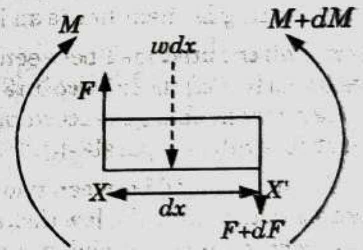


Fig. 1.24.3. Enlarged view of element dx.

4. Sum of all vertical forces $\Sigma F_Y = 0$

$$-wdx + F - (F + dF) = 0 \Rightarrow -wdx + F - F - dF = 0$$

$$\frac{dF}{dx} = -w$$

5. The slope dF/dx of the shear force curve is negative. The numerical value of the slope at any point is equal to the load per unit length at that point.
6. Sum of the moments about X', $\Sigma M_{X'} = 0$

$$(M + dM) - M - Fdx + wdx\left(\frac{dx}{2}\right) = 0$$

$$dM = Fdx - \frac{1}{2}w(dx)^2$$

7. Neglecting the higher powers of small terms, we get

$$Fdx = dM$$

$$\frac{dM}{dx} = F$$

8. The slope $\frac{dM}{dx}$ of the bending moment curve is equal to the value of the shear force.
9. The shear force will be zero at the points where the bending moment is maximum.

Que 1.25. **Explain in brief about the relation between loading, shear force and bending moment.**

Answer

1. If there is a point load at a section on the beam, the shear force suddenly changes (*i.e.*, the shear force line is vertical). But the bending moment remains the same.
2. If there is no load between two points, then the shear force does not change (*i.e.*, shear force line is horizontal). But the bending moment changes linearly (*i.e.*, bending moment line is an inclined straight line).
3. If there is a uniformly distributed load between two points, than the shear force changes linearly (*i.e.*, shear force line is an inclined straight line). But the bending moment changes according to the parabolic law. (*i.e.*, bending moment line will be a parabola).
4. If there is a uniformly varying load between two points then the shear force changes according to the parabolic law (*i.e.*, shear force line will be a parabola). But the bending moment changes according to the cubic law.

Que 1.26. **Determine the reactions at *B* and *E* of the beam, loaded as shown in Fig. 1.26.1 below.**

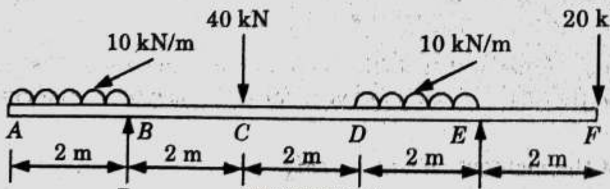


Fig. 1.26.1.

Answer

Given : Fig. 1.26.1.
To Find : Reactions at *B* and *E*.

1. Considering the equilibrium of the beam,

$$\Sigma F_y = 0$$

$$R_B + R_E = 10 \times 2 + 40 + 10 \times 2 + 20$$

$$R_B + R_E = 100 \text{ kN} \quad \text{...(1.26.1)}$$

2. Now taking moment about *B*, we have

$$\Sigma M_B = 0$$

$$-10 \times 2 \times 1 + 40 \times 2 + 10 \times 2 \times 5 - R_E \times 6 + 20 \times 8 = 0$$

$$R_E = 53.33 \text{ kN}$$

3. From eq. (1.26.1), we get

$$R_B = 100 - R_E = 100 - 53.33$$

$$R_B = 46.67 \text{ kN}$$

Que 1.27. **Calculate the support reactions in the given cantilever beam as shown in Fig. 1.27.1.**

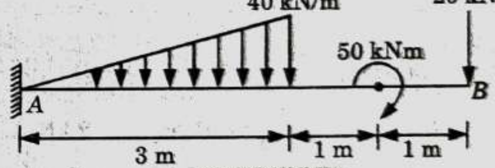


Fig. 1.27.1.

Answer

Given : Fig. 1.27.1.
To Find : Support reactions.

1. Considering the equilibrium of the beam,

$$\Sigma F_y = 0$$

$$R_A - \frac{1}{2} \times 3 \times 40 - 20 = 0$$

$$R_A = 80 \text{ kN}$$

2. Taking moment about point *A*, $\Sigma M_A = 0$

$$M_A - \frac{1}{2} \times 3 \times 40 \times \frac{2}{3} \times 3 - 50 - 20 \times 5 = 0$$

$$M_A = 120 + 50 + 100$$

$$M_A = 270 \text{ kN-m}$$

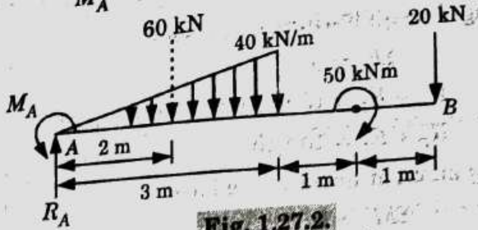


Fig. 1.27.2.

Que 1.28. **For the beam shown in Fig. 1.28.1, draw the shear force and bending moment diagram.**

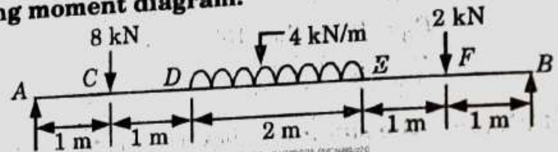


Fig. 1.28.1.

Answer

Given : Fig. 1.28.1.
To Find : SFD and BMD.

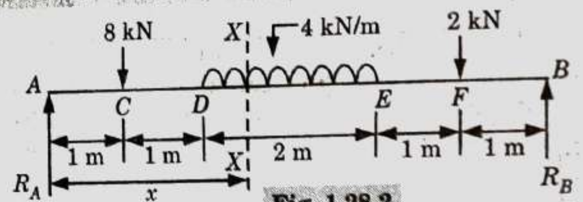


Fig. 1.28.2.

1. Considering, equilibrium of beam,

i. $$\Sigma F_y = 0 \Rightarrow R_A + R_B = 8 + 4 \times 2 + 2 = 18 \text{ kN}$$

ii. Bending moment about point A,

$$\Sigma M_A = 0 \Rightarrow 8 \times 1 + 4 \times 2 \times (2/2 + 2) + 2 \times 5 - R_B \times 6 = 0$$

$$R_B = 7 \text{ kN and } R_A = 11 \text{ kN}$$

2. **Shear Force :**

i. **Portion AC :** At point A, SF = 11 kN and it remains constant upto just left point C because there is no loading between this segment.

SF just on right side of $C = 11 - 8 = 3$ kN

ii. **Portion CD :** SF just left point of D is constant and SF at point $D = 3$ kN

iii. **Portion DE :** Consider any section at distance x from A

$$\text{SF} = 11 - 8 - (x - 2) \times 4 = 11 - 8 - 4x + 8 = 11 - 4x$$

SF just left side of E at $x = 4$ m

$$\text{SF} = 11 - 4x = 11 - 4 \times 4 = -5 \text{ kN}$$

SF just Right side of $E = -5$ kN

Shear force will be zero at $x = 11/4 = 2.75$ m

iv. **Portion EF :** SF at point $F = -5 - 2 = -7$ kN

v. **Portion FB :** SF at point $B = 0$

3. **Bending Moment :**

i. **Portion AC :** BM at point $A = 0$

BM at point $C = 11 \times 1 = 11$ kN-m

ii. **Portion CD :** BM at point $D = 11 \times 2 - 8 \times 1 = 14$ kN-m

iii. **Portion DE :** Consider any section at distance x from the end point A.

$$M_x = 11x - 8(x - 1) - 4(x - 2) \times \left(\frac{x - 2}{2}\right)$$

$$M_x = 3x + 8 - 2(x - 2)^2$$

At point D, $x = 2$, $M_D = 3 \times 2 + 8 = 14$ kN-m

At point D', $x = 2.75$, $M_{D'} = 3 \times 2.75 + 8 - 2(2.75 - 2)^2 = 15.125$ kN-m

At point E, $x = 4$, $M_E = 12 + 8 - 8 = 12$ kN-m

iv. **Portion EF :**

BM at point F, $x = 5$, $M_F = 11 \times 5 - 8 \times 4 - (4 \times 2) \times 2 = 7$ kN-m

v. **Portion FB :**

BM at point B, $M_B = 11 \times 6 - 8 \times 5 - (4 \times 2) \times 3 - 2 \times 1 = 0$

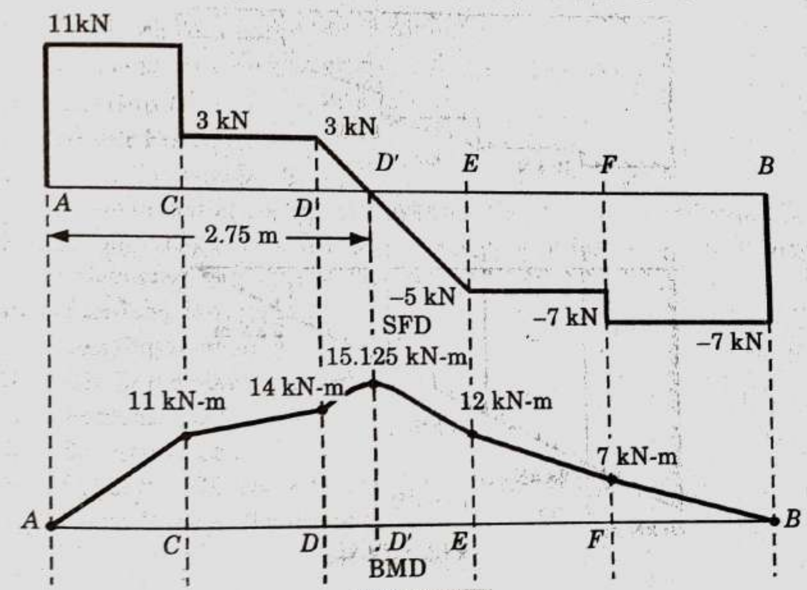
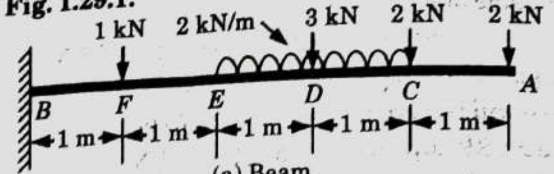


Fig. 1.28.3.

Que 1.29. **Draw the SFD and BMD diagrams for a cantilever loaded as shows in Fig. 1.29.1.**



(a) Beam

Fig. 1.29.1.

Answer

Given : Fig. 1.29.1.
To Find : SFD and BMD.

A. Calculations of Shear force :

$$S_A = -2 \text{ kN}$$
$$S_C = -2 - 2 = -4 \text{ kN}$$

1. From C to D, SF will change uniformly from -4 kN to -6 kN and total value of SF at D *i.e.* $S_D = -6 - 3 = -9$ kN
2. From D to E, SF will change uniformly from -9 kN to -11 kN
3. Shear force just after point F, $S_F = -11 - 1 = -12$ kN
$$S_B = -12 \text{ kN}$$
4. SFD is shown in Fig. 1.29.2(a)

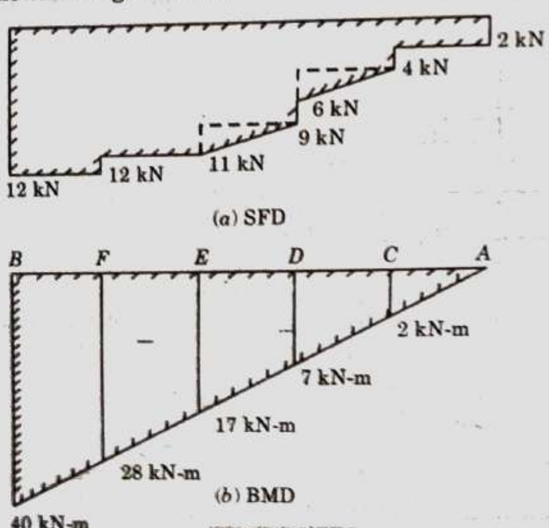


Fig. 1.29.2.

B. Calculations of Bending Moment :

1. $M_A = 0$, $M_C = -2 \times 1 = -2$ kN-m
2. $M_D = -2\,(1 + 1) - 2 \times 1 - 2 \times 1 \times 1/2 = -7$ kN-m
3. $M_E = -2(1 + 1 + 1) - 2 \times (1 + 1) - 3 \times 1 - 2 \times 2 \times 2/2 = -17$ kN-m
4. $M_F = -2(1 + 1 + 1 + 1) - 2 \times (1 + 1 + 1) - 3(1 + 1) - 2 \times 2(2/2 + 1)$
$= -8 - 6 - 6 - 8 = -28$ kN-m
5. $M_B = -2(1 + 1 + 1 + 1 + 1) - 2(1 + 1 + 1 + 1) - 3(1 + 1 + 1)$
$-2 \times 2(2/2 + 1 + 1) - 1 \times 1$
$= -10 - 8 - 9 - 12 - 1 = -40$ kN-m
6. BM diagram is shown in Fig. 1.29.1(b).

Que 1.30. **Determine the support reactions for the cantilever beam shown in Fig. 1.30.1 and sketch shear force and bending moment diagrams.**

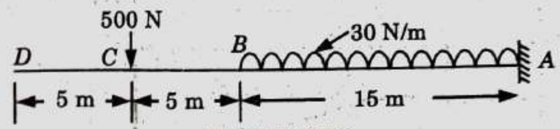


Fig. 1.30.1.

Answer

Given : Fig. 1.30.1.
To Find : i. Support reaction
ii. SFD and BMD.

A. Support Reactions and Moment :

Let, support reaction be $R_A = 500 + 30 \times 15 = 950$ N

B. Portion DC :

i. Shear Force :

1. Shear force at $D = 0$
As no load is acting in portion DC so the shear force till point $C = 0$
2. At point C a downward force of 500 N is acting hence shear force of C will change suddenly $= -500$ N

ii. Bending Moment :

1. Bending moment at $D = 0$
2. Bending moment till point $C = 0$.

C. Portion CB :

i. Shear Force :

1. In portion CB, shear force will be constant till point B.
2. Shear force at B = Shear force at $C = -500$ N

ii. Bending Moment :

1. Bending moment at point $C = 0$
2. Bending moment in portion CB is a straight line.
3. Bending moment at point $B = -500 \times 5 = -2500$ N-m

D. Portion *BA* :

i. Shear Force :

1. In portion BA, shear force will be a straight line.
2. Shear force at $B = -500$ N
3. Shear force at $A = -500 - 30 \times 15 = -950$ N

ii. Bending Moment :

1. Bending moment in portion BA will be a parabola due to UDL.
2. Bending moment at $A = -500 \times 20 - (30 \times 15) \times 15/2 = -13375$ N-m

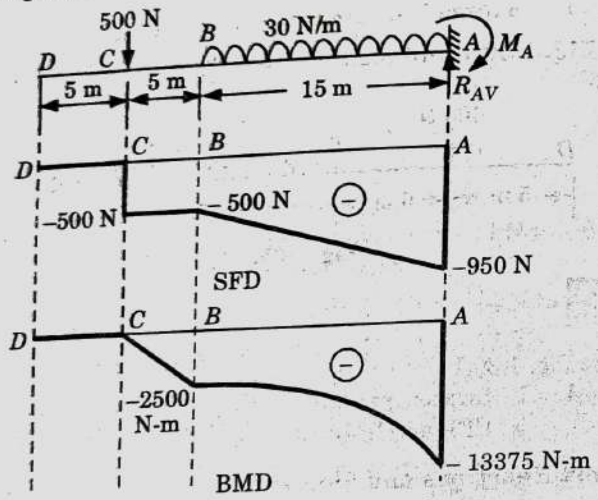


Fig. 1.30.2.

Que 1.31. **Draw the SFD and BMD of the loaded beam as shown in Fig. 1.31.1.**

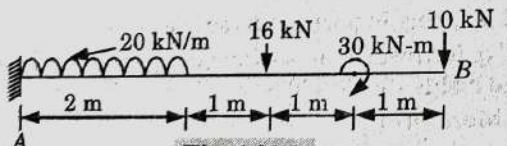


Fig. 1.31.1.

Answer

Given : Fig. 1.31.1.
To Find : SFD and BMD.

A. Support Reactions :

1. $$\Sigma F_V = 0,$$
$$R_A - 20 \times 2 - 16 - 10 = 0 \Rightarrow R_A = 66 \text{ kN}$$
2. $$+\circlearrowleft \Sigma M_A = 0$$
$$M_A - (2 \times 20 \times 1) - (16 \times 3) - 30 - (10 \times 5) = 0$$
$$M_A = 168 \text{ kN-m}$$

B. Shear Force :

1. Shear force at $A = R_A = 66$ kN
2. Shear force in portion AC, $F_x = R_A - 20x = 66 - 20x$
3. At point C, Shear force, $F_{AC} = 66 - 20 \times 2 = 26$ kN
4. Shear force in portion CD, $F_{CD} = 26$ kN
5. Shear force at D, $F_D = 26 - 16 = 10$ kN
6. Shear force in portion DE and EB, $F_{DE} = 10$ kN
7. Shear force at point B, $F_B = 10 - 10 = 0$ kN

C. Bending Moment :

1. Bending moment at A, $M_A = 168$ kN-m
2. Bending Moment in portion AC,
$$M_x = 168 - R_A \times x + 20 \times x \times x / 2 = 168 - 66x + 10x^2$$
3. BM at C, $M_C = 168 - 66 \times 2 + 10 \times 2^2 = 76$ kN-m
4. BM at D, $M_D = 168 - (66 \times 3) + (40 \times 2) = 50$ kN-m
5. BM at LHS of E, $M_E = 168 - (66 \times 4) + (40 \times 3) + 16 \times 1 = 40$ kN-m
6. BM at RHS of E, $M_E = 168 - (66 \times 4) + (40 \times 3) + (16 \times 1) - 30 = 10$ kN-m
7. BM at B, $M_B = 168 - (66 \times 5) + (40 \times 4) + (16 \times 2) - 30 = 0$ kN-m

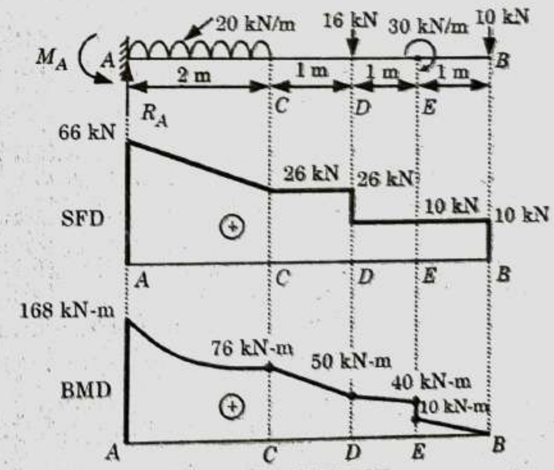


Fig. 1.31.2.

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2
UNIT

Introduction to IC Engines and RAC

CONTENTS

PART-1

IC Engine : Basic Components, Construction and Working of Two Stroke and Four Stroke SI and CI Engine.

CONCEPT OUTLINE

IC Engines : The engines in which the combustion takes place inside the engine or within the cylinder are known as internal combustion engines.

Types of IC Engine :

1. Spark Ignition (SI) engine.
2. Compression Ignition (CI) engine.

Two Stroke Engine : The engines in which cycle of operation completes in two stroke of piston or one revolution of crankshaft are known as two stroke engines.

Four Stroke Engine : The engines in which cycle of operation completes in four stroke of piston or two revolution of crankshaft are known as four stroke engines.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. **Classify the internal combustion engine.**

Answer

Internal combustion engine can be classified as follows :

i. **According to Basic Engine Design :**
1. Reciprocating engine, and
2. Rotary engine.

ii. **According to Working Cycle :**
1. Otto cycle engine, and
2. Diesel cycle engine.

iii. **According to Number of Stroke :**
1. Four stroke engine, and
2. Two stroke engine.

iv. **According to Fuel Employed :**
1. Gasoline or petrol engine,
2. Diesel engine,

3. LPG engine, and
4. CNG engine.

v. According to Fuel Supply and Mixture Preparation :

1. Carbureted type : Fuel is supplied through carburetor.
2. Injection type : Fuel injected into inlet port or inlet manifold.

vi. According to Method of Ignition :

1. Battery ignition, and
2. Magneto ignition.

vii. According to Method of Cooling :

1. Water cooled engine, and
2. Air cooled engine.

viii. According to Cylinder Arrangement :

1. Inline engine,
2. *V* - engine, and
3. Radial engine.

Que 2.2. Describe the basic terminologies used in internal combustion engine.

Answer

Basic terminologies used in internal combustion engine are as follows :

i. **Cylinder Bore :** It is the nominal inner diameter of the working cylinder. It is represented by *D* or *d*.

ii. **Piston Area :** It is the area of a circle of diameter equal to the cylinder bore.

iii. **Stroke :** It is the distance through which a working piston moves between two successive reversals of its direction of motion. It is represented by *L*.

iv. **Bottom Dead Centre (BDC) :** It is the dead centre when the piston is nearest to the crankshaft or lowest position of the piston towards the crank end side of cylinder.

v. **Top Dead Centre (TDC) :** It is the dead centre when the piston is farthest from the crankshaft or top most position of the piston towards cover end side of cylinder.

vi. **Displacement Volume or Piston Swept Volume :** This is the volume swept by the piston moving from one dead centre to other. It is calculated as the product of piston area and stroke.

$$v_s = \text{Piston area } (A) \times \text{Stroke } (L)$$

vii. **Clearance Volume :** The volume contained in the cylinder above the top of the piston when the piston is at top dead centre is called clearance volume.

viii. **Cylinder Volume :** The sum of swept volume and clearance volume is known as cylinder volume,

$$v = v_s + v_c$$

ix. **Compression Ratio :** This is defined as the ratio of the volume at the beginning of compression to the volume at the end of compression.

$$r = \frac{v_c + v_s}{v_c} = 1 + \frac{v_s}{v_c}$$

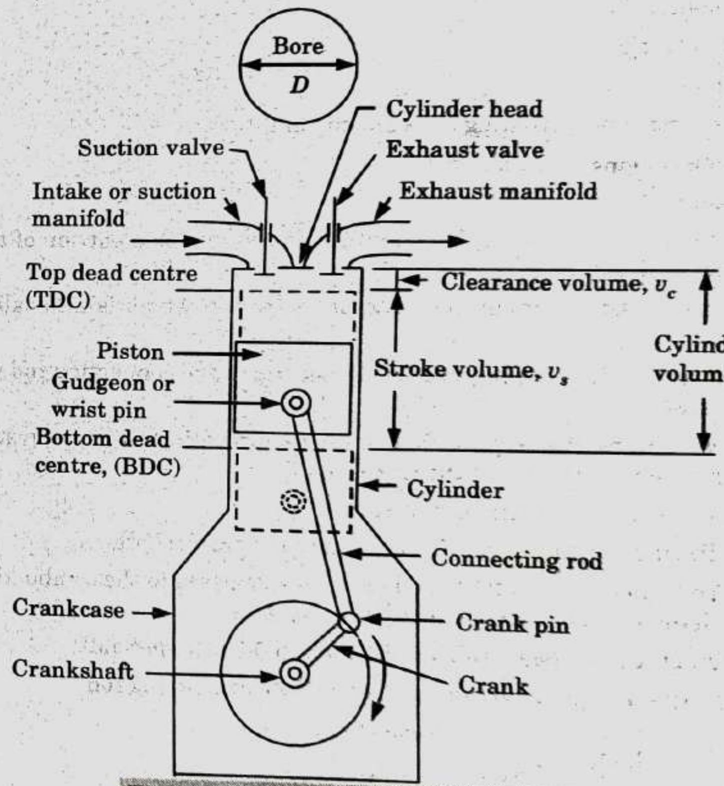


Fig. 2.2.1. Parts and terminology of IC engine.

Que 2.3. List out the main parts of internal combustion engine and explain with neat sketches any two important parts.

Answer

A. Main Parts of Internal Combustion Engine :

1. Cylinder head,
2. Manifolds,

3. Sump or oil span,
4. Gasket,
5. Cylinder,
6. Pistons,
7. Piston rings,
8. Connecting rod,
9. Piston pins,
10. Crankshaft,
11. Main bearings,
12. Mufflers,
13. Valves and valve actuating mechanism, and
14. Cylinder block and crank case.

B. Piston :

1. A piston is cylindrical in shape and forms the movable portion of the combustion chamber.
2. The gas pressure acts on the head of the piston which is also called crown.
3. The force due to this pressure is transmitted to the connecting rod via the piston.
4. The connecting rod helps to change the reciprocating motion of piston into a revolving motion at the crank shaft.
5. Following are the functions of piston :
   i. To transmit the force of explosion to the crank shaft.
   ii. To form a seal, so that the high pressure gases in the combustion chamber do not escape into the crank case.
   iii. It serves as a heat transfer medium to the cylinder walls.
   iv. It acts as a guide to the small end of the connecting rod.

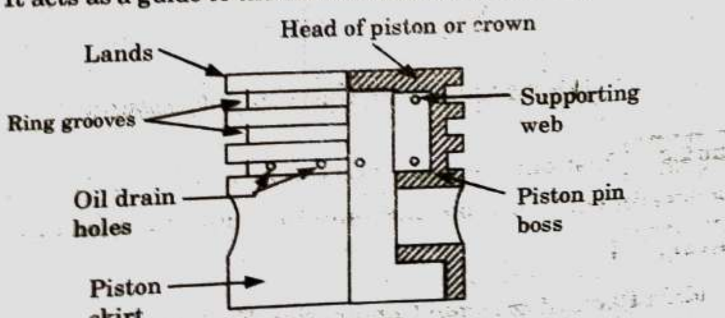


Fig. 2.3.1.

C. Piston Ring :

1. The construction of piston ring and nomenclature of its various parts is shown in (Fig. 2.3.2).
2. The ring is generally casted individually and machined carefully so that it is able to exert uniform pressure against the cylinder walls.

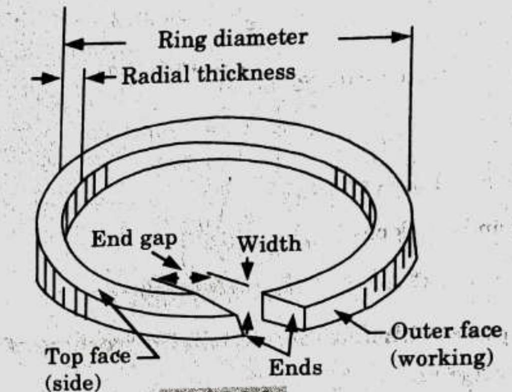


Fig. 2.3.2.

3. Following are the functions of piston ring :
   i. To form a seal for the high pressure gases from the combustion chamber against leak into the crank case.
   ii. To provide easy passage for heat flow from the piston crown to the cylinder walls.
   iii. To maintain sufficient lubricating oil on cylinder walls throughout the entire length of the piston travel.

