MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

(Autonomous Institution – UGC, Govt. of India)

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(Affiliated to JNTUH, Hyderabad, Approved by AICTE - Accredited by NBA & NAAC – 'A' Grade - ISO 9001:2015 Certified)
Maisammaguda, Dhulapally (Post Via. Kompally), Secunderabad – 500100, Telangana State, India

DEPARTMENT OF MECHANICAL ENGINEERING

DIGITAL NOTES OF ELEMENTS OF MECHANICAL ENGINEERING

For

B.Tech – II YEAR – I

Prepared by

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CONTENTS

ELEMENTS OF MECHANICAL ENGINEERING

Objectives:

- To give an insight to students about the behavior of materials under external forces.
- The concept of stress, strain, elasticity etc. as applied to various structures under loading are included.
- The student able to learn about concept of fluids, turbines and engines.

UNIT – I

Stresses and strains: kinds of – stress-strains, elasticity and plasticity, Hooks law, stress – strain diagrams, modules of elasticity, Poisson's ratio, linear and volumetric strain, relation between E, N, and K, bars of uniform strength, compound bars and temperature stresses.

UNIT – II

Engineering Materials and Joining Processes:

Engineering Materials: Types and applications of nonferrous metals and alloys

Composites: Introduction, Definition, Classification and applications (Air Craft and Automobiles)

Soldering, Brazing and Welding:

Definitions, Classification and method of soldering, Brazing an welding. Difference between Soldering, Brazing and Welding. Description of electric Arc Welding and Oxy-Acetylene Welding

UNIT – III

Properties of Fluid : Stream line , streak line , path line , continuity equation pipes are in series, pipes are in parallel, HGL, TGL , Bernoullis equation .

Hydraulic pumps and turbines: working principles and velocity diagrams.

UNIT – IV

Internal combustion engines: classification of IC engines, basic engine components and nomenclature, working principle of engines, Four strokes and two stroke petrol and diesel engines, comparison of CI and SI engines, comparison of four stroke and two stroke engines, simple problems such as indicated power, brake power, friction power, specific fuel consumption, brake thermal efficiency, indicated thermal efficiency and mechanical efficiency.

UNIT - V

Belts - Ropes and chain: belt and rope drives, velocity ratio, slip, length of belt , open belt and cross belt drives, ratio of friction tensions, centrifugal tension in a belt, power transmitted by belts and ropes, initial tensions in the belt, simple problems.

Gear trains: classification of gears, gear trains velocity ratio, simple, compound –reverted and epicyclic gear trains

TEXT BOOKS:

1. Strength of Materials, R.K. Bansal, S.Chand Publications
2. Thermal Engineering, Ballaney,P.L., Khanna Publishers, 2003 .
3. Theory of Machines, S.S. Rattan , Tata McGraw Hill.

4. Fluid Mechanics and Hydraulic Machinery R.K. Bansal .

REFERENCE BOOKS:

1. Thermal Engineering, R.K. Rajput , Laxmi Publications .
2. Theory of Machines, R.S. Khurmi, S. Chand Publications.
3. Fluid Mechanics and Hydraulic Machinery, Modi & Seth.
4. Manufacturing Technology, P.N.Rao.

OUTCOMES:

- The student would be exposed to basic mechanical engineering machinery.
- The student learned about mechanical components.

Students understand about engines and turbines

UNIT – I

Stresses and strains: Kinds of – stress-strains, elasticity and plasticity, Hooks law, stress – strain diagrams, modules of elasticity, Poisson's ratio, linear and volumetric strain, relation between E, N, and K, bars of uniform strength, compound bars and temperature stresses.

Stress

It is the ratio of the internal force F, produced when the substance is deformed, to the area A over which this force acts. The SI Unit of stress is newton per square meter (Nm^{-2}).In CGS units, stress is measured in dyne-cm^{-2}. Dimensional formula of stress is $ML^{-1}T^{-2}$

Types of Stress

- **Normal stress**: It is the restoring force per unit area perpendicular to the surface of the body. It is of two types: tensile and compressive stress.
- **Tangential stress**: When the elastic restoring force or deforming force acts parallel to the surface area, the stress is called tangential stress.

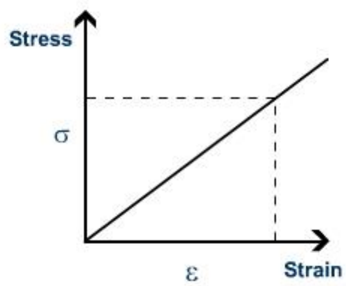
Strain

It is the ratio of the change in size or shape to the original size or shape. It has no dimensions, it is just a number.

Types of Strain

- **Longitudinal strain:** If the deforming force produces a change in length alone, the strain produced in the body is called longitudinal strain or tensile strain. It is given as:
- **Volumetric strain:** If the deforming force produces a change in volume alone, the strain produced in the body is called volumetric strain. It is given as:
- **Shear strain:** The angle tilt caused in the body due to tangential stress expressed is called shear strain. It is given as:

The maximum stress to which the body can regain its original status on the removal of the deforming force is called the **elastic limit**.



Elasticity

A body regains its original configuration (length, shape or volume) after you remove the deforming forces. This is elasticity.

Perfectly Elastic Body

A perfectly elastic body regains its original configuration immediately and completely after the removal of deforming force from it. Quartz and phosphor bronze are the examples of nearly perfectly elastic bodies.

Plasticity

A plastic body is unable to return to its original size and shape even on removal of the deforming force.

Hooke's Law

Hooke's law states that, within elastic limits, the ratio of stress to the corresponding strain produced is a constant. This constant is called the modulus of elasticity.

Stress-Strain Curve

Stress-strain curves are useful to understand the tensile strength of a given material. The given figure shows a stress-strain curve of a given metal.

- The curve from O to A is linear. In this region, the material obeys the Hooke's Proportional limit law.
- In the region from A to C stress and strain are not proportional. Still, the body regains its original dimension, once we remove the load.
- Point B in the curve is the yield point or elastic limit and the corresponding stress is the yield strength of the material.
- The curve beyond B shows the region of plastic deformation.
- The point D on the curve shows the tensile strength of the material. Beyond this point, additional strain leads to fracture, in the given material.

Kinds of – stress-strains:

- **Stress:**

When some external system of force or loads acts on the body, the internal forces are setup at various sections of body, which resist the external forces. This internal force per unit area at any section or portion of the body is stress.

Stress is the resisting force developed in the body per unit area.

Stress, = P/A

Where P = Force or load acting on the body (N)

A = Cross sectional area of the body (m^2)

- **Strain:**

When a system of forces or load acts on a body, it undergoes some deformation. This deformation per unit length is "strain". It is denoted by ε.

Strain, ε = Change in length / original length

= δL/ L

Where δL= Change in length under load.

L = Original length.

Strain has no unit.

Types of Stress:

1. **Tensile Stress:**

Tensile stress is the stress induced at any section of the body, when a body is subjected to equal and opposite axial forces P (called as tensile load).

Figure: Tensile stress

2.**Compressive Stress:**

When body is subjected to two equal and opposite forces, the stress induced at any section of the body is called as "compressive stress".

Fig: Compressive stress

3.Shear Stress;
When the body is subjected to two equal and opposite forces acting tangentially across the section, the stress induced in the section is known as shear stress.

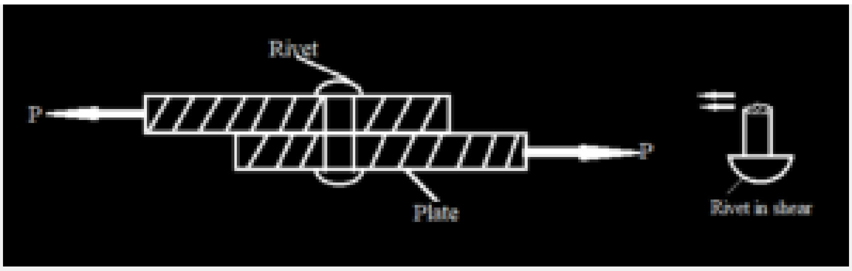


Fig:shear stress

4. **Crushing Stress:**
Crushing stress is a localized compressive stress at the area of contact between two members.

5. **Thermal stress:**
Thermal stress is induced when a body is subjected to a change of temperature and its deformation is prevented.

Types of Strain:

1. **Tensile strain:**

Due to tensile load, there will be decrease in cross sectional area and increase in the length of body.

"Tensile strain" is the ratio of increase length to the original length.

Tensile strain = Increase in length / Original Length

= δL / L

2. Compressive strain:
Due to compressive load there will be increase in cross sectional area and decrease in the length of the body.

"Compressive strain" is the ratio of decrease in length to the original length.

Compressive strain = decrease in length / Original Length

= δL / L

3. Shear Strain:
Shear strain is the angular distortion of body under the action of shear force.

4. Volumetric Strain:
It is the ratio of the change in volume to the original volume.

Volumetric strain = Change in volume / Original Volume

= δV / V

where, δV = Change in volume

V = Original Volume

Elasticity and plasticity:

Elasticity and plasticity in building engineering – theoretical basement for the theory of structures (important for steel, concrete, timber structures design) - to be able design safe structures (to resist mechanical load, temperature load…) Statics: external forces, internal forces Elasticity and plasticity new terms: 1) stress 2) strain 3) stability

Hooke's Law:

Within the elastic limit stress is directly proportional to the strain is called the Hooke's law.

Stress ∝ strain

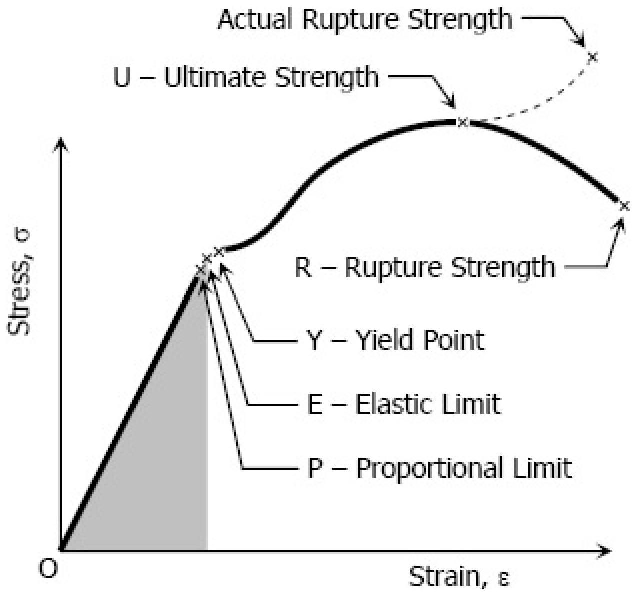
p=Ee

E=p/e, E=elastic constant (or) modulus of elasticity

Stress –Strain diagrams:

Suppose that a metal specimen be placed in tension-compression-testing machine. As the axial load is gradually increased in increments, the total elongation over the gauge length is measured at each increment of the load and this is continued until failure of the specimen takes place. Knowing the original cross-sectional area and length of the specimen, the normal stress σ and the strain ε can be obtained. The graph of these quantities with the stress σ along the y-axis and the strain ε along the x-axis is called the stress-strain diagram. The stress strain diagram differs in form for various materials.

The diagram shown below is that for a medium-carbon structural steel. Metallic engineering materials are classified as either ductile or brittle materials. A ductile material is one having relatively large tensile strains up to the point of rupture like structural steel and aluminium, whereas brittle materials has a relatively small strain up to the point of rupture like cast iron and concrete. An arbitrary strain of 0.05 mm/mm is frequently taken as the dividing line betweenthesetwoclasses.



ElasticLimit

The elastic limit is the limit beyond which the material will no longer go back to its original shape when the load is removed, or it is the maximum stress that may e developed such that there is no permanent or residual deformation when the load is entirely removed.

Elastic and Plastic Ranges

The region in stress-strain diagram from O to P is called the elastic range. The region from P toRiscalled the plasticrange.

Yield Point

Yield point is the point at which the material will have an appreciable elongation or yielding withoutany increase in load.

Ultimate Strength

The maximum ordinate in the stress-strain diagram is the ultimate strength or tensile strength.

Rapture Strength

Rapture strength is the strength of the material at rupture. This is also known as the breakingstrength.

Modulus of Resilience

Modulus of resilience is the work done on a unit volume of material as the force is gradually increased from O to P, in N·m/m^3. This may be calculated as the area under the stress-strain curve from the origin O to up to the elastic limit E (the shaded area in the figure). The resilience of the material is its ability to absorb energy without creating a permanent distortion.

Modulus of Toughness

Modulus of toughness is the work done on a unit volume of material as the force is gradually increased from O to R, in N·m/m^3. This may be calculated as the area under the entire stress-strain curve (from O to R). The toughness of a material is its ability to absorb energywithoutcausingittobreak.

Working Stress, AllowableStress,and Factor of Safety

Working stress is defined as the actual stress of a material under a given loading. The maximum safe stress that a material can carry is termed as the allowable stress. The allowable stress should be limited to values not exceeding the proportional limit. However, since proportional limit is difficult to determine accurately, the allowable tress is taken as either the yield point or ultimate strength divided by a factor of safety. The ratio of this strength (ultimate or yield strength) to allowable strength is called the factor of safety.

Modulus of Elasticity:

The ratio of stress to strain is called **Modulus of Elasticity, and is given by**

E=stress/strain (E=p/e)

Poisson's ratio:

The ratio of lateral strain to linear strain is called poisson's ratio.

μ=lateral strain/linear strain

Linear strain: the deformation of the bar per unit length in the direction of force i.e.,dl/l is known as primary strain or linear strain

Linear strain= change in the length/original length

Lateral strain: the strain at right angles to the direction of applied load is known as lateral strain

.lateral strain= change in width/original width

Volumetric strain

Change in volume to the original volume is known as volumetric strain

Relation between E, G and K:

Let us establish a relation among the elastic constants E,G and kConsider a cube of material of side ‘a' subjected to the action of the shear and complementary shear stresses as shown in the figure and producing the strained shape as shown in the figure below.

Assuming that the strains are small and the angle A C B may be taken as 45^0.

Therefore, strain on the diagonal OA

= Change in length / original length

Since angle between OA and OB is very small hence OA ≈ OB therefore BC, is the change in the length of the diagonal OA

$$\text{Thus, strain on diagonal OA} = \frac{BC}{OA}$$

$$= \frac{AC\cos 45^0}{OA}$$

$$OA = \frac{a}{\sin 45^0} = a.\sqrt{2}$$

$$\text{hence} \qquad \text{strain} = \frac{AC}{a\sqrt{2}}.\frac{1}{\sqrt{2}}$$

$$= \frac{AC}{2a}$$

but $AC = a\gamma$

where γ = shear strain

$$\text{Thus, the strain on diagonal} = \frac{a\gamma}{2a} = \frac{\gamma}{2}$$

From the definition

$$G = \frac{\tau}{\gamma} \text{ or } \gamma = \frac{\tau}{G}$$

$$\text{thus, the strain on diagonal} = \frac{\gamma}{2} = \frac{\tau}{2G}$$

Now this shear stress system is equivalent or can be replaced by a system of direct stresses at 45^0 as shown below. One set will be compressive, the other tensile, and both will be equal in value to the applied shear strain.

Thus, for the direct state of stress system which applies along the diagonals:

$$\text{strain on diagonal} = \frac{\sigma_1}{E} - \mu\frac{\sigma_2}{E}$$
$$= \frac{\tau}{E} - \mu\frac{(-\tau)}{E}$$
$$= \frac{\tau}{E}(1+\mu)$$

equating the two strains one may get

$$\frac{\tau}{2G} = \frac{\tau}{E}(1+\mu)$$
$$\text{or} \quad \boxed{E = 2G(1+\mu)}$$

We have introduced a total of four elastic constants, i.e E, G, K . It turns out that not all of these are independent of the others. Infact given any two of then, the other two can be found.