Que 2.4. **Explain the working of two stroke engine with a suitable sketch.**

Answer

1. In two stroke engine, working is completed in two stroke of the piston or in one revolution of the crank.
2. In a two stroke engine, suction is achieved by air compressed in crankcase or blower. The induction of compressed air in the cylinder removes the product of combustion. Thus no separate piston motions are required for suction and exhaust.
3. The air or charge is suck through the spring loaded inlet valve during the upward motion of piston in compression stroke.
4. After compression, ignition and expansion takes place in usual way. During expansion stroke, the air in the crankcase is compressed.

5. Near the end of the expansion stroke the piston uncovers the exhaust ports. The cylinder pressure drop to atmospheric temperature as the combustion product leaves the cylinder.
6. Further downward motion of the piston uncovers the transfer ports, thus allowing the slightly compressed air in the crankcase to enter the cylinder space.

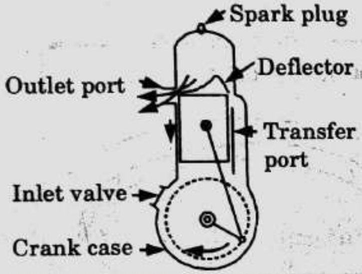


Fig. 2.4.1. Two stroke engine.

Que 2.5. **Explain with suitable sketch, the working of four stroke spark ignition engine.**

Answer

Working of four stroke spark ignition engine is as follows :

i. Suction Stroke :

1. Suction stroke (Fig. 2.5.1) starts when the piston is at top dead centre position and about to move toward bottom dead centre.
2. During this stroke, inlet valve is open and outlet valve is closed.
3. Due to the suction created by downward motion of the piston, charge consists of mixture of air and fuel drawn into the cylinder.
4. At the end of suction stroke, both the inlet and outlet valves are closed.

ii. Compression Stroke :

1. The fresh charge taken into the cylinder during the suction stroke is compressed during the return stroke of the piston.
2. In this stroke, both the inlet and outlet valves remain closed.
3. Just before the end of the compression stroke, mixture of air and fuel is ignited with the help of spark plug.
4. Burning takes place when the piston is almost at top dead centre.
5. During the burning process, chemical energy of the charge is converted into sensible energy and producing a temperature rise of about 2000 °C and pressure is also increased.

iii. Expansion or Working Stroke :

1. Due to high pressure, burnt gases forces the piston towards the bottom dead centre so power is obtained during this stroke.

2. Both pressure and temperature decreases during this stroke.
3. In this stroke, both the valves remain closed.

iv. Exhaust stroke :

1. In this stroke, inlet valve is closed and outlet valve is open.
2. Piston moving from bottom dead centre to top dead centre and burnt gases sweeps out from the cylinder.
3. This stroke is shown in Fig. 2.5.1.

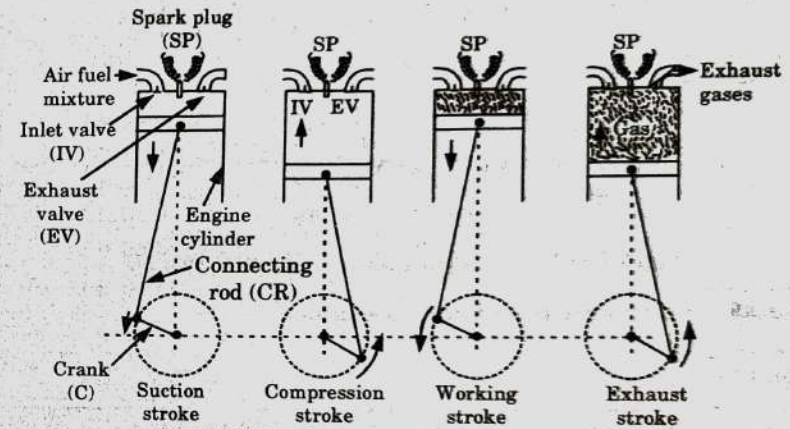


Fig. 2.5.1. Four stroke spark ignition engine.

Que 2.6. **Explain the working of a four stroke compression ignition (CI) engine with the suitable sketch.**

Answer

The working operation for the four stroke CI engine is as follows :

i. Suction Stroke :

1. Only air is inducted during the suction stroke.
2. During this stroke inlet valve is open while outlet valve is closed.

ii. Compression Stroke :

1. Both the valves are closed during compression stroke.
2. Air drawn during the suction stroke is compressed to high temperature and pressure.

iii. Expansion or Working Stroke :

1. During the beginning of this stroke, fuel is injected.
2. The rate of injection is such that the combustion maintains the pressure constant.
3. After the injection of fuel, the products of combustion expand.

4. Both the valves are closed during this stroke.

iv. Exhaust Stroke :

1. In this stroke, the exhaust valve is open and inlet valve remains closed.
2. Burnt gases escape from the cylinder by upward motion of the piston.

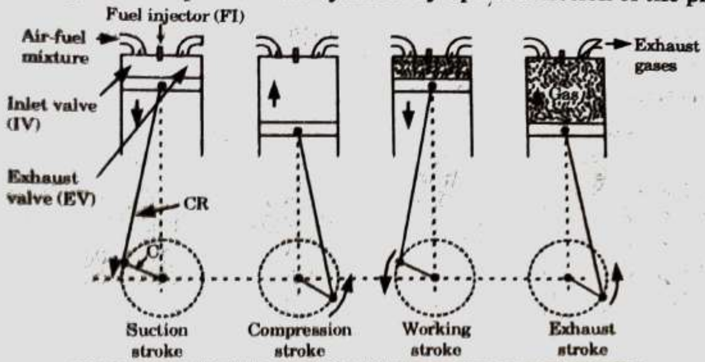


Fig. 2.6.1. Four stroke compression ignition engine.

Que 2.7. **Compare the SI and CI engine.**

Answer

S. No.	Description	SI engine	CI engine
1.	Basic cycle	Otto cycle	Diesel cycle
2.	Fuel used	Gasoline (petrol)	Diesel
3.	Ignition	Spark plug is used.	Self ignition due to high pressure and temperature caused of compression of air.
4.	Compression ratio	6 to 10	14 to 22
5.	Weight	Lighter	Heavier
6.	Speed	High speed	Low speed
7.	Efficiency	Lower efficiency.	Higher efficiency.

Que 2.8. **Differentiate between four stroke and two stroke engines.**

Answer

S. No.	Four Stroke Engine	Two Stroke Engine
1.	Cycle is completed in four stroke of piston or two revolution of the crankshaft.	Cycle is completed in two stroke of the piston or one revolution of crankshaft.
2.	Turning moment is not so uniform and hence heavier flywheel is needed.	More uniform turning moment and hence lighter flywheel is needed.
3.	Due to one power stroke in two revolutions, power produced for same size of engine is small.	Due to one power stroke in one revolution, power produced for same size of engine is more.
4.	Due to one power stroke in two revolutions, lesser cooling is required.	Due to one power stroke in one revolution, greater cooling and lubrication required.
5.	It contains valves.	It contains ports.
6.	Greater volumetric efficiency.	Less volumetric efficiency.
7.	Higher thermal efficiency.	Lower thermal efficiency.

PART-2

Merits and Demerits, Scavenging Process, Introduction to Electric, and Hybrid Electric Vehicles.

CONCEPT OUTLINE

Scavenging Process : In a two stroke engine because of non-availability of an exhaust stroke at the end of an expansion stroke, its combustion chamber is left full of combustion products. The process of clearing the cylinder after the expansion stroke is called scavenging process.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.9. **Write down the merits and demerits of internal combustion engine.**

Answer

A. Merits of Internal Combustion Engine :

1. Size of engine is very less compared to external combustion engines.
2. Power to weight ratio is high.
3. Very suitable for small power requirement applications.
4. Starting time is very less.
5. High efficiency than external combustion engine.
6. No chances of leakage of working fluids and requires less maintenance.

B. Demerits of Internal Combustion Engine :

1. Variety of fuels that can be used is limited to very fine quality gaseous and liquid fuel.
2. Fuel used is costly like petrol or diesel.
3. Engine emissions are generally high compared to external combustion engine.
4. Not suitable for large scale power generation.
5. In case of reciprocating internal combustion noise is generated due to detonation of fuel.

Que 2.10. **What do you understand by hybrid electric vehicle (HEV) ? What are the components of HEV ? Also state its advantages.**

Answer

A. Hybrid Electric Vehicle :

1. The hybrid electric vehicle (HEV) is progressive step in reducing the environmental impacts of automobile use without losing comfort, performance, storage room and extended driving range.
2. Hybrid electric vehicle is an intelligent combination of benefits of internal combustion engine with electric motor.

B. Components of HEV :

i. Battery :

1. The battery in an HEV system is the energy storage device.
2. It consists of two or more electrochemical energy cells connected together to provide electrical energy.

ii. Generator :

1. The generator is similar to an electric motor.
2. It converts rotary mechanical energy into electrical power.

iii. Electric Motor :

1. The electric motor provides mechanical rotary energy to the shaft as per the electrical input provided.
2. Advanced electronics allow it to act as a motor as well as a generator.

C. Advantages of HEV :

1. The HEV system contains parts of both internal combustion engine and electric vehicles in an attempt to get the best of both worlds.
2. It is able to operate nearly twice as efficiently as traditional internal combustion vehicles.
3. It has equivalent power, range, cost and safety of a conventional vehicle while reducing fuel costs and harmful emissions.

Que 2.11. **Write short note on electric vehicles.**

Answer

1. An electric vehicle (EV), also called electrics is a vehicle that uses one or more electric motors or traction motors for propulsion.
2. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels, fuel cells or an electric generator to convert fuel to electricity.
3. It is one that operates on an electric motor, instead of an internal combustion engine that generates power by burning a mix of fuel and gases.
4. Therefore, such as vehicle is seen as a possible replacement for current-generation automobile, in order to address the issue of rising pollution, global warming, depleting natural resources, etc.
5. Though the concept of electric vehicles has been around for a long time, it has drawn a considerable amount of interest in the past decade amid a rising carbon footprint and other environmental impacts of fuel-based vehicles.

PART-3

Refrigeration : Its Meaning and Application, Unit of Refrigeration, Coefficient of Performance.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.12. **What do you mean by refrigeration ? Also write applications of refrigeration.**

Answer

A. Refrigeration :

1. Refrigeration means the cooling or removal of heat from a system.
2. It is the science of the producing and maintaining temperatures below that of the surrounding atmosphere *i.e.*, removal of heat from a substance under controlled conditions.

B. Applications of Refrigeration :

1. Making of ice.
2. It is used in transportation of food at a required temperature.
3. It is used in industrial and comfort air conditioning.
4. It is used in processing food products and beverages.
5. It is used in manufacturing and treatment of metals.

Que 2.13. **Define the following terms :**

i. Refrigerating effect,
ii. Unit of refrigeration, and
iii. Coefficient of performance (COP).

Answer

i. **Refrigerating Effect :** It is defined as the amount of cooling produced by a system. This cooling is obtained at an expense of some energy.

ii. **Unit of Refrigeration :**

1. The practical unit of refrigeration is expressed in terms of tonne of refrigeration or TR.
2. A tonne of refrigeration is defined as the amount of refrigeration effect produced by the uniform melting of one tonne of ice at 0 °C in 24 hours.
3. In actual practice, one tonne of refrigeration is taken as equivalent to 210 kJ / min or 3.5 kW (*i.e.*, 3.5 kJ / s).

iii. **Coefficient of Performance (COP) :**

1. The ratio of heat extracted (Q) in the refrigerator to the work done (W) on the refrigerant is known as coefficient of performance.
2. Mathematically,

$$(\text{COP})_{th} = Q/W$$

PART-4

Methods of Refrigeration, Construction and Working of Domestic Refrigerator.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.14. **What are the different methods of producing refrigeration ?**

Answer

Different methods of producing refrigeration are as follows :

i. **Ice Refrigeration :**

1. In this method the ordinary ice is used for keeping the space at temperature below the surrounding temperature.
2. The temperature of ice is considered to be 0 °C hence it can be used to maintain the temperatures of about 5 to 10 °C. To use the ice for refrigerating effect a closed and insulated chamber is required.
3. On one side of the chamber ice is kept while on the other side there is a space which is to be cooled where some material to be cooled can be placed.
4. If the temperature below 0 °C is required, then the mixture of ice and salt is used. This method of cooling is still being used for cooling the cold drinks, keeping the water chilled in thermos, etc.

ii. **Steam-Jet Refrigeration :**

1. This system is one of the methods employed by chemical agent machines for achieving mechanical refrigeration. Evidently water is used here as refrigerant.
2. Steam-Jet system is primarily used in installations where chilled water is required or the systems like cold storage where the temperatures required are more than 5 °C as water starts changing its volume at 4 °C and starts freezing at 0 °C. The principle of flash cooling is employed in achieving the objective.

iii. **Thermo-Electric Refrigeration :**

1. Thermoelectric effects refer to phenomenon involving the interchange of heat and electrical energy.
2. One familiar example is the heating effect due to the flow of an electric current in a resistor.

3. The electric power dissipation depends on the current flow I and the potential V according to the equation $P = VI$ or $P = I^2R$.
4. This type of energy conversion is irreversible, although some thermoelectric effects are reversible.

iv. Vapour Compression Refrigeration System :

1. Vapour compression refrigeration systems are the most commonly used among all refrigeration systems.
2. As the name implies, these systems belong to the general class of vapour cycles, wherein the working fluid (refrigerant) undergoes phase change at least during one process.
3. In a vapour compression refrigeration system, refrigeration is obtained as the refrigerant evaporates at low temperatures.
4. The input to the system is in the form of mechanical energy required to run the compressor. Hence these systems are also called as mechanical refrigeration systems.
5. Vapour compression refrigeration systems are available to suit almost all applications.

v. Vapour Absorption Refrigeration Systems :

1. Vapour Absorption Refrigeration Systems (VARS) belong to the class of vapour cycles similar to vapour compression refrigeration systems.
2. However, unlike vapour compression refrigeration systems, the required input to absorption systems is in the form of heat. Hence these systems are also called as heat operated or thermal energy driven systems.
3. Since conventional absorption systems use liquids for absorption of refrigerant, these are also sometimes called as wet absorption systems.
4. Similar to vapour compression refrigeration systems, vapour absorption refrigeration systems have also been commercialized and are widely used in various refrigeration and air conditioning applications.

Que 2.15. **Explain the construction and working of domestic refrigerator with neat sketch.**

Answer

A. Construction of Domestic Refrigerator :

1. The common type of domestic refrigerator is [redacted] cabinet shaped with compressor, [redacted] condenser and receiver fitted in the [redacted] basement.
2. The expansion valve and evaporator coils are exposed in the storage cabinet with the [redacted] carrying liquid refrigerant passing through the body. pipe(s)
3. The system works on closed cyclic operation with the help of heat transfer media called refrigerant.

B. Working of Domestic Refrigerator :

1. The heat of the items, to be cooled is carried to the evaporator coils by means of air trapped in the cabinet. The working fluid, known as a refrigerant, used in refrigerator readily evaporates and condenses or changes alternately between the vapour and liquid phases without leaving the refrigerator.
2. The refrigerant keeps circulating from evaporator coil to condenser till compressor motor is connected to the supply.
3. During evaporation, it absorbs heat from items placed in the refrigerator and in condensing or cooling it rejects heat outside the refrigerator.
4. The heat absorbed from items placed in the refrigerator during evaporation is used as its latent heat for converting it from liquid to vapor. Thus a cooling effect is created in the working fluid. And this decreases the temperature inside the refrigerator.

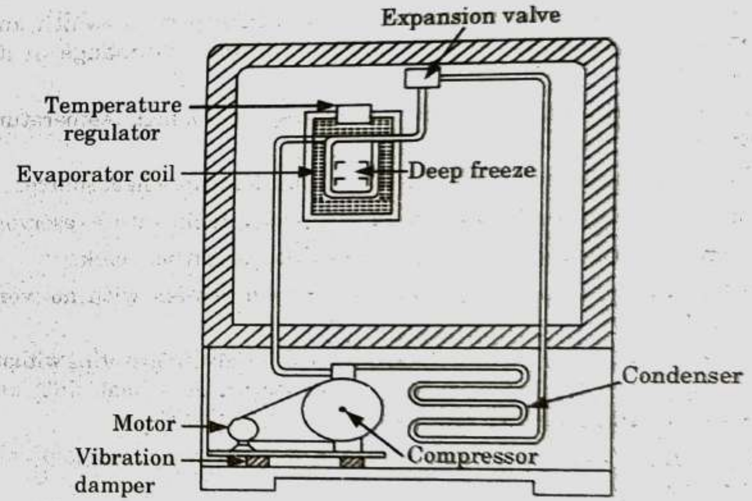


Fig. 2.15.1. Domestic refrigerator.

5. When a predetermined value of the temperature is achieved inside the refrigerator, thermostat switch operates and disconnects the compressor motor from the electric supply. Further circulation of refrigerant and its cooling effect stops.
6. After some time, when the temperature increases and reaches up to a predetermined value, thermostat operates again and connects the compressor motor to the supply. And the cooling process starts again. This cycle is repeated continuously to maintain the temperature in a predetermined temperature range.
7. In this way, the refrigerant is circulated through the coils of the refrigerator to maintain the temperature in the required temperature range.

PART-5

Concept of Heat Pump, Formula Based Numerical Problems on Cooling Load.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.16. **What do you mean by heat reservoir ?**

Answer

1. A heat reservoir is a body with a very large heat capacity to which, and from which, heat can be transferred without any change in its temperature.
2. Such a body at high temperature is referred to as a high temperature reservoir.
3. If heat is transferred from it, then it is considered as a heat source.
4. A body at low temperature is referred to as a low temperature reservoir.
5. If heat is transferred to it, then it is considered as a heat sink.
6. By definition, a heat reservoir is a closed system with no work interaction.
7. The environment constitutes the largest heat reservoir operating without any change in temperature usually employed as a heat sink, and sometimes as a heat source.
8. The mediums in the environment which are used as such are generally the following :
   i. Atmosphere air,
   ii. Ocean, river or well water, and
   iii. Ground.
9. The characteristic which remains constant for a heat reservoir is its temperature. Hence, a heat reservoir is characterised by its temperature.

Que 2.17. **Write short note on the following :**

i. **Heat pump.**
ii. **Refrigerator.**

Answer

i. **Heat Pump :**

1. A heat pump is a reversed heat engine. It receives heat from a low temperature reservoir (source) and rejects it to a high temperature reservoir (sink).
2. This transfer of heat from a low temperature body to a high temperature one is essentially a non-spontaneous process. And that calls for the help of an external work which is supplied to the heat pump (Fig. 2.17.1).
3. A heat pump extracts Q_2 amount of heat from the low temperature (T_2) source and delivers Q_1 amount of heat to the high temperature (T_1) sink by consuming W amount of external work.
4. Now, the first law of efficiency of a heat pump cycle is usually called the coefficient of performance.
5. It is the desired effect upon the external work supplied for obtaining that desired effect,

$$\text{COP} = \frac{\text{Desired effect}}{\text{Work input}}$$

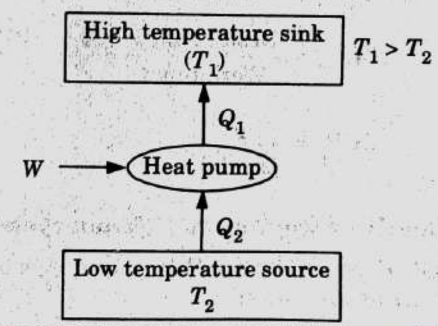


Fig. 2.17.1. A schematic diagram of a heat pump.

6. Now, the desired effect for a heat pump is to supply heat Q_1 to the hot body. Therefore,

$$\text{COP}_{\text{HP}} = \frac{Q_1}{W}$$

or

$$\text{COP}_{\text{HP}} = \frac{Q_1}{Q_1 - Q_2} \qquad (\because \; Q_1 - Q_2 = W)$$

ii. **Refrigerator :**

1. A refrigerator is similar to a heat pump.
2. It operates as a reversed heat engine.
3. Its duty is to extract heat as much as possible from the cold body/space and deliver the same to high temperature body/surroundings.

4. The desired effect of a refrigerator, under a steady state, is to pump out the heat in the same rate as is infiltrating into the system (Q_2) and in order to do so, the refrigerator or an air conditioner takes up W amount of external work (Fig. 2.17.2).

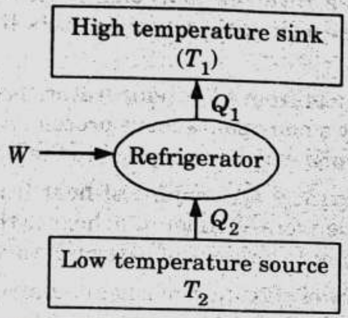


Fig. 2.17.2. A schematic diagram of a refrigerator.

5. The desired effect of a refrigerator is to remove Q_2 heat infiltrating into the cold space.
6. By using the external work, it rejects Q_1 heat to the high temperature reservoir (surroundings). Therefore,

$$\text{COP}_R = \frac{\text{Desired effect}}{\text{Work input}} = \frac{Q_2}{W}$$

or
$$\text{COP}_R = \frac{Q_2}{Q_1 - Q_2} \qquad (\because \; Q_1 - Q_2 = W)$$

Que 2.18. **A machine working on a Carnot cycle operates between 305 K and 360 K. Determine the COP when it is operated as :**
i. A refrigerating machine;
i. A heat pump.

Answer

Given : $T_1 = 260$ K, $T_2 = 305$ K
To Find : i. COP of a refrigerating machine, and
ii. COP of a heat pump.

1. COP of a refrigerating machine,

$$(\text{COP})_R = \frac{T_1}{T_2 - T_1} = \frac{260}{305 - 260} = 5.78$$

2. COP of a heat pump,

$$(\text{COP})_P = \frac{T_2}{T_2 - T_1} = \frac{305}{305 - 260} = 6.78$$

Que 2.19. **A Carnot refrigeration cycle absorbs heat at 270 K and rejects it at 300 K.**
i. Calculate the coefficient of performance of this refrigeration cycle.
ii. If the cycle is absorbing 1130 kJ/min at 270 K, how many kJ of work is required per second ?

Answer

Given : $T_1 = 270$ K, $T_2 = 300$ K, $Q_1 = 1130$ kJ/min

1. Coefficient of performance of Carnot refrigeration cycle.

$$(\text{COP})_R = \frac{T_1}{T_2 - T_1} = \frac{270}{300 - 270} = 9$$

2. Heat absorbed at 270 K,

$$Q_1 = 1130 \text{ kJ/min} = \frac{1130}{60} = 18.83 \text{ kJ/s}$$

3. We know that $(\text{COP})_R = \dfrac{Q_1}{W_R}$

$$9 = \frac{18.83}{W_R}$$

$$\therefore \quad W_R = 2.1 \text{ kJ/s}$$

Que 2.20. **A cold storage is to be maintained at – 5 °C while the surroundings are at 35 °C. The heat leakage from the surroundings into the cold storage is estimated to be 29 kW. The actual COP of the refrigeration plant is one-third of an ideal plant working between the same temperatures. Find the power required to drive the plant.**

Answer

Given : $T_1 = -5$ °C $= 268$ K, $T_2 = 35$ °C $= 308$ K, $Q_1 = 29$ kW
$(\text{COP})_{\text{actual}} = 1/3(\text{COP})_{\text{ideal}}$
To Find : Power required to drive the plant.

1. We know that the coefficient of performance of an ideal refrigeration plant is given as

$$(\text{COP})_{\text{ideal}} = \frac{T_1}{T_2 - T_1} = \frac{268}{308 - 268} = 6.7$$

2. Actual coefficient of performance,

$$(\text{COP})_{\text{actual}} = \frac{1}{3}(\text{COP})_{\text{ideal}} = \frac{1}{3} \times 6.7 = 2.233$$

3. We also know that,

$$(\text{COP})_{\text{actual}} = \frac{Q_1}{W_R}$$

$$W_R = \frac{Q_1}{(\text{COP})_{\text{actual}}} = \frac{29}{2.233} = 12.987 \text{ kW}$$

PART-6

Air Conditioning : Its Meaning and Application, Humidity, Dry Bulb, Wet Bulb and Dew Point Temperatures.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

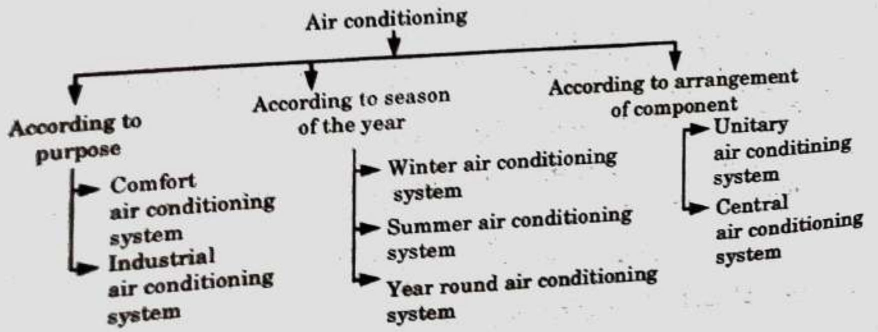
Que 2.21. What do you understand by air conditioning ? Describe three major ways of classifying air conditioning systems.

Answer

A. Air Conditioning :

1. It is that branch of engineering science which deals with the study of conditioning of air *i.e.*, supplying and maintaining desirable internal conditioning of air *i.e.*, supplying and maintaining desirable internal atmospheric condition for human comfort, irrespective of external conditions.
2. It is an assembly of different parts of the system used to produce a specified condition of air within a required space of building.

B. Classification of Air Conditioning :



Que 2.22. What are the main equipments used in an air conditioning system ?

Answer

The basic components of air conditioning system are as follows :

i. **Circulation Fan :** It is used to move air to and from the room.
ii. **Air Conditioning Unit :** It is a unit which consists of cooling and dehumidifying processes for summer air conditioning or heating and humidification processes for winter air conditioning.
iii. **Supply Duct :** It directs the conditioned air from the circulating fan to the space to be air conditioned at proper point.
iv. **Supply Outlets :** These are grills which distribute the conditioned air evenly in the room.
v. **Return Outlets :** These are the openings in a room surface which allow the room air to enter the return duct.
vi. **Filters :** It is used for removing the dust, dirt and other harmful bacteria.

Que 2.23. What are the applications of air conditioning in industry ?

Answer

Applications of air conditioning in industry are as follows :

1. To provide comforts to the workers.
2. To provide necessary low temperature conditions required for the manufacture of certain products in industries such as textile, printing and refineries.
3. To provide a clean room for the precision work, laboratories and quality control rooms.
4. To preserve food during storage and transportation.
5. For drying of products.

Que 2.24. What do you mean by psychrometry ? Briefly describe the terms related with psychrometry.

Answer

A. Psychrometry : It is that branch of engineering science which deals with the study of moist air *i.e.*, dry air mixed with water vapour or humidity.

B. Psychrometric Term :

i. **Dry Air :**

1. The dry air is a mixture of a number of gases such as nitrogen, oxygen,

carbon dioxide, hydrogen, argon, etc.

2. The molecular mass of dry air is taken as 28.966 and the gas constant (R_{air}) is 0.287 kJ/kg-K

ii. **Moist Air :**

1. It is a mixture of dry air and water vapour.
2. The amount of water vapour present in the air depends upon the absolute pressure and temperature of the mixture.

iii. **Saturated Air :** It is a mixture of dry air and water vapour, when the air has diffused the maximum amount of water vapour into it.

iv. **Degree of Saturation :** It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it is saturated at the same temperature.

v. **Humidity or Specific Humidity :** It is the mass of water vapour present in 1 kg of dry air and is generally expressed in terms of grams of water per kg of dry air.

vi. **Absolute Humidity :** It is the mass of water vapour present in 1 m^3 of dry air and is generally expressed in terms of gram per cubic meter of dry air.

vii. **Relative Humidity :** It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure.

viii. **Dry Bulb Temperature (DBT) :**

1. It is the temperature of air recorded by an ordinary thermometer, when it is not affected by the moisture present in the air.
2. It is generally denoted by T_d or T_{db}.

ix. **Wet Bulb Temperature (WBT) :**

1. It is the temperature of air recorded by a thermometer, when its bulb is surrounded by a wet cloth exposed to the air.
2. It is generally denoted by T_w or T_{wb}.

x. **Wet Bulb Depression :**

1. It is the difference between dry bulb and wet bulb temperature at any point *i.e.*, $(T_{db} - T_{wb})$.
2. It indicates relative humidity of the air.

xi. **Dew Point Temperature (DPT) :** It is the temperature of air recorded by a thermometer, when the moisture (water vapour) present in it begins to condense.

xii. **Dew Point Depression :** It is the difference between the dry bulb and dew point temperature *i.e.*, $(T_{db} - T_{dp})$.

xiii. **Sensible Heat :** It is the heat that changes the temperature of a substance when added or removed from it.

PART-7

Comfort Conditions, Construction and Working of Window Air Conditioner.

CONCEPT OUTLINE

Human Comfort : It is that condition of mind, which expresses satisfaction with the thermal environment.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.25. **Discuss in brief about thermal analysis of human body.**

Answer

1. The human body works best at a certain temperature but it cannot tolerate wide range of variations in their environmental temperatures.
2. The human body maintains its thermal equilibrium with the environment by means of three modes of heat transfer *i.e.*, evaporation, radiation and convection.
3. A human body feels comfortable when the heat produced by metabolism of human body is equal to the sum of the heat dissipated to the surroundings and the heat stored in human body by raising the temperature of body tissues.
4. The human body feels comfortable when there is no change in the body temperature, *i.e.*, when the heat stored in the body is zero. Any variation in the body temperature acts as a stress to the brain which ultimately results in either perspiration or shivering.

Que 2.26. **Explain the factors which affect human comfort. What is the use of comfort chart for comfort air conditioning ?**

Answer

A. **Factors Affecting Human Comfort :**

i. **Effective Temperature :** The numerical value of effective temperature is made equal to the temperature of still saturated air, which produces the same sensation of warmth or coolness as produced under the given conditions.

ii. **Heat Production and Regulation in Human Body :** The human body acts like a heat engine which gets its energy from the combustion of food within the body. The process of combustion produces heat and energy due to oxidation. The rate at which the body produces heat is termed as metabolic rate.

iii. **Heat and Moisture Loss from the Human Body :** The heat is given off from the human body as either sensible or latent heat or both. In order to design any air conditioning system for spaces which human bodies are to occupy, it is necessary to know the rates at which these two forms of heat are given off under different conditions of air temperature and body activity.

iv. **Moisture Content of Air :** The moisture content of outside air during winter is generally low and it is above the average during summer because the capacity of the air to carry moisture is dependent upon its dry bulb temperature.

v. **Quality of Air :** The air in an occupied space at all times should be free from toxic, unhealthful or disagreeable fumes such as CO_2. It should always be free from dust and odour.

vi. **Air Motion :** The air motion which includes the distribution of air is very important to maintain uniform temperature in the conditioned space. No air conditioning system is satisfactory unless the air handled is properly circulated and distributed.

vii. **Cold or Hot Surfaces :** The cold or hot objects in a conditioned space may cause discomfort to the occupants. A single glass of large area when exposed to the outdoor air during winter will produce discomfort to the occupant of a room by absorbing heat from them by radiation.

viii. **Air Stratification :** It order to achieve comfortable conditions in the occupied space, the air conditioning system must be designed to reduce the air stratification to a minimum.

B. **Use of Comfort Chart for Comfort Air Conditioning :** The comfort chart gives the following information :

1. The most desirable relative humidity lies between 30-70 %. If the relative humidity is below 30 %, the skin surface becomes too dry and if the relative humidity is above 70 %, there is a tendency for a clammy or sticky sensation to develop.
2. During summer, the chart indicates that a maximum of 98 % people felt comfortable for an effective temperature of 21.6 °C and during winter, the chart indicates that an effective temperature of 20 °C was desired by 97.7 % people.
3. All the men and women above 40 years of age prefer 0.5 °C higher effective temperature than the person below 40 years of age.
4. The comfort conditions for persons at work vary with the rate of work and the amount of clothing worn.

Que 2.27. **Differentiate between the comfort and industrial air conditioning.**

Answer

S. No.	Comfort Air Conditioning	Industrial Air Conditioning
1.	In this, the dry bulb temperature of air and relative humidity is brought to the required condition for human health, efficiency and comfort.	In this, the dry bulb temperature and relative humidity is kept constant for proper functioning of machines and electronic items.
2.	It has a sensible heat ratio of 0.60 to 0.90.	It has been designed with a sensible heat ratio of 0.85 to 1.0.
3.	It requires 15 watts per square foot.	It requires 75 watts per square foot.
4.	It supplies 350 to 400 cubic feet per minute per cooling ton.	It supplies 500 to 900 cubic feet per minute per cooling ton.
5.	It has no humidity control.	The optimal relative humidity range is 45-50 %.
6.	It uses residential type air filters that are 10 % efficient.	It has higher quality internal filter chambers that are 20-30 % efficient.
7.	It is used in homes, offices, shops, etc.	It is used in textile mills, paper mills, tool rooms, etc.

Que 2.28. **Draw a labelled sketch and explain working of window air conditioning system.**

Answer

1. Fig. 2.28.1 shows the schematic diagram of a typical window air conditioner.
2. Consider that a room is maintained at constant temperature of 25 °C.
3. In the air conditioner, the air from the room is drawn by a fan and is made to pass over a cooling coil, the surface of which is maintained, say, at a temperature of 10 °C. After passing over the coil the air is cooled (e.g., to 15 °C) before being supplied to the room.
4. After picking up the room heat, the air is again returned to the cooling coil at 25 °C.

5. Now, in the cooling coil, a liquid working substance called a refrigerant, such as $CHClF_2$ (monochloro-difluoro methane), also called refrigerant (*R*-22), enters at a temperature of, say, 5 °C and evaporates, thus absorbing its latent heat of vaporization from the room air.

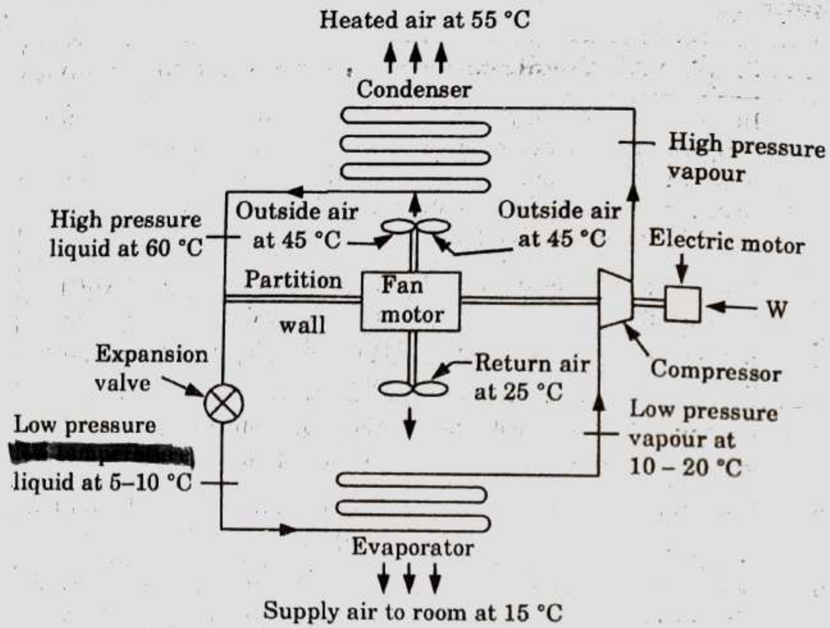


Fig. 2.28.1. Schematic diagram of a window air conditioner.

6. After evaporation, the refrigerant becomes vapour. To enable it to condense back and to release the heat which it has absorbed from the room while passing through the evaporator its pressure is raised by a compressor.
7. Following this, the high pressure vapour enters the condenser.
8. In the condenser, the outside atmospheric air, say, at a temperature of 45 °C in summer is circulated by a fan.
9. After picking up the latent heat of condensation from the condensing refrigerant, the air is let out into the environment, say, at a temperature of 55 °C.
10. The condensation of refrigerant may occur, for example, at a temperature of 60 °C.
11. After condensation, the high pressure liquid refrigerant is reduced to the low pressure of the evaporator by passing it through a pressure reducing device called the expansion device and thus the cycle of operation is completed.

☺☺☺

3
UNIT

Introduction to Fluid Mechanics and Applications

CONTENTS

PART-1

Introduction : Fluid Properties, Pressure, Density, Dynamic and Kinematic Viscosity, Specific Gravity.

CONCEPT OUTLINE

Fluid : A fluid is a substance which deforms continuously when subjected to external shearing force.

Pressure : Pressure is defined as the physical force exerted on an object. The force applied is perpendicular to the surface of objects per unit area. Unit of pressure is Pascal (Pa).

Kinematic Viscosity : It is defined as the ratio between the dynamic viscosity and density of fluid. It is denoted by ν.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. **Discuss some physical properties of fluids in brief.**

Answer

Some physical properties of fluids are as follows :

i. **Density or Mass Density :**

1. It may be defined as the mass per unit volume at a standard temperature and pressure. It is also known as specific mass. It is denoted by ρ and its unit is kg/m^3.

Mathematically, $\rho = \dfrac{m}{V}$

Where, m = Mass (kg), and

V = Volume (m^3).

ii. **Weight Density :**

1. It can be defined as the weight per unit volume at the standard temperature and pressure. It is also known as specific weight. It is denoted by W and its unit is N/m^3.

Mathematically, $W = \dfrac{\text{Weight}}{\text{Volume}} = \dfrac{mg}{V} = \rho g$ $\quad \left(\because \dfrac{m}{V} = \rho\right)$

iii. **Specific Volume :**

1. It is defined as the volume per unit mass of fluid.

Mathematically, $v = \dfrac{V}{m} = \dfrac{1}{\rho}$

iv. **Specific Gravity :**

1. It is the ratio of the specific weight of the given fluid to the specific weight of a standard fluid.

$$S = \frac{\text{Specific weight of given fluid}}{\text{Specific weight of standard fluid}}$$

2. For liquids, standard fluid is pure water at 4 °C and air is standard fluid for gases.

v. **Viscosity :**

1. It is defined as the property of a fluid which determines its resistance to shearing stresses. Its SI unit is Pa-s and CGS unit is poise.
2. An ideal fluid has no viscosity.
3. Viscosity of fluids is due to cohesion and adhesion.

Que 3.2. **State Newton's law of viscosity and derive the same. What are its applications ?**

Answer

A. **Newton's Law of Viscosity :**

1. This law states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain.

Mathematically, $\tau = \mu \dfrac{du}{dy}$

B. **Derivation :**

1. From Fig. 3.2.1, let two layers of fluid at a distance 'dy' apart, move one over the other at different velocities u and $u + du$.
2. The viscosity together with relative velocity causes shear stress acting between fluid layers.
3. This shear stress is proportional to the rate of change of velocity with respect to y. It is denoted by τ.

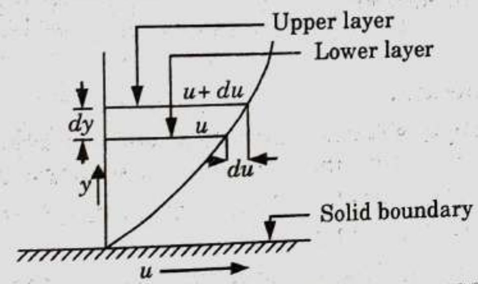


Fig. 3.2.1. Velocity variation near a solid boundary.

Mathematically, $\tau \propto \frac{du}{dy}$ or $\tau = \mu \frac{du}{dy}$

Where, μ = Constant of proportionality and is known as coefficient of dynamic viscosity or viscosity.

$\frac{du}{dy}$ = Rate of shear deformation or velocity gradient.

C. Applications :

1. Lubrication in bearings.
2. Relative movement between two plates.

Que 3.3. What is the difference between dynamic viscosity and kinematic viscosity ?

Answer

S. No.	Dynamic Viscosity	Kinematic Viscosity
1.	It is defined as the property of a fluid which determines its resistance to shearing stresses.	It is defined as the ratio between the dynamic viscosity and density of fluid.
2.	It is denoted by μ.	It is denoted by ν.
3.	Mathematically, $\mu = \frac{\tau}{\left[\frac{du}{dy}\right]}$	Mathematically, $\nu = \frac{\mu}{\rho}$
4.	The unit of μ is Ns/m^2.	The unit of ν is m^2/s.

Que 3.4. Explain the following :

i. Compressibility,
ii. Surface tension, and
iii. Incompressible flow.

Answer

i. Compressibility :

1. The property by virtue of which fluids undergo a change in volume under the action of external pressure is known as compressibility.
2. It is the reciprocal of bulk modulus of elasticity which is defined as the ratio of compressive stress to volumetric strain.
3. Let, V = Volume of gas enclosed in the cylinder, and
p = Pressure of gas when volume is V.

4. If the pressure is increased to $p + dp$, the volume of gas decreases from V to $V - dV$.

$$\therefore \text{Volumetric strain} = -\frac{dV}{V}$$

5. Bulk modulus, $K = \frac{\text{Increase of pressure}}{\text{Volumetric strain}} = \frac{dp}{-dV/V}$

And, compressibility $= \frac{1}{K}$

ii. Surface Tension :

1. It is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids.
2. It is denoted by sigma (σ) and its SI unit is N/m.
3. This occurs due to the force of cohesion at the free surface as shown in Fig. 3.4.1.

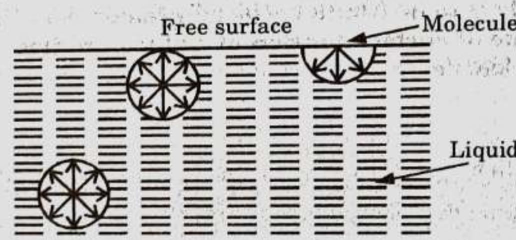


Fig. 3.4.1.

4. Consider a liquid molecule in the interior of liquid mass, surrounded by other molecules all around and is in equilibrium.
5. At the free surface of the liquid, there are no liquid molecules above the surface to balance the force of the molecules below it.
6. As a result, there is a net inward force on the molecule and this force is normal to the surface.
7. Thus at the free surface a thin layer of molecules is formed which acts as membrane because of which a thin small needle can float on the free surface.

iii. Incompressible Flow :

1. It is that type of flow in which the density is constant for the fluid flow.
i.e., ρ = Constant
2. Incompressible flow is also known as isochoric flow which means same area or space.
3. These type of flow are easy to model as temperature and pressure of liquid and gases do not vary in incompressible flow.

Que 3.5. **Determine the bulk modulus of elasticity and compressibility of a liquid. If the pressure of liquid is increased from 70 N/cm² to 130 N/cm². The volume of liquid decreases by 0.15 %.**

Answer

Given : $dp = 130 - 70 = 60$ N/cm², $dV = 0.15$ %
To Find : Bulk modulus of elasticity and compressibility of liquid.

1. Bulk modulus, $K = \dfrac{dp}{dV} = \dfrac{60}{\dfrac{0.15}{100}} = 4 \times 10^4 \text{ N/cm}^2$

2. Compressibility of liquid $= \dfrac{1}{\text{Bulk modulus}} = \dfrac{1}{4 \times 10^4} = 2.5 \times 10^{-5} \text{ cm}^2/\text{N}$

Que 3.6. **What should be the diameter of a droplet of water, if the pressure inside is to be 0.0018 kg(f)/cm² greater than the outside ? Given the value of surface tension of water in contact with air at 20 °C as 0.0075 kg(f)/m.**

Answer

Given : $p = 0.0018$ kg(f)/cm², $\sigma = 0.0075$ kg(f)/m $= 7.5 \times 10^{-5}$ kg(f)/cm
To Find : Diameter of droplet of water.

1. For water droplet,

$$p = \frac{4\sigma}{d}$$

$$\therefore \quad d = \frac{4\sigma}{p}$$

$$d = \frac{4 \times 7.5 \times 10^{-5}}{0.0018} = 0.1667 \text{ cm}$$

Que 3.7. **Define the following terms :**
i. **Absolute pressure,**
ii. **Atmospheric pressure,**
iii. **Gauge pressure, and**
iv. **Vacuum pressure.**

Answer

i. **Absolute Pressure :**
1. The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum (*i.e.*, absolute zero pressure).

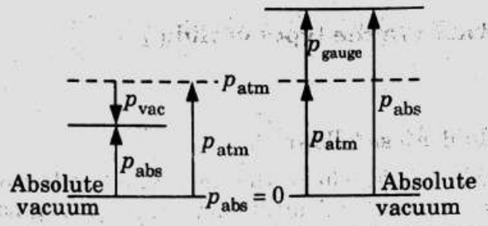


Fig. 3.7.1. Absolute, gauge and vacuum pressures.

ii. **Atmospheric Pressure :**
1. The atmospheric air exerts a normal pressure upon all surfaces with which it is in contact, and it is known as atmospheric pressure.
2. The atmospheric pressure varies with the altitude and it can be measured by means of a barometer. As such it is also called the barometric pressure.

iii. **Gauge Pressure :**
1. Gauge pressure is defined as the difference between absolute pressure and the local atmospheric pressure.
2. Gauge pressure can be positive or negative.

iv. **Vacuum Pressure :**
1. Pressures below atmospheric pressure are called as vacuum pressures.

PART-2

Newtonian and Non-Newtonian Fluid, Pascal's Law, Continuity Equation.

CONCEPT OUTLINE

Examples of Newtonian Fluid : Water, benzene etc.
Examples of Non-Newtonian Fluid : Plaster, slumics, pastes etc.
Continuity Equation : It is based on the principle of conservation of mass. It states that, if no fluid is added or removed from the pipe in any length then the mass passing across different section shall be same.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.8. **What are the types of fluid ?**

Answer

Types of fluid are as follows :

i. **Ideal Fluid :** A fluid, which is incompressible and is having no viscosity, is known as an ideal fluid. Ideal fluid is only an imaginary fluid as all the fluids, which exist, have some viscosity.

ii. **Real Fluid :** A fluid, which possesses viscosity, is known as real fluid. All the fluids, in actual practice, are real fluids.

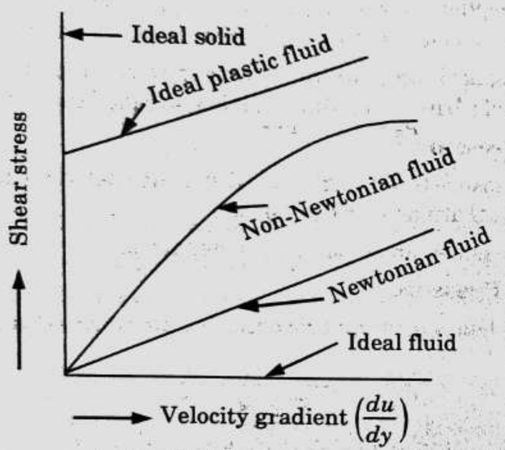


Fig. 3.8.1. Types of fluids.

iii. **Newtonian Fluid :** A real fluid, in which the shear stress is directly, proportional to the rate of shear strain (or velocity gradient), is known as a Newtonian fluid.

iv. **Non-Newtonian Fluid :** A real fluid, in which the shear stress is not proportional to the rate of shear strain (or velocity gradient), known as a Non-Newtonian fluid.

v. **Ideal Plastic Fluid :** A fluid, in which shear stress is more than the yield value and shear stress is proportional to the rate of shear strain (or velocity gradient), is known as ideal plastic fluid.

Que 3.9. **State and prove the Pascal's law.**

Answer

1. Pascal's law states that the pressure at any point in a static fluid is equal in all directions.
2. The fluid element is of very small dimensions *i.e.*, dx, dy and ds.

3. Consider an arbitrary fluid element of wedge shape in a fluid mass at rest as shown in Fig. 3.9.1.

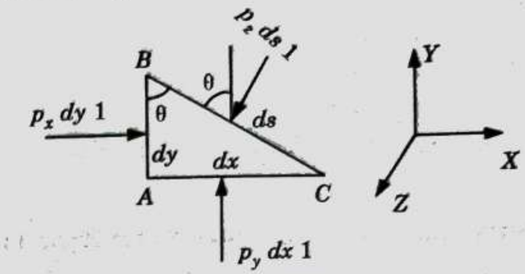


Fig. 3.9.1.

4. Let the width of the element perpendicular to the plane of paper is unity and p_x, p_y and p_z are the pressures acting on the face AB, AC and BC respectively.
5. Let $\angle ABC = \theta$.
6. Then the forces acting on the element are :
   i. Pressure forces normal to the surfaces.
   ii. Weight of element in the vertical direction.
7. Force on the face $AB = p_x \times$ Area of face AB

$$= p_x \times dy \times 1$$

Similarly force on the face $AC = p_y \times dx \times 1$

Force on the face $BC = p_z \times ds \times 1$

8. Weight of element = (Mass of element) × g

$$= \left(\frac{AB \times AC}{2} \times 1\right) \rho g$$

Where, ρ = Density of fluid.

9. Resolving the forces in x-direction,

$p_x \times dy \times 1 - p\,(ds \times 1) \sin (90° - \theta) = 0$

$p_x \times dy \times 1 - p_z\, ds \times 1 \cos \theta = 0.$

10. But from Fig. 3.9.1, $ds \cos \theta = AB = dy$

$$\therefore \quad p_x \times dy \times 1 - p_z\, dy \times 1 = 0$$

$$p_x = p_z \qquad ...(3.9.1)$$

11. Similarly, resolving the forces in y-direction,

$$p_y \times dx \times 1 - p_z \times ds \times 1 \cos (90° - \theta) - \frac{dx \times dy}{2} \times 1 \times \rho \times g = 0$$

or

$$p_y \times dx - p_z\, ds \sin \theta - \frac{dxdy}{2} \times \rho \times g = 0$$

12. But $ds \sin \theta = dx$ and also the element is very small and hence weight is negligible.

$\therefore \quad p_y dx - p_z dx = 0$

or $\quad p_y = p_z$ ...(3.9.2)

13. From eq. (3.9.1) and eq. (3.9.2),

$$p_x = p_y = p_z \quad ...(3.9.3)$$

14. The eq. (3.9.3) shows that the pressure at any point in x, y and z directions is equal.

Que 3.10. Derive the continuity equation for fluid flow through a pipe.

Answer

1. Consider two cross-section of a pipe as shown in Fig. 3.10.1.

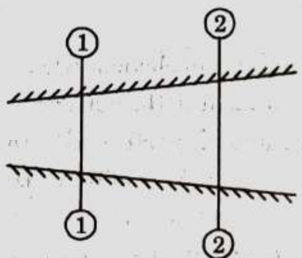


Fig. 3.10.1. Fluid flow through a pipe.

2. Let, A_1 = Area of the pipe at section 1–1,
   v_1 = Velocity of the fluid at section 1–1,
   ρ_1 = Density of the fluid at section 1–1,
   A_2, v_2, ρ_2 = Corresponding values at section 2–2.
3. The total quantity of fluid passing through section 1–1 = $\rho_1 A_1 v_1$
   The total quantity of fluid passing through section 2–2 = $\rho_2 A_2 v_2$
4. From the law of conservation of matter (theorem of continuity), we have

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \quad ...(3.10.1)$$

5. Eq. (3.10.1) is applicable to the compressible as well as incompressible fluids and is called continuity equation. In case of incompressible fluids, $\rho_1 = \rho_2$ and the continuity eq. (3.10.1) reduces to

$$A_1 v_1 = A_2 v_2 \quad ...(3.10.2)$$

PART-3

Bernoulli's Equation and its Applications, Basic Numerical Problems.

CONCEPT OUTLINE

Bernoulli's Equation : It can be mathematically stated as :

Pressure energy + Kinetic energy + Potential energy = Constant

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{Constant}$$

Venturimeter : It is a device used for measuring the rate of flow of a fluid flowing through a pipe.

Pitot Tube : It is a device used for measuring the velocity of flow at any point in a pipe or a channel.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.11. Write assumption of Bernoulli equation. Also state Bernoulli theorem.

Answer

A. Assumptions of Bernoulli Equation :

1. The fluid should be ideal, *i.e.*, viscosity is zero.
2. The flow should be steady.
3. The flow should be incompressible.
4. The flow should be irrotational.

B. Bernoulli's Theorem :

1. Bernoulli's theorem states that in a steady, ideal flow of an incompressible fluid, the total energy at any point of the fluid is constant.
2. It can be mathematically stated as given below,
   Pressure energy + Kinetic energy + Potential energy = Constant

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{Constant}$$

3. Bernoulli's equation for real fluids is,

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2+h_L$$

Where, h_L = Loss of energy.

Que 3.12. **Water flows through a 0.9 m diameter pipe at the end of which there is a reducer connecting to a 0.6 m diameter pipe. If the gauge pressure at the entrance to the reducer is 412.02 kN/m² and the velocity is 2 m/s, determine the resultant thrust on the reducer, assuming that the frictional loss of head in the reducer is 1.5 m.**

Answer

Given : d_1 = 0.9 m, d_2 = 0.6 m, p_1 = 412.02 kN/m², v_1 = 2 m/s, h_f = 1.5 m

To Find : Resultant thrust.

1. From continuity equation,

$$v_1A_1=v_2A_2$$

$$v_2=\frac{v_1A_1}{A_2}=\left(\frac{d_1}{d_2}\right)^2\times v_1=\left(\frac{0.9}{0.6}\right)^2\times 2=4.5 \text{ m/s}$$

2. Applying Bernoulli's theorem at section (1) and (2), we get

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2+h_f$$

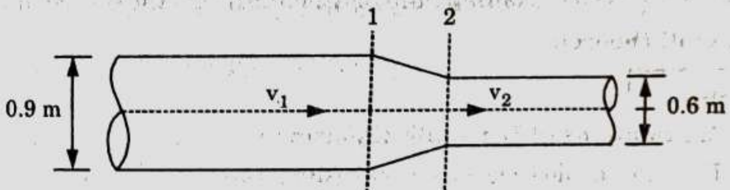


Fig. 3.12.1.