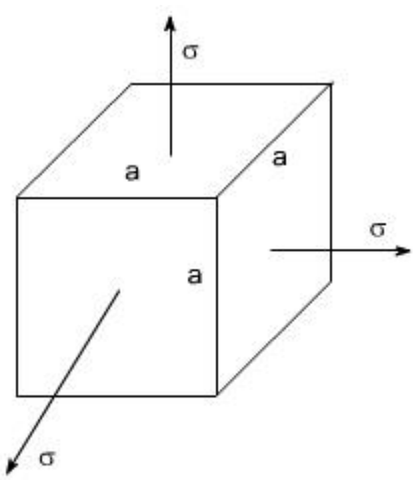
$$\text{Again} \quad E = 3K(1-2\gamma)$$
$$\Rightarrow \frac{E}{3(1-2\gamma)} = K$$
$$\text{if } \gamma = 0.5 \quad K = \infty$$
$$\epsilon_v = \frac{(1-2\gamma)}{E}(\epsilon_x + \epsilon_y + \epsilon_z) = 3\frac{\sigma}{E}(1-2\gamma)$$
$$(\text{for } \epsilon_x = \epsilon_y = \epsilon_z \text{ hydrostatic state of stress})$$
$$\epsilon_v = 0 \text{ if } \gamma = 0.5$$

rrespective of the stresses i.e, the material is incompressible.

When ? = 0.5 Value of k is infinite, rather than a zero value of E and volumetric strain is zero, or in other words, the material is incompressible.

Relation between E, K and G :

Consider a cube subjected to three equal stresses ? as shown in the figure below



The total strain in one direction or along one edge due to the application of hydrostatic stress or volumetric stress ? is given as

$$= \frac{\sigma}{E} - \gamma\frac{\sigma}{E} - \gamma\frac{\sigma}{E}$$

$$= \frac{\sigma}{E}(1-2\gamma)$$

volumetre strain = 3.linear strain

volumetre strain = $\epsilon_x + \epsilon_y + \epsilon_z$

or thus, $\epsilon_x = \epsilon_y = \epsilon_z$

volumetric strain $= 3\frac{\sigma}{E}(1-2\gamma)$

By definition

Bulk Modulus of Elasticity (K) $= \frac{\text{Volumetric stress}(\sigma)}{\text{Volumetric strain}}$

or

Volumetric strain $= \frac{\sigma}{k}$

Equating the two strains we get

$$\frac{\sigma}{k} = 3.\frac{\sigma}{E}(1-2\gamma)$$

$$\boxed{E = 3K(1-2\gamma)}$$

Relation between E, G and K :

The relationship between E, G and K can be easily determained by eliminating from the already derived relations

E = 2 G (1 + μ) and E = 3 K (1 -2μ)

Thus, the following relationship may be obtained

$$\boxed{E = \frac{9\,GK}{(3K+G)}}$$

Relation between E, K and μ (Y):

From the already derived relations, E can be eliminated

$$E = 2G(1+\gamma)$$

$$E = 3K(1-2\gamma)$$

Thus,we get

$$3k(1-2\gamma) = 2G(1+\gamma)$$

therefore

$$\gamma = \frac{(3K-2G)}{2(G+3K)}$$

or

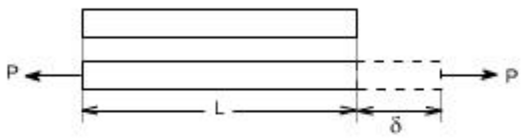
$$\boxed{\gamma = 0.5(3K-2G)(G+3K)}$$

BARS OF UNIFROM STRENGTH

Members in Uni – axial state of stress

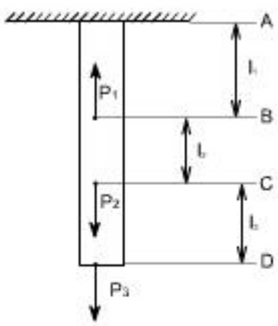
Introduction: [For members subjected to uniaxial state of stress]

For a prismatic bar loaded in tension by an axial force P, the elongation of the bar can be determined as



$$\delta = \frac{PL}{AE} \qquad (1)$$

Suppose the bar is loaded at one or more intermediate positions, then equation (1) can be readily adapted to handle this situation, i.e. we can determine the axial force in each part of the bar i.e. parts AB, BC, CD, and calculate the elongation or shortening of each part separately, finally, these changes in lengths can be added algebraically to obtain the total charge in length of the entire bar.



When either the axial force or the cross – sectional area varies continuosly along the axis of the bar, then equation (1) is no longer suitable. Instead, the elongation can be found by considering a deferential element of a bar and then the equation (1) becomes

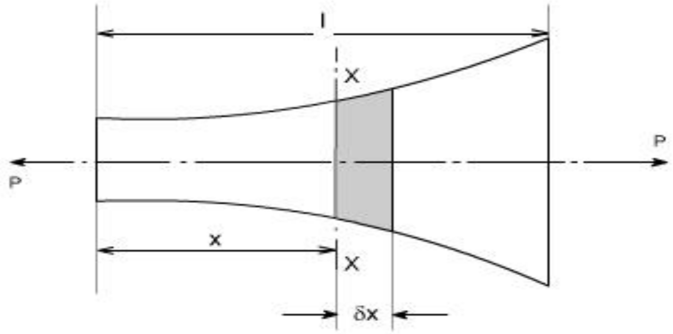
$$d\delta = \frac{P_x dx}{E.A_x}$$

$$\delta = \int_0^l \frac{P_x dx}{E.A_x}$$

i.e. the axial force $P_x$and area of the cross – section A_x must be expressed as functions of x. If the expressions for $P_x$and A_x are not too complicated, the integral can be evaluated analytically, otherwise Numerical methods or techniques can be used to evaluate these integrals.

stresses in Non – Uniform bars

Consider a bar of varying cross section subjected to a tensile force P as shown below.



Let

a = cross sectional area of the bar at a chosen section XX

then

Stress σ = p / a

If E = Young's modulus of bar then the strain at the section XX can be calculated

$\varepsilon = \sigma / E$

Then the extension of the short element δx. = ε .original length = σ / E. δx

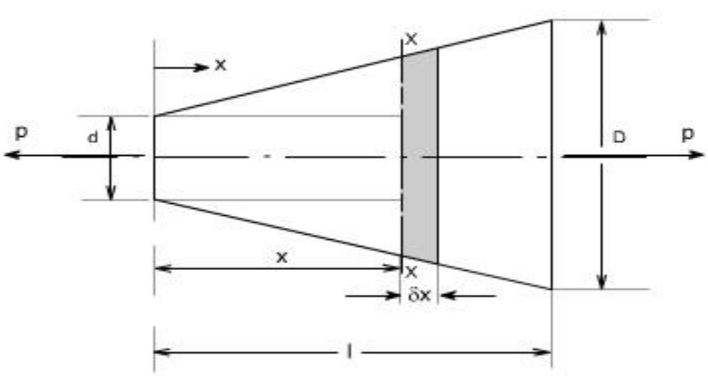
$$= \frac{P}{E} \cdot \frac{\delta x}{a}$$

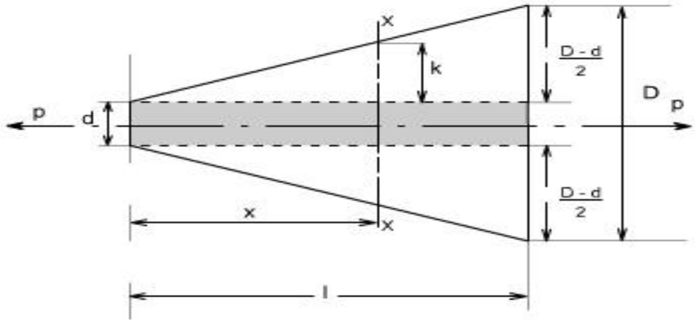
Thus, the extension for the entire bar is

$$\delta = \int_0^l \frac{P}{E} \frac{\delta x}{a}$$

$$\text{or total extension} = \frac{P}{E} \int_0^l \frac{\delta x}{a}$$

Now let us for example take a case when the bar tapers uniformly from d at x = 0 to D at x = l





In order to compute the value of diameter of a bar at a chosen location let us determine the value of dimension k, from similar triangles

$$\frac{(D-d)/2}{l} = \frac{k}{x}$$

$$\text{Thus, } k = \frac{(D-d)x}{2l}$$

therefore, the diameter 'y' at the X-section is

or = d + 2k

$$y = d + \frac{(D-d)x}{l}$$

Hence the cross –section area at section X- X will be

$$A_x \text{ or } a = \frac{\pi}{4}y^2$$

$$= \frac{\pi}{4}\left[d + (D-d)\frac{x}{l}\right]^2$$

hence the total extension of the bar will be given by expression

$$= \frac{P}{E}\int_0^l \frac{\delta x}{a}$$

subsitituting the value of 'a' to get the total extention of the bar

$$= \frac{\pi P}{4E}\int_0^l \frac{\delta x}{\left[d + (D-d)\frac{x}{l}\right]^2}$$

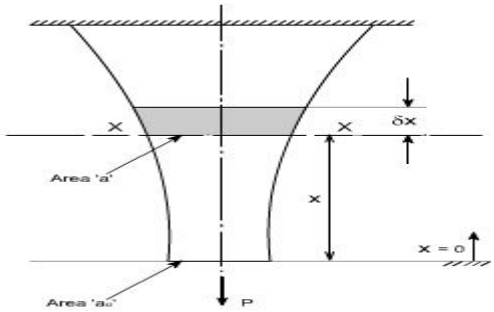
after carrying out the intergration we get

$$= -\frac{4.P.l}{\pi E}\left[\frac{1}{D} - \frac{1}{d}\right]$$

$$= \frac{4.P.l}{\pi E D.d}$$

$$\text{hence the total strain in the bar} = \mathbf{\frac{4.P.l}{\pi E\ D.d}}$$

An interesting problem is to determine the shape of a bar which would have a uniform stress in it under the action of its own weight and a load P.



$$= \int_0^x \rho g a \, dx$$

where ρ is density of the bar.

thus the stress at XX is

$$\sigma = \frac{P + \int_0^x \rho g a \, dx}{a}$$

$$\text{or } \sigma.a = P + \int_0^x \rho.g.a \, dx$$

Differentiating the above equation with respect to x we get

$$\sigma.\frac{da}{dx} = \rho.g.a$$

$$\frac{da}{a} = \frac{\rho.g}{\sigma}.dx$$

intergrating the above equation we get

$$\int \frac{da}{a} = \int \frac{\rho.g}{\sigma} dx$$

$$\log_e{}^a = \frac{\rho.g.x}{\sigma} + \text{constant}$$

In order to determine the constant of integration let us apply the boundary conditions

at $x = 0;\ a = a_0$

thus, constant $= \log_e{}^{a_0}$

or

$$\log_e{}^a = \frac{\rho.g.x}{\sigma} + \log_e{}^{a_0}$$

$$\log_e\left(\frac{a}{a_0}\right) = \frac{\rho.g.x}{\sigma}$$

$$\text{or } \boxed{e^{\frac{\rho.g.x}{\sigma}} = \frac{a}{a_0}}$$

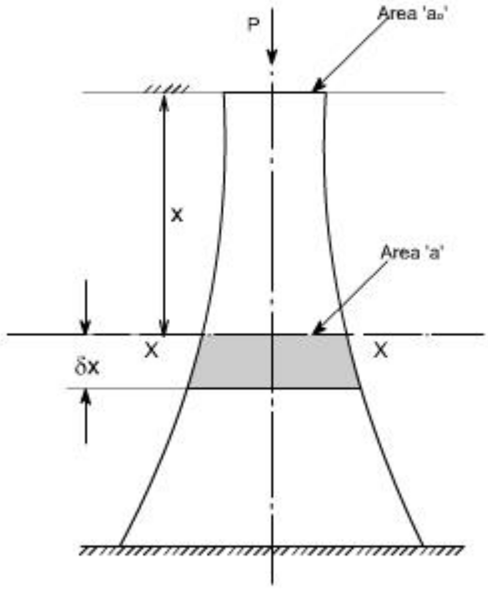
also at $x = 0$

$$\sigma = \frac{P}{a_0}$$

Thus,

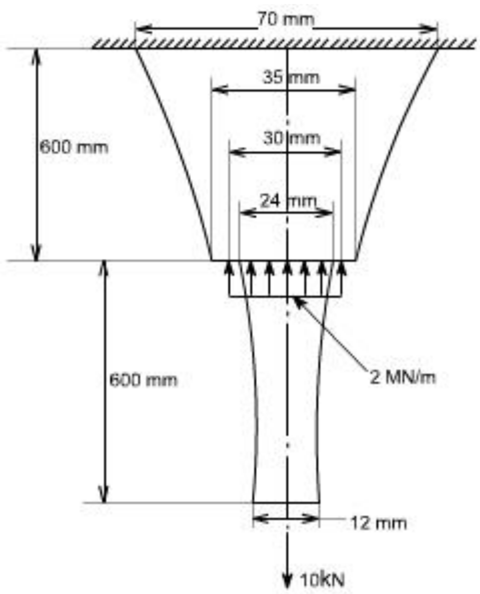
$$\frac{a}{a_0} = e^{\frac{\rho.g.x.a_0}{P}}$$

The same results are obtained if the bar is turned upside down and loaded as a column as shown in the figure below:



Illustrative Problem 1: Calculate the overall change in length of the tapered rod as shown in figure below. It carries a tensile load of 10kN at the free end and at the step change in section a compressive load of 2 MN/m evenly distributed around a circle of 30 mm diameter take the value of E = 208 GN / m^2.

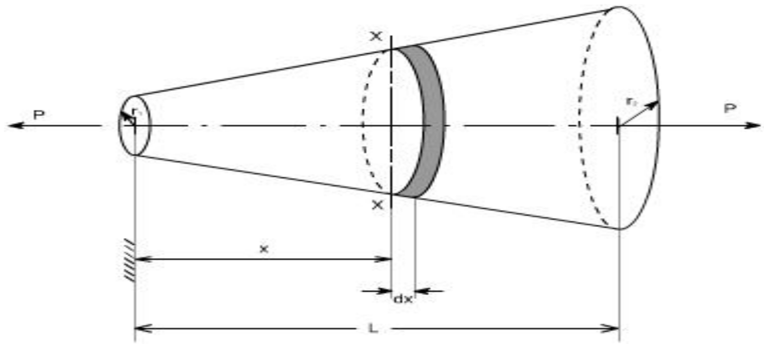
This problem may be solved using the procedure as discussed earlier in this section



Illustrative Problem 2: A round bar, of length L, tapers uniformly from radius r_1 at one end to radius $r_2$at the other. Show that the extension produced by a tensile axial load P is $\frac{PL}{2\pi E r_1^2}$

If $r_2 = 2r_1$, compare this extension with that of a uniform cylindrical bar having a radius equal to the mean radius of the tapered bar.