3. As it is horizontal pipe, hence $z_1=z_2$

$$\therefore \quad \frac{p_1}{\rho g}+\frac{v_1^2}{2g}=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+h_f$$

$$\frac{412.02\times10^3}{1000\times9.81}+\frac{2^2}{2\times9.81}=\frac{p_2}{1000\times9.18}+\frac{(4.5)^2}{2\times9.18}+1.5$$

$$p_2=389.18 \text{ kN/m}^2$$

Hence, resultant thrust on the reducer = 389.18 kN/m²

Que 3.13. **Define venturimeter. Also derive the expression for the same.**

Answer

A. Venturimeter :

1. A venturimeter is a device used for measuring the rate of flow of a fluid flowing through a pipe.
2. It consists of three parts, as given below :
   i. A short converging part,
   ii. Throat, and
   iii. Diverging part.
3. It works on the principle of Bernoulli's theorem.

B. Expression for Venturimeter :

1. As shown in Fig. 3.13.1, a venturimeter is fitted in a horizontal pipe through which a fluid is flowing.

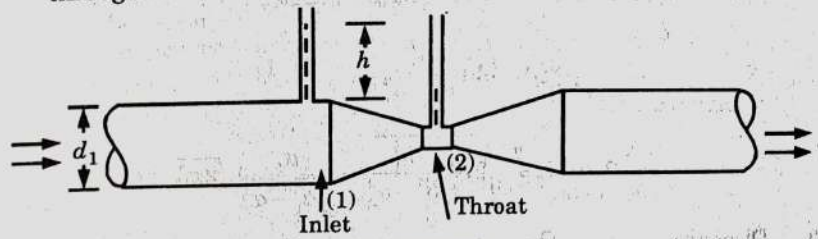


Fig. 3.13.1.

2. Let, d_1 = Diameter of pipe at section (1),
   p_1 = Pressure at section (1),
   v_1 = Velocity of fluid at section (1), and
   a_1 = Area at section (1) = $\frac{\pi}{4}d_1^2$.
   d_2, p_2, v_2, a_2 = Corresponding values at section (2).
3. By applying Bernoulli's theorem at section (1) and (2), we get

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2 \quad ...(3.13.1)$$

4. As it is horizontal pipe, hence $z_1=z_2$

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}$$

$$\frac{p_1-p_2}{\rho g}=\frac{v_2^2}{2g}-\frac{v_1^2}{2g} \quad ...(3.13.2)$$

5. But $\frac{p_1-p_2}{\rho g}$ is the difference of pressure heads at sections (1) and (2) and it is equal to h,

$$\frac{p_1 - p_2}{\rho g} = h$$

$$\therefore \quad h = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \qquad ...(3.13.3)$$

6. Applying continuity equation at sections (1) and (2), we have

$$a_1 v_1 = a_2 v_2 \text{ or } v_1 = \frac{a_2 v_2}{a_1}$$

7. Substituting this value of v_1 in eq. (3.13.3), we get

$$h = \frac{v_2^2}{2g} - \frac{\left(\frac{a_2 v_2}{a_1}\right)^2}{2g} = \frac{v_2^2}{2g}\left[1 - \frac{a_2^2}{a_1^2}\right]$$

or $$v_2^2 = 2gh \frac{a_1^2}{a_1^2 - a_2^2}$$

$$\therefore \quad v_2 = \sqrt{2gh \frac{a_1^2}{a_1^2 - a_2^2}} = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

8. Discharge, $Q = a_2 v_2$

$$Q = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh} \qquad ...(3.13.4)$$

9. Eq. (3.13.4) gives the discharge under ideal conditions called as theoretical discharge whereas actual discharge will be less than theoretical discharge and is given by,

$$\therefore \quad Q_{act} = \frac{C_d \, a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}} \qquad \left(\because C_d = \frac{Q_{act}}{Q_{theo}}\right)$$

Where C_d is the coefficient of discharge for venturimeter and its value is less than unity.

Que 3.14. **What is orifice meter ? Derive the formula of orifice meter.**

Answer

A. Orifice Meter :

1. It works on the Bernoulli's principle and is a device used for measuring the rate of flow of a fluid flowing through a pipe.

2. It consists of a flat circular plate which has a circular sharp edged hole called orifice, which is concentric with the pipe.
3. It is cheaper device as compared to venturimeter.

B. Derivation :

1. As shown in Fig. 3.14.1, let,

p_1 = Pressure at section (1),
v_1 = Velocity of flow at section (1),
a_1 = Area of pipe at section (1), and
p_2, v_2, a_2 = Corresponding values at section (2).

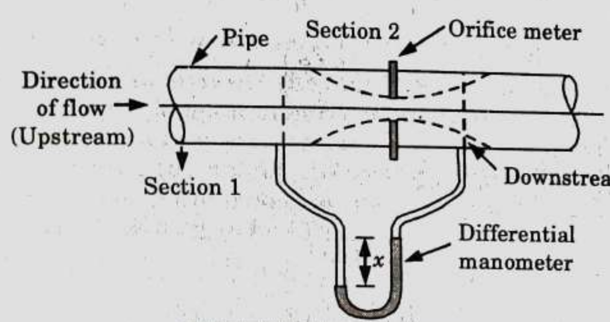


Fig. 3.14.1. Orifice meter.

2. Applying Bernoulli's equation at section (1) and (2), we get

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

$$\left(\frac{p_1}{\rho g} + z_1\right) - \left(\frac{p_2}{\rho g} + z_2\right) = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

Where, $\left(\frac{p_1}{\rho g} + z_1\right) - \left(\frac{p_2}{\rho g} + z_2\right) = h$ = Differential head

$$h = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

$$v_2 = \sqrt{2gh + v_1^2} \qquad ...(3.14.1)$$

3. Now section (2) is at the vena-contracta and a_2 represents the area at the vena-contracta.
4. If a_0 is the area of orifice then,

$$C_C = \frac{a_2}{a_0}$$

$$a_2 = a_0 C_C \quad ...(3.14.2)$$

Where, C_C = Coefficient of contraction.

5. By continuity equation,

$$a_1 v_1 = a_2 v_2$$

$$v_1 = \frac{a_0 C_C}{a_1} v_2 \quad ...(3.14.3)$$

6. Substituting the value of v_1 in eq. (3.14.1), we get

$$v_2 = \sqrt{2gh + \left(\frac{a_0 C_C}{a_1}\right)^2 v_2^2}$$

$$v_2^2 = 2gh + \left(\frac{a_0 C_C}{a_1}\right)^2 v_2^2$$

$$v_2^2\left[1 - \left(\frac{a_0}{a_1}\right)^2 C_C^2\right] = 2gh$$

$$\therefore \quad v_2 = \frac{\sqrt{2\,gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_C^2}}$$

7. Discharge, $Q = v_2 a_2 = v_2 \times a_0 C_C$ $\quad (\because a_2 = a_0 C_C)$

i.e.,

$$Q = \frac{a_0 C_C \sqrt{2\,gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}} \quad ...(3.14.4)$$

8. The above expression can be simplified by using,

$$C_d = C_C \frac{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_C^2}}$$

$$C_C = C_d \frac{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_C^2}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2}}$$

9. Substituting the value of C_C in eq. (3.14.4), we get

$$Q = a_0 \times C_d \frac{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2}} \times \frac{\sqrt{2gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}}$$

$$= \frac{C_d a_0 \sqrt{2\,gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2}} = \frac{C_d a_0 a_1 \sqrt{2\,gh}}{\sqrt{a_1^2 - a_0^2}}$$

Where, C_d = Coefficient of discharge for orifice meter.

Que 3.15. A horizontal venturimeter with a discharge coefficient of 0.98 is being used to measure the flow rate of a liquid of density 1030 kg/m^3. The pipe diameter at entry to the venturi is 75 mm and the venturi throat has an area of 1000 mm^2. If the flow rate is 0.011 m^3/s. Determine the height difference recorded on a *U*-tube manometer connecting the throat to the upstream pipe. Take the relative density of mercury to be 13.6.

Answer

Given : $C_d = 0.98$, $\rho_l = 1030$ kg/m^3, $S_l = \frac{1030}{1000} = 1.03$ kg/m^3, $S_{Hg} = 13.6$, $d_1 = 75$ mm $= 0.075$ m, $Q = 0.011$ m^3/s, $a_2 = 1000$ mm^2 $= 1 \times 10^{-3}$ m^2

To find : Height difference.

1. As we know, flow rate, $Q = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}$

$$a_1 = \frac{\pi}{4} d_1^2 = \frac{\pi}{4} \times (.075)^2 = 4.4178 \times 10^{-3} \text{ m}^2$$

$$0.011 = 0.98 \times \frac{4.4178 \times 10^{-3} \times 1 \times 10^{-3}}{\sqrt{(4.4178 \times 10^{-3})^2 - (1 \times 10^{-3})^2}} \times \sqrt{2 \times 9.81 \times h}$$

$$h = 6.092 \text{ m}$$

2. We know that, $h = x\left[\frac{S_{Hg}}{S_l} - 1\right]$

$$6.092 = x\left[\frac{13.6}{1.03} - 1\right]$$

$$6.092 = x \times \frac{12.57}{1.03}$$
$$x = 0.4992 \text{ m}$$

Que 3.16. **What is pitot tube ? How will you determine the velocity at any point with the help of pitot tube ?**

Answer

A. **Pitot Tube :** It is a device used for measuring the velocity of flow at any point in a pipe or a channel.

B. **Expression of Velocity at any Point :**

1. Let
p_1 = Intensity of pressure at point (1),
v_1 = Velocity of flow at (1),
p_2 = Pressure at point (2),
v_2 = Velocity at point (2),
H = Depth of tube in the liquid, and
h = Rise of liquid in the tube above the free surface.

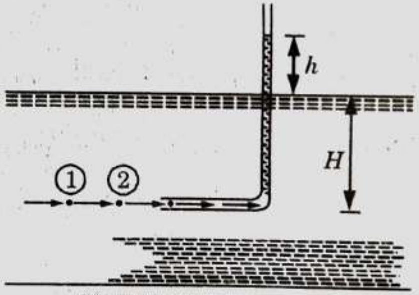


Fig. 3.16.1. Pitot-tube.

2. Applying Bernoulli's equation at point (1) and (2),

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 \quad ...(3.16.1)$$

3. Since $z_1 = z_2$ as point (1) and (2) are on the same line and $v_2 = 0$.

$$\frac{p_1}{\rho g} = \text{Pressure head at (1)} = H \quad ...(3.16.2)$$

$$\frac{p_2}{\rho g} = \text{Pressure head at (2)} = (h + H) \quad ...(3.16.3)$$

4. Substituting values of eq. (3.16.2) and eq. (3.16.3) in eq. (3.16.1), we get

$$\therefore \quad H + \frac{v_1^2}{2g} = (h + H)$$

$$h = \frac{v_1^2}{2g} \quad \text{or} \quad v_1 = \sqrt{2gh}$$

$\because$ This is theoretical velocity.

5. Actual velocity is given by,

$$(v_1)_{act} = C_v \sqrt{2gh}$$

Where, C_v = Coefficient of pitot tube.

6. Velocity at any point,

$$v = C_v \sqrt{2gh}$$

Que 3.17. **In an experiment of flow through orifices the following data were recorded :**
Diameter of sharp orifice = 100 mm
Diameter of jet at vena-contracta = 78.42 mm
Height of water tank maintained = constant = 3.60 m
Discharge measured (Tank-method) = 0.0385 m³/s
Determine C_c, C_v and C_d.

Answer

Given : d = 100 mm = 0.1 m
Jet diameter at vena-contracta = 78.42 mm = 0.07842 m
H = 3.60 m, Q_{act} = 0.0385 m³/s
To Find : C_c, C_v and C_d

1. We know, $Q_{th} = v_{th} \times$ Area of orifice

$$v_{th} = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 3.60} = 8.40 \text{ m/s}$$

$$\therefore \quad Q_{th} = 8.40 \times \frac{\pi}{4} d^2 = 8.40 \times \frac{\pi}{4} \times (0.1)^2$$
$$= 0.066 \text{ m}^3/\text{s}$$

2. Coefficient of discharge,

$$C_d = \frac{\text{Actual discharge } (Q_{act})}{\text{Theoretical discharge } (Q_{th})}$$

$$C_d = \frac{0.0385}{0.066} = 0.58$$

3. Coefficient of contraction,

$$C_c = \frac{a_c}{a}$$

$$a_c = \frac{\pi}{4} (\text{jet diameter})^2 = \frac{\pi}{4} \times (0.07842)^2$$
$$= 0.0048 \text{ m}^2$$

$$a = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (0.1)^2 = 0.0079 \text{ m}^2$$

$$C_c = \frac{0.0048}{0.0079} = 0.61$$

4. We know that, $C_d = C_v \times C_c$

$$\therefore \quad C_v = \frac{C_d}{C_c} = \frac{0.58}{0.61}$$

$$C_v = 0.95$$

PART-4

Working Principles of Hydraulic Turbines and Pumps and their Classifications.

CONCEPT OUTLINE

Hydraulic Turbines : The hydraulic machines which convert hydraulic energy into mechanical energy.

Pumps : The hydraulic machines which convert the mechanical energy into hydraulic energy.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.18. **Classify hydraulic turbines with examples in detail.**

Answer

Hydraulic turbines are classified as follows :

A. **According to the Type of Energy Available at Inlet :**

i. **Impulse Turbine :** In an impulse turbine, all the available energy of water is converted into kinetic energy.
Example : Pelton wheel turbine.

ii. **Reaction Turbine :** In a reaction turbine, at the entrance to the runner, only a part of the available energy of water is converted into kinetic energy and a substantial part remains in the form of pressure energy.
Example : Francis turbine, Kaplan turbine.

B. **According to the Direction of Flow through Runner :**

i. **Tangential Flow Turbine :** In this turbine, the water flows along the tangent to the path of rotation of the runner.
Example : Pelton wheel turbine.

ii. **Radial Flow Turbine :** In this turbine, the water flows along the radial direction.
Example : Francis turbine.

iii. **Axial Flow Turbine :** In this turbine, water flows through the runner along the direction parallel to the axis of rotation of the runner.
Example : Kaplan turbine.

iv. **Mixed Flow Turbine :** In this turbine, water enters the runner at the outer periphery in radial direction and leaves it at the centre in the direction parallel to the axis of rotation of the runner.
Example : Modern Francis turbine.

C. **According to the Head at Inlet of Turbine :**

i. **High Head Turbine :** These are the turbines which are capable of working under very high head ranging more than 250 m.
Example : Pelton wheel turbine.

ii. **Medium Head Turbine :** These are the turbines which are capable of working under head ranging from 60 m to 250 m.
Example : Francis turbine.

iii. **Low Head Turbine :** These are the turbines which are capable of working under head less than 60 m.
Example : Kaplan turbine.

D. **According to the Specific Speed of the Turbine :**

i. **Low Specific Speed Turbine :** Low specific speed ranging less than 60.
Example : Pelton wheel turbine.

ii. **Medium Specific Speed Turbine :** Ranging between 60 to 300.
Example : Francis turbine.

iii. **High Specific Speed Turbine :** Ranging between 300 to 1000.
Example : Kaplan turbine.

Que 3.19. **Explain construction and working of Pelton wheel turbine.**

Answer

A. **Construction of Pelton Wheel Turbine :**

i. **Nozzle and Flow Regulating Arrangement :**

1. The amount of water striking the buckets of runner is controlled by providing a spear in the nozzle.

2. Spear has the streamlined head which is fixed to end of the rod.
3. The spear is push forward in the nozzle to reduce the water flow and is push backward to increase the water flow.

ii. Runner Reduce Gap with Buckets :

1. Runner consists of a circular disc with a number of buckets evenly spaced around its periphery.
2. Each bucket is divided into two symmetrical parts by a dividing wall which is known as splitter.
3. The jet of water impinges on the splitter which divides the jet into two equal portions.

iii. Casing :

1. Fig. 3.19.1 shows the casing of a Pelton wheel turbine.
2. The function of the casing is to prevent the splashing of the water and to discharge water to tail race.
3. The casing of the Pelton wheel does not perform any hydraulic function.

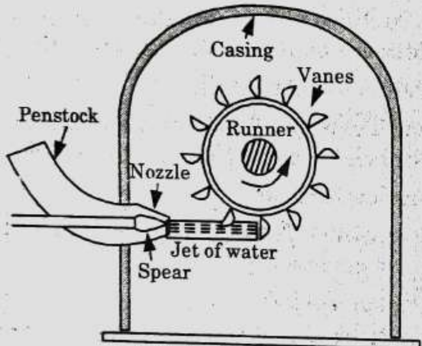


Fig. 3.19.1. Pelton turbine.

iv. Breaking Jet :

1. When the nozzle is completely closed by the motion of spear in forward direction, the amount of water striking the runner reduces to zero.
2. But due to inertia, runner goes on revolving. Therefore a jet from back of vane is used to stop the wheel known as breaking jet.

B. Working of Pelton Wheel Turbine :

1. The water stored at high head is made to flow through the penstock and reaches the nozzle of the Pelton turbine.
2. The nozzle increases the kinetic energy of the water and directs the water in the form of jet.
3. The jet of water from the nozzle strikes the bucket (vanes) of the runner. This made the runner to rotate at very high speed.
4. The quantity of water striking the vanes or buckets is controlled by the spear present inside the nozzle.

5. The generator is attached to the shaft of the runner which converts the mechanical energy of the runner into electrical energy.

Que 3.20. **Give classification of pumps. What do you mean by centrifugal and reciprocating pump ?**

Answer

A. Classification of Pumps :

- Pumps
  - Positive displacement
    - Rotary
      - Gear
      - Vane
      - Screw
    - Reciprocating
  - Non-positive displacement
    - Centrifugal
    - Axial flow
    - Radial flow

B. Centrifugal Pump :

1. If the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, then the hydraulic machine is called centrifugal pump.
2. It is a radial outward flow machine. It acts as the reverse of an inward radial flow reaction turbine.
3. It works on the principle of forced vortex flow.

C. Reciprocating Pump :

1. If mechanical energy is converted into pressure energy by means of reciprocating motion of a piston into a cylinder, then pump is known as reciprocating pump.
2. It is a positive displacement pump as it sucks and raises the liquid by actually displacing it with a piston that executes a reciprocating motion in a closely fitted cylinder.
3. The amount of liquid pumped is equal to the volume displaced by the piston.

Que 3.21. **Give the constructional details of a centrifugal pump. Also explain its working.**

Answer

A. Construction of Centrifugal Pump :

i. Impeller : An impeller is a wheel (or rotor) with a series of backward curved vanes (or blades). It is mounted on a shaft which is coupled to an electric motor.

ii. **Casing :** The casing is an air tight chamber surrounding the pump impeller.

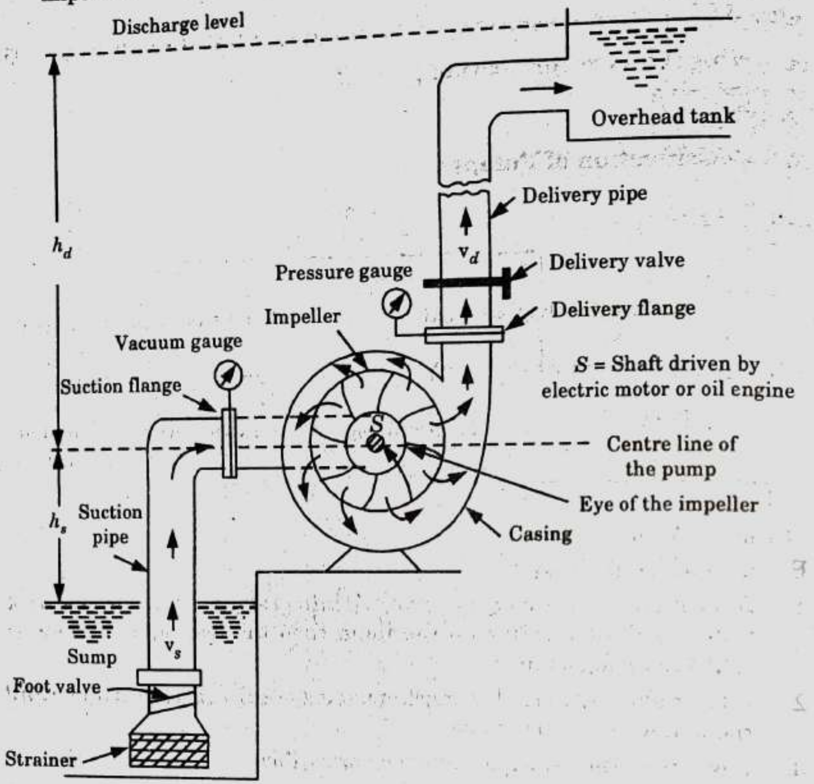


Fig. 3.21.1. Centrifugal pump.

iii. **Suction Pipe :** The pipe which connects the centre/eye of the impeller to sump from which liquid is to be lifted is known as suction pipe.

iv. **Delivery Pipe :** The pipe which is connected at its lower end to the outlet of the pump and delivers the liquid to the required height is known as delivery pipe.

B. **Working of Centrifugal Pump :**

1. The first step in the operation of a centrifugal pump is priming.
2. Priming is the operation in which the suction pipe, casing of the pump and the portion of the delivery pipe upto the delivery valve are completely filled with the liquid which is to be pumped, so that no air pocket is left.
3. After the pump is primed, the delivery valve is kept closed and the electric motor is started to rotate the impeller.
4. The rotation of the impeller in the casing full of liquid produces a forced vortex which imparts a centrifugal head to the liquid and thus results in an increase of pressure throughout the liquid mass.

5. Now as long the delivery valve is closed and the impeller is rotating, it just churns the liquid in the casing.
6. When the delivery valve is opened the liquid is made to flow in an outward radial direction thereby leaving the vanes of the impeller at the outer circumference with high velocity and pressure.

PART-5

Hydraulic Accumulators, Hydraulic Lift and their Applications.

CONCEPT OUTLINE

Hydraulic Accumulator : It is a device which is used for storing the energy of fluid in the form of pressure energy. This energy can be applied for any sudden requirement.

Hydraulic Lift : It is a device used for carrying passenger or goods from one floor to another in multi-storeyed building.

Applications of Hydraulic Lifts :

1. Wheel chair lift,
2. Truck trailer,
3. Material handling, and
4. Industrial hydraulic application.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.22. **Define hydraulic accumulator. Draw the neat sketch and explain the construction and working of hydraulic accumulator.**

Answer

A. **Hydraulic Accumulator :** It is a device which is used to store the energy of fluid under pressure and make this energy available to hydraulic machines such as presses, lifts and cranes.

B. **Construction of Hydraulic Accumulator :**

1. Fig. 3.22.1 shows a simple hydraulic accumulator.
2. It consists of a fixed vertical cylinder, containing a sliding ram.
3. A weight is placed on the top, to create pressure in the cylinder chamber.
4. One side of the cylinder is connected to the pump and the other side to the machine.

C. Working of Hydraulic Accumulator :

1. In the beginning, the ram is at the lowermost position.

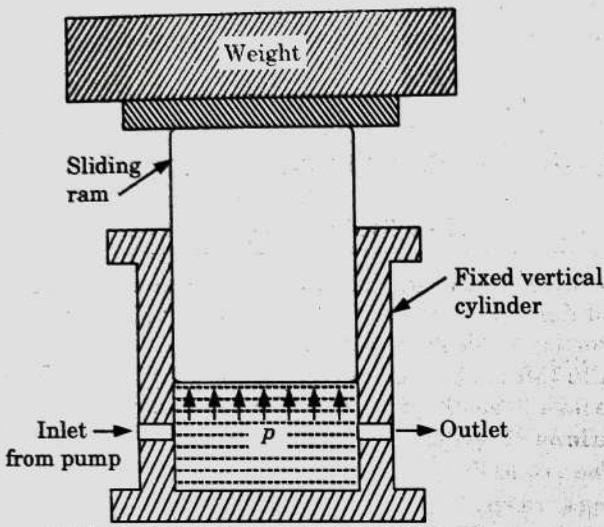


Fig. 3.22.1. Hydraulic accumulator.

2. During idle periods of driven machine high pressure liquid from the pump is admitted in the hollow space of the cylinder, it raises the ram, on which the heavy load is placed.
3. Flow of more liquid continues till the ram is at its uppermost position. At this position maximum amount of pressure energy is accumulated.
4. This accumulated energy is later discharged to the driven machine, during its working stroke *i.e.*, when it requires maximum amount of energy.

Que 3.23. **Describe with the help of neat sketch the construction and working of a differential hydraulic accumulator.**

Answer

A. Construction of Differential Hydraulic Accumulator :

1. It consists of a fixed vertical cylinder of small diameter as shown in Fig. 3.23.1.

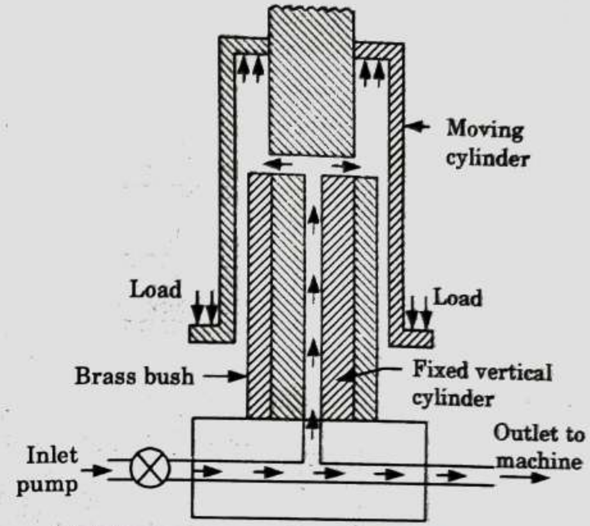


Fig. 3.23.1. Differential hydraulic accumulator.

2. The fixed vertical cylinder is surrounded by closely fitting brass bush, which is surrounded by an inverted moving cylinder, having circular projected collar at the base on which weights are placed.

B. Working of Differential Hydraulic Accumulator :

1. The liquid from the pump is supplied to the fixed vertical cylinder.
2. The liquid moves up through the small diameter of fixed vertical cylinder and then enters the inverted cylinder.
3. The water exerts an upward pressure force on the internal annular area of the inverted moving cylinder, which is loaded at the base.
4. The internal annular area of the inverted moving cylinder is equal to the sectional area of the brass bush.
5. When the inverted moving cylinder moves up, the hydraulic energy is stored in the accumulator.

Que 3.24. **Explain in brief about hydraulic lift.**

Answer

1. It consists of a ram, sliding in fixed cylinder as shown in Fig. 3.24.1.
2. At the top of the sliding ram, a cage is fitted.
3. The liquid under pressure flows into the fixed cylinder and exerts force on the sliding ram, which moves vertically up and thus raises the cage to the required height.

4. The cage moves in downward direction when the liquid from the fixed cylinder is removed.

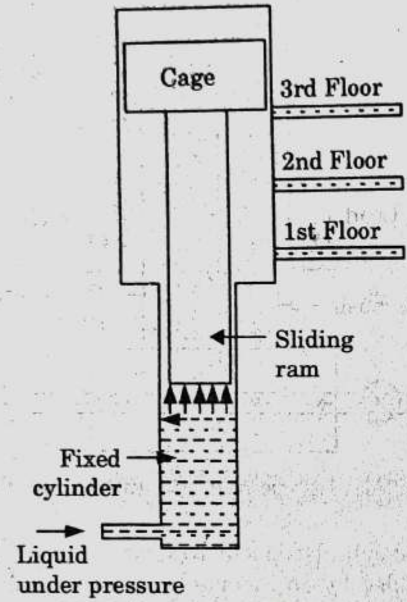


Fig. 3.24.1. Hydraulic lift.

Que 3.25. **Draw neat sketch and explain suspended hydraulic lift.**

Answer

1. It is a modified form of hydraulic lift.
2. It consists of a cage which is suspended from a wire rope.
3. A jigger, consisting of a fixed cylinder, a sliding ram and a set of two pulley blocks, is provided at the foot of the hole of the cage.
4. One of the pulley blocks is movable and the other is a fixed one. The end of the sliding ram is connected to the movable pulley block.
5. A wire rope, one end of which is fixed at *A* and the other end is taken round all the pulleys of the movable and fixed blocks and finally over the guide pulleys as shown in Fig. 3.25.1.

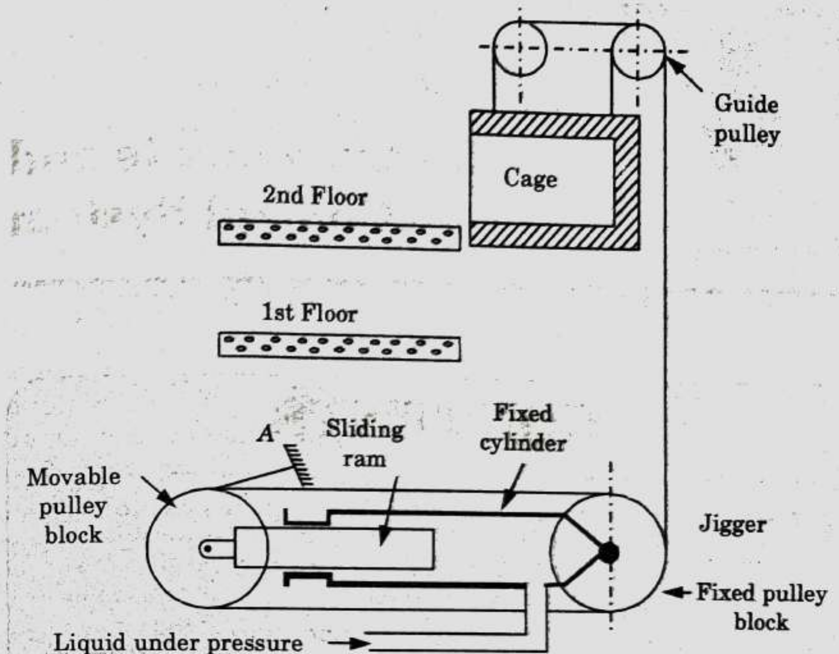


Fig. 3.25.1. Suspended hydraulic lift.

6. The cage is suspended from the other end of the rope.
7. The raising or lowering of the cage of the lift is done by the jigger as given below :
   i. When water under high pressure is admitted into the fixed cylinder of the jigger, the sliding ram forced to move towards left.
   ii. As one end of the sliding ram is connected to the movable pulley block hence the movable pulley block moves towards the left, thus increasing the distance between two pulley blocks.
   iii. The wire rope connected to the cage is pulled and the cage is lifted.
   iv. For lowering the cage, water from the fixed cylinder is taken out.
   v. The sliding ram moves towards right and hence movable pulley blocks also moves towards right.
   vi. This decreases the distance between two pulley blocks and the cage is lowered due to increased length of the rope.

☺☺☺

4

UNIT

Measurements and Control System

CONTENTS

PART-1

Measurements and Control System : Concept of Measurement, Error in Measurements, Calibration.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. What is measurement ? Write down the scope and requirement of measurement.

Answer

A. **Measurement :** It is the process of comparing unknown magnitude of certain parameter with the known predefined standard of that parameter.

B. **Scope of Measurement :**

1. Measurements are one of crucial parts of engineering fields.
2. Every branch of engineering involves two processes :
   i. Design, and
   ii. Operations and maintenance.
3. The design may be building design, circuit design, transportation design, automobile design etc.
4. The operations part involves operation of the machines, automobiles, various plants, circuits etc.
5. Both, the design, and operations and maintenance involve measurements.
6. For instance while designing automobile we have to consider dimensions of various parts of the automobiles, the loads they can pick up etc.
7. Similarly during the operations of the plant, say like industrial refrigeration plant, we have to measure parameters like pressure, temperature etc.

C. **Requirements of Measurement :**

1. The standard used for comparison purposes must be accurately defined and should be commonly acceptable.
2. The standard must be of the same character as the measurand.
3. The apparatus used and the method adopted for the purposes of comparison must be provable.

Que 4.2. **Explain various methods of measurement.**

Answer

Various methods of measurement are as follows :

i. Direct Method :

1. In these methods, the unknown quantity is directly compared against a standard. The result is expressed as a numerical number and a unit. The standard, in fact, is a physical embodiment of a unit.
2. Direct methods are quite common for the measurement of physical quantities like length, mass and time.

ii. Indirect Method :

1. In the indirect method of measurements some transducing device, called transducer is used which is coupled to a chain of the connecting apparatus that forms the part of the measuring system.
2. In this system the quantity which is to be measured (input) is converted into some other measurable quantity (output) by the transducer. The transducer used is such that the input and the output are proportional to each other.
3. The readings obtained from the transducer are calibrated to as per the relations between the input and the output thus the reading obtained from the transducer is the actual value of the quantity to be measured. Such type of conversion is often necessary to make the desired information intelligible.
4. The indirect method of measurements comprises of the system that senses, converts and finally presents an analogues output in the form of a displacement or chart.
5. This analogues output can be in various forms and often it is necessary to amplify it to read it accurately and make the accurate reading of the quantity to be measured.
6. The majority of the transducers convert mechanical input into analogues electrical output for processing, though there are transducers that convert mechanical input into analogues mechanical output that is measured easily.

Que 4.3. **Draw a block diagram representation of a generalized measurement system. Identify various elements and explain their functions.**

Answer

A. Block Diagram of Generalized Measurement System :

In generalized measuring instrument there are three main elements :

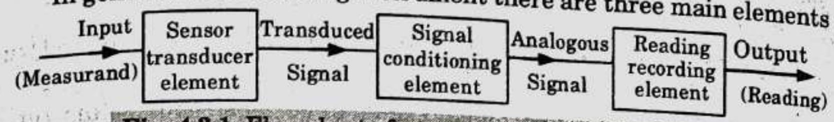


Fig. 4.3.1. Flow chart of generalized measuring system.

B. Various Elements and their Functions :

i. Initial Sensing Element : It is also known as sensor transducer element or simply transducer element. It is the first element which detects or senses the measurand.

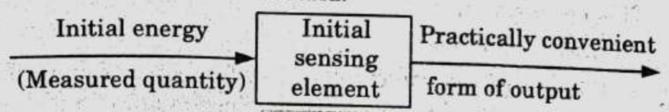


Fig. 4.3.2.

Function : It is the part which first receives energy from the measured medium and converts this input into a more practically convenient form of output.

ii. Signal Conditioning Elements :

1. Signal conditioning elements are used to modify the transduced information into a form that is acceptable to reading recording elements.
2. These include variable transformation element, variable manipulation element and data transmission element.

Function : Many times, the output of the transducer is so small that it is insufficient to operate an indicator. Hence it should be suitably manipulated by signal conditioning element.

iii. Reading Recording Element :

1. It is also called data presentation element. The data is finally transmitted to data presentation element.
2. This element is used to display information of measured quantity to the observer.
3. The most common form of data presentation element consists of a pointer moving over a scale to give the reading of measured quantity.

Function :

1. These element act as data storage elements.
2. The desired data may be retrieved repeatedly whenever required.

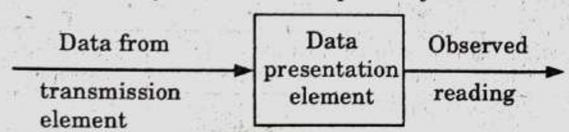


Fig. 4.3.3.

Que 4.4. **What is error ? Also explain sources of error.**

Answer

A. Error :

1. An error can be defined as difference between measured value and true value.
2. An ideal measuring instrument should be designed and manufactured for precise and unambiguous measurement of parameters of interest. But since hundred percent control is unattainable, error does occur.

B. Sources of Error :

1. The major sources of error that may contaminate the result are :
   i. The measurer, and
   ii. The instrument itself.
2. Sometimes, the measurer may suffer from temporary factors like fatigue, boredom, anxiety or other distractions. Such factors limit the ability of the measurer to take the measurements accurately and fully. Hunger, impatience, or general variation in mood can also affect the readings.
3. Any condition that creates strain on the user during the measurement session can have serious effect on data collection.
4. A defective instrument can also cause error in measurement.
5. The error also occurs due to noise, response time, design limitations, effect of friction in the instrument movement, resolving power, transmission, errors of observation and interpretation.

Que 4.5. **Explain classification of measurement errors.**

Answer

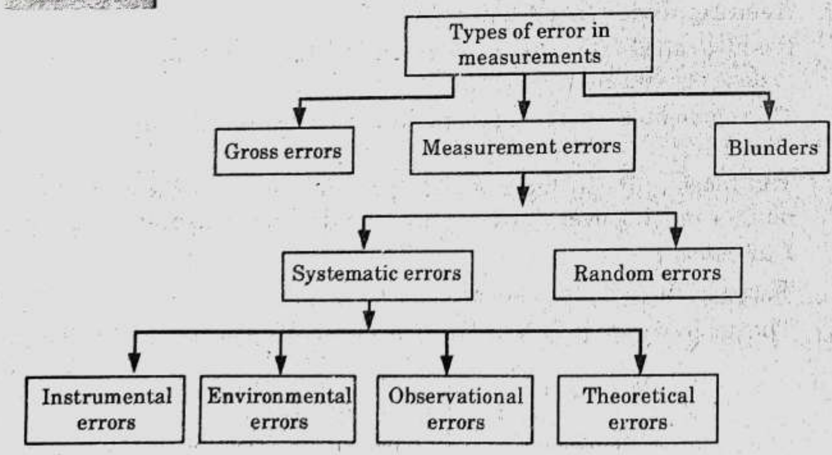


Fig. 4.5.1.

Classification of the measurement errors are as follows :

A. Gross Errors :

1. Gross errors are caused by mistake in using instruments or meters, calculating measurement and recording data results.
2. The best example of these errors is a person or operator reading pressure gage 1.01 N/m^2 as 1.10 N/m^2.

B. Measurement Errors :

1. The measurement error is the result of the variation of a measurement of the true value.
2. Usually, measurement error consists of a systematic error and random error.

a. Systematic Errors :

1. The errors that occur due to fault in the measuring device are known as systematic errors. Usually they are called as zero error a positive or negative error.
2. These errors can be detached by correcting the measurement device and classify as follows :

i. Instrumental Errors :

1. Instrumental errors occur due to wrong construction of the measuring instruments.
2. These errors may occur due to hysteresis or friction.

ii. Environmental Errors :

1. The environmental errors occur due to some external conditions of the instrument. External conditions mainly include pressure, temperature, humidity etc.
2. In order to reduce the environmental errors, try to maintain the humidity and temperature constant in the laboratory by making some arrangements.

iii. Observational Errors :

1. These types of errors occur due to wrong observations or reading in the instruments.
2. In order to reduce error highly accurate meters are needed e.g., meters provided with mirror scales.

iv. Theoretical Errors :

1. Theoretical errors are caused by simplification of the model system.
2. For example, a theory states that the temperature of the system surrounding will not change the readings taken when it actually does, then this factor will begin a source of error in measurement.

b. Random Errors :

1. Random errors are caused by the sudden change in experimental conditions and noise and tiredness in the working persons. These errors are either positive or negative.

2. Examples : Changes in humidity, unexpected change in temperature and fluctuation in voltage.
3. These errors may be reduced by taking the average of a large number of readings.

C. Blunders :

1. Blunders are final source of errors and these errors are caused by faulty recording or due to a wrong value while recording a measurement, or misreading a scale or forgetting a digit while reading a scale.
2. These blunders should stick out like sore thumbs if one person checks the work of another person. It should not be comprised in the analysis of data.

Que 4.6. **Write short notes on calibration and static calibration.**

Answer

A. Calibration :

1. Calibration may be defined as process of determining output scale of a measuring instrument.
2. For this, known magnitudes of the input quantity must be fed into the sensor-transducer and the system's output behaviour has to be observed.
3. Such comparison allows the magnitude of output to be correctly interpreted in terms of the magnitude of the input.
4. Hence, calibration establishes the correct output scale for the measuring instrument.
5. Calibration process may be categorized as :

i. **Single Point Calibration :** A single value of input and corresponding output is sufficient to evaluate the constant of proportionality. This is called single point calibration.

ii. **Multi Point Calibration :** If the output is not proportional to input, then to improve accuracy of calibration, a number of input values are fed to the instrument and the corresponding output deflections are observed. This is called multi point calibration.

B. Static Calibration :

1. In static calibration, a known value is input to the system under calibration and the system output is recorded.
2. The term static refers to a calibration procedure in which the value of the variables involved remain constant during a measurement, *i.e.*, they do not change with time.
3. In static calibrations, only the magnitudes of the known input and the measured output are important.

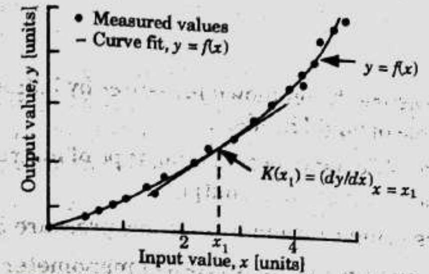


Fig. 4.6.1. A static calibration curve.

4. A representative static calibration is shown in Fig. 4.6.1.
5. The measured data points describe the static input-output relationship for a measurement system.
6. A polynomial curve fit to the data may be conveniently used to describe this relationship as $y = f(x)$.

Where, y = Output values, and
x = Input values.

PART-2

Measurements of Pressure, Temperature, Mass Flow Rate, Strain, Force and Torques.

CONCEPT OUTLINE

Pressure Measurement : Pressure measurement is not only concerned with determination of force per unit area but is also involved in many liquid level, density flow and temperature measurement.

Force Measurement : Force is usually measured by applying it to a calibrated device which resists the force and indicates or records its magnitude.

Radiation Pyrometer : A radiation pyrometer is basically a thermocouple instrument placed in a black tube.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.7. **What do you understand by manometers ? Also write down the types of manometers. Explain any one.**

Answer

A. Manometers :

1. Manometers measure the unknown pressures by balancing against the gravitational force of liquid heads.
2. Manometers are self-balancing deflection type of instruments and have continuous rather than stepwise output.
3. They are used as primary standards for low pressure measurements.

B. Types of Manometers : Various types of manometers are as follows :

1. *U*-tube manometer,
2. Well type manometer,
3. Inclined tube manometer,
4. Ring balance manometer, and
5. Micromanometer.

C. *U*-Tube Manometer :

1. The *U*-tube manometer shown in Fig. 4.7.1 may be used for measurement of liquid or gas pressure.

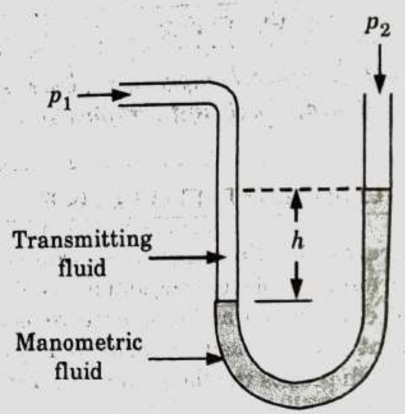


Fig. 4.7.1. *U*-tube manometer.

2. The manometer is filled with a manometric fluid whose specific gravity is known.
3. The difference between the pressure gravity on two limbs of the manometer is a function of h, the difference between the levels of the manometric fluid into two limbs.
4. The pressure balance equation is,

$$p_1 + gh\rho_f = p_2 + gh\rho_m$$

$\therefore$ Differential pressure $p = p_1 - p_2 = gh(\rho_m - \rho_f)$

Where, g is gravitational constant (9.81 m/s²) and ρ_m and ρ_f are respectively the specific gravities of manometric fluid and the transmitting fluid in kg/m³.

5. The height h can be read off a scale placed alongside the *U*-tube. It is to be noted that the distance h is measured parallel to the gravitational force and that the differential pressure $p = p_1 - p_2$ is measured at the location designated by the dashed line.
6. In case the pressure due to transmitting fluid can be neglected, difference in pressure,

$$p = p_1 - p_2 = gh\rho_m$$

7. If p_1 is the pressure being measured, the *U*-tube manometer may be used for measurement of :
   i. Absolute pressure if $p_2 = 0$,
   ii. Gauge pressure if $p_2 = p_s$ = Atmospheric pressure, and
   iii. Differential pressure, if p_2 is the second pressure to be compared with p_1.
8. *U*-tube manometers are available with ranges up to 40 kN/m² and maximum operating pressure upto 3 MN/m² (gauge).

Que 4.8. **Describe Pirani gauge and its working principle. What is the range of absolute pressure which can be measured with this instrument ?**

Answer

A. Pirani Gauge :

1. It is a device that measures the pressure through change in thermal conductivity of a gas which changes the temperature of a heated element.

B. Working Principle :

1. It is based on the principle that the temperature of a current carrying conductor will not only depend upon the magnitude of current and the resistivity of conductor but also on rate at which heat is dissipated.
2. With drop in pressure the density of gases surrounding the current carrying conductor decreases which in turn reduces the rate of heat dissipation and results in rise of temperature of the conducting wire.

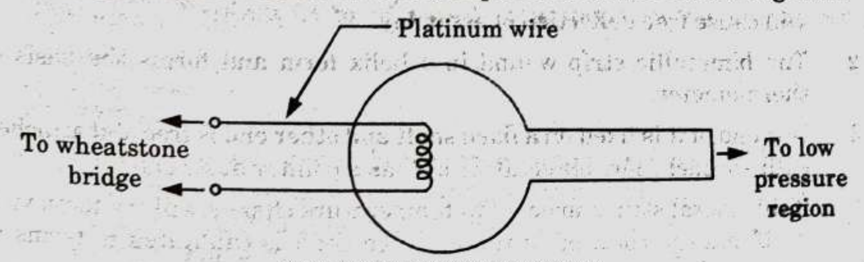


Fig. 4.8.1. Pirani gauge.

3. It consists of a single filament which is made up of tungsten or platinum. Filament is present in form of coils. It is covered with glass tube whose pressure is to be measured.
4. With the drop in pressure of gas surrounding the filament temperature reduces and hence its resistance also changes.
5. The resistance change in the filament in the measuring cell is measured by connecting with the Wheatstone bridge which is calibrated in terms of pressure.

C. **Range of Pirani Gauge :** It covers the range from about 10^{-5} to 1 Torr.

Que 4.9. **What is the principle of temperature measurement ?**

Answer

1. The basic principle of temperature measurement depends upon the establishment of thermodynamic equilibrium between the system and the device used to sense the temperature *e.g.* thermometer.
2. Some scales for measurement of temperatures are as follows :
   i. Degree Celsius,
   ii. Fahrenheit scale, and
   iii. Kelvin scales.
3. Relation between degree Celsius, Fahrenheit and Kelvin scales :

$$\frac{C}{5} = \frac{F-32}{9} = \frac{K-273}{5}$$

Where, C = In degree Celsius,
F = In Fahrenheit, and
K = In Kelvin.

Que 4.10. **Explain the principle of bimetallic thermometer with its advantages.**

Answer

A. **Bimetallic Thermometer :**

1. It is based on the principle that when two metal strips having different coefficient of expansion are brazed together then a change in temperature will cause free deflection of assembly.
2. The bimetallic strip wound in a helix form and forms the basis of thermometer.
3. One end of it is fixed on a fixed shaft and other end is free and attached with another movable shaft which has a pointer at its end.
4. If this metal strip subjected to temperature change will try to unwind itself and the rotation of the movable shaft is calibrated in terms of temperature.

B. **Advantages of Bimetallic Thermometer :**

1. It is simple, compact and robust in construction.
2. It has the capability to work under over ranged condition without harm.
3. It is inexpensive.

Que 4.11. **Explain briefly the construction and working of a radiation pyrometer.**

Answer

A. **Construction of Radiation Pyrometer :**

1. It consists of a light-directing means (as baffles or lenses) and an approximate black body receiver with means for sensing temperature.
2. Sensing element generally has some form of thermopile or pyroelectric sensor.

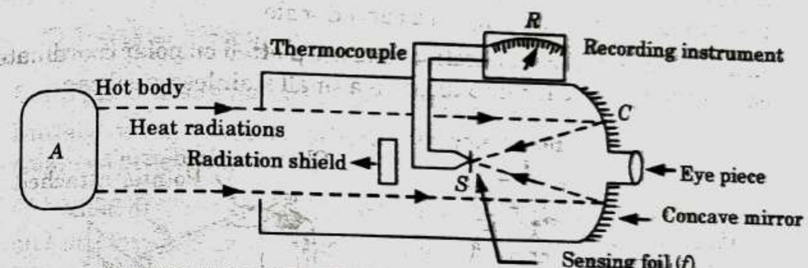


Fig. 4.11.1. A simplified form of radiation pyrometer.

B. **Working of Radiation Pyrometer :**

1. It works on Stefan Boltzmann law which states that the total energy emitted by a unit area of a perfect radiator per second is proportional to the fourth power of its absolute temperature.
2. Radiations coming from the hot body A are focusing on the sensing elements through a concave mirror C as shown in Fig. 4.11.1.
3. The sensing element S, absorbs the radiation and the temperature of corresponding junction of the thermocouple rises and an emf is induced which can be calibrated in terms of temperature by a recording device R.
4. It is used to measure the temperature in range 700 °C to 2000 °C.

Que 4.12. **Explain in brief about rotameter for measurement of flow rate.**

Answer

1. Rotameter can measure the flow of both liquids and gases. Its operations is based on the variable area principle, where the flow raises a metering float in a tapered tube by increasing the area for passage of flow as shown in Fig. 4.12.1. The greater the flow, the higher the float is raised. Thus float height is directly proportional to flow rate.

2. Float reaches a stable position in the tube when upward force exerted by the flowing fluid equals downward gravitational force exerted by the weight of the float.
3. A change in flow rate upsets this force balance. Float then moves up or down, changing the annular area, until it again reaches a position of equilibrium.
4. Rotameters use a magnetic follower to translate vertical linear motion of float into a rotary motion.
5. Follower consists of a steel magnetic helix supported rigidly between bearings. Leading edge of helix is constantly attracted to a magnet contained in float or extension of float.
6. Every vertical position of the float is converted into a corresponding positive radial position of the helix.
7. A pointer with a zero adjustment is attached to the top of helix assembly to indicate flow rate directly on a curved scale.
8. Actual rotameter flow calibration data are plotted on polar coordinates, and resulting curve is reproduced on a small stainless steel cam.

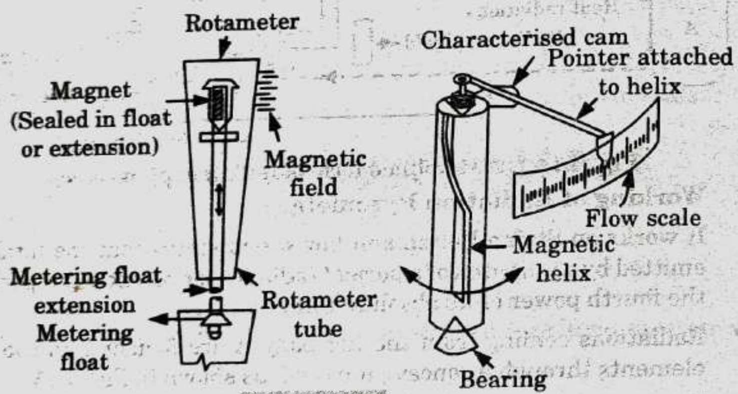


Fig. 4.12.1.

Que 4.13. What are the strain gauge circuits ? Discuss Wheatstone bridge circuit as static strain measurement.

Answer

A. Strain Gauge Circuits :

1. The change in resistance can be measured by using a proper circuit called strain gauge circuits.
2. These change in resistance can be measured by electrical circuits using potentiometer or Wheatstone bridge.

B. Static Strain Measurement by using Wheatstone Bridge Circuit :

1. *It is used to measure static strain only.*

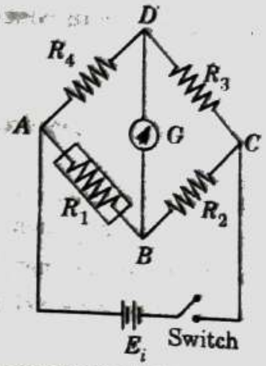


Fig. 4.13.1. Wheatstone bridge circuit for strain measurement.

2. Let R_1 represents the strain gauge resistance.
3. Initially when there is no strain in gauge, Wheatstone bridge is in balanced condition.
4. At balanced condition, Potential at B = Potential at D and no current flows through galvanometer G, thus we can write

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad \text{...(4.13.1)}$$

5. If R_1 changes to $R_1 + \Delta R_1$ then changes from R_2 to $R_2 + \Delta R_2$.

So,
$$\frac{R_1 + \Delta R_1}{R_2 + \Delta R_2} = \frac{R_3}{R_4}$$

$$R_1 + \Delta R_1 = R_2 \frac{R_3}{R_4} + \Delta R_2 \frac{R_3}{R_4}$$

$$= R_1 + \Delta R_2 \frac{R_3}{R_4} \qquad \left\{\because \frac{R_1}{R_2} = \frac{R_3}{R_4}\right\}$$

$$\Delta R_1 = \frac{R_3}{R_4} \Delta R_2$$

6. If all resistances have equal values then

$$R_1 = R_2 = R_3 = R_4 = R$$

$$\Rightarrow \quad \Delta R_1 = \Delta R_2$$

And
$$\frac{dR}{R} = G_f \in$$

$$\Delta R_1 = G_f \in R_1 = \Delta R_2$$

7. So, change in measurement of R_2 is direct measure of strain and can be calibrated in terms of strain.

Que 4.14. **Write short note on strain rosettes.**

Answer

1. Strain rosettes are used for strain measurement in complex machine element.
2. When strain gets developed in more than one direction and the specimen surface is open or free, strain measurement is done by strain rosettes.
3. It has three or four grids with various angular positions.
4. This gauge is bonded to test specimen which may be subjected to tensile or compressive loads.
5. When the member is stressed axially, then strain induced is calculated by the given formula :

$$\sigma = \in E$$

Where, σ = Stress,

$\in$ = Strain, and

E = Modulus of elasticity.