Solution:



consider the above figure let r_1 be the radius at the smaller end. Then at a X cross section XX located at a distance x from the smaller end, the value of radius is equal to

$$= r_1 + \frac{x}{L}(r_2 - r_1)$$

$$= r_1(1 + kx)$$

$$\text{where } k = \left(\frac{r_2 - r_1}{L}\right).\frac{1}{r_1}$$

$$\text{stress at section XX} = \frac{\text{load}}{\text{area}}$$

$$= \frac{P}{\pi r_1^2 (1 + kx)^2}$$

$$\text{hence strain at this section} = \frac{\text{stress}}{E}$$

$$= \frac{P}{E.\pi r_1^2 (1 + kx)^2}$$

Thus, for a small length dx of the bar at this section the extention is $\frac{P.dx}{E\pi r_1^2 (1 + kx)^2}$

Total extension of the bar can be found by integrating the above expression within the limits from x=0 to x=L

$$\text{Extension} = \int_0^L \frac{P.dx}{E.\pi r_1^2 (1 + k.x)^2}$$

$$= \frac{P}{E.\pi r_1^2} \int_0^L (1 + k.x)^{-2} dx$$

$$= \frac{P}{E.\pi r_1^2} \left[\frac{(1+kx)^{-1}}{-k}\right]_0^L$$

$$= \frac{P}{E.\pi r_1^2} \left[\frac{(1 + kx)^{-1}}{-k} - \frac{1}{-k}\right]$$

$$= \frac{P}{E.\pi r_1^2.k} \left[1 - \frac{1}{1 + kL}\right]$$

$$= \frac{PL}{E.\pi r_1^2 (1 + kL)}$$

$$\text{since } k = \frac{(r_2 - r_1)}{r_1 L}$$

$$\text{Thus, } 1 + kL = {}^{r_2}\!/\!{}_{r_1}$$

$$\text{Therefore, the extension} = \frac{PL}{\pi E r_1 r_2}$$

Comparing of extensions

For the case when $r_2 = 2.r_1$, the value of computed extension as above becomes equal to $\frac{PL}{2\pi E r_1^2}$

The mean radius of taper bar

$= 1 / 2(r_1 + r_2)$

$= 1 / 2(r_1 +2 r_2)$

$= 3 / 2 .r_1$

Therefore, the extension of uniform bar

= Orginal length . strain

$$= L.\frac{\sigma}{E}$$

$$= \frac{L}{E}.\frac{P}{\pi\left(3/2\, r_1\right)^2}$$

$$= \frac{4PL}{g\pi E\pi r_1^2}$$

hence the

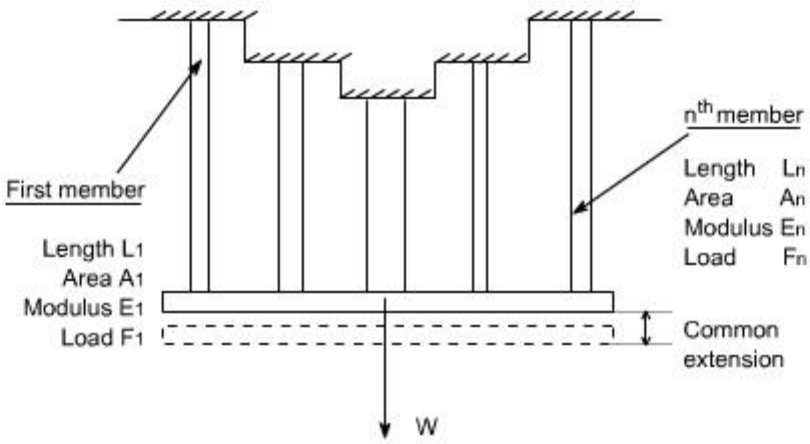
$$\frac{\text{Extension of uniform}}{\text{Extension of tapered}} = \left(\frac{4PL}{g\pi E\pi r_1^2}\right) \Big/ \frac{PL}{2\pi E r_1^2}$$

$$= \frac{8}{g}$$

Thermal stresses, Bars subjected to tension and Compression

Compound bar: In certain application it is necessary to use a combination of elements or bars made from different materials, each material performing a different function. In over head electric cables or Transmission Lines for example it is often convenient to carry the current in a set of copper wires surrounding steel wires. The later being designed to support the weight of the cable over large spans. Such a combination of materials is generally termed compound bars.

Consider therefore, a compound bar consisting of n members, each having a different length and cross sectional area and each being of a different material. Let all member have a common extension ‘x' i.e. the load is positioned to produce the same extension in each member.



For the 'n' the members

$$\frac{\text{stress}}{\text{strain}} = E_n = \frac{F_n / A_n}{x_n / L_n}$$

$$= \frac{F_n . L_n}{A_n . x_n}$$

$$\text{or} \quad F_n = \frac{E_n . A_n . x_n}{L_n} = \frac{E_n . A_n . x}{L_n} \quad .....(1)$$

Where F_n is the force in the nth member and A_n and L_n are its cross - sectional area and length.

Let W be the total load, the total load carried will be the sum of all loads for all the members.

$$W = \sum \frac{E_n . A_n . x}{L_n}$$

$$= x . \sum \frac{E_n . A_n}{L_n} \quad ....(2)$$

From equation (1), force in member 1 is given as

$$F_1 = \frac{E_1 . A_1 . x}{L_1}$$

from equation (2)

$$x = \frac{W}{\sum \frac{E_n . A_n}{L_n}}$$

$$\text{Thus, } F_1 = \frac{E_1 . A_1}{L_1} . \frac{W}{\sum \left(\frac{E_n . A_n}{L_n} \right)}$$

Therefore, each member carries a portion of the total load W proportional of EA / L value.

The above expression may be writen as $$F_1 = \frac{\frac{E_1.A_1}{L_1}}{\sum \frac{E_n.A_n}{L_n}}.W$$

if the length of each individual member in same then, we may write $$F_1 = \frac{E_1.A_1}{\sum E.A}.W$$

Thus, the stress in member '1' may be determined as $\sigma_1 = F_1 / A_1$

Determination of common extension of compound bars: In order to determine the common extension of a compound bar it is convenient to consider it as a single bar of an imaginary material with an equivalent or combined modulus E_c.

Assumption: Here it is necessary to assume that both the extension and original lengths of the individual members of the compound bar are the same, the strains in all members will than be equal.

Total load on compound bar = $F_1 + F_2 + F_3 + \ldots\ldots\ldots + F_n$

where F_1 , F_2 ,….,etc are the loads in members 1,2 etc

But force = stress . area,therefore

$\sigma (A_1 + A_2 + \ldots\ldots + A_n) = \sigma_1 A_1 + \sigma_2 A_2 + \ldots\ldots\ldots + \sigma_n A_n$

Where σ is the stress in the equivalent single bar

Dividing throughout by the common strain ϵ .

$$\frac{\sigma}{\in}(A_1 + A_2 + \ldots + A_n) = \frac{\sigma_1}{\in}A_1 + \frac{\sigma_2}{\in}A_2 + \ldots\ldots \frac{\sigma_n}{\in}A_n$$

$$\text{i.e } E_c(A_1 + A_2 + \ldots + A_n) = E_1A_1 + E_2A_2 + \ldots E_n.A_n$$

$$\text{or } E_c = \frac{E_1A_1 + E_2A_2 + \ldots E_n.A_n}{A_1 + A_2 + \ldots + A_n}$$

$$\text{or } E_c = \frac{\sum EA}{\sum A}$$

with an external load W applied stress in the equivalent bar may be computed as

$$\text{stress} = \frac{W}{\sum A}$$

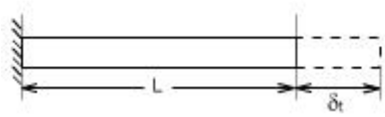
$$\text{strain inthe equivalent bar} = \frac{x}{L} = \frac{W}{\sum A E_c}$$

$$\text{hence commen extension } x = \frac{W.L}{E_c \sum A}$$

Compound bars subjected to Temperature Change : Ordinary materials expand when heated and contract when cooled, hence , an increase in temperature produce a positive thermal strain. Thermal strains usually are reversible in a sense that the member returns to its original shape when the temperature return to its original value. However, there here are some materials which do not behave in this manner. These metals differs from ordinary materials in a sence that the strains are related non linearly to temperature and some times are irreversible .when a material is subjected to a change in temp. is a length will change by an amount.

dl= Lαt

p=αtE



α = coefficient of linear expansoin for the material

L = original Length

t = temp. change

Thus an increase in temperature produces an increase in length and a decrease in temperature results in a decrease in length except in very special cases of materials with zero or negative coefficients of expansion which need not to be considered here.

If however, the free expansion of the material is prevented by some external force, then a stress is set up in the material. They stress is equal in magnitude to that which would be produced in the bar by initially allowing the bar to its free length and then applying sufficient force to return the bar to its original length.

Changein Length = α L t

Therefore, strain = α L t / L

= α t

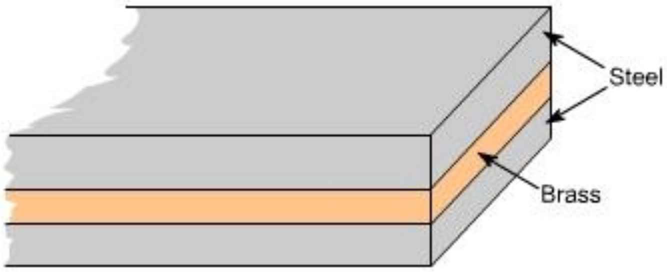
Therefore ,the stress generated in the material by the application of sufficient force to remove this strain

= strain x E

or Stress = E α t

Consider now a compound bar constructed from two different materials rigidly joined together, for simplicity.

Let us consider that the materials in this case are steel and brass.

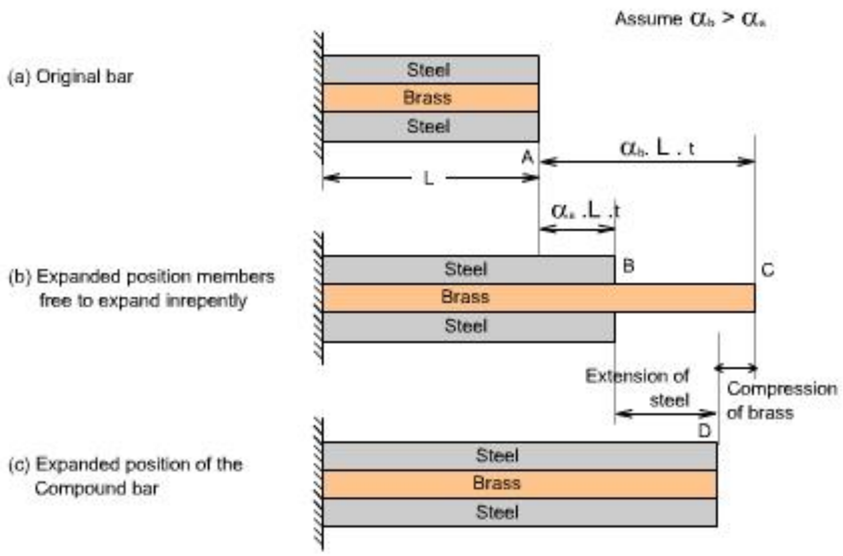


If we have both applied stresses and a temp. change, THERAMAL strains may be added to those given by generalized hook's law equation –e.g.

$$\in_x = \frac{1}{E}\left[\sigma_x - \gamma(\sigma_y + \sigma_z)\right] + \alpha\Delta t$$
$$\in_x = \frac{1}{E}\left[\sigma_y - \gamma(\sigma_x + \sigma_z)\right] + \alpha\Delta t$$
$$\in_x = \frac{1}{E}\left[\sigma_z - \gamma(\sigma_x + \sigma_y)\right] + \alpha\Delta t$$

While the normal strains a body are affected by changes in temperatures, shear strains are not. Because if the temp. of any block or element changes, then its size changes not its shape therefore shear strains do not change.

In general, the coefficients of expansion of the two materials forming the compound bar will be different so that as the temp. rises each material will attempt to expand by different amounts. Figure below shows the positions to which the individual materials will expand if they are completely free to expand (i.e not joined rigidly together as a compound bar). The extension of any Length L is given by ⍰ L t



In general, changes in lengths due to thermal strains may be calculated form equation ⍰$_t$ = ⍰ Lt, provided that the members are able to expand or contract freely, a situation that exists in statically determinates structures. As a consequence no stresses are generated in a statically determinate structure when one or more members undergo a uniform temperature change. If in a structure (or a compound bar), the free expansion or contraction is not allowed then the member becomes s statically indeterminate, which is just being discussed as an example of the compound bar and thermal stresses would be generated.

Thus the difference of free expansion lengths or so called free lengths

$= \alpha_B.L.\ t - \alpha_S\ .L\ .t$

$= (\ \alpha_B - \alpha_S\ ).L\ .t$

Since in this case the coefficient of expansion of the brass α_B is greater then that for the steel α_S. the initial lengths L of the two materials are assumed equal.

If the two materials are now rigidly joined as a compound bar and subjected to the same temp. rise, each materials will attempt to expand to its free length position but each will be affected by the movement of the other. The higher coefficient of expansion material (brass) will therefore, seek to pull the steel up to its free length position and conversely, the lower coefficient of expansion martial (steel) will try to hold the brass back. In practice a compromised is reached, the compound bar extending to the position shown in fig (c), resulting in an effective compression of the brass from its free length position and an effective extension of steel from its free length position.

Therefore, from the diagrams,we may conclude the following

Conclusion 1.

Extension of steel + compression brass = difference in “ free” length

Applying Newton 's law of equal action and reaction the following second Conclusion also holds good.

Conclusion 2.

The tensile force applied to the short member by the long member is equal in magnitude to the compressive force applied to long member by the short member.

Tensile force in steel = compressive force in brass

These conclusions may be written in the form of mathematical equations as given below:

for conclusion 1

$$\frac{\sigma_s.L}{E_s} + \frac{\sigma_B.L}{E_B} = (\alpha_B - \alpha_s)L.t$$

for conclusion 2

$$\sigma_s.A_s = \sigma_B.A_B$$

Using these two equations, the magnitude of the stresses may be determined.