6. When any machine part is stressed in only one direction then it also has a lateral strain along with axial strain.
7. There are three types of strain gauge rosettes :
   i. Rectangular rosette,
   ii. Delta rosette, and
   iii. T-delta rosette,

Que 4.15. **What are the various types of load cell used in force measurement ?**

Answer

Various types of load cell used in force measurement are as follows :

i. Hydraulic Load Cell :

1. In hydraulic load cell the force is subjected on the diaphragm which deflects and the force is transferred to liquid.
2. The liquid is contained in confined space when the force applied on diaphragm liquid pressure is increased and equal to the applied force divided by effective area of diaphragm.
3. The pressure gauge can also be directly calibrated in units of force.

ii. Pneumatic Load Cell :

1. It is based on the force balance principle. It consists of a chamber and nozzle flap sensor which covered with elastic diaphragm.
2. When pressurized air is supplied through a pipe, it deflects and gap between nozzle and diaphragm decreases while pressure in the chamber increases.
3. Its pressure is indicated by the height of mercury in a manometer.

iii. Strain Gauge Load Cell :

1. These load cells convert the force into electrical outputs which are provided by strain gauge.
2. It consists of a steel cylinder having four identical strain gauge mounted upon it.
3. Its output is connected to various measuring instruments for indicating, recording and controlling the weight of force.
4. Strain gauges are directly applied to force developing device and the device is calibrated against strain gauge output.

iv. Piezoelectric Load Cell :

1. Piezoelectric load cells works on the principle of piezoelectric effect which can be stated as "certain materials can generate an electrical change when subjected to mechanical strain or vice-verse".
2. Piezoelectric load cells employ piezoelectric transducers are useful for measuring dynamic loading, especially of an impact or abruptly applied nature.
3. The transducer produces an electrostatic charge, which is generally conditioned through use of a charge amplifier.
4. Desirable qualities include wide ranges of working load in a given unit, excellent frequency response, great stiffness, high resolution, and relatively small size.
5. When a quartz master crystal is sliced to produce transducer elements, the selection of slicing planes yields elements with different properties.
6. Slices may be taken to produce elements selectively sensitive to tension-compression, shear, or bending.
7. By taking advantage of these characteristics, piezoelectric load cells may be designed that provide various combinations of orthogonal load and/or torque outputs.

Que 4.16. **Write short note on followings :**

i. Elastic force transducer, and

ii. LVDT force transducer.

Answer

i. **Elastic Force Transducer :**

1. It is based on the principle that every elastic material has a particular deflection for a particular load (within its elastic limit).
2. By measuring the deflection for elastic material we can easily get the value of corresponding load or force.
3. Consider an axially loaded elastic element as shown in Fig. 4.16.1, under the action of force F, it undergoes deflection of FL/AE.

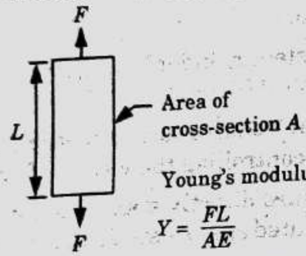


Fig. 4.16.1. Axially loaded member.

ii. **LVDT Force Transducer :**

1. It can be used for static as well as dynamic force measurement.
2. LVDT can be used together with elastic elements such as diaphragm to produce LVDT force transducer. The extended core of LVDT is fixed to the diaphragm as shown in Fig. 4.16.2.
3. When some force acts on the elastic diaphragm, it gets deflected and in turn moves the core of LVDT thereby producing some output voltage e_0.

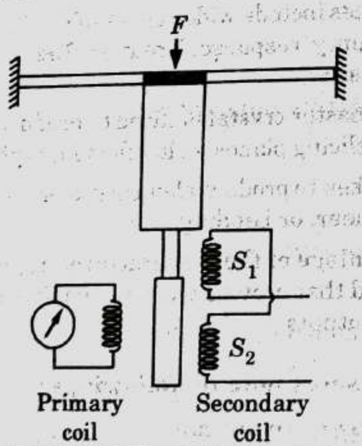


Fig. 4.16.2. LVDT force transducer.

Que 4.17. **Explain in detail prony brake dynamometer for torque measurement with neat sketch.**

Answer

1. It consists of two wooden blocks, placed around a pulley of radius r as shown in Fig. 4.17.1.

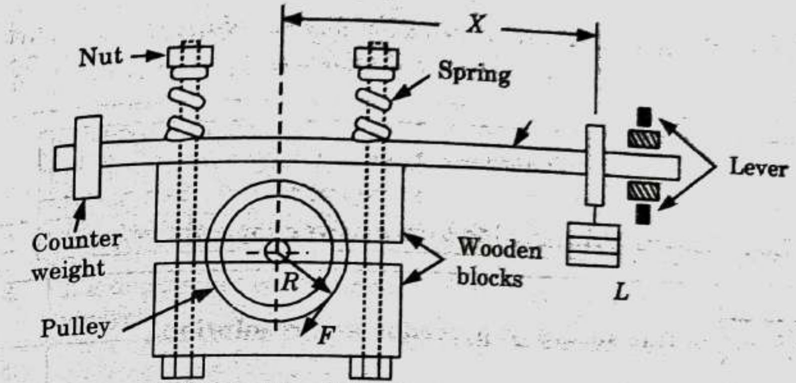


Fig. 4.17.1. Prony brake dynamometer.

2. The pulley is keyed to the shaft of the engine whose power has to be measured.
3. The wooden blocks are clamped by two nuts and bolts.
4. A helical spring is placed between the nut and the upper wooden block in order to adjust the pressure on the pulley and hence control its speed.
5. The upper block also has a long lever attached to it which carries a load L at its outer end.
6. A counter weight is placed on the other end of lever to balance the brake when unloaded.
7. The stops limit the motion of the lever.
8. To measure shaft power using prony brake dynamometer, the lever is loaded with suitable load L and nuts tightened such that the engine shaft runs at a constant speed and the lever is in horizontal position.
9. Under such working condition, moment due to load L balances moment due to frictional resistances force F between wooden blocks and the pulley.
10. Hence, torque (T) on the shaft is given by relation

$$T = L \times x = F \times r$$

11. Work done in 1 revolution = Torque × Angle turned

$$= T \times 2\pi$$

12. Work done per minute = $T \times 2\pi N$

Where, N is the shaft speed in rpm.

13. Power transmitted by the engine shaft,

$$P = \frac{\text{Work done}}{\text{Time}} = \frac{T \times 2\pi N}{60} \text{ watts.}$$

PART-3

Concept of Accuracy, Precision and Resolution, Basic Numerical Problems.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.18. **Define accuracy, precision and resolution.**

Answer

i. Accuracy :

1. Accuracy is defined as degree of closeness of the output to the true value of measured quantity.
2. It is specified as percentage deviation or inaccuracy in measurement from true value of measured quantity.

$$\text{Percentage accuracy} = \frac{\text{Measured value} - \text{True value}}{\text{True value}} \times 100$$

ii. Precision :

1. It is defined as the ability to reproduce the same output repeatedly for the same input.
2. If a Vernier is used to measure the width of a bar and it produces same output then it is said to have high precision.
3. It may be a fact that an instrument have high precision but have low accuracy.

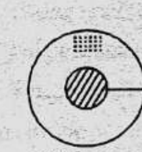
iii. Resolution :

1. Resolution is the ability of the measurement system to detect and faithfully indicate small changes in the characteristic of the measurement result.
2. It is the ratio between the maximum signal measured to the smallest part that can be resolved usually with an analog-to-digital (A/D) converter.

3. It is the degree to which a change can be theoretically detected, usually expressed as a number of bits. This relates the number of bits of resolution to the actual voltage measurements.

Que 4.19. **What is the difference between precision and accuracy ?**

Answer

S. No.	Precision	Accuracy
1.	It represents degree of repeatability of several independent measurements of the desired input at the same reference conditions.	It represents the degree of correctness of the measured value with respect to the true value.
2.	It depends on random errors.	It depends on systematic errors.
3.	It is determined by statistical analysis.	It is determined by proper calibration of the instrument.
4.	 High precision	 High accuracy

Que 4.20. **For a platinum resistance thermometer, the resistance at 22 °C is 130 Ω and the resistance coefficient for temperature for wire is 0.004 Ω/Ω °C. Find the resistance at 40 °C and temperature at which resistance will 8.5 Ω.**

Answer

Given : $R_0 = 130\ \Omega$, $T_0 = 22\ °C = 295$ K, $\alpha = 0.004\ \Omega/\Omega\ °C$

To Find : i. Resistance at 40 °C.

ii. Temperature at 8.5 Ω.

1. We know that,

$$R = R_0 [1 + \alpha (T - T_0)] \quad \text{...(4.20.1)}$$

At $T = 40$ °C = 313 K,

$$R = 130\ [1 + 0.004(313 - 295)]$$
$$= 130\ [1 + 0.072]$$
$$R = 139.36\ \Omega.$$

2. When $R = 8.5\ \Omega$,

From eq. (4.20.1),

$$8.5 = 130\,[1 + 0.004(T - 295)]$$

$$0.065 = 1 + 0.004(T - 295)$$

or $$T = 61.25\text{ K} = -211.75\,°\text{C}.$$

Que 4.21. **A strain gauge is bounded to a 0.2 m long workpiece that has a cross-sectional area of 6 cm² and E = 210 GN/m² and unstrained resistance is 240 Ω and GF = 2.2. When load is applied the resistance of this plate changes by 0.013 Ω. Calculate the change in length and the force applied.**

Answer

Given : $L = 0.2$ m, $A = 6\text{ cm}^2 = 6 \times 10^2\text{ mm}^2$, $R = 240\ \Omega$, $E = 210\text{ GN/m}^2$
GF = 2.2, $\Delta R = 0.013\ \Omega$

To Find : i. Change in length
ii. Force applied.

1. We know that, Gauge factor

$$\text{GF} = \frac{\Delta R / R}{\Delta L / L}$$

$$2.2 = \frac{(0.013/240)}{(\Delta L/0.2)}$$

$$\Delta L = 4.92 \times 10^{-6}\text{ m} = 0.0049\text{ mm}$$

2. Stress is given as, $\sigma = E\epsilon$

or $$\frac{P}{A} = E\left(\frac{\Delta L}{L}\right)$$

$$P = EA\left(\frac{\Delta L}{L}\right)$$

$$P = 210 \times 10^3 \times 6 \times 10^2 \times \left(\frac{0.0049}{0.2 \times 10^3}\right)$$

$$P = 3087\text{ N}$$

PART-4

System of Geometric Limit, Fit, Tolerance and Gauges, Basic Numerical Problems.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.22. **Define the following terms :**

i. ***Limit,***
ii. ***Fits, and***
iii. ***Tolerance.***

Answer

i. **Limit :**
1. The two extreme permissible size for any object is known as limit.
2. The minimum size is called lower limit and maximum size is called upper limit.

ii. **Fits :**
1. During assembly of two mating parts, there may be either tightness or looseness between them. The degree of tightness or looseness between them is termed as fits.
2. There are three types of fits as follows :
   i. Clearance fit,
   ii. Interference fit, and
   iii. Transition fit.

iii. **Tolerance :**
1. It is defined as the difference between the high and low limits of size.
2. There are two types of tolerances as follows :
   i. Unilateral tolerance, and
   ii. Bilateral tolerance.

Que 4.23. **Discuss various types of fits with neat sketches.**

Answer

Types of fits are as follows :

i. **Clearance Fit :**
1. In this the maximum permissible shaft diameter is smaller than the minimum permissible limit of hole, so that the shaft can rotate or slide in the hole.
2. Example : Shaft rotating in a bearing.

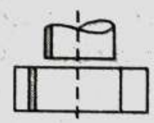


Fig. 4.23.1. Clearance fit.

ii. Interference Fit :

1. In this the minimum permissible shaft diameter is larger than the maximum allowable diameter of the hole.
2. Example : Bearing bushes in their housing and smaller end of connecting rod in engine.

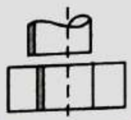


Fig. 4.23.2. Interference fit.

iii. Transition Fit :

1. In this the diameter of the maximum allowable hole is larger than that of the smaller limit of shaft but the smaller limit of hole is smaller than the largest limit of shaft.
2. Example : Coupling rings and recesses.

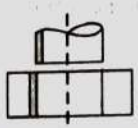


Fig. 4.23.3. Transition fit.

Que 4.24. **Explain briefly basis of fits or limit system.**

Answer

Basis of fits or limit system are as follows :

i. Hole Based System :

1. In the hole based system, the size of hole is kept constant and different types of fits are obtained by varying the size of the shaft.
2. Refer Fig. 4.24.1(a) in this system, lower deviation of hole is zero.
3. The upper limit of the hole and upper and lower limit of shaft can be varied to get the desired type of fit.

ii. Shaft Based System :

1. In this system, the diameter of shaft is kept constant and different fits are obtained by varying the size of hole.
2. Refer Fig. 4.24.1(b) this system, the upper deviation of shaft is zero.
3. Various fits can be obtained varying the lower limit of shaft and lower and upper limit of hole.

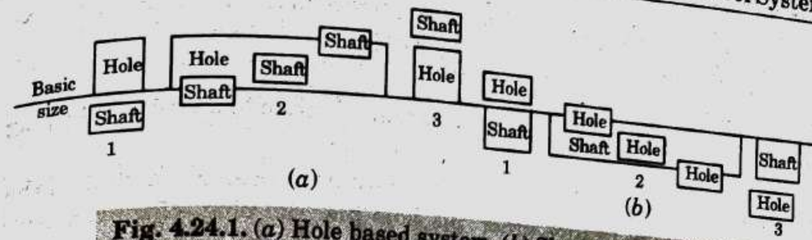


Fig. 4.24.1. (a) Hole based system, (b) Shaft based system.

Que 4.25. **Write short notes on followings :**

i. Slip gauge
ii. Angle gauge.

Answer

i. Slip Gauge :

1. This is a rectangular block made up of hardened steel with two opposite faces separated by defined distance.
2. These are available in varying thickness and faces are flat and finished.
3. Slip gauges have been divided into five grades as :
   - i. Reference grade
   - ii. Calibration grade
   - iii. 0 grade
   - iv. I grade
   - v. II grade

ii. Angle Gauge :

1. It is made up of hardened steel and this gauge can be combined to form various angular dimensions.
2. Their sizes are available from 76 mm length to 16 mm wide and faces are machined and lapped to form precise angle.
3. They are available in sets of thirteen gauges which are as follows :
   1°, 3°, 9°, 27°, 41°, 1', 3', 9', 27', 3", 6", 18" and 30".

Que 4.26. **Explain the Taylor's principle of gauge design. Define ring gauge and plug gauge.**

Answer

A. Taylor's Principle of Gauge Design : According to Taylor, 'Go' gauge corresponds to maximum metal condition while 'No Go' gauge corresponds to minimum metal condition.

i. For shafts :

1. 'Go' ring gauge provides maximum metal limit of shaft and 'No Go' ring gauge corresponds to minimum metal limit of shaft.

2. It is said that the shaft is within the specified limits if it cannot enter 'No Go' ring but can pass through 'Go' ring gauge.

ii. For holes :

1. 'Go' plug gauge provides minimum metal limit of hole and 'No Go' plug provides the maximum metal limit of hole.
2. It is said that hole is manufactured within the prescribed limits if the 'No Go' gauge cannot enter the hole but 'Go' plug gauge can pass through the hole.

B. Plug Gauge :

1. This gauge is an accurate cylinder used as an internal gauge for size control of holes.
2. It has a handle for holding and made in a variety of style.
3. These gauges may be single or double end.

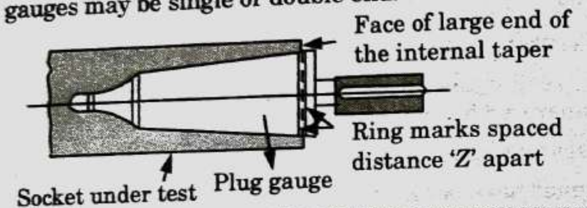


Fig. 4.26.1. Testing taper of socket with plain plug gauge.

C. Ring Gauge :

1. It is used for outside diameter and is used in pairs a 'Go' and 'No Go'.
2. The Go gauge corresponds to upper limit of shaft while 'No Go' ring gauge corresponds to lower limit of shaft diameter.

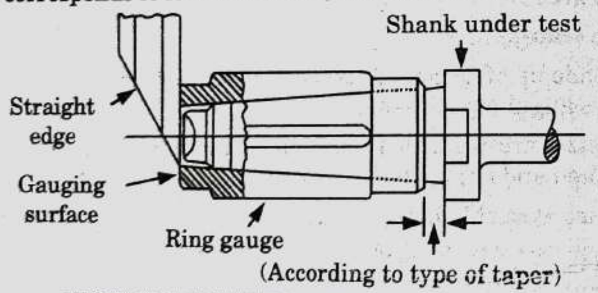


Fig. 4.26.2. Testing taper with ring gauge.

Que 4.27. **What are the gauges ? Give its classification ?**

Answer

A. Gauge :

1. It can be defined as a tool which measure or compare a component.
2. The sensitivity of this instrument which have fixed dimension is used to determine whether the size of some component exceed or less than the size of gauge.

3. The gauge cannot be used for longer parts and the surface of Go end of gauge wears on continuous use, no magnification is provided in a gauge while comparator can be used for compare dimension of large rests and no wear as in case of electrical compensations.

B. Classification of Gauges :

i. Snap Gauge :

1. It is used for measuring plain external dimension.
2. It consists of a *U*-shaped frame having jaw equipped with suitable gauging surface. Mostly gauges are provided with the 'Go' and 'No Go' feature in a single jaw.
3. This gauge has been selected because it incorporates most of the advantages of similar gauge.
4. It is easily adjustable, rigid, rapid and light weight.

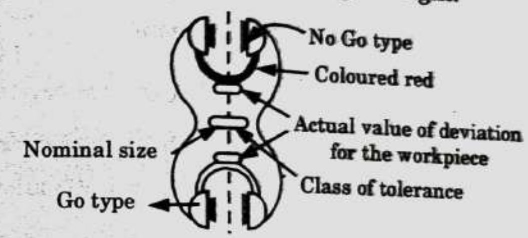


Fig. 4.27.1. 'Go' and 'No Go' snap gauges for sizes over 3 mm and upto 100 mm.

ii. Universal Surface Gauge :

1. It is used for non-precision measurement and is used for surface measurement.
2. It consists of scriber, spindle and universal clamp. Spindle carries a scriber in a universal clamp attached.
3. The scriber used for scribing lines can be set at position by screw. It is also used for centering of machine.

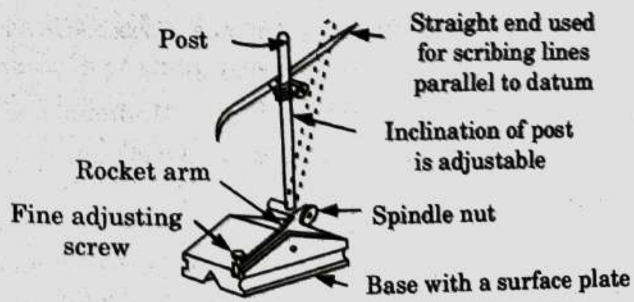


Fig. 4.27.2. Universal surface gauge.

iii. Ring Gauge : Refer Q. 4.26, Page 4–24H, Unit-4.

iv. Plug Gauge : Refer Q. 4.26, Page 4–24H, Unit-4.

Que 4.28. **Determine the dimensions and tolerances of shaft and hole having size of 30 *H7/h8* fit. Also find the allowance (minimum clearance) and maximum clearance.**

Answer

Given : Shaft and hole size 30*H7/h8*.
To Find : i. Dimensions.
ii. Tolerances of shaft and hole.
iii. Allowance.
iv. Maximum clearance.

1. For hole $H7$ and shaft $h8$, the fundamental deviation is zero.
   As 30 mm lies in the range of 18 and 30 mm,
   $$D = \sqrt{18 \times 30} = 23.2 \text{ mm}$$
2. $$\text{Value of } i = 0.45\ (\sqrt[3]{D}) + 0.001\, D$$
   $$= 0.45\ (\sqrt[2]{23.2}) + 0.001 \times 23.2 \text{ microns}$$
   $$= 0.45 \times 2.855 + 0.023 = 1.308 \text{ microns}$$
3. $$\text{Value of } IT7 = 16\, i = 16 \times 1.308 \text{ microns}$$
   $$= \frac{16 \times 1.308}{1000} \text{ mm} \approx 0.0020928 \approx 0.0021 \text{ mm}$$
4. Minimum size of hole = 30.0000 mm
   Maximum size of hole = 30.0021 mm
5. Maximum size of shaft = 30.0000 mm
6. Value of $IT8$ for shaft = 25 i = 25 × 1.308 = = 32.7 microns = 0.0033 mm
7. Minimum size of shaft = 30.0000 – 0.0033 = 29.9967 mm
8. Allowance or minimum clearance
   = Minimum size of hole – Maximum size of shaft
   = 30.0000 – 30.0000 = 0
9. Maximum clearance = Maximum size of hole – Minimum size of shaft
   = 30.0021 – 29.9967 = 0.0054 mm.

PART-5

Control System Concepts : Introduction to Control Systems, Elements of control System, Basic of Open and Closed Loop Control with Example.

CONCEPT OUTLINE

Control System : It is an arrangement of physical components connected or related in such a manner as to command, direct or regulate itself or another system.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.29. **What do you mean by control system ? Also write down the elements of control system.**

Answer

A. Control System :

1. It is that mean by which any quantity of interest in a machine, mechanism or other equipment is maintained or altered in accordance with a desired manner.
2. Consider, for example, the driving system of an automobile.
3. Speed of the automobile is a function of the position of its accelerator.

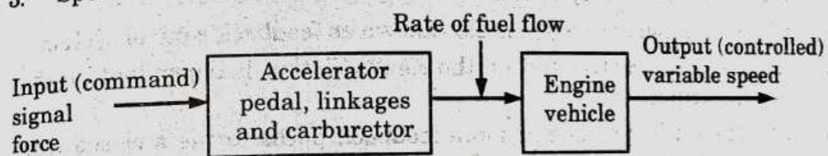


Fig. 4.29.1.

4. The desired speed can be maintained by controlling pressure on the accelerator pedal.
5. This automobile driving system constitutes a control system.

B. Elements of Control System : Elements of a control system are as follows :

1. Controlled variable,
2. Indirectly controlled variable,
3. Command,
4. Reference input,
5. Actuating signal,
6. Disturbance, and
7. System error.

Que 4.30. **Explain open loop and closed loop control system with the help of suitable examples.**

Answer

A. Open loop control system :

1. The open loop control system is also known as control system without feedback or non-feedback control system.
2. In open loop systems the control action is independent of the desired output.
3. In this system the output is not compared with the reference input.
4. The component of the open loop systems are controller and controlled process.

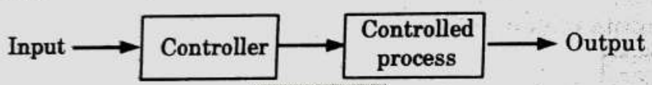


Fig.4.30.1.

i. **Examples :**

1. Automatic washing machine
2. Immersion rod
3. A field control DC motor.

B. Closed loop control system :

1. Closed loop control system is also known as feedback control system.
2. In closed loop control system the control action is dependent on the desired output.
3. Any system having one or more feedback paths forms a closed loop system. In closed loop systems the output is compared with the reference input and error signal is produced.
4. The error signal is fed to the controller to reduce the error and desired output is obtained.

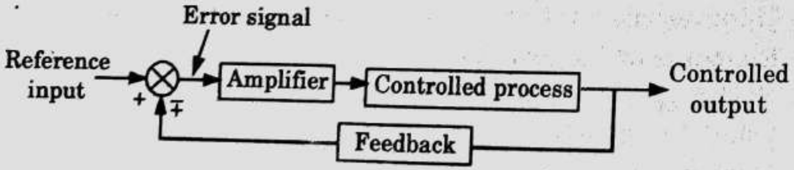


Fig. 4.30.2.

i. **Examples :**

1. Air conditioners,
2. Autopilot aeroplane, and
3. Electric iron.

Que 4.31. **Compare the open loop control system and closed loop control system.**

Answer

S. No.	Open loop	Closed loop
1.	Feedback is not present. So any change in output has no effect on the input.	Feedback is present. So changes in output effects input.
2.	It is not much accurate.	It is very accurate.
3.	It is very sensitive to errors and disturbances.	Less sensitive to errors and disturbances.
4.	It has small bandwidth.	It has large bandwidth.
5.	Simple in construction and is cheap.	Complicated in design and costly.
6.	Highly affected by non-linearity.	Less affected by non-linearity.
7.	**Examples :** Washing machine, traffic signal.	**Examples :** Electric iron, automatic gear.

☺☺☺

5

UNIT

Introduction to Mechatronics

CONTENTS

PART-1

Introduction to Mechatronics : Evolution, Scope, Advantages and Disadvantages of Mechatronics, Industrial Applications of Mechatronics.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. **What do you understand by mechatronics ? Give the evolution level of mechatronics.**

Answer

A. **Mechatronics :**

1. The interdisciplinary field of engineering dealing with the design of products whose function relies on the synergistic integration of mechanical and electronic components coordinated by a control architecture.
2. Mechatronics involves a number of technologies such as :
   i. Mechanical engineering,
   ii. Electronic engineering,
   iii. Electrical engineering, and
   iv. Computer technology.

B. **Evolution Levels of Mechatronics :** Evolution levels of mechatronics are as follows :

i. **Primary Level Mechatronics :**

1. This level incorporates input and output devices such as sensors, and actuators that integrate electrical signals with mechanical action at the basic control level.
2. Examples : Electrically controlled fluid valves and relays.

ii. **Secondary Level Mechatronics :**

1. This level integrates microelectronics into electrically controlled devices.
2. Example : Cassette player.

iii. **Third Level Mechatronics :**

1. This level incorporates advanced feedback functions into control strategy thereby enhancing the quality in terms of sophistication called smart system.

2. Examples : Control of electrical motor used to activate industrial robots, hard disk, CD drives, automatic washing machines.

iv. **Fourth Level Mechatronics :**

1. This level incorporates intelligent control in mechatronic system.
2. It introduces intelligence and fault detection and isolation (FDI) capability system.

Que 5.2. **Enlist the features/characteristics of mechatronics system.**

Answer

Features/characteristics of mechatronics system are as follows :

1. High quality product.
2. Safe.
3. Low cost.
4. Portable.
5. Produced quickly.
6. Serviceability, maintainability and upgradability.

Que 5.3. **What are the objectives and scope of mechatronics ?**

Answer

A. **Objectives of Mechatronics :**

1. To improve products and processes.
2. To develop novel mechanisms.
3. To design new products.
4. To create new technology using novel concepts.

B. **Scope of Mechatronics :**

1. Better design of product.
2. Better process planning.
3. Reliable and quality-oriented manufacturing.
4. Intelligent process control.

Que 5.4. **Mention advantages, disadvantages and applications of mechatronics.**

Answer

A. **Advantages of Mechatronics :**

1. The products produced are cost effective and of very good quality.

2. The performance characteristics of mechatronics products are such which are otherwise very difficult to achieve without the synergistic combination.
3. High degree of flexibility.
4. A mechatronics product can be better than just sum of its parts.
5. Greater extent of machine utilization.

B. **Disadvantages of Mechatronics :**

1. It is expensive to incorporate mechatronics approach to an existing/old system.
2. Imperative to have knowledge of different engineering fields for design and implementation.
3. Specific problems for various systems will have to be addressed separately and properly.
4. High initial cost of the system.

C. **Applications of Mechatronics :**

1. Automotive mechanics.
2. Fax and photocopier mechanics.
3. Air conditioners, elevator controls.
4. Flexible manufacturing systems.
5. Integrated circuits manufacturing systems.
6. Robotics employed in welding, nuclear inspection etc.

Que 5.5. **Write a short note on use of mechatronics in industries. Give examples of mechatronics systems.**

Answer

A. **Use of Mechatronics in Industries :**

1. Mechatronic products have become increasingly dominant in every aspect of commercial market place as technologies, electronics, and computers continue to be developed.
2. Presently major commercial markets for mechatronic products are in the form of automobiles, aeronautical systems, and biological systems.
3. The automobile industry has been the major user of mechatronics technology during the recent decades.
4. Another commercial application of mechatronics is in biomedical and biological sciences.
5. Aircraft and rocket technologies are the other areas where the use of mechatronic systems has been growing rapidly.
6. Advancements in mechatronics in the areas of automobile engineering, biotechnology, and aircraft and rocket engineering, have given rise to specialized disciplines of autotronics, bionics, and avionics respectively.

B. **Examples of Mechatronics Systems :** Examples of mechatronics systems are as follows :

i. **Home Appliances :**
1. Washing machines, and
2. Bread machines.

ii. **Automobiles :**
1. Electrical fuel injection, and
2. Antilock brake system.

iii. **Aircraft :**
1. Flight control, and
2. Navigation system.

iv. **Automated Manufacturing :**
1. Robots, and
2. Numerically controlled (NC) machine tools.

PART-2

Introduction to Autotronics, Bionics and Avionics and their Applications.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.6. **Explain the term autotronics. Give the application of autotronics in automobiles.**

Answer

A. **Autotronics :**
1. Autotronics can be defined as the combination of automobile and electronics or we can say that the use of electronic science in automobile vehicle is called autotronics.
2. The use of electronics in the automobile field makes the system safe, improved and efficient.
3. It helps to improve overall automobile system. In a vehicle almost all significant parts are featured with electronic items.
4. In the autotronic systems the use of control units like sensors, motors and digital equipment establishes a communication between the various essential system and components of the vehicle.

5. The application area of autotronics is very vast; brakes, steering system, engine controlling unit, transmission and suspension in the vehicle are the main phases where autotronics is used.

B. **Applications of Autotronics in Automobiles :**
1. Manifold control pressure sensor,
2. Air flow control,
3. Exhaust gas analysis and control,
4. Crankshaft position control,
5. Fuel pump pressure and fuel injection control,
6. Transmission force and pressure control,
7. Engine knocking detection for high power output, and
8. Seat control for passenger comfort.

Que 5.7. **What do you mean by bionics ? Explain bionics with an example.**

Answer

A. **Bionics :**
1. It is the application of biological methods and systems found in nature to study and design of engineering systems and modern technology.
2. Examples of bionic in engineering include the hulls of boats imitating the thick skin of dolphins, sonar, radar and medical ultrasound imaging imitating animal echolocation.
3. The study of bionics often emphasizes implementing a function found in nature rather than imitating biological structures.
4. Bionics also means the replacement or enhancement of organs or other body parts by mechanical visions in medicine.

B. **Molecular Motors :**
1. Molecular motors are proteins or protein complexes that transform chemical energy into mechanical energy at a molecular level scale.
2. These are responsible for producing and transducing the energy stored in ATP, which is the common energy currency of the body for powering every process and action.
3. The sodium / potassium, called ATP molecule, actually acts as a rotary motor.
4. A critical amount of the nanostructure rotates around a pivot and the outside part of the nanostructure reacts differently with the chemical group around the periphery.
5. This rotary motor is one of the several molecular motor mechanisms that are now understood to play important roles in the functional biology of a cell.

6. Molecular motors also allow us to manage the availability of the different components of the cell as they move about within the cellular structure.
7. Kinesin is a nanoscale molecular motor that carries molecular cargo through the cell by moving along nanoscale tracks, called microtubes, within the cell.
8. Molecular motion is also responsible for signal transduction in the human ear. Molecular motion may provide acceleration and motional energy for both artificial nanostructures within the body and in more complex nanostructure assemblies.

Que 5.8. **Define avionics ? Give the major applications of avionics.**

Answer

A. Avionics :
1. Avionics can be defined as the combination of electronics and aviation.
2. Avionic systems include communications, navigation, the display and management of multiple systems.
3. It helps in reduction of kerosene consumption, maintenance cost, etc.

B. Applications of Avionics :
1. Avionics systems are generally used on aircraft, artificial satellite and spacecraft.
2. The application of avionics also includes the areas of military aviation, radar, sonar, etc.
3. It includes control, monitoring, communication, navigation, weather and anti-collisions systems in an aircraft. The cockpit of an aircraft is such an example.

PART-3

Sensors and Transducer : Types of Sensors, Types of Transducers and their Characteristics.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.9. **Define sensors. Discuss various types of sensors along with their applications, advantages and limitations.**

Answer

A. Sensors : These are the devices which sense the condition, state or value of the process variable and produce an output corresponding to its condition or state.

B. Types of Sensors : Various types of sensors are as follows :

i. **Thermal Sensors :** These measure the amount of heat energy or even coldness that is generated by an object or system.

a. **Advantages :**
   1. High sensitivity allows them to work well over small temperature range.
   2. Low cost.

b. **Disadvantages :**
   1. Non linearity.
   2. Least stability.

c. **Applications :**
   1. Industrial, factory automation.
   2. Down hole drilling.

ii. **Motion Sensors :** The term motion sensor can be used to any kind of sensing system which is used to detect motion. These are also called motion detector.

a. **Advantages :**
   1. It can measure movement upto 8 meters.
   2. Data can be exported to other programs.

b. **Disadvantages :**
   1. Expensive.
   2. Requires technical knowledge.

c. **Applications :**
   1. Used in mine explosive and rockets launcher.
   2. These are used in security systems as triggers for automatic lights.

iii. **Force Sensors :** These are used to measure force by the measurement of displacement.

a. **Advantages :**
   1. High accuracy.
   2. Good shock resistance.

b. **Disadvantages :**
   1. Dynamic sensing only.
   2. Temperature sensitive.

c. Applications :

1. In control system when motion feedback is employed.
2. In process testing, monitoring and diagnostics applications.

iv. Speed Sensor : It is a type of tachometer. Tachometer is an instrument which either continuously indicates the value of rotary speed or continuously displays a reading of average speed over rapidly operated short-intervals of time.

a. Advantages :

1. The maintenance requirement are negligible, there are no mechanical surfaces.
2. Output voltage is linearly proportional to velocity.

b. Disadvantages :

1. The frequency response is usually limited and is stated.
2. Not useful for measurement of vibrations.

c. Applications :

1. To measure the rotating speed of shaft.
2. To estimate traffic speed.

Que 5.10. Discuss in brief, the static performance characteristics of a sensor.

Answer

1. The static characteristics are the values given when steady state conditions occur, *i.e.*, the values given when the transducer has settled down after having received some input.
2. The following terms are used to define the static performance characteristics of sensors :

i. Range and Span :

1. The range of a transducer defines the limits between which the input can vary.
2. The span is the maximum value of the input minus the minimum value.
3. Thus, for example, a load cell for the measurement of forces might have a range of 0 to 50 kN and a span of 50 kN.

ii. Error :

1. It is the difference between the result of the measurement and the true value of the quantity being measured.

$$\text{Error} = \text{Measured value} - \text{True value.}$$

iii. Accuracy :

1. It is the extent to which the value indicated by a measurement system might be wrong.

2. It is thus the summation of all the possible errors that are likely to occur, as well as the accuracy to which the transducer has been calibrated.

iv. Sensitivity :

1. It is the relationship indicating how much output there is per unit input, *i.e.*, output/input.
2. For example, a resistance thermometer may have a sensitivity of 0.5 $\Omega/°C$.

v. Repeatability / Reproducibility :

1. The terms repeatability and reproducibility of a transducer are used to describe its ability to give the same output for repeated applications of the same input value.
2. The error resulting from the same output not being given with repeated applications is usually expressed as a percentage of the full output :

$$\text{Repeatability} = \frac{\text{max.} - \text{min. values given}}{\text{Full range}} \times 100$$

vi. Stability :

1. The stability of a transducer is its ability to give the same output when used to measure a constant input over a period of time.

vii. Dead Band / Time :

1. The dead band or dead space of a transducer is the range of input values for which there is no output.
2. For example, bearing friction in a flow meter using a rotor might mean that there is no output until the input has reached a particular velocity threshold.
3. The dead time is the length of time from the application of an input until the output begins to respond and change.

Que 5.11. Give definition of a transducer. What are the characteristics of transducer ?

Answer

A. Transducer :

1. It is a sensing device which converts physical quantity into electrical quantity.
2. In other words, transducer is a device which converts the energy from one form to another such as electrical energy into mechanical energy and non-electrical physical quantity into electrical signal.

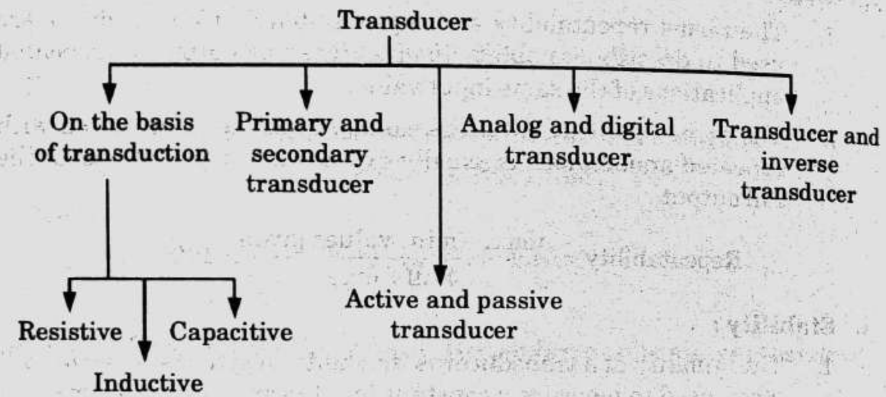
B. Characteristics of Transducer :

1. Transducers are small sized and light in weight.

2. Transducers are reliable.
3. Transducers are highly sensitive.
4. They can withstand wide range of environmental conditions.
5. Transducers have a linear relationship between input and output.
6. They also have low cost.

Que 5.12. **Classify transducers.**

Answer



i. **Classification based on the Principle of Transduction :**
1. The transducer is classified by the transduction medium.
2. The transduction medium may be resistive, inductive or capacitive depends on the conversion process that how input transducer converts the input signal into resistance, inductance and capacitance respectively.

ii. **Primary and Secondary Transducer :**

a. **Primary transducer :**
1. The transducer consists of mechanical as well as the electrical devices.
2. The mechanical devices of the transducer change the physical input quantities into a mechanical signal. This mechanical device is known as the primary transducers.

b. **Secondary transducer :**
1. The secondary transducer converts the mechanical signal into an electrical signal.
2. The magnitude of the output signal depends on the input mechanical signal.

iii. **Passive and Active Transducer :**

a. **Passive transducer :**
1. The transducer which requires the power from an external supply source is known as the passive transducer.
2. They are also known as the external power transducer.

3. The capacitive, resistive and inductive transducers are the example of the passive transducer.

b. **Active transducer :**
1. The transducer which does not require the external power source is known as the active transducer.
2. Such type of transducer develops theirs owns voltage or current, hence known as a self-generating transducer.
3. The output signal is obtained from the physical input quantity.

iv. **Analog and Digital Transducer :**

a. **Analog transducer :**
1. The analog transducer changes the input quantity into a continuous function.
2. The strain gauge, LVDT, thermocouple and thermistor are the examples of the analog transducer.

b. **Digital transducer :** These transducers convert an input quantity into a digital signal or in the form of the pulse. The digital signals work on high or low power.

v. **Transducer and Inverse Transducer :**

a. **Transducer :** The device which converts the non-electrical quantity into an electric quantity is known as the transducer.

b. **Inverse transducer :** The transducer which converts the electric quantity into a physical quantity, such type of transducers is known as the inverse transducer. The transducer has high electrical input and low non-electrical output.

PART-4

Overview of Mechanical Actuation System : Kinematic Chains, Cam, Train Ratchet Mechanism, Gears and its Type, Belt, Bearing.

CONCEPT OUTLINE

Kinematic Chain : It refers to an assembly of rigid bodies connected by joints to provide constrained motion that is the mathematical model for a mechanical system.

Ratchet : It is mechanical device that allows continuous linear or rotary motion in only one direction while preventing motion in the opposite direction.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.13. **What do you mean the chain and chain drive ?**

Answer

A. **Chain :** A chain consists of links connected by joints which provide for articulation or flexibility of the chain.

B. **Chain drive :**

1. A chain drive consists of two sprockets and chain.
2. Chain drives, or transmissions, with several driven sprockets are also employed.
3. Besides the enumerated components, chain drives may also include tensioning devices, lubricating devices and guards.
4. Example : The drive mechanism used in a bicycle.

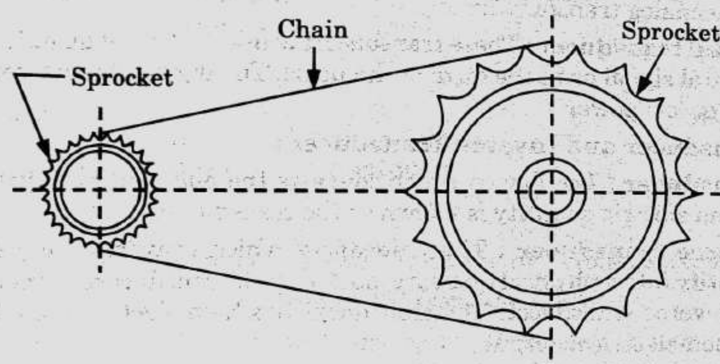


Fig. 5.13.1. Chain drive.

Que 5.14. **Define cam. Explain its different types.**

Answer

A. **Cam :**

1. A cam is a mechanical member used to impart desired motion to a follower by direct contact.
2. It may be rotating or reciprocating.

B. **Types of Cams :**

i. **Radial or Disc Cams :**

1. A cam in which the follower moves radially from the center of rotation of the cam is known as a radial or a disc cam (Fig. 5.14.1(*a*) and (*b*)).
2. Radial cams are very popular due to their simplicity and compactness.

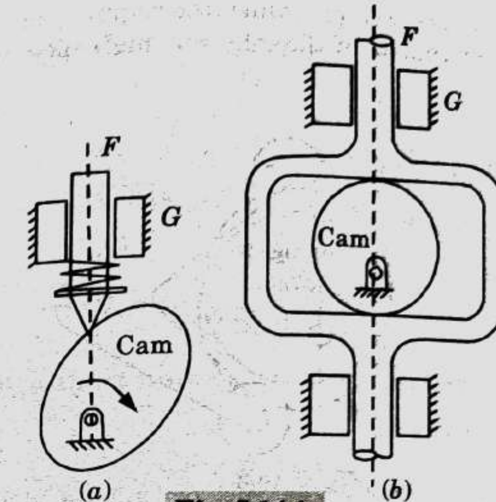


Fig. 5.14.1.

ii. **Spiral Cams :**

1. A spiral cam is a face in which a groove is cut in the form of a spiral as shown in Fig. 5.14.2.

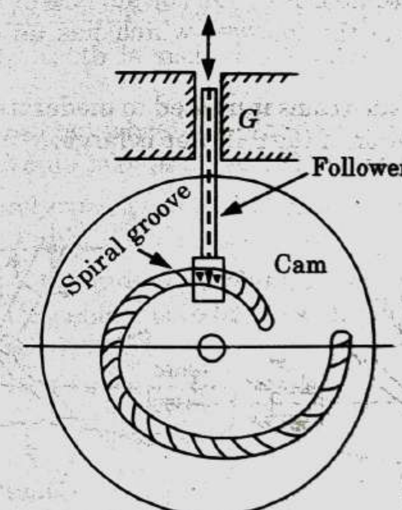


Fig. 5.14.2.

2. The spiral groove consists of teeth which mesh with a pin gear follower.
3. The use of such a cam is limited as the cam has to reverse the direction to reset the position of the follower.

iii. **Cylindrical Cams :** In cylindrical cam, a cylinder which has a circumferential contour cut in the surface, rotates about its axis.

iv. **Conjugate Cams :**

1. A conjugate cam is a double-disc cam, the two discs being keyed together and are in constant touch with the two rollers of a follower (Fig. 5.14.3). Thus, the follower has positive constraint.

2. Such a type of cam is preferred when the requirement are less wear, less noise, better control of the follower, high speed, high dynamic loads, etc.

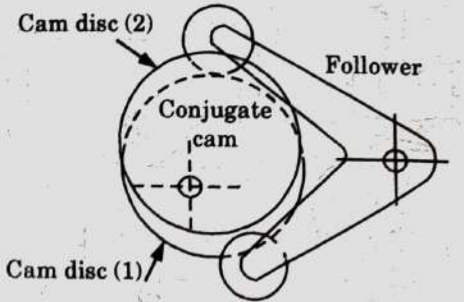


Fig. 5.14.3.

v. Globodial Cams :

1. A globodial cam can have two types of surfaces, convex or concave.
2. A circumferential contour is cut on the surface of rotation of the cam to impart motion to the follower which has an oscillatory motion (Fig. 5.14.4).
3. The application of such cams is limited to moderate speeds and where the angle of oscillation of the follower is large.

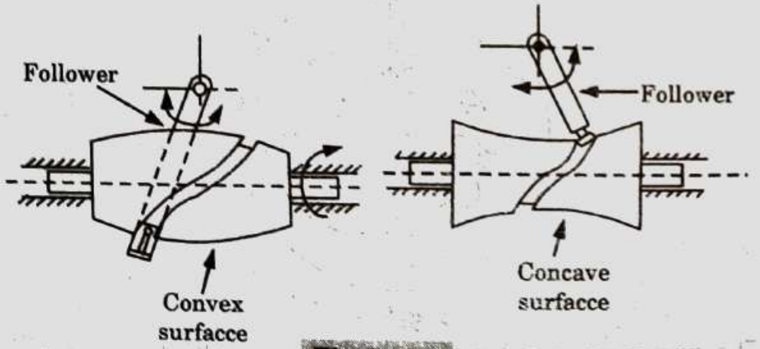


Fig. 5.14.4.

vi. Spherical Cams :

1. In a spherical cam, the follower oscillates about an axis perpendicular to the axis of rotation of the cam.
2. A spherical cam is in the form of a spherical surface which transmits motion to the follower (Fig. 5.14.5).

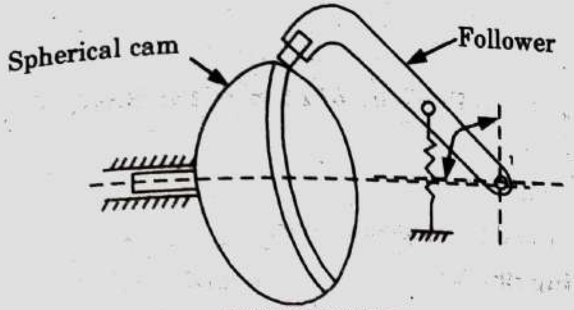


Fig. 5.14.5.

Que 5.15. **Write short note on ratchet and pawl mechanism.**

Answer

1. Ratchets can be used to lock a mechanism when it is holding a load.
2. Fig. 5.15.1 shows a ratchet and pawl.
3. The mechanism consists of a wheel, called a ratchet, with saw-shaped teeth which engage with an arm called a pawl.
4. The arm is pivoted and can move back and forth to engage the wheel.
5. The shape of the teeth is such that rotation can occur in only one direction.
6. Rotation of the ratchet wheel in a clockwise direction is prevented by the pawl and can only take place when the pawl is lifted.
7. The pawl is normally spring loaded to ensure that it automatically engages with the ratchet teeth.
8. Thus a winch used to wind up a cable on a drum may have a ratchet and pawl to prevent the cable unwinding from the drum when the handle is released.

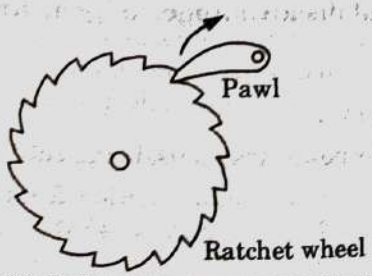


Fig. 5.15.1. Ratchet and pawl.

Que 5.16. **Give a brief classification of toothed wheels or gears.**

Answer

A. According to the Position of Axes of the Shafts :

i. Parallel Shaft :

1. Spur gear, and
2. Helical gear and herringbone gear.

ii. Intersecting Shaft :

1. Bevel gear, and
2. Helical bevel gear.

iii. Non Intersecting Shaft :

1. Spiral gears (or skew bevel gears).

B. According to Peripheral Velocity of the Gears :

i. **Low Velocity :** The gears having velocity less than 3 m/s.

ii. **Medium Velocity :** The gears having velocity between 3 to 15 m/s.

iii. **High Velocity :** The gears having velocity more than 15 m/s.

C. According to the Type of Gearing :

i. **External Gearing :** It provides unlike motion to the two wheels.

ii. **Internal Gearing :** It provides like motion to the two wheels.

iii. **Rack and Pinion :** It converts the rotary motion to linear motion.

D. According to Position of Teeth on the Gear Surface :

i. Straight,

ii. Inclined, and

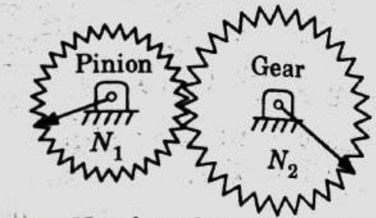
iii. Curved.

Que 5.17. **Discuss in brief about gear transmission. Also write down advantages and disadvantages of gear drive.**

Answer

A. Gear Transmission :

1. The use of gears for power transmission in robots is very common.
2. Gears are used to transmit rotary motion from one shaft to another. This transfer may be between parallel shafts, intersecting shafts, or skewed shafts.
3. The simplest types of gears are for transmission between parallel shafts and are known as spur gears.
4. Fig. 5.17.1 illustrates a simple spur gear train.
5. The driving gear, in this case the smaller one, is known as the pinion and the other gear is the driven gear.
6. This gear train is referred to as a speed reducer.



N_1 = Number of teeth on pinion

N_2 = Number of teeth on gear

Fig. 5.17.1. Spur gear train.

B. Advantages of Gear Drive :

1. It transmits exact velocity ratio.
2. It may be used to transmit large power.
3. It has high efficiency.
4. It has reliable service.
5. It has compact layout.

C. Disadvantages of Gear Drive :

1. The manufacture of gears requires special tools and equipment.
2. The error in cutting teeth may cause vibrations and noise during operation.

Que 5.18. **Define belt ? What are the different types of belts and drives ?**

Answer

A. **Belt :** It is a continuous band of flexible material passing over pulleys to transmit motion from one shaft to another.

B. Different Types of Belts :

i. **Flat Belt :** The flat belt has a rectangular cross-section. Such a drive has an efficiency of about 98 % and produces little noise. They can transmit power over long distances between pulley centres.

ii. **Round Belt :** The round belt has a circular cross-section and is used with grooved pulleys.

iii. **V-Belt :** *V*-belts are used with grooved pulleys and are less efficient than flat belts but a number of them can be used on a single wheel and so give a multiple drive.

iv. **Timing Belt :** It requires toothed wheels, having teeth which fit into the grooves on the wheels. These belts, unlike the other belts does not stretch or slip and consequently transmits power at a constant angular velocity ratio. The teeth make it possible for the belt to be run at slow or fast speeds.

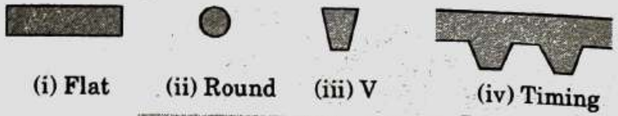


Fig. 5.18.1. Types of belt.

C. Different Types of Belt Drives :

i. **Light Drives :** These are used to transmit small powers at belt speeds upto 10 m/s, as in agriculture machines and small machine tools.

ii. **Medium Drives :** These are used to transmit medium power at belt speeds over 10 m/s but upto 22 m/s, as in machine tools.

iii. **Heavy Drives :** These are used to transmit large powers at belts speeds above 22 m/s, as in compressors and generators.

Que 5.19. **Define the term bearing and write down its functions.**

Answer

A. **Bearing :** It is a mechanical element that permits relative motion between two parts, such as the shaft and the housing with minimum friction.

B. **Functions of Bearing :** The functions of bearing are as follows :

1. The bearing ensures free rotation of the shaft or the axle with minimum friction.
2. The bearing supports the shaft or the axle and holds it in the correct position.
3. The bearing takes up the forces that act on the shaft or the axle and transmits them to the frame or the foundation.

Que 5.20. **Give the classification of bearing.**

Answer

Bearing may be classified in following ways :

A. **Depending upon the Direction of Load to be supported :**

i. **Radial Bearing :** In this type of bearing, the main load acts perpendicular to the axis of rotation of the moving element.

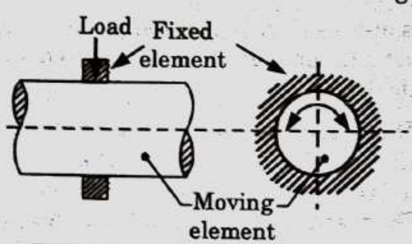


Fig. 5.20.1. Radial bearing.

ii. **Thrust Bearing :** In this bearing, the load acts along the axis of rotation.

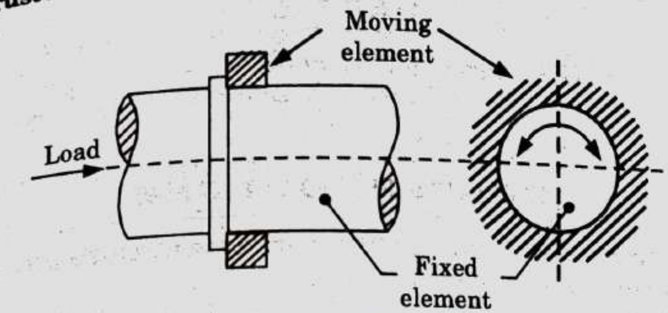


Fig. 5.20.2. Thrust bearing.