Important Questions:

1. Define the terms: a) stress-strains,b)elasticity and c)plasticity and d)Hooks law.
2. Describe stress –strain curve of medium carbon steel.
3. Define modules of elasticity, Poisson's ratio, linear and volumetric strain in detail.
4. Derive the relation between E and K.
5. what is stess and strain?define their types in detail.
6. Explain bars of uniform strength with figures.
7. Explain thermal stresses when bars are subjected to tension and Compression

UNIT-II

Engineering Materials and Joining Processes:
Engineering Materials: Types and applications of nonferrous metals and alloys
Composites: Introduction, Definition, Classification and applications (Air Craft and Automobiles)
Soldering, Brazing and Welding:

Definitions, Classification and method of soldering, Brazing an welding. Difference between Soldering, Brazing and Welding. Description of electric Arc Welding and Oxy-Acetylene Welding

Introduction

Materials play an important role for our existence, for our day to day needs ,and even for our survival. In the stone age the naturally accessible materials were stone, wood, bone, fur etc Gold was the 1st metal used by the mankind followed by copper. In the bronze age Copper and its alloy like bronze was used and in the iron age they discovered Iron (sponge iron & later pig iron). 1960's Engineering Materials Metals Design Choice of Material New Materials New Products Number of Materials 40 – 80,000! General Definition of Material According to Webster's dictionary, materials are defined as 'substances of which something is composed or made

Engineering Material: Part of inanimate matter, which is useful to engineer in the practice of his profession (used to produce products according to the needs and demand of society)

Material Science: Primarily concerned with the search for basic knowledge about internal structure, properties and A processing of materials and their complex interactions/relationships

Material Engineering: Mainly concerned with the use of fundamental and applied knowledge of materials, so that they may be converted into products, as needed or desired by the society (bridges materials knowledge from basic sciences to engineering disciplines)

Classification

It is the systematic arrangement or division of materials into groups on the basis of some common characteristic

1. According to General Properties
2. According to Nature of Materials
3. According to Applications

1. According to General Properties (a). Metals (e.g. iron, aluminium, copper, zinc, lead, etc) Iron as the base metal, and range from plain carbon (> 98 % Fe) to (i). Ferrous: high alloy steel (< 50 % alloying elements), e.g. cast iron, wrought iron, steel, alloys like high-speed steel, spring steel, etc (ii). Non-Ferrous: Rest of the all other metals and their alloys, e.g. copper, aluminium, zinc lead, alloys like brass, bronze, duralumin, etc

(b). Non-Metals (e.g. leather, rubber, asbestos, plastics, etc)

2. According to Nature of Materials (a). Metals: e.g. Iron & Steel, Alloys &Superalloys, Intermetallic Compounds, etc

(b). Ceramics: e.g. Structural Ceramics (high-temperature load bearing), Refractories (corrosion-resistant, insulating), Whitewares (porcelains), Glass, Electrical Ceramics (capacitors, insulators, transducers), Chemically Bonded Ceramics (cement & concrete)

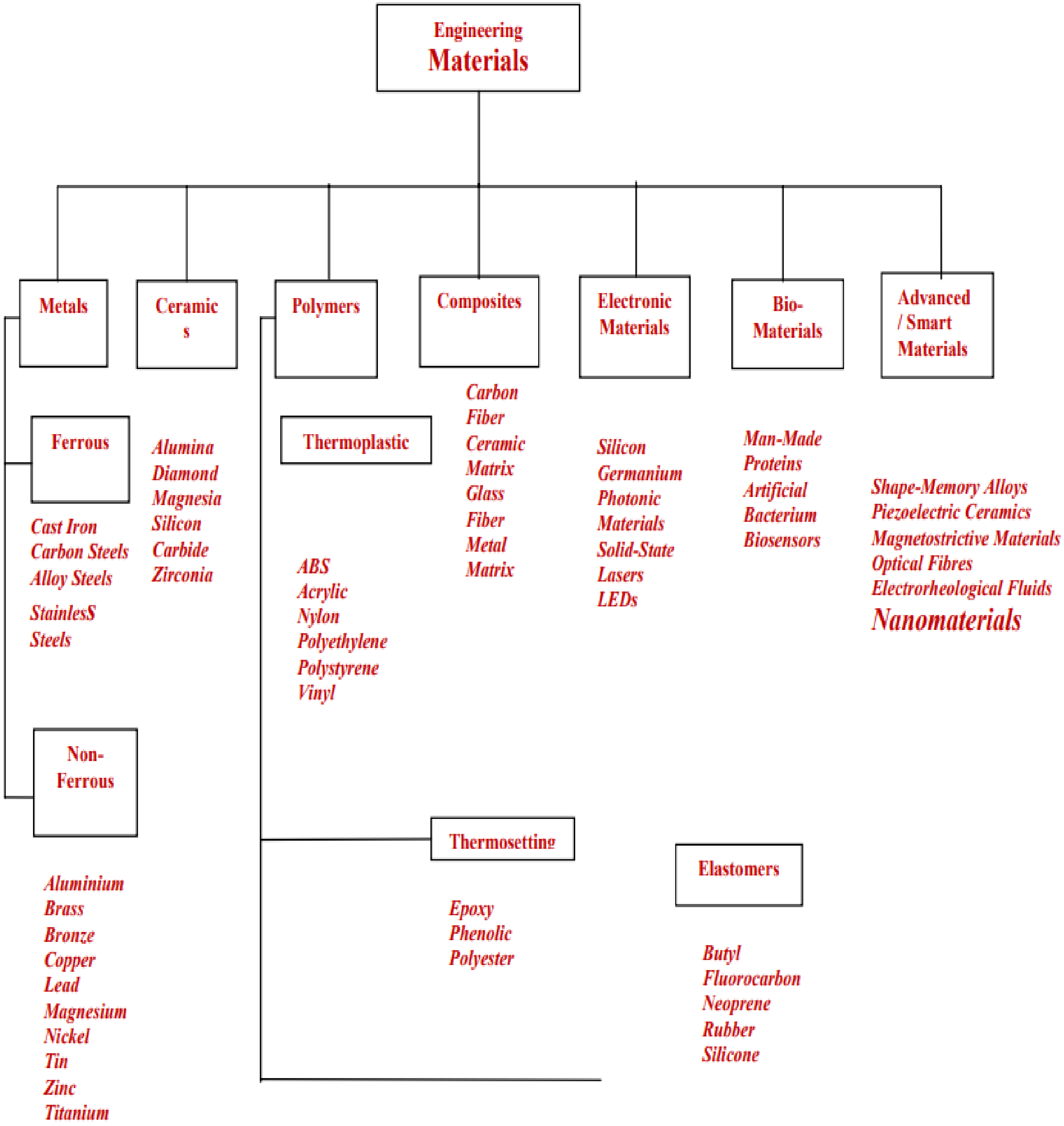
(c).Polymers: e.g. Plastics, Liquid Crystals, Adhesives

(d). Electronic Materials: e.g. Silicon, Germanium, Photonic materials (solid-state lasers, LEDs)

(e). Composites: e.g. Particulate composites (small particles embedded in a different material), Laminate composites (golf club shafts, tennis rackets), Fiber reinforced composites (fibreglass)

(f). Biomaterials: e.g. Man-made proteins (artificial bacterium), Biosensors, etc (g). Advanced / Smart Materials: e.g. materials in computers (VCRs, CD Players, etc), fibreoptic systems, spacecrafts, aircrafts, rockets, shape-memory alloys, piezoelectric ceramics, magnetostrictive materials, optical fibres, microelectromechanical (MEMs) devices, electrorheological / magnetorheological fluids, Nanomaterials, etc

3. According to Applications (a). Electrical Materials: e.g. conductors, insulators, dielectrics, etc (b). Electronic Materials: e.g. conductors, semi-conductors, etc (c). Magnetic Materials: e.g. ferromagnetic, paramagnetic & diamagnetic materials, etc (d). Optical Materials: e.g. glass, quartz, etc (e). Bio Materials: e.g. man-made proteins, artificial bacterium



Composite materials:

A **composite material** (also called a **composition material** or shortened to **composite,** which is the common name) is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components.

Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, racing car bodies, shower stalls, bathtubs, storage tanks, imi tation

granite and cultured marble sinks and countertops.

The most advanced examples perform routinely on spacecraft and aircraft in demanding environments.

I. ADVANTAGES COMPOSITES IN AEROSPACE STRUCTURE

The composites offer several of these features as given below:

Light-weight due to high specific strength and stiffness

- Fatigue-resistance and corrosion resistance
- Capability of high degree of optimization: tailoring the directional strength and stiffness
- Capability to mould large complex shapes in small cycle time reducing part count and assembly times:
- Good for thin-walled or generously curved construction Capability to maintain dimensional and alignment stability in space environment
- Possibility of low dielectric loss in radar transparency
- Possibility of achieving low radar cross-section
- These composites also have some inherent weaknesses:

- Laminated structure with weak interfaces: poor resistance to out-of-plane tensile loads
- Susceptibility to impact-damage and strong possibility of internal damage going unnoticed
- Moisture absorption and consequent degradation of high temperature performance
- Multiplicity of possible manufacturing defects and variability in material properties

II. MATERIALS FOR AEROSPACE COMPOSITES

The materials systems which have been considered useful in aerospace sector are based on reinforcing fibers and matrix resins. Most aerospace composites use prepregs as raw materials with autoclave moulding as a popular fabrication process. Oven curing or room temperature curing is used mostly with glass fibre composites used in low speed small aircraft. It is common to use composite tooling where production rates are small or moderate; however, where large number of components are required, metallic conventional tooling is preferred. Resin injection moulding also finds use in special components such as radomes. Some of the popular systems are given in table 4 along with the types of components where they are used in a typical high-performance aircraft.

SOLDERING AND BRAZING

INTRODUCTION

Soldering and brazing provide permanent joint to bond metalpieces. Soldering and brazing process lie some where in between fusion welding and solid state welding. These processes have some advantages over welding process. These can join the metal having poor weldability, dissimilar metals, very less amount of heating is needed. The major disadvantage is joint made by soldering and brazing has low strength as compared to welded joint.

Objectives

After studying this unit, you should be able to

• Introduction to allied welding processes,

• welding soldering and brazing comparative study,

• different methods of soldering and brazing and machine tool, and

• defects and applications of soldering and brazing.

DIFFERENT TYPES OF SOLDERS

Most of the solder metals are the alloy of tin and lead. These alloys exhibit a wide range of melting point so different type of soldering metal can be used for variety of applications. Percentage of lead is kept least due to its toxic properties. Tin becomes chemically active at soldering temperature and promotes the wetting action required for making the joint. Copper, silver and antimony are also used in soldering metal as per the strength requirements of the joint. Different solder their melting point and applications are given in the Table

Filler Metal Compositions					Melting Point	Applications
Tin	Lead	Silver	Zinc	Antimony		
–	96	04	–	–	305°C	Joint making at elevated temperature
60	40	–	–	–	188°C	Electronic circuits
50	50	–	–	–	199°C	Wire joining
40	60	–	–	–	208°C	Automobile radiators
91	–	–	09	–	200°C	Joining of aluminium wires
95	–	–	–	05	238°C	Plumbing, etc.

SOLDERING METHODS

There is a lot of similarity between soldering and brazing processes. The major difference between them is less heat and lower temperature is required in case of soldering. The different processes (methods) used in soldering are touch soldering, furnace soldering, resistance soldering, dip soldering and infrared soldering. All the above methods are common to both soldering and brazing processes. There are some more methods used in case of soldering only, these are hand soldering; wave soldering and reflow soldering. These methods are described below.

Hand Soldering

Hand soldering is done manually using solder iron. Small joints are made by this way in very short duration approximately in one second.

Wave Soldering

Wave soldering is a mechanical and technique that allows multiple lead wires to be soldered to a Printed Circuit Board (PCB) as it passes over a wave of molten solder. In this process a PCB on which electronic components have been placed with their lead wires extending through the through the holes in the board, is loaded onto a conveyor for transport through the wave soldering equipment. The conveyor supports the PCB on its sides, so its underside is exposed to the processing steps, which consists of the following :

(a) flux is applied through foaming, spraying, brushing, and

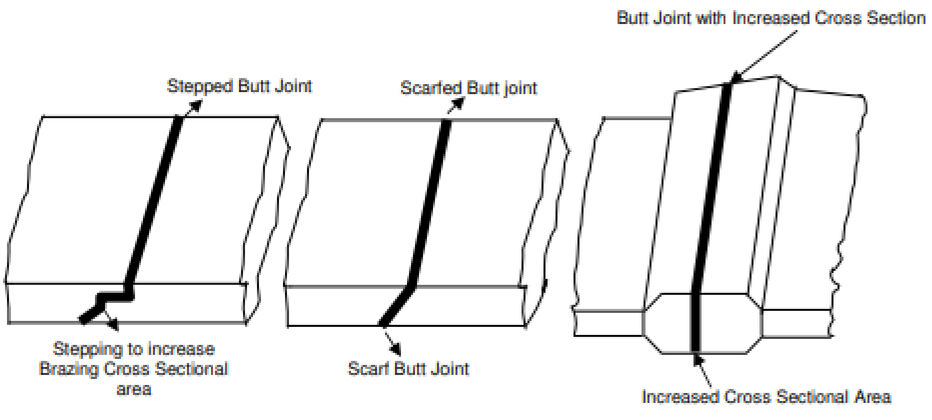
(b) wave soldering is used pump liquid solder from a molten both on to the bottom of board to make soldering connections between lead wire and metal circuit on the board.

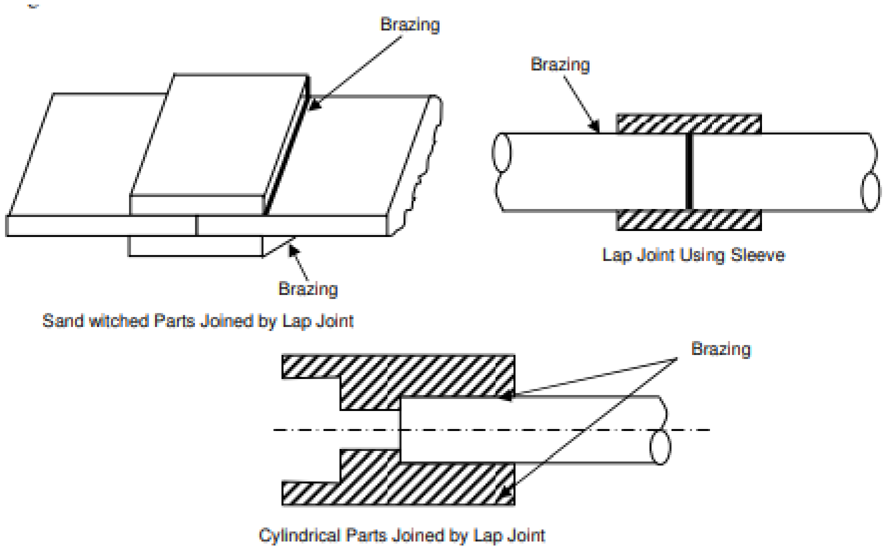
Reflow Soldering

This process is also widely used in electronics to assemble surface mount components to print circuit boards. In this process a solder paste consisting of solder powders in a flux binder is applied to spots on the board where electrical contacts are to be made between surface mount components and the copper circuit. The components are placed on the paste spots, and the board is heated to melt the solder, forming mechanical and electrical bonds between the component leads and the copper on the circuit board.

BRAZING PROCESSES

All the processes covered here can also be applied to soldering processes. These common processes are being described below.





Examples of Lap Joints by Brazing

Torch Brazing In case of torch brazing, flux is applied to the part surfaces and a torch is used to focus flame against the work at the joint. A reducing flame is used to prevent the oxidation. Filler metal wire or rod is added to the joint. Torch uses mixture of two gases, oxygen and acetylene, as a fuel like gas welding.

Furnace Brazing In this case, furnace is used to heat the workpieces to be joined by brazing operation. In medium production, usually in batches, the component parts and brazing metal are loaded into a furnace, heated to brazing temperature, and then cooled and removed. If high production rate is required all the parts and brazing material are loaded on a conveyer to pass through then into a furnace. A neutral or reducing atmosphere is desired to make a good quality joint.

Induction Brazing

Induction brazing uses electrical resistance of workpiece and high frequency current induced into the same as a source of heat generation. The parts are pre-loaded with filler metal and placed in a high frequency AC field. Frequencies ranging from 5 to 5000 kHz is used. High frequency power source provides surface heating, however, low frequency causes deeper heating into the workpieces. Low frequency current is recommended for heavier and big sections (workpieces). Any production rate, low to high, can be achieved by this process.

Resistance Brazing

In case of resistance welding the workpieces are directly connected to electrical --- - rather than induction of electric current line induction brazing. Heat to melt the filler metal is obtained by resistance to flow of electric current through the joint to be made. Equipment for resistance brazing is same that is used for resistance welding, only lower power ratings are used in this case. Filler metal into the joint is placed between the electrode before passing current through them. Rapid heating cycles can be achieved in resistance welding. It is recommended to make smaller joints.

Dip Brazing

In this case heating of the joint is done by immersing it into the molten soft bath or molten metal bath. In case of salt bath method, filler metal is pre-loaded to the joint and flux is contained in to the hot salt bath. The filler metal melts into the joint when it is submerged into the hot bath. Its solidification and formation of the joint takes place after taking out the workpiece from the bath. In case of metal bath method, the bath contains molten filler metal. The joint is applied with flux and dipped to the bath. Molten filler metal, fills the joint through capillary action. The joint forms after its solidification after taking it out from molten metal bath. Fast heating is possible in this case. It is recommended for making multiple joints in a single workpiece or joining multiple pairs of workpieces simultaneously.