B. **Depending upon the Nature of Contact :**

i. **Sliding Contact Bearing :** In this bearing, sliding action takes place along the surface of contact between the moving element and fixed element. The sliding contact bearing is also known as plain bearing.

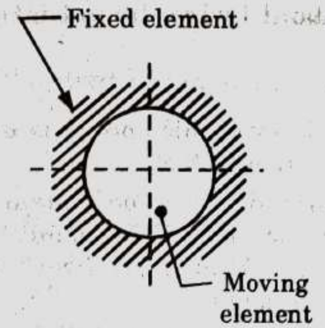


Fig. 5.20.3. Sliding contact bearing.

ii. **Rolling Contact Bearing :** In this type of bearing, steel balls or rollers are interposed between the working surfaces. These bearings are also known as anti-friction bearing due to less friction imposed on moving element.

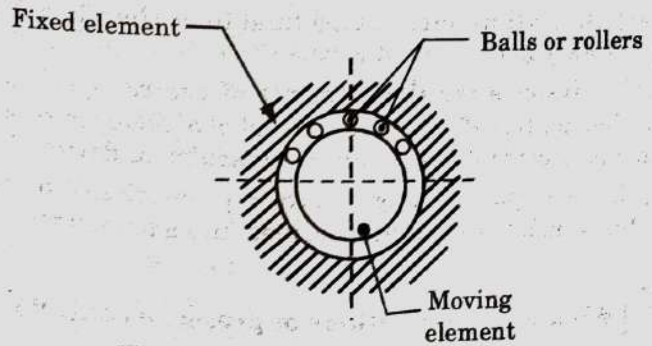


Fig. 5.20.4. Rolling contact bearing.

PART-5

Hydraulic and Pneumatic Actuation Systems : Overview, Pressure Control Valves, Cylinders, Direction Control Valves.

CONCEPT OUTLINE

Pressure Control Valves : These valves control the pressure of flow medium required by the system.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.21. **Discuss about hydraulic actuation system.**

Answer

1. An actuator where in hydraulic energy is used to import motion is called hydraulic actuation system.
2. The principle of hydraulic actuation system is similar to pneumatic actuation system except that instead of air, fluid such as water or oil supplies the inlet power. Although the working principle remains the same, the structural design varies.
3. Main elements of hydraulic actuation system are :
   - i. Pump.
   - ii. Pressure regulator.
   - iii. Valve.
   - iv. Distribution system.
   - v. Basic structure.
4. These devices utilize pressurized fluid to produce linear motion and force or rotary motion and torque.
5. Actuation systems are the elements of control systems which are responsible for transforming the output of a microprocessor or control system into a controlling action on a machine or device.
6. Thus, for example, we might have an electrical output from the controller which has to be transformed into a linear motion to move a load.

Que 5.22. **What are the functions of pressure control valve ? Also classify it on the basis of their primary function.**

Answer

A. Function of Pressure Control Valves :

1. To regulate or reduce oil pressure in certain portions of the circuit.
2. To unload system pressure.
3. To limit maximum system pressure as a safety measure.
4. To assist sequential operation of actuators in a circuit by pressure control.
5. To perform any other pressure related functions by virtue of pressure control.

B. Classification of Pressure Control Valve on the Basis of Primary Function : Based on primary functions, the pressure control valves are classified as follows :

1. Pressure relief valve.
2. Pressure sequencing valve.
3. Pressure reducing or regulating valve.
4. Pressure unloading valve.
5. Pressure brake valve.

Que 5.23. **What is fluid power hydraulic cylinder ? Also mention various type of cylinder.**

Answer

A. Fluid Power Hydraulic Cylinder :

1. A fluid power hydraulic cylinder is a linear actuator which is most useful and effective in converting fluid energy to an output force in a linear direction for performing work such as pulling or pushing in a variety of engineering applications such as in machine tools and other industrial machinery, earth moving equipment, construction equipment and space applications.
2. A hydraulic cylinder usually consists of a movable element, a piston and a piston rod operating within a cylindrical bore.

B. Types of cylinders :

i. According to Function Performed :

1. Single acting cylinders.
2. Double acting cylinders.

ii. According to Construction :

1. Tie rod cylinders.
2. Mill type cylinders.
3. One-piece welded cylinders.
4. Threaded head cylinders.

iii. Special Types :

1. Plunger or ram cylinders.

2. Telescoping cylinders.
3. Cable cylinders.
4. Rotary cylinders etc.

Que 5.24. **Define direction control valves also classify it.**

Answer

A. Direction Control Valves :
1. Direction control valves start, stop and control the direction of flow for reversing the direction of motion of the actuator.
2. Direction control valves are employed in a hydraulic system to determine the direction of the fluid in the hydraulic circuit.
3. Sometimes they are also used as a selector switch.

B. Classification of Direction Control Valves :

i. On the Basic of Internal Valving Element :
1. Poppet (Ball or piston), and
2. Spool valve.

ii. On the Basis of Flow Paths :
1. Two way,
2. Three way, and
3. Four way.

iii. On the Basis of Actuation of Internal Valving Element :
1. Manual,
2. Mechanical,
3. Electrical, and
4. Hydraulic.

iv. On the Basis of Method of Connection :
1. Pipe thread,
2. Straight thread,
3. Flanged or subplot, and
4. Manifold mounted.

Que 5.25. **Discuss pneumatic actuation system with their advantages and disadvantages.**

Answer

A. Pneumatic Actuation System :
1. A pneumatic actuation system is a system that uses compressed air to transmit and control power.
2. The other components of pneumatic actuation systems are same as of hydraulic actuation systems.
3. Main elements of pneumatic actuation system are :
i. **Compressor :** It is used to compress the air having capacity of 500 kpa – 1.0 Mpa.

ii. **Air Treatment Units :** After compression of air, air must be treated to remove the moisture or heat. For this air treatment unit is used.
iii. **Reservoir :** It is used to store the compressed air. Storage is arranged with pressure sensitive switch which indicate the decrement of pressure.
iv. **Control Valve and Actuators :** It is used for functioning and controlling the actuation system.
4. Pneumatic actuation systems are used in controlling train doors, automatic production lines, mechanical clamps, etc.

B. Advantages of Pneumatic Actuation System :
1. High effectiveness.
2. High durability and reliability.
3. Simple design.
4. High adaptability to harsh environment.

C. Disadvantages of Pneumatics Actuation System :
1. Relatively low accuracy.
2. A pneumatic actuation system cannot drive loads that are too heavy.
3. Uneven moving speed.

PART-6

Rotary Actuators, Accumulators, Amplifiers and Pneumatic Sequencing Problems.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.26. **Write short note on rotary actuators.**

Answer

1. Rotary actuators are the hydraulic pneumatic equivalents of electric motors.
2. For a given torque and power, a rotary converter is more compact than an equivalent motor.
3. It cannot be damaged by an indefinite stall and can be safely used in an explosive atmosphere.
4. For variable speed applications, the complexity and maintenance requirements of a rotary actuator are similar to a thyristor-controlled DC drive, but for fixed applications, the AC induction motor is simpler to install and maintain.

5. An hydraulic motor is a rotary actuator where in hydraulic energy is converted into mechanical energy in the form of rotary motion and torque which may be used for doing work.

Que 5.27. **Write short note on accumulators.**

Answer

1. Accumulators can increase efficiency, provide smoother, more reliable operation, and store emergency power in case of electrical failure.
2. Accumulators usually are installed in hydraulic systems to store energy and to smooth out pulsations.
3. Accumulators also can act as surge or pulsation absorbers, much as an air dome is used on pulsating piston or rotary pumps.
4. Accumulators will cushion hydraulic hammer, reducing shocks caused by rapid operation or sudden starting and stopping of power cylinders in a hydraulic circuit.
5. There are four principal types of accumulators :
   i. The weight-loaded piston type,
   ii. Diaphragm (or bladder) type,
   iii. Spring type, and
   iv. The hydro-pneumatic piston type.

Que 5.28. **Define amplifier and mention its types.**

Answer

A. Amplifier :

1. An amplifier is a device which is used to increase or augment the weak signal.
2. It may operate on mechanical (levers, gears etc.) optical, pneumatic and hydraulic, or electrical and electronic principles.
3. The ratio of output signal (I_0) to input signal (I_i) for an amplifier is termed as gain, amplification or magnification.
4. The gain of amplification (G) is expressed as,

$$G = \frac{I_0}{I_i}$$

B. Types of Amplifiers :

1. Mechanical amplifiers.
2. Fluid amplifiers.
3. Optical amplifiers.
4. Electrical and electronic amplifiers.

Que 5.29. **Discuss in brief about pneumatic cylinder sequencing.**

Answer

1. In sequential control with cylinders it is common practice to give each cylinder a reference letter *A*, *B*, *C*, *D* etc., and to indicate the state of each cylinder by using a + sign if it is extended or a – sign if retracted.
2. Initially both the cylinders have retracted pistons. Start push-button on valve 1 is pressed. This applies pressure to valve 2, as initially limit switch b – is activated; hence valve 3 is switched to apply pressure to cylinder A for extension.

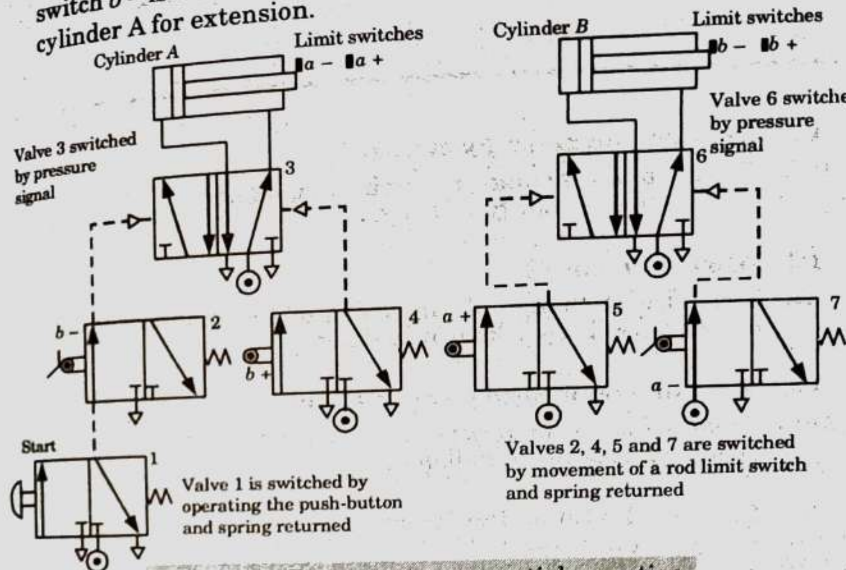


Fig. 5.29.1. Two-actuator sequential operation.

3. Cylinder *A* extends, releasing limit switch a –. When cylinder *A* is fully extended, limit switch a + operates. This switches valve 5 and causes pressure to be applied to valve 6 to switch it and so apply pressure to cylinder *B* to cause its piston to extend.
4. Cylinder *B* extends, releasing limit switch b –. When cylinder *B* is fully extended, limit switch b + operates. This switches valve 4 and causes pressure to be applied to valve 3 and so applies pressure to cylinder *A* to start its piston retracting.
5. Cylinder *A* retracts, releasing limit switch a +. When cylinder *A* is fully retracted, limit switch a – operates. This switches valve 7 and causes pressure to be applied to valve 5 and so applies pressure to cylinder *B* to start its piston retracting.
6. Cylinder *B* retracts, releasing limit switch b +. When cylinder *B* is fully retracted, limit switch b – operates to complete the cycle.
7. The cycle can be started again by pushing the start button. If we wanted the system to run continuously then the last movement in the sequence would have to trigger the first movement.

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1 UNIT

Introduction to Solid Mechanics (2 Marks Questions)

1.1. What do you mean by stress ?

Ans. The force of resistance per unit area, offered by a body against deformation is known as stress.

1.2. What is strain ?

Ans. The ratio of change of dimension of the body to the original dimension of body is known as strain.

1.3. What do you mean by shear strain ?

Ans. Shear strain is defined as the change in the right angle of the element measured in radians.

1.4. Explain the following terms :
i. Young's modulus.
ii. Modulus of rigidity.

Ans.

i. **Young's Modulus :** It is the ratio between tensile stress and tensile strain or compressive stress and compressive strain.

ii. **Modulus of Rigidity :** It is defined as the ratio of shear stress to shear strain.

1.5. Define bulk modulus of elasticity.

Ans. Bulk modulus of elasticity is defined as the ratio of normal stress to volumetric strain.

1.6. Define shear force.

Ans. Shear force is the force that tries to shear off the section of a beam (or structure). It is obtained as algebraic sum of all forces acting normal to axis of beam, either to the left or to the right of section.

1.7. Define bending moment.

Ans. Bending moment is the moment that tries to bend the beam (or structure) and is obtained as algebraic sum of moment of all forces about the section acting either left or to the right of section.

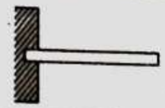
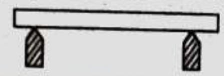
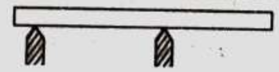
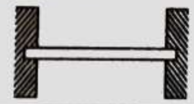
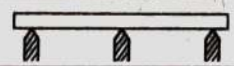
1.8. Define SFD and BMD.

Ans. **SFD :** SFD stands for shear force diagram. It represents the variation of shear force along the length of the beam.

BMD : BMD stands for bending moment diagram. It represents the variation of bending moment along the length of beam.

1.9. With neat sketches describe in brief different types of beams.

Ans. Following are the different types of beams :

S. No.	Type of beam	Diagram
i.	Cantilever beam	
ii.	Simply supported beam	
iii.	Overhanging beam	
iv.	Fixed beam	
v.	Continuous beam	

1.10. What do you understand by the term point of contraflexure ?

Ans. The point of contraflexure is a point which represents the section on the beam where bending moment is zero or bending moment changes its sign.

1.11. Define point load, UDL and UVL.

Ans. **Point Load :** A point load is one which acts over a very small area or portion.

UDL : Uniformly distributed load (UDL) acts over a finite length of a beam. UDL implies the intensity of loading is constant over a finite length and its unit is kN / m.

UVL : Uniformly varying load (UVL) implies the intensity of loading increases or decreases linearly (at constant rate) along the length of beam.

1.12. Define Hooke's law.

Ans. According to Hooke's law, within elastic limits, stress is proportional to strain produced in a body.

$$\text{Stress} \propto \text{Strain}$$

$$\sigma = Ee$$

$$E = \frac{\sigma}{e}$$

1.13. What do you mean by Poisson's ratio ?

Ans. Within the elastic limit, if a body is stressed, then the ratio of lateral strain to linear strain is constant. This constant is known as Poisson's ratio and is denoted by μ.

$$\mu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

1.14. Define factor of safety and working stress.

Ans. **Factor of Safety :** The ratio of ultimate stress to working stress is called factor of safety.

$$\text{Factor of safety} = \frac{\text{Ultimate stress}}{\text{Working stress}}$$

Working Stress : The maximum stress to which any member is designed, is much less than the ultimate stress, is called working stress.

1.15. Determine the maximum bending moment in a simply supported beam of span 5 m, carrying uniformly distributed load of 2 kN/m over its entire span.

Ans.

Given : $w = 2$ kN/m, $l = 5$ m

To Find : Maximum bending moment.

1. Maximum bending moment for a simply supported beam carrying uniformly distributed load is given by as,

$$(\text{BM})_{max} = \frac{wl^2}{8} = \frac{2 \times 5^2}{8} = \frac{25}{4} = 6.25 \text{ kN-m}$$

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2 UNIT

Introduction to IC Engines and RAC (2 Marks Questions)

2.1. What is an internal combustion engine ?

Ans. It is an engine in which combustion takes place inside the cylinder. Examples : Petrol engine and diesel engine.

2.2. State two differences between two stroke and four stroke engines.

Ans.

S. No.	Two Stroke Engine	Four Stroke Engine
1.	Cycle is completed in two stroke of the piston or one revolution of the crankshaft.	Cycle is completed in four stroke of the piston or two revolution of the crankshaft.
2.	It contains ports.	It contains valves.

2.3. Compare SI and CI engine with respect to compression ratio and ignition.

Ans.

S. No.	Description	SI Engine	CI Engine
1.	Compression ratio	6 to 10.	16 to 20.
2.	Ignition	Spark plug is used.	Self ignition due to high pressure and temperature caused of compression of air.

2.4. Define refrigeration.

Ans. Refrigeration is the science of the producing and maintaining temperatures below that of the surrounding atmosphere *i.e.*, removing heat from a substance under controlled conditions.

2.5. What is the purpose of refrigeration ?

Ans. Purpose of refrigeration is as follows :

1. Preservation of food.

2. Manufacturing of ice.
3. Control of air temperature and humidity in the air conditioning system.
4. Transportation of food.

2.6. What do you mean by refrigeration effect and unit of refrigeration ?

Ans. **Refrigeration Effect :** The amount of heat extracted from the system is termed as refrigeration effect.

Unit of Refrigeration : The practical unit of refrigeration is expressed in terms of tonne of refrigeration or TR. 1 TR is equal to amount of refrigeration effect produced by uniform melting of 1 tonne of ice at 0 °C in 24 hours.

2.7. Differentiate between refrigerator and heat pump.

Ans.

S. No.	Refrigerator	Heat Pump
1.	It is a reversed heat engine which cools or maintains the temperature of a body lower than the atmospheric temperature.	A heat pump is a device, which operating in a cycle, maintains a body, at a temperature higher than the temperature of the surroundings.
2.	$(COP)_R = \frac{Q_1}{W_R}$	$(COP)_P = \frac{Q_2}{W_P}$

2.8. Define energy performance ratio (EPR).

Ans. The performance of a heat pump is expressed by the ratio of the amount of heat delivered to the hot body to the amount of work required to be done on the system. This ratio is called energy performance ratio (EPR).

2.9. What is air conditioning ?

Ans. Air conditioning is that branch of engineering science which deals with the study of conditioning of air.

2.10. Define the term dry air.

Ans. The term dry air is used to indicate the water free contents of air having zero degree of moisture.

2.11. What is dry bulb temperature ?

Ans. Dry bulb temperature (DBT) is the temperature, recorded by an ordinary thermometer whose reading is not affected by moisture present in the air or by thermal radiation.

2.12. Define wet bulb temperature.

Ans. Wet bulb temperature (WBT) is the temperature recorded by a thermometer whose bulb is covered with a wet cloth and exposed to current of moving air (atmospheric air).

2.13. Define dew point temperature.

Ans. Dew point temperature (DPT) is the temperature to which air must be cooled at constant pressure in order to cause condensation of any of its water vapour.

2.14. Differentiate between natural and mechanical refrigeration.

Ans.

S. No.	Natural Refrigeration	Mechanical Refrigeration
1.	Natural refrigeration can be done by : i. Melting of a solid. ii. Sublimation of a solid. iii. Evaporation of a liquid.	Mechanical refrigeration is mostly dependent on evaporation of a liquid called refrigerant.
2.	It does not require components such as evaporator, compressor, condenser and expansion valve.	It requires the components such as evaporator, compressor, condenser and expansion valve.

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3 UNIT

Introduction to Fluid Mechanics and Applications (2 Marks Questions)

3.1. Define the term fluid.

Ans. A fluid is a substance which deforms continuously when subjected to external shearing force.

3.2. Define real fluids.

Ans. A real practical fluid is one which has viscosity, surface tension and compressibility in addition to the density. The real fluids are actually available in nature.

3.3. Enumerate some important properties of liquid.

Ans. Some important properties of liquid are :

1. Density,
2. Viscosity,
3. Adhesion,
4. Specific gravity,
5. Cohesion, and
6. Surface tension.

3.4. What is kinematic viscosity ?

Ans. Kinematic viscosity is defined as the ratio of the dynamic viscosity to the density of fluid. It is denoted by ν.

3.5. Define viscosity.

Ans. Viscosity may be defined as the property of a fluid which determines its resistance to shearing stresses. It is a measure of the internal fluid friction which causes resistance to flow.

3.6. What are Newtonian fluids ?

Ans. Newtonian fluids are those fluids which obey the Newton's law of viscosity. For such fluids, viscosity does not change with rate of deformation.

3.7. Define non-Newtonian fluids.

Ans. Fluids which do not follow the Newton's law of viscosity are known as non-Newtonian fluids.

3.8. What is venturimeter ?

Ans. A venturimeter is a device used for measuring the rate of flow of a fluid flowing through a pipe.

3.9. Define the term turbines.

Ans. Turbines are defined as the hydraulic machines which convert hydraulic energy into mechanical energy.

Example : Pelton wheel, Francis turbine, Kaplan turbine, etc.

3.10. What is centrifugal pump ?

Ans. The hydraulic machine which converts the mechanical energy into pressure energy by means of centrifugal force acting on the fluid is known as centrifugal pump.

3.11. State the Bernoulli's theorem.

Ans. Bernoulli's theorem states that in a steady, ideal flow of an incompressible fluid, the total energy at any point of the fluid is constant.

3.12. What is coefficient of discharge ?

Ans. Coefficient of discharge is defined as the ratio of the actual discharge to the theoretical discharge of flow.

3.13. What is hydraulic accumulator ?

Ans. Hydraulic accumulator is a device which is used for storing the energy of liquid in the form of pressure energy. This energy can be supplied for any sudden requirement.

3.14. Define hydraulic lift and gives its type.

Ans. **Hydraulic Lift :** It is a device used for carrying goods or passengers from one floor to another in multi-storeyed buildings.

Types of Hydraulic Lift :

1. Direct acting hydraulic lift.
2. Suspended hydraulic lift.

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4 UNIT

Measurements and Control System (2 Marks Questions)

4.1. What is measurement ?

Ans. Measurement is the process of comparing unknown magnitude of certain parameter with the known predefined standard of that parameter.

4.2. Write down the methods of measurement.

Ans. Methods of measurement are as follows :

1. Direct method, and
2. Indirect method.

4.3. Define error of measurement.

Ans. Error of measurement is the difference between the true value of the size being measured and the value found by measurement.

4.4. What is the difference between relative error, random error and systematic error ?

Ans.

S. No.	Relative Error	Random Error	Systematic Error
1.	It is the absolute error of measurement divided by the conventional true value of the measurand.	It is a component of the error of measurement which, in the course of a number, of measurements of the same measurand, varies in an unpredictable manner. This error can't be corrected.	It is a component of the error of measurement which, in the course of a number of measurements of the same measurand, remains constant or varies in a predictable way.

4.5. Define calibration of a measuring instrument.

Ans. Calibration is the process of determining the values of the quantity being measured corresponding to a pre-established arbitrary scale.

4.6. Name some low pressure measuring devices.

Ans. Low pressure measuring devices are as follows :

1. Pirani gauge,
2. Ionization gauge, and
3. Mcleod gauge.

4.7. Define strain and strain gauge.

Ans. **Strain :** It is defined as the ratio of change in shape to its original shape. It is a dimensionless quantity.

Strain Gauge : The transducers which measure the strain in a body or object are known as strain gauge.

4.8. Name any four instruments used for temperature measurement.

Ans. Instruments used for temperature measurement are as follows :

1. Glass thermometers,
2. Pressure-gauge thermometers,
3. Electrical resistance thermometers, and
4. Thermocouple pyrometers.

4.9. Distinguish between force and torque.

Ans.

S. No.	Force	Torque
1.	Force is directly proportional to the rate of change of momentum.	Torque is directly proportional to the rate of change of angular momentum.
2.	The SI unit of force is newton (N).	The SI unit of torque is newton-metre (N-m).

4.10. Define zero error.

Ans. Zero error is defined as the condition where a measuring instrument registers a reading when there should not be any reading.

4.11. Define accuracy.

Ans. Accuracy is defined as degree of closeness of the output to the true value of measured quantity. It is specified as percentage deviation or inaccuracy in measurement from true value of measured quantity.

$$\text{Percentage accuracy} = \frac{\text{Measured value} - \text{True value}}{\text{True value}} \times 100$$

4.12. Define precision.

Ans. Precision is defined as the ability to reproduce the same output repeatedly for the same input. If a Vernier scale is used to measure the width of a bar and it produces same output then it is said to have high precision.

4.13. Define resolution of the instrument.

Ans. Resolution is the smallest increment of change in the measured value that can be determined from the instrument's read out scale. The resolution is often on the same order as the precision, sometimes it is smaller.

4.14. What is limit, fit and tolerance ?

Ans. **Limit :** The two extreme permissible size for any object is known as limit. The minimum size is called lower limit and maximum size is called upper limit.

Fit : During assembly, the degree of tightness or looseness between the mating parts is termed as fits.

Tolerance : It is defined as the difference between the high and low limits of size.

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5 UNIT

Introduction to Mechatronics (2 Marks Questions)

5.1. What do you understand by mechatronics ?

Ans. Mechatronics is defined as the interdisciplinary field of engineering dealing with the design of products whose functions relies on the synergistic integration of mechanical and electronic components coordinated by a control architecture.

5.2. What are the evolution levels of mechatronics ?

Ans. The evolution levels of mechatronics are as follows :
1. Primary level mechatronics,
2. Secondary level mechatronics,
3. Third level mechatronics, and
4. Fourth level mechatronics.

5.3. Give two advantages and disadvantages of mechatronics.

Ans. **Advantages of Mechatronics :**
1. The products produced are cost effective and of very good quality.
2. High degree of flexibility.

Disadvantages of Mechatronics :
1. High initial cost of the system.
2. Imperative to have knowledge of different engineering fields for design and implementation.

5.4. Give the applications of mechatronics.

Ans. Applications of mechatronics are as follows :
1. Design and modeling,
2. Actuators and sensors,
3. Intelligent control,
4. Robotics, and
5. Manufacturing.

5.5. Give the examples of mechatronics systems in industry.

Ans. The examples of mechatronics systems in industry are as follows :
1. Home appliances,
2. Automobile,

3. Aircraft, and
4. Automated manufacturing.

5.6. Explain the scope of mechatronics in industrial sector.

Ans. The scope of mechatronics in industrial sector are as follows :
1. Better design of product,
2. Better process of planning,
3. Reliable and quality-oriented manufacturing, and
4. Intelligent process control.

5.7. Define autotronic.

Ans. Autotronics is automotive-electronic control devices which are integrated with the mechanical system in the vehicle applications.

5.8. What do you mean by bionics ?

Ans. Bionics is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology.

5.9. Define transducer.

Ans. Transducer is a device, usually electrical, electronic, or electro-mechanical, that converts one type of energy into another for various purposes including measurement or information transfer.

5.10. Define sensor.

Ans. Sensor is defined as an element which when subjected to some physical change experiences a relative change.

5.11. Define kinematic chain.

Ans. Kinematic chain refers to an assembly of rigid bodies connected by joints to provide constrained motion that is the mathematical model for a mechanical system.

5.12. Differentiate between hydraulic and pneumatic actuation system.

Ans.

S. No.	Hydraulic Actuation System	Pneumatic Actuation System
1.	Operates at high pressure.	Operates at low pressure.
2.	Pump is necessary.	No pump at all.
3.	More expensive.	Less expensive.
4.	Cavitation is a big problem.	No cavitation problem.

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