Infrared Brazing

It uses infrared lamps. These lamps are capable of focused heating of very thin sections. They can generate upto 5000 watts of radiant heat energy. The generated heat is focused at the joint for brazing which are pre-loaded with filler metal and flux. The process is recommended and limited to join very thin sections.

Introduction to welding process

Introduction Welding is a process in which two or more parts are joined permanently at their touching surfaces by a suitable application of heat and/or pressure. Often a filler material is added to facilitate coalescence. The assembled parts that are joined by welding are called a weldment. Welding is primarily used in metal parts and their alloys.

Welding processes are classified into two major groups:

1. Fusion welding: In this process, base metal is melted by means of heat. Often, in fusion welding operations, a filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the joint. Commonly used fusion welding processes are: arc welding, resistance welding, oxyfuel welding, electron beam welding and laser beam welding.

2. Solid-state welding: In this process, joining of parts takes place by application of pressure alone or a combination of heat and pressure. No filler metal is used. Commonly used solid-state welding processes are: diffusion welding, friction welding, ultrasonic welding.

3. Arc welding : Arc welding is a method of permanently joining two or more metal parts. It consists of combination of different welding processes wherein coalescence is produced by heating with an electric arc, (mostly without the application of pressure) and with or without the use of filler metals depending upon the base plate thickness. A homogeneous joint is achieved by melting and fusing the adjacent portions of the separate parts. The final welded joint has unit strength approximately equal to that of the base material. The arc temperature is maintained approximately 4400°C. A flux material is used to prevent oxidation, which decomposes under the heat of welding and releases a gas that shields the arc and the hot metal. The second basic method employs an inert or nearly inert gas to form a protective envelope around the arc and the weld. Helium, argon, and carbon dioxide are the most commonly used gases.

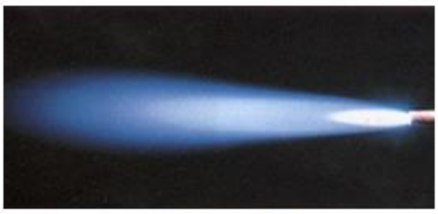
4. Oxyacetylene welding

Oxyacetylene welding, commonly referred to as gas welding, is a process which relies on combustion of oxygen and acetylene. When mixed together in correct proportions within a hand-held torch or blowpipe, a relatively hot flame is produced with a temperature of about 3,200 deg.C. The chemical action of the oxyacetylene flame can be adjusted by changing the ratio of the volume of oxygen to acetylene.

Three distinct flame settings are used, neutral, oxidising and carburising.

Neutral flame

Oxidising flame



Carburising flame

Welding is generally carried out using the neutral flame setting which has equal quantities of oxygen and acetylene. The oxidising flame is obtained by increasing just the oxygen flow rate while the carburising flame is achieved by increasing acetylene flow in relation to oxygen flow. Because steel melts at a temperature above 1,500^0 C, the mixture of oxygen and acetylene is used as it is the only gas combination with enough heat to weld steel. However, other gases such as propane, hydrogen and coal gas can be used for joining lower melting point non-ferrous metals, and for brazing and silver soldering.

COMPARISON OF SOLDERING, BRAZING AND WELDING

The three processes soldering, brazing and welding have similarity that these are bonding processes. All the three uses filler metal, flux and application of heat. These processes also are dissimilar regarding the cost involved, performance, application area, etc. This comparison is tabulated below.

Sl. No.	Welding	Soldering	Brazing
1.	These are the strongest joints used to bear the load. Strength of a welded joint may be more than the strength of base metal.	These are weakest joint out of three. Not meant to bear the load. Use to make electrical contacts generally.	These are stronger than soldering but weaker than welding. These can be used to bear the load upto some extent.
2.	Temperature required is upto 3800^{o}C of welding zone.	Temperature requirement is upto 450^{o}C.	It may go to 600^{o}C in brazing.
3.	Workpiece to be joined need to be heated till their melting point.	No need to heat the workpieces.	Workpieces are heated but below their melting point.

Important questions:

1. Explain Engineering Materials and their types and applications of nonferrous metals and alloys
2. what is a Composite materials?Give some examples
3. write the composite materials and advantages of composites in aerospace structure
4. Define the terms Soldering, Brazing and Welding.
5. Explain the Different Types Of Solders?
6. Explain the Soldering Methods?
7. Explain the Brazing Processes?
8. Explain the Welding processes?
9. Explain electric Arc Welding and Oxy-Acetylene Welding?

UNIT-III

Properties of Fluid : Stream line , streak line , path line , continuity equation pipes are in series, pipes are in parallel, HGL, TGL , Bernoullis equation .
Hydraulic pumps and turbines: working principles and velocity diagrams.

A substance in liquid / gas phase is referred as 'fluid'. Distinction between a solid & a fluid is made on the basis of substance's ability to resist an applied shear (tangential) stress that tends to change its shape. A solid can resist an applied shear by deforming its shape whereas a fluid deforms continuously under the influence of shear stress, no matter how small is its shape. In solids, stress is proportional to strain, but in fluids, stress is proportional to 'strain rate

1.Pressure (p) : It is the normal force exerted by a fluid per unit area. In SI system the unit of pressure can be written as, N/m2

2.Density: The density of a substance is the quantity of matter contained in unit volume of the substance.

Density (ρ)= mass/volume
Units: kg/m^3

3.Viscosity (µ): When two solid bodies in contact, move relative to each other, a friction force develops at the contact surface in the direction opposite to motion. The situation is similar when a fluid moves relative to a solid or when two fluids move relative to each other. The property that represents the internal resistance of a fluid to motion (i.e. fluidity) is called as viscosity.

$$\tau = \mu \, du/dy$$

4.Coefficient of compressibility/Bulk modulus(Ev):

It is the property of that fluid that represents the variation of density with pressure at constant temperature.

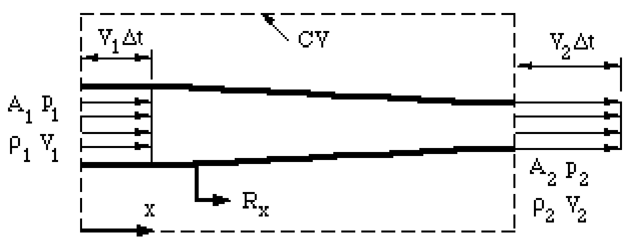
5.Specific heats: It is the amount of energy required for a unit mass of a fluid for unit rise in temperature

6.Surface Tension (σ): When a liquid and gas or two immiscible liquids are in contact, an unbalanced force is developed at the interface stretched over the entire fluid mass. The intensity of molecular attraction per unit length along any line in the surface is called as surface tension.

Streamlines, streaklines and pathlines are field lines in a fluid flow. They differ only when the flow changes with time, that is, when the flow is not steady. Considering a velocity vector field in three-dimensional space in the framework of continuum mechanics, we have that:

- **Streamlines** are a family of curves that are instantaneously tangent to the velocity vector of the flow. These show the direction in which a massless fluid element will travel at any point in time.[3]
- **Streaklines** are the loci of points of all the fluid particles that have passed continuously through a particular spatial point in the past. Dye steadily injected into the fluid at a fixed point extends along a streakline.
- **Pathlines** are the trajectories that individual fluid particles follow. These can be thought of as “recording” the path of a fluid element in the flow over a certain period. The direction the path takes will be determined by the streamlines of the fluid at each moment in time.

When a fluid is in motion, it must move in such a way that mass is conserved. To see how mass conservation places restrictions on the velocity field, consider the steady flow of fluid through a duct (that is, the inlet and outlet flows do not vary with time). The inflow and outflow are one-dimensional, so that the velocity V and density \rho are constant over the area A



One-dimensional duct showing control volume

Now we apply the principle of mass conservation. Since there is no flow through the side walls of the duct, what mass comes in over A_1 goes out of A_2, (the flow is steady so that there is no mass accumulation). Over a short time interval \Delta t,

$$\text{volume flow in over } A_1 = A_1 V_1 \Delta t$$
$$\text{volume flow out over } A_2 = A_2 V_2 \Delta t$$

Therefore

$$\text{mass in over } A = \rho A_1 V_1 \Delta t$$
$$\text{mass out over } A = \rho A_2 V_2 \Delta t$$

$$\text{So:} \quad \boxed{\rho A_1 V_1 = \rho A_2 V_2}$$

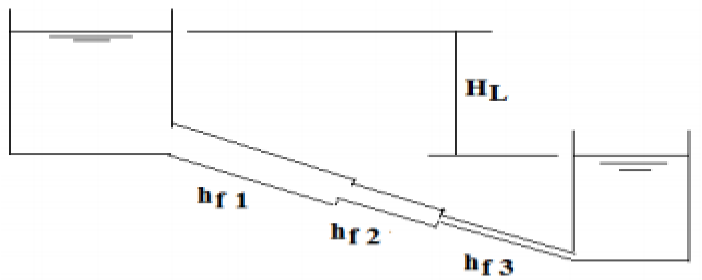
This is a statement of the principle of mass conservation for a steady, one-dimensional flow, with one inlet and one outlet. This equation is called the continuity equation for steady one-dimensional flow. For a steady flow through a control volume with many inlets and outlets, the net mass flow must be zero, where inflows are negative and outflows are positive.

Flow through Pipe Systems:

Pipes in series are pipes with different diameters and lengths connected together forming a pipe line. Consider pipes in series discharging water from a tank with higher water level to another with lower water level, as shown in the figure

Neglecting secondary losses, it is obvious that the total head loss HL between the two tanks is the sum of the friction losses through the pipe line.

Friction losses through the pipe line are the sum of friction loss of each pipe.



$$H_L = h_{f\,1} + h_{f\,2} + h_{f\,3} + ...$$

$$H_L = \frac{4f_1L_1v_1^{\,2}}{2gd_1} + \frac{4f_2L_2v_2^{\,2}}{2gd_2} + \frac{4f_3L_3v_3^{\,2}}{2gd_3} + ...$$

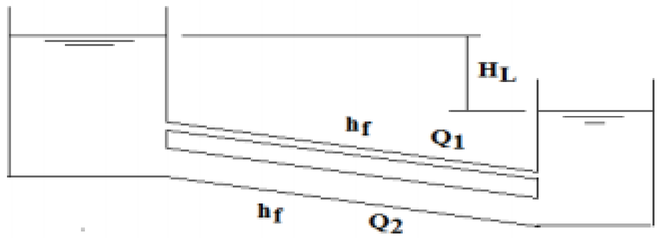
OR:

$$H_L = \frac{32f_1L_1Q^2}{\pi^2\,g\,d_1^{\,5}} + \frac{32f_2L_2Q^2}{\pi^2\,g\,d_2^{\,5}} + \frac{32f_3L_3Q^2}{\pi^2\,g\,d_3^{\,5}} + ...$$

Pipes in Parallel: Pipes in parallel are pipes with different diameters and same lengths, where each pipe is connected separately to increase the discharge. Consider pipes in parallel discharging water from a tank with higher water level to another with lower water level, as shown in the figure.

Neglecting minor losses, it is obvious that the total head loss HL between the two tanks is the same as the friction losses through each pipe.

The friction losses through all pipes are the same, and all pipes discharge water independently.



$$H_L = h_{f\,1} = h_{f\,2} = \ldots..$$

$$L_1 = L_2 = L$$

$$H_L = \frac{4 f_1 L v_1^2}{2 g d_1} = \frac{4 f_2 L v_2^2}{2 g d_2} = \ldots..$$

$$H_L = \frac{32 f_1 L Q_1^{\,2}}{\pi^2 g d_1^{\,5}} = \frac{32 f_2 L Q_2^{\,2}}{\pi^2 g d_2^{\,5}} = \ldots..$$

$$Q = Q_1 + Q_2$$

- **Hydraulic Gradient Line (H.G.L)**

is defined as the line which gives the sum of pressure head (p/w) and datum head (z) of flowing fluid in a pipe w.r.t some reference line

- **Total Energy LIne (T.E.L)**

It is defined as the line which gives the sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe w.r.t some reference line.

Bernoulli's principle

Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of kinetic energy, potential energy and internal energy remains constant

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{constant}$$

hydraulic jump

The hydraulic jump is the phenomenon that occurs where there is an abrupt transition from supercritical (inertia dominated) flow to sub critical (gravity dominated) flow. The most important factor that affects the hydraulic jump is the initial Froude number F.

$$F=V/gD$$

in which V is the longitudinal average velocity at the initial section, g is the acceleration due to gravity and D is the hydraulic mean depth (ratio of area of flow at free surface width).

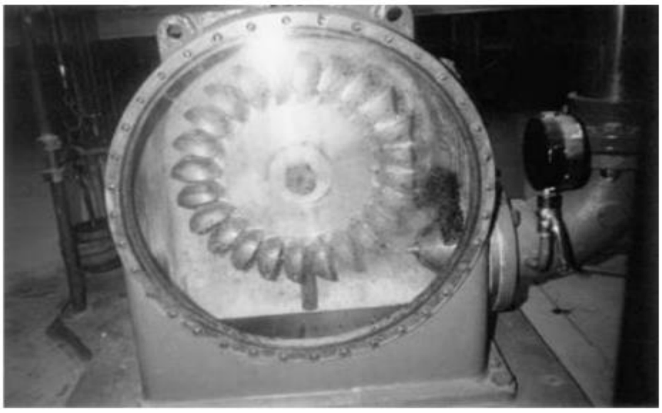
TURBINES

Working Principle

A hydraulic machine is a device in which mechanical energy is transferred from the liquid flowing through the machine to its operating member (runner, piston and others) or from the operating member of the machine to the liquid flowing through it. Hydraulic machines in which, the operating member receives energy from the liquid flowing through it and the inlet energy of the liquid is greater than the outlet energy of the liquid are referred as hydraulic turbines. Hydraulic machines in which energy is transmitted from the working member to the flowing liquid and the energy of the liquid at the outlet of the hydraulic machine is less than the outlet energy are referred to as pumps. It is well known from Newton's Law that to change momentum of fluid, a force is required. Similarly, when momentum of fluid is changed, a force is generated. This principle is made use in hydraulic turbine. In a turbine, blades or buckets are provided on a wheel and directed against water to alter the momentum of water. As the momentum is changed with the water passing through the wheel, the resulting force turns the shaft of the wheel performing work and generating power. A hydraulic turbine uses potential energy and kinetic energy of water and converts it intousable mechanical energy. The mechanical energy made available at the turbine shaft is used to run an electric power generator which is directly coupled to the turbine shaft.The electric power which is obtained from the hydraulic energy is known as Hydro- electric energy. Hydraulic turbines belong to the category of roto- dynamic machinery.The hydraulic turbines are classified according to type of energy available at the inlet ofturbine, direction of flow through vanes, head at the inlet of the turbines and specific speed of the turbines.

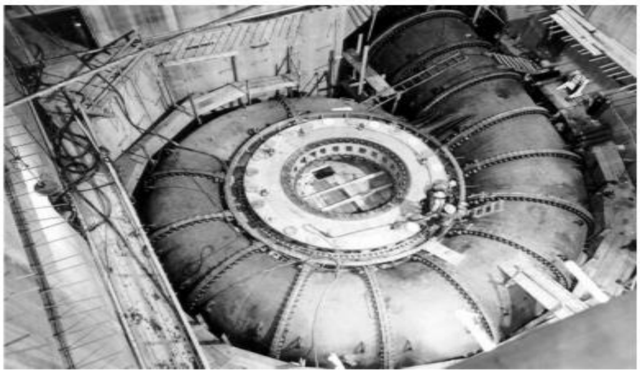
1.According to the type of energy at inlet:

Impulse turbine: - In the impulse turbine, the total head of the incoming fluid is converted in to a large velocity head at the exit of the supply nozzle. That is the entire available energy of the water is converted in to kinetic energy. Although there are various types of impulse turbine designs, perhaps the easiest to understand is the Pelton wheel turbine. It is most efficient when operated with a large head and lower flow rate.



Pelton wheel

Reaction turbine: Reaction turbines on the other hand, are best suited -for higher flow rate and lower head situations. In this type of turbines, the rotation of runner or rotor (rotating part of the turbine) is partly due to impulse action and partly due to change in pressure over the runner blades; therefore, it is called as reaction turbine. For, a reaction turbine, the penstock pipe feeds water to a row of fixed blades through casing. These fixed blades convert a part of the pressure energy into kinetic energy before water enters the runner. The water entering the runner of a reaction turbine has both pressure energy and kinetic energy. Water leaving the turbine is still left with some energy (pressure energy and kinetic energy). Since, the flow from the inlet to tail race is under pressure, casing is absolutely necessary to enclose the turbine. In general, Reaction turbines are medium to low-head, and high-flow rate devices. The reaction turbines in use are Francis and Kaplan



Francis turbine

2. According to the direction of flow through runner:

Tangential flow turbines: In this type of turbines, the water strikes the runner in the direction of tangent to the wheel. Example: Pelton wheel turbine

Radial flow turbines: In this type of turbines, the water strikes in the radial direction. accordingly, it is further classified as,

a.Inward flow turbine: The flow is inward from periphery to the centre (centripetal type). Example: old Francis turbine.

b. Outward flow turbine: The flow is outward from the centre to periphery (centrifugal type). Example: Fourneyron turbine.

3. According to the head at inlet of turbine:

High head turbine: In this type of turbines, the net head varies from 150m to 2000m or even more, and these turbines require a small quantity of water. Example: Pelton wheel turbine.

Medium head turbine: The net head varies from 30m to 150m, and also these turbines¬ require moderate quantity of water. Example: Francis turbine.

Low head turbine: The net head is less than 30m and also these turbines require large¬ quantity of water. Example: Kaplan turbine.

VELOCITY TRAINGLE

Runner of the Francis Turbine

The shape of the blades of a Francis runner is complex. The exact shape depends on its specific speed. It is obvious from the equation of specific speed that higher specific speed means lower head. This requires that the runner should admit a comparatively large quantity of water for a given power output and at the same time the velocity of discharge at runner outlet should be small to avoid cavitation. In a purely radial flow runner, as developed by James B. Francis, the bulk flow is in the radial direction. To be more clear, the flow is tangential and radial at the inlet but is entirely radial with a negligible tangential component at the outlet. The flow, under the situation, has to make a 90^o turn after passing through the rotor for its inlet to the draft tube. Since the flow area (area perpendicular to the radial direction) is small, there is a limit to the capacity of this type of runner in keeping a low exit velocity. This leads to the design of a mixed flow runner where water is turned from a radial to an axial direction in the rotor itself. At the outlet of this type of runner, the flow is mostly axial with negligible radial and tangential components. Because of a large discharge area (area perpendicular to the axial direction), this type of runner can pass a large amount of water with a low exit velocity from the runner. The blades for a reaction turbine are always so shaped that the tangential or whirling component of velocity at the outlet becomes zero $(V_{w_2} = 0)$. This is made to keep the kinetic energy at outlet a minimum.

Figure 29.1 shows the velocity triangles at inlet and outlet of a typical blade of a Francis turbine. Usually the flow velocity (velocity perpendicular to the tangential direction) remains constant throughout, i.e. $V_{f_1} = V_{f_2}$ and is equal to that at the inlet to the draft tube.

The Euler's equation for turbine [Eq.(1.2)] in this case reduces to

$$E/m = e = V_{w_1} U_1 \qquad (29.1)$$

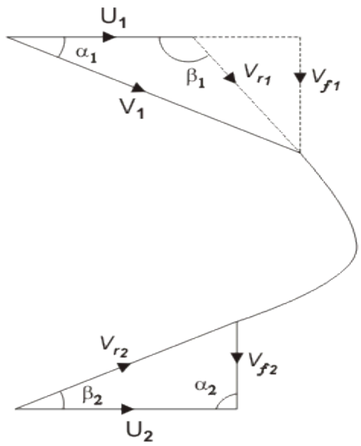
where, e is the energy transfer to the rotor per unit mass of the fluid. From the inlet velocity triangle shown in Fig. 29.1

$$V_{w_1} = V_{f_1} \cot \alpha_1 \qquad (29.2a)$$

and $$U_1 = V_{f_1} (\cot \alpha_1 + \cot \beta_1) \qquad (29.2b)$$

Substituting the values of V_{w_1} and U_1 from Eqs. (29.2a) and (29.2b) respectively into Eq. (29.1), we have

$$e = V_{f_1}^2 \cot \alpha_1 (\cot \alpha_1 + \cot \beta_1) \qquad (29.3)$$



Velocity triangle for a Francis runner

The loss of kinetic energy per unit mass becomes equal to $V_{f_2}^2/2$. Therefore neglecting friction, the blade efficiency becomes

$$\eta_b = \frac{e}{e + (V_{f_2}^2/2)}$$

$$= \frac{2V_{f_1}^2 \cot \alpha_1 (\cot \alpha_1 + \cot \beta_1)}{V_{f_2}^2 + 2V_{f_1}^2 \cot \alpha_1 (\cot \alpha_1 + \cot \beta_1)}$$

since $V_{f_1} = V_{f_2}, \eta_b$ can be written as

$$\eta_b = 1 - \frac{1}{1 + 2\cot \alpha_1 (\cot \alpha_1 + \cot \beta_1)}$$

The change in pressure energy of the fluid in the rotor can be found out by subtracting the change in its kinetic energy from the total energy released. Therefore, we can write for the degree of reaction.

$$R = \frac{e - \frac{1}{2}\left(V_1^2 - V_{f_2}^2\right)}{e} = 1 - \frac{\frac{1}{2}V_{f1}^2 \cot^2 \alpha_1}{e}$$

$$V_1^2 - V_{f_2}^2 = V_1^2 - V_{f1}^2 = V_{f1}^2 \cot^2 \alpha_1]$$

Important Questions:

1. Write the Properties of Fluid?
2. Define the terms density, surface tension,and thermal conductivity.
3. Explain Stream line , streak line , path line.
4. Derive the continuity equation? And write the Bernoulli's principle?
5. Explain the pipes in series and parallel?
6. Define Hydraulic Gradient Line and Total Energy Line.
7. Define turbine and write the types of turbine
8. Explain the velocity triangle for the Francis turbine?
9. Derive Bernoulli's equations?

UNIT – IV

Internal combustion engines: classification of IC engines, basic engine components and nomenclature, working principle of engines, Four strokes and two stroke petrol and diesel engines, comparison of CI and SI engines, comparison of four stroke and two stroke engines, simple problems such as indicated power, brake power, friction power, specific fuel consumption, brake thermal efficiency, indicated thermal efficiency and mechanical efficiency.

Internal combustion engines:

The internal combustion engine is an engine in which the burning of a fuel occurs in a confined space called a combustion chamber. This exothermic reaction of a fuel with an oxidizer creates gases of high temperature and pressure, which are permitted to expand. The defining feature of an internal combustion engine is that useful work is performed by the expanding hot gases acting directly to cause movement, for example by acting on pistons, rotors, or even by pressing on and moving the entire engine itself.

This contrasts with external combustion engines, such as steam engines, which use the combustion process to heat a separate working fluid, typically water or steam, which then in turn does work, for example by pressing on a steam actuated piston.

The term Internal Combustion Engine (ICE) is almost always used to refer specifically to reciprocating engines, Wankel engines and similar designs in which combustion is intermittent. However, continuous combustion engines, such as Jet engines, most rockets and many gas turbines are also internal combustion engines.

Internal combustion engines are seen mostly in transportation. Several other uses are for any portable situation where you need an non-electric motor. The largest application in this situation would be an Internal combustion engine driving an electric generator. That way, you can use standard electric tools driven by an internal combustion engine.

Classification of IC engines:

There is a wide range of internal combustion engines corresponding to their many varied applications. Likewise there is a wide range of ways to classify internal-combustion engines, some of which are listed below.

Although the terms sometimes cause confusion, there is no real difference between an "engine" and a "motor." At one time, the word "engine" (from Latin, via Old French, ingenium, "ability") meant any piece of machinery. A "motor" (from Latin motor, "mover") is any machine that produces mechanical power. Traditionally, electric motors are not referred to as "engines," but combustion engines are often referred to as "motors." (An electric engine refers to locomotive operated by electricity.)

With that said, one must understand that common usage does often dictate definitions. Many individuals consider engines as those things which generate their power from within, and motors as requiring an outside source of energy to perform their work. Evidently, the roots of the words seem to actually indicate a real difference. Further, as in many definitions, the root word only explains the beginnings of the word, rather than the current usage. It can certainly be argued that such is the case with the words motor and engine.

Principles of operation

Reciprocating:

- Crude oil engine
- Two-stroke cycle
- Four-stroke cycle
- Hot bulb engine
- Poppet valves
- Sleeve valve
- Atkinson cycle
- Proposed
  - Bourke engine
- Improvements
- Controlled Combustion Engine

Rotary:

- Demonstrated:
  - Wankel engine
- Proposed:
  - Orbital engine
  - Quasiturbine
  - Rotary Atkinson cycle engine
  - Toroidal engine

Continuous combustion:

- Gas turbine
- Jet engine
- Rocket engine

Engine cycle

Two-stroke

Engines based on the two-stroke cycle use two strokes (one up, one down) for every power stroke. Since there are no dedicated intake or exhaust strokes, alternative methods must be used to scavenge the cylinders. The most common method in spark-ignition two-strokes is to use the downward motion of the piston to pressurize fresh charge in the crankcase, which is then blown through the cylinder through ports in the cylinder walls. Spark-ignition two-strokes are small and light (for their power output), and mechanically very simple. Common applications include snowmobiles, lawnmowers, weed-whackers, chain saws, jet skis, mopeds, outboard motors, and some motorcycles. Unfortunately, they are also generally louder, less efficient, and far more polluting than their four-stroke counterparts, and they do not scale well to larger sizes. Interestingly, the largest compression-ignition engines are two-strokes, and are used in some locomotives and large ships. These engines use forced induction to scavenge the cylinders. two stroke engines are less fuel efficient than other types of engines because unspent fuel being sprayed into the combustion chamber can sometimes escape out of the exhaust duct with the previously spent fuel.

Without special exhaust processing, this will also produce very high pollution levels, requiring many small engine applications such as lawnmowers to employ four stroke engines, and smaller two-strokes to be outfitted with catalytic converters in some jurisdictions.

Four-stroke

Engines based on the four-stroke cycle or Otto cycle have one power stroke for every four strokes (up-down-up-down) and are used in cars, larger boats and many light aircraft. They are generally quieter, more efficient and larger than their two-stroke counterparts. There are a number of variations of these cycles, most notably the Atkinson and Miller cycles. Most truck and automotive Diesel engines use a four-stroke cycle, but with a compression heating ignition system. This variation is called the diesel cycle.

Five-stroke

Engines based on the five-stroke cycle are a variant of the four stroke cycle. Normally the four cycles are intake, compression, combustion and exhaust. The fifth cycle added by Delautour[2] is refrigeration. Engines running on a five-stroke cycle are up to 30 percent more efficient than an equivalent four stroke engine.

Bourke engine

In this engine, two diametrically opposed cylinders are linked to the crank by the crank pin that goes through the common scottish yoke. The cylinders and pistons are so constructed that there are, as in the usual two stroke cycle, two power strokes per revolution. However, unlike the common two stroke engine, the burnt gases and the incoming fresh air do not mix in the cylinders, contributing to a cleaner, more efficient operation. The scotch yoke mechanism also has low side thrust and thus greatly reduces friction between pistons and cylinder walls. The Bourke engine's combustion phase more closely approximates constant volume combustion than either four stroke or two stroke cycles do. It also uses less moving parts, hence needs to overcome less friction than the other two reciprocating types have to. In addition, its greater expansion ratio also means more of the heat from its combustion phase is utilized than is used by either four stroke or two stroke cycles.

Controlled combustion engine

These are also cylinder based engines may be either single or two stroke but use, instead of a crankshaft and piston rods, two gear connected, counter rotating concentric cams to convert reciprocating motion into rotary movement. These cams practically cancel out sideward forces that would otherwise be exerted on the cylinders by the pistons, greatly improving mechanical efficiency. The profiles of the cam lobes(which are always odd and at least three in number) determine the piston travel versus the torque delivered. In this engine, there are two cylinders that are 180 degrees apart for each pair of counter rotating cams. For single stroke versions, there are the same number of cycles per cylinder pair as there are lobes on each cam, twice as much for two stroke units.

Wankel

The Wankel engine operates with the same separation of phases as the four-stroke engine (but with no piston strokes, would more properly be called a four-phase engine), since the phases occur in separate locations in the engine. This engine provides three power "strokes" per revolution per rotor, giving it a greater power-to-weight ratio, on average, than piston engines. This type of engine is used in the Mazda current RX8 and earlier RX7 as well as other models.

Gas turbine

With gas turbine cycles (notably Jet engines), rather than use the same piston to compress and then expand the gases, instead separate compressors and gas turbines are employed; giving continuous power. Essentially, the intake gas (air normally) is compressed, and then combusted with a fuel, which greatly raises the temperature and volume. The larger volume of hot gas from the combustion chamber is then fed through the gas turbine which is then easily able to power the compressor.

Disused methods

In some old non-compressing internal combustion engines: In the first part of the piston down stroke a fuel/air mixture was sucked or blown in. In the rest of the piston down stroke the inlet valve closed and the fuel/air mixture fired. In the piston upstroke the exhaust valve was open. This was an attempt at imitating the way a piston steam engine works.

Fuel and oxidizer types

Fuels used include petroleum spirit (North American term: Gasoline, British term: Petrol), auto gas (liquefied petroleum gas), compressed natural gas, hydrogen, diesel fuel, jet fuel, landfill gas, biodiesel, bio butanol, peanut oil and other vigils, bio ethanol, bio methanol (methyl or wood alcohol), and other bio fuels. Even fluidized metal powders and explosives have seen some use. Engines that use gases for fuel are called gas engines and those that use liquid hydrocarbons are called oil engines. However, gasoline engines are unfortunately also often colloquially referred to as "gas engines."

The main limitations on fuels are that the fuel must be easily transportable through the fuel system to the combustion chamber, and that the fuel release sufficient energy in the form of heat upon combustion to make use of the engine practical.

The oxidizer is typically air, and has the advantage of not being stored within the vehicle, increasing the power-to-weight ratio. Air can, however, be compressed and carried aboard a vehicle. Some submarines are designed to carry pure oxygen or hydrogen peroxide to make them air-independent. Some race cars carry nitrous oxide as oxidizer. Other chemicals, such as chlorine or fluorine, have seen experimental use; but most are impractical.

Diesel engines are generally heavier, noisier, and more powerful at lower speeds than gasoline engines. They are also more fuel-efficient in most circumstances and are used in heavy road vehicles, some automobiles (increasingly more so for their increased fuel efficiency over gasoline engines), ships, railway locomotives, and light aircraft. Gasoline engines are used in most other road vehicles including most cars, motorcycles, and mopeds. Note that in Europe, sophisticated diesel-engined cars have become quite prevalent since the 1990s, representing around 40 percent of the market. Both gasoline and diesel engines produce significant emissions. There are also engines that run on hydrogen, methanol, ethanol, liquefied petroleum gas (LPG), and biodiesel. Paraffin and tractor vaporising oil (TVO) engines are no longer seen.

Hydrogen

Some have theorized that in the future hydrogen might replace such fuels. Furthermore, with the introduction of hydrogen cell technology, the use of internal combustion engines may be phased out. The advantage of hydrogen is that its combustion produces only water. This is unlike the combustion of fossil fuels, which produce carbon dioxide, a principle cause of global warming, monoxide resulting from incomplete combustion, and other local and atmospheric pollutants such as sulphur dioxide and nitrogen oxides that lead to urban respiratory problems, acid rain, and ozone gas problems. However, free hydrogen for fuel does not occur naturally, burning it liberates less energy than it takes to produce hydrogen in the first place by the simplest and most widespread method, electrolysis. Although there are multiple ways of producing free hydrogen, those require converting currently combustible molecules into hydrogen, so hydrogen does not solve any energy crisis, moreover, it only addresses the issue of portability and some pollution issues. The big disadvantage of hydrogen in many situations is its storage. Liquid hydrogen has extremely low density- 14 times lower than water and requires extensive insulation, whilst gaseous hydrogen requires very heavy tankage. Although hydrogen has a higher specific energy, the volumetric energetic storage is still roughly five times lower than petrol, even when liquefied. (The "Hydrogen on Demand" process, designed by Steven Amendola, creates hydrogen as it is needed, but this has other issues, such as the raw materials being relatively expensive.) Other fuels that are kinder on the environment include bio fuels. These can give no net carbon dioxide gains.

Basic Engine Components:

The core of the engine is the cylinder, with the piston moving up and down inside the cylinder. Single cylinder engines are typical of most lawn mowers, but usually cars have more than one cylinder (four, six and eight cylinders are common). In a multi-cylinder engine, the cylinders usually are arranged in one of three ways: inline, V or flat(also known as horizontally opposed or boxer), as shown in the figures to the left.

So that inline four we mentioned at the beginning is an engine with four cylinders arranged in a line. Different configurations have different advantages and disadvantages in terms of smoothness, manufacturing cost and shape characteristics. These advantages and disadvantages make them more suitable for certain vehicles.

Spark plug

The spark plug supplies the spark that ignites the air/fuel mixture so that combustion can occur. The spark must happen at just the right moment for things to work properly.

Valves

The intake and exhaust valves open at the proper time to let in air and fuel and to let out exhaust. Note that both valves are closed during compression and combustion so that the combustion chamber is sealed.

Piston

A piston is a cylindrical piece of metal that moves up and down inside the cylinder.

Piston Rings

Piston rings provide a sliding seal between the outer edge of the piston and the inner edge of the cylinder. The rings serve two purposes:

- They prevent the fuel/air mixture and exhaust in the combustion chamber from leaking into the sump during compression and combustion.
- They keep oil in the sump from leaking into the combustion area, where it would be burned and lost.

Most cars that "burn oil" and have to have a quart added every 1,000 miles are burning it because the engine is old and the rings no longer seal things properly. Many modern vehicles use more advance materials for piston rings. That's one of the reasons why engines last longer and can go longer between oil changes.

Connecting rod

The connecting rod connects the piston to the crankshaft. It can rotate at both ends so that its angle can change as the piston moves and the crankshaft rotates.

Crankshaft

The crankshaft turns the piston's up-and-down motion into circular motion just like a crank on a jack-in-the-box does.

Sump

The sump surrounds the crankshaft. It contains some amount of oil, which collects in the bottom of the sump (the oil pan).

Next, we'll learn what can go wrong with engines.

Working principle of engines:

For the engine to work properly it has to perform some cycle of operations continuously. The principle of operation of the spark ignition (SI) engines was invented by Nicolaus A. Otto in the year 1876; hence SI engine is also called the Otto engine. The principle of working of compression ignition engine (CI) was found out by Rudolf Diesel in the year 1892, hence CI engine is also called the Diesel engine.

The principle of working of both SI and CI engines are almost the same, except the process of the fuel combustion that occurs in both engines. In SI engines, the burning of fuel occurs by the spark generated by the spark plug located in the cylinder head. The fuel is compressed to high pressures and its combustion takes place at a constant volume. In CI engines the burning of the fuel occurs due to compression of the fuel to excessively high a pressure which does not require any spark to initiate the ignition of fuel. In this case the combustion of fuel occurs at constant pressure.

Both SI and CI engines can work either on two-stroke or four stroke cycle. Both the cycles have been described below:

1) **Four-stroke engine**: In the four-stroke engine the cycle of operations of the engine are completed in four strokes of the piston inside the cylinder. The four strokes of the 4-stroke engine are: suction of fuel, compression of fuel, expansion or power stroke, and exhaust stroke. In 4-stroke engines the power is produced when piston performs expansion stroke. During four strokes of the engine two revolutions of the engine's crankshaft are produced.

2) **Two-stroke engine**: In case of the 2-stroke, the suction and compression strokes occur at the same time. Similarly, the expansion and exhaust strokes occur at the same time. Power is produced during the expansion stroke. When two strokes of the piston are completed, one revolution of the engine's crankshaft is produced.

In 4-stroke engines the engine burns fuel once for two rotations of the wheel, while in 2-stroke engine the fuel is burnt once for one rotation of the wheel. Hence the efficiency of 4-stroke engines is greater than the 2-stroke engines. However, the power produced by the 2-stroke engines is more than the 4-stroke engines.

Four strokes and two stroke petrol and diesel engines:

Two-stroke (or two-cycle) engine is a type of internal combustion engine which completes a power cycle with two strokes (up and down movements) of the piston during only one crankshaft revolution. As the name suggests two stroke it has only two cycles. This is in contrast to a "four-stroke engine", which requires four strokes of the piston to complete a power cycle during two crankshaft revolutions. In a two-stroke engine, the end of the combustion stroke and the beginning of the compression stroke happen simultaneously, with the intake and exhaust (or scavenging) functions occurring at the same time.

In a two stroke engine power is produced in one revolution of the crankshaft(360° rotation) where as in case of four-stroke engine power is produced in two revolution of the crankshaft(720°rotation).

There are two cycles in two stroke engine. Suction- compression in 1st stroke and Power-exhaust in 2nd stroke.

Working:

Two stroke engines may be petrol or diesel engines. So the working of the two stroke petrol and two stroke diesel engines are somewhat different but the principle is same for both that is there is only 2 cycles.

1) Two stroke petrol engine:

a) Upward Stroke:

During the upward stroke, the piston moves from bottom dead center to top dead center, compressing the air-petrol mixture in the cylinder. The cylinder is connected to a closed crank chamber. Due to upward movement of the piston, a partial vacuum is created in the crankcase, and a new charge is drawn into the crankcase through the uncovered inlet port. The exhaust port and transfer port are covered when the piston is at the top dead center position. The compressed charge is ignited in the combustion chamber by a spark provided by the spark plug.

b) Downward Stroke:

As soon as the charge is ignited, the hot gases force the piston to move downwards, rotating the crankshaft, thus doing the useful work. During this stroke the inlet port is covered by the piston and the new charge is compressed in the crank case. Further downward movement of the piston uncovers first the exhaust port and then the transfer port. The burnt gases escape through the exhaust port.

As soon as the transfer port opens, the compressed charge from the crankcase flows into the cylinder. The charge is deflected upwards by the pump provided on the head of the piston and pushes out most of the exhaust gases. It may be noted that the incoming air-petrol mixture helps the removal of burnt gases from the engine cylinder, which is called as the scavenging process. If in case these exhaust gases do not leave the cylinder, the fresh charge gets diluted and efficiency of the engine will decrease. The cycle of events is then repeated.

2**) Two stroke diesel engine:**

In a two stroke cycle diesel engine, only air is compressed inside the cylinder and the diesel is injected by an injector. There is no spark plug in this engine. The remaining operations of the two stroke cycle diesel engine are exactly the same as those of the two stroke cycle petrol engine.

Its two strokes are described as follows:

a) Upward Stroke:

During the upward stroke, the piston moves from bottom dead center to top dead center. It compresses the air in the cylinder. The cylinder is connected to a closed crank chamber. Due to upward movement of the piston, a partial vacuum is created in the crankcase. A new charge is drawn into the crankcase through the uncovered inlet port. The exhaust port and transfer port are covered when the piston is at the top dead center position. The compressed charge is mixed with the injected diesel. It gets auto-ignited in the combustion chamber because of the high pressure and temperature present.

b) Downward Stroke:

As soon as the fuel is ignited, the hot gases force the piston to move downwards, rotating the crankshaft, thus doing the useful work. During this stroke the inlet port is covered by the piston and the new charge is compressed in the crank case. Further downward movement of the piston uncovers first the exhaust port and then the transfer port. The burnt gases escape through the exhaust port.

As soon as the transfer port opens, the compressed charge from the crankcase flows into the cylinder. The charge is deflected upwards by the pump provided on the head of the piston and pushes out most of the exhaust gases. It may be noted that the incoming air helps the removal of burnt gases from the engine cylinder, which is called as scavenging process. If in case these exhaust gases do not leave the cylinder, the fresh charge gets diluted and efficiency of the engine will decrease. The cycle of events is then repeated.

Applications:

1. Old vehicles are generally seen with two stroke engines.

2. Useful in chainsaws, Weed-eaters, outboards, lawnmowers ,etc.

Advantages:

1. They are lighter in weight and they can also produce a higher power-to-weight ratio.
2. Two-cycle engines are also easier to start in cold temperatures.
3. Useful in small applications like chainsaws, Weed eaters, outboards, lawnmowers ,etc.
4. Can work in any orientation as there is no oil reservoir.
5. Mechanical simplicity, design is not complicated.

Disadvantages:

1. It creates more pollutants and harmful gases. Because, the two stroke lubricating mixture is also burned in the engine.
2. It is less efficient.
3. Wear and tear is more in this engine as there is no lubricating system.

Comparison of CI and SI engines:

The most prominent difference between Spark Ignition (SI) and Compression Ignition (CI) engines is the type of fuel used in each. In SI engines petrol or gasoline is used as fuel, hence these engines are also called petrol engines. In CI engines diesel is used as fuel, hence they are also called diesel engines.

Here are some other major differences between the SI and CI engines:

1) Type of cycle used: In the case of SI engines, the Otto cycle is used. In this cycle, addition of heat or fuel combustion occurs at a constant volume. The basis of working of CI engines is the Diesel cycle. In this cycle the addition of heat or fuel combustion occurs at a constant pressure.
2) Introduction of fuel in the engine: In the case of SI engines, during the piston's suction stroke, a mixture of air and fuel is injected from cylinder head portion of the cylinder. The air-fuel mixture is injected via the carburetor that controls the quantity and the quality of the injected mixture. In the case of CI engines, fuel is injected into the combustion chamber towards the end of the compression stroke. The fuel starts burning instantly due to the high pressure. To inject diesel in SI engines, a fuel pump and injector are required. In CI engines, the quantity of fuel to be injected is controlled but the quantity of air to be injected is not controlled.
3) Ignition of fuel: By nature petrol is a highly volatile liquid, but its self-ignition temperature is high. Hence for the combustion of this fuel a spark is necessary to initiate its burning process. To generate this spark in SI engines, the spark plug is placed in the cylinder head of the engine. The voltage is provided to the spark plug either from the battery or from the magneto. With diesel, the self-ignition temperature is comparatively lower. When diesel fuel is compressed to high pressures, its temperature also increases beyond the self-ignition temperature of the fuel. Hence in the case of CI engines, the ignition of fuel occurs due to compression of the air-fuel mixture and there is no need for spark plugs.

4) Compression ratio for the fuel: In the case of SI engines, the compression ratio of the fuel is in the range of 6 to 10 depending on the size of the engine and the power to be produced. In CI engines, the compression ratio for air is 16 to 20. The high compression ratio of air creates high temperatures, which ensures the diesel fuel can self-ignite.

Comparison of four stroke and two stroke engines:

Comparison between two-stroke and four-stroke engines can be done in aspects like strokes required for thermodynamic cycle completion, weight of flywheel used, engine size for producing the same power, rate of wear and tear in engine, by identifying valves are present or not, engine cost, volumetric efficiency and thermal efficiency.

Main difference between 2 strokes vs 4 stroke engines.
In simple words, stroke is the distance of cylinder between piston moves. If a piston moves 2 times in the cylinder, that means, engine is known as two stroke engine and if it moves 4 times in a four stroke engine. The crankshaft rotates one time between 2strokes.

S.No	Two-Stroke Engine	Four-Stroke Engine
1	In two-stroke engine thermodynamics cycle is completed in two strokes of the piston or in one revolution of the crankshaft. Thus there is one power stroke for every revolution of the crankshaft.	In four-stroke engine thermodynamic cycle is completed in four strokes of the piston or in two revolutions of the crankshaft. Thus, one power stroke for every two revolutions of the crankshaft.
2	Because of the above, turning moment is more uniform and hence a lighter flywheel can be used.	Because of the above, turning moment is not so uniform and hence a heavier flywheel is required.
3	Again, Because of one power stroke for every evolution, power produced for same size of two-stroke engine is twice, or for the same power of the engine is lighter and more compact.	Because of one power stroke for two revolutions, power produced for same size of four-stroke engine is less or for the same power the engine is heavier and bulkier.
4	Because of one power stroke in one revolution greater cooling and lubrication requirements. Higher rate of wear and tear in two-stroke compared to four-stroke engine.	Because of one power stroke in two revolutions lesser cooling and lubrication requirements. Lower rate of wear and tear in four-stroke engine.
5	Two-stroke engines have no valves but only ports (some two-stroke engines are fitted with convectional exhaust valve or reed valve).	Four-stroke engines have valves and valve actuating mechanisms for opening and closing of the intake and exhaust valves.

6	Because of light weight and simplicity due to the absence of the valve actuating mechanism, initial cost of the two-stroke engine is less.	Because of comparatively higher weight and complicated valve mechanism, the initial cost of the four-stroke engine is more.
7	Two-stroke engine is used where low cost, compactness and light weight are important, viz., in scooters, motorcycles, hand sprayers etc.	Four-stroke engine is used where efficiency is important, viz., in cars, buses, tucks, tractors, industrial engines, airplane, power generation etc.
8	Volumetric efficiency is lower due to lesser time for mixture intake.	Volumetric efficiency is higher due to more time for mixture intake.
9	Lesser thermal efficiency is lower; part load efficiency is poor.	Higher thermal efficiency; part load efficiency is better

Indicated power:

Indicated Power is the Theoretical Power Output of an IC Engine. The Actual Power output (Brake Power) differs from Indiacted Power due to frictional losses.

Theoretically,

IP = 1/60 * P*L*A*N*k

where, P : Mean Effective Pressure of Gas exerted on to the Piston during Power Stroke

L : Stroke (From TDC to BDC)

A : Area of Cylinder

N : Number of revolutions per minute of the Crankshaft

k : Factor, It is 1/2 for Four Stroke Engine whereas 1 for Two Stroke Engine

Practically, if Frictional Power losses can be accessed, then Indicated Power will be the sum of Brake Power and Frictional Power Loss

Brake power:

Analytically it is power produced after burning the fuel minus mechanical or frictional power loss.

The brake power (briefly written as B.P.) of an IC Engine is the power available at the crankshaft. The brake power of an I.C. engine is, usually, measured by means of a brake mechanism (prony brake or rope brake).

Friction power:

The term Friction power is generally used in context with Engines.

As an engine, say bikes or car engine, houses many mechanical elements like gears, crankshaft, pistons etc. So, the power required or power lost to overcome the friction between the mating members of engine, is called friction power.

Specific fuel consumption:

Specific fuel consumption is a more appropriate way of comparing engine of different size on its efficiency. According to the definition it is ratio of fuel consumption per unit time (in Kg/hr) to power produced by engine (in kWh).

According to the power produce (Indicate power or brake power), it has two types indicate SFC and brake SFC. Indicate specific fuel consumption is an ideal condition so practically, when we talk about SFC, we fully mean it brake specific fuel consumption.

Specific fuel Consumption = Fuel consume per unit time / power produced

If an engine has high SFC it means it consume more fuel to produce unit power, hence it is less efficient.

If an engine has less SFC it means it is high efficient.

Brake thermal efficiency:

Brake Thermal Efficiency is defined as break power of a heat engine as a function of the thermal input from the fuel. It is used to evaluate how well an engine converts the heat from a fuel to mechanical energy.

Indicated thermal efficiency:

Initially we must get clear with two words Fuel power and Indicated power and finally brake power

Fuel power

There is term called calorific value of fuel, it is defined as amount of energy (heat energy) produced when 1 kg of fuel is burned completely. Fuel power is obtained by multiplyingCalorificvalue with Mass of fuel consumed

Indicated power

The amount of power developed in the cylinder ,can also be considered as the power exerted on the piston . Actually fuel power is converted into indicated power ,but there are various loss like heat loss from cylinder walls ,by cooling water , heat lost in exhaustgas.HencethisIPislower than FP.

Brake power

The amount of power available in the crankshaft. Brake power is lower than indicated poweras BP includes the friction loss between cylinder and wall,crankshaft bearing.

Indicated efficiency thermal efficiency of engine is ratio of IP and FP

Mechanical efficiency:

Mechanical efficiency is a dimensionless number that measures the effectiveness of a machine in transforming the power input to the device to power output. A machine is a mechanical linkage in which force is applied at one point, and the force does work moving a load at another point. At any instant the power input to a machine is equal to the input force multiplied by the velocity of the input point, similarly the power output is equal to the force exerted on the load multiplied by the velocity of the load. The mechanical efficiency of a machine (often represented by the Greek letter eta) is a dimensionless number between 0 and 1 that is the ratio between the power output of the machine and the power input[1]

Since a machine does not contain a source of energy, nor can it store energy, from conservation of energy the power output of a machine can never be greater than its input, so the efficiency can never be greater than 1.

All real machines lose energy to friction; the energy is dissipated as heat. Therefore their power output is less than their power input

Therefore the efficiency of all real machines is less than 1. A hypothetical machine without friction is called an ideal machine, such a machine would not have any energy losses, so its output power would equal its input power, and its efficiency would be 1. (100%)

Important Questions:

1. Explain Internal Combustion Engines?
2. Explain classification of IC engines
3. Explain working principle of engines
4. Write the comparison of CI and SI engines
5. Write comparison of four stroke and two stroke engines
6. Define the terms: Brake power, friction power, specific fuel consumption, brake thermal efficiency, indicated thermal efficiency and mechanical efficiency.
7. Explain Four strokes and two stroke petrol and diesel engines

UNIT – V

Belts - Ropes and chain: belt and rope drives, velocity ratio, slip, length of belt , open belt and cross belt drives, ratio of friction tensions, centrifugal tension in a belt, power transmitted by belts and ropes, initial tensions in the belt, simple problems.
Gear trains: classification of gears, gear trains velocity ratio, simple, compound –reverted and epicyclic gear trains

Belts - Ropes and chain

Introduction:

The belts or ropes are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds.

The amount of power transmitted depends upon the following factors :

1. The velocity of the belt.
2. The tension under which the belt is placed on the pulleys.
3. The arc of contact between the belt and the smaller pulley.
4. The conditions under which the belt is used.

It may be noted that
(a) The shafts should be properly in line to insure uniform tension across the belt section.
(b) The pulleys should not be too close together, in order that the arc of contact on the smaller pulley
may be as large as possible.
(c) The pulleys should not be so far apart as to cause the belt to weigh heavily on the shafts, thus increasing the friction load on the bearings.
(d) A long belt tends to swing from side to side, causing the belt to run out of the pulleys, which in turn develops crooked spots in the belt.
(e) The tight side of the belt should be at the bottom, so that whatever sag is present on the loose side will increase the arc of contact at the pulleys.
(f) In order to obtain good results with flat belts, the maximum distance between the shafts should not exceed 10 metres and the minimum should not be less than 3.5 times the diameter of the larger pulley.

2. Selection of a Belt Drive:
Following are the various important factors upon which the selection of a belt drive depends:
1. Speed of the driving and driven shafts,
2. Speed reduction ratio,
3. Power to be transmitted,
4. Centre distance between the shafts,
5. Positive drive requirements,
6. Shafts layout,
7. Space available, and

8. Service conditions.

3. Types of Belt Drives

The belt drives are usually classified into the following three groups :

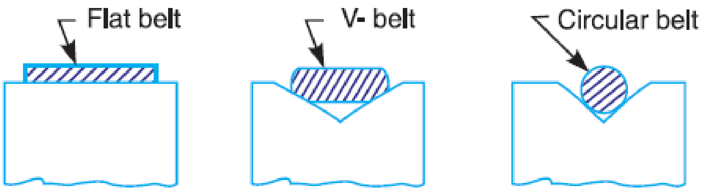
1. **Light drives**: These are used to transmit small powers at belt speeds up to about 10 m/s, as in agricultural machines and small machine tools.
2. **Medium drives.** These are used to transmit medium power at belt speeds over 10 m/s but up to 22 m/s, as in machine tools
3. **Heavy drives.** These are used to transmit large powers at belt speeds above 22 m/s, as in compressors and generators.

4. Types of Belts:

(a) Flat belt.
(b) V-belt.
(c) Circular belt.

Though there are many types of belts used these days, yet the following are important from the subject point of view:

1. **Flat belt.** The flat belt, as shown in Fig.1 (a), is mostly used in the factories and workshops, where a moderate amount of power is to be transmitted, from one pulley to another when the two pulleys are not more than 8 meters apart.
2. **V-belt.** The V-belt, as shown in Fig.1 (b), is mostly used in the factories and workshops, where a moderate amount of power is to be transmitted, from one pulley to another, when the two pulleys are very near to each other.
3. **Circular belt or rope**. The circular belt or rope, as shown in Fig.1 (c), is mostly used in the factories and workshops, where a great amount of power is to be transmitted, from one pulley to another, when the two pulleys are more than 8 meters apart.



(*a*) Flat belt. (*b*) V-belt. (*c*) Circular belt.

Types of Flat Belt Drives:

The power from one pulley to another may be transmitted by any of the following types of belt drives:

1. Open belt drive. The open belt drive, as shown in Fig.2, is used with shafts arranged parallel and rotating in the same direction. In this case, the driver A pulls the belt from one side (i.e. lower side RQ) and delivers it to the other side (i.e. upper side LM). Thus the tension in the lower side belt will be more than that in the upper side belt. The lower side belt (because of more tension) is known as **tight side** whereas the upper side belt (because of less tension) is known as **slack side**, as shown in Fig.

Velocity Ratio:

One is the reciprocal of the other

Detailed answer:
Gearratio=No.of teethin driven/No.of teeth in drive
Gear ratio = Dia. of driven/Dia. of drive
Gear ratio = Torque at driven/Torque at drive
Gear ratio = Speed at drive/Speed at driven

So, for (speed) reduction drives where torque gets multiplied, gear ratio is >1. For overdrives, where the velocity or speed gets multiplied, gear ratio is <1.

Gear ratio is the ratio of pcd/no. Of teeth on driven to drive gear.

Velocity ratio is the inverse of gear ratio.

For ex if a drive is taken from smaller to larger gear. The gear ratio is greater than one and the velocity ratio is less than one

Usually gears are used for torque multiplication

Length of belt:

The length of a V-belt can be specified in several ways, including outside length, effective length, and pitch (or datum) length. Outside length is measured around the belt's outer diameter with no tension, but is only an approximation and is not useful for sizing or selection. Effective length is measured at the effective outside diameter of the sheaves (pulleys), which is the location on the sheave where the groove's top width is measured. Alternatively, the pitch length is measured at the pitch diameter of the sheaves. Both effective length and pitch length are measured with the belt tensioned by a specified amount.

Pitch length vs datum length

Improvements in belt design have moved the tensile cord to a position higher in the belt cross-section.
Image credit: Gates Corporation

Pitch length is difficult to measure directly, primarily because it is based on the pitch line of the belt. According to ISO 1081:2013, the pitch line is "any circumferential line which keeps the same length when the belt is bent perpendicularly to its base." In other words, the **pitch line is the line internal to the belt that does not change length when the belt is in use**. The diameter that is formed on the sheave by the pitch line of the belt is the sheave's pitch diameter.

A belt's pitch line typically corresponds to the location of its internal tensile cord. But improvements in belt construction have moved the tensile cord to a location higher in the belt. This resulted in changes to the belt's pitch length, and in turn, to the sheave's pitch diameter. (This design change gives the tensile cord a larger moment arm and more support below it for transmitting forces to the sheave walls.)

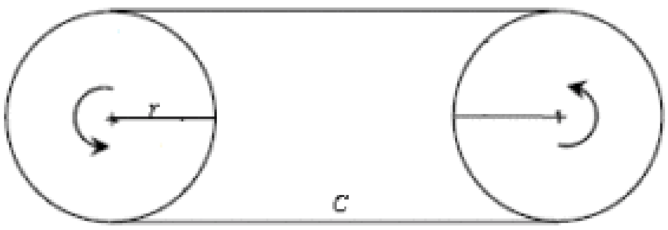
In order to accommodate the changes in belt pitch length, and thus, sheave pitch diameter, the datum system was introduced. **For most belts and sheaves, the dimensions formerly referred to as pitch length (belts) and pitch diameter (sheaves) are now referred to as datum length and datum diameter.** In terms of sheave dimensions, the pitch diameter is now equal to the outer diameter for most standard sheaves. The datum diameter, however, is slightly less than the outer diameter. This is important when calculating the length of a belt, because the datum length, which is the norm for standard V-belt measurements today, is based on the datum diameter of the sheave. In contrast, the formerly used pitch length calculation was based on the sheave's pitch diameter.

How to calculate datum length

Case 1: Pulleys with equal diameters

Belt length is based on two factors: the center-to-center distance between pulleys and the arc of contact between the belt and the pulleys, which depends on the relative pulley diameters.

When the belt's only purpose is to transmit power, pulleys of equal diameter are used on each end of the belt. In this case, the arc of contact is 180 degrees on each pulley. This means that the belt has contact with exactly one-half of circumference of each pulley, or the equivalent of one full pulley circumference. In order to determine the belt datum length, simply add the pulley circumference to twice the center distance between the pulleys.

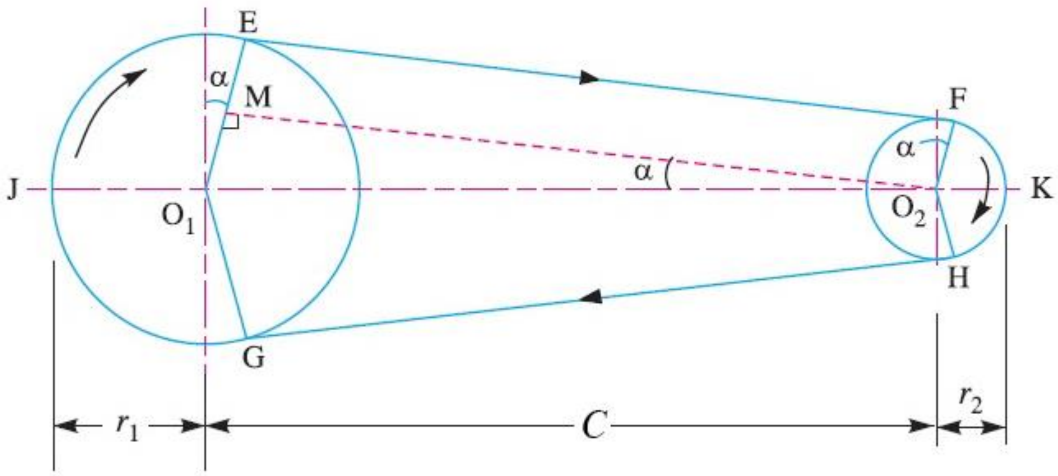


$$L_D = 2\pi r + 2C$$

Case 2: Pulleys with unequal diameters

When the belt is used to reduce speed or multiply torque, pulleys of different diameters are used. When the pulley diameters differ, the arc of contact is less than 180 degrees on the smaller pulley and greater than 180 degrees on the larger pulley. In this case, the formula for belt datum length requires determining the arc of contact on each pulley, as well as the length of belt between pulleys on both the top and bottom.

$$L_D = arcGJE + EF + arcFKH + HG$$



As shown in the figure, arc GJE is greater than 180 degrees, and arc FKH is less than 180 degrees, as determined by the angle α, or more specifically, by the sine of α, which is given as:

$$\sin\alpha = \frac{r_1 - r_2}{C}$$

The arc GJE equals half of the larger sheave circumference, plus twice the length given by sin α:

$$arcGJE = r_1\left(\pi + 2\frac{(r_1 - r_2)}{C}\right)$$

Similarly, the arc FKH equals half of the smaller sheave circumference, minus twice the length given by sin α:

$$arcFKH = r_2\left(\pi - 2\frac{(r_1 - r_2)}{C}\right)$$

Note that MO_2 is equal in length to EF and GH, so we can solve for MO_2 to determine the length of belt between the pulleys. Using the Pythagorean theorem, we get:

$$MO_2 = \sqrt{(O_1O_2)^2 - (O_1M)^2}$$

Which can be expressed as:

$$EF = MO_2 = C - \frac{(r_1 - r_2)^2}{2C}$$

Adding arcGJE, arcFKH, and twice the length EF (for the belt between pulleys on both top and bottom), gives:

$$L_D = \pi(r_1 + r_2) + \frac{(r_1 - r_2)^2}{C} + 2C$$

Or, in terms of diameter:

$$L_D = \frac{\pi}{2}(d_1 + d_2) + \frac{(d_1 - d_2)^2}{4C} + 2C$$

Open belt and Cross belt:

Belt drive is one type of flexible and reliable mechanical power transmission system that is commonly used to transmit and modify power and motion between driving shaft (usually a prime mover such as an electric motor) to driven shaft. It can transmit power and motion to a considerably larger distance (even up to 15m). Being a friction drive, belt drive is associated with slip (non-positive drive) and thus it can protect the transmission system from overloading. There exist two different types of belt arrangement—open belt and crossed belt. Each of them has unique advantages over the other one.

In open belt drive arrangement, belt proceeds from top of one pulley to the top of other pulley without crossing. So the driver shaft and driven shaft rotate in same direction. Contrary to this, in crossed belt drive, belt proceeds from the top of one pulley to the bottom of other pulley and thus crosses itself in between two pulleys. Here driving shaft and driven shaft rotate in opposite directions. It offers higher contact angle, so power or torque transmission capacity also increases. However, due to crossing, belt continuously rubs itself, which leads to reduced belt life. Various similarities and differences between open belt drive and closed belt drive are given below in table form.

Similarities between open belt drive and closed belt drive

- In both the cases, driving and driven shafts must be parallel.
- Both can transmit power and motion for substantially large distances, as compared to gear or chain drive.

- Slip can occur in both the cases. So they are non-positive drive.

Differences between open belt drive and closed belt drive

Open Belt Drive	Cross Belt Drive
In open belt drive, belt proceeds from top of one pulley to the top of other pulley without crossing.	In crossed belt drive, belt proceeds from top of one pulley to the bottom of other pulley and thus crosses itself.
In open belt drive, driving shaft and driven shaft rotate in same direction.	In close belt drive, driving shaft and driven shaft rotate in opposite direction.
Contact angle (or wrap angle) between the belt and pulley is comparatively small (always below 180º).	Contact angle between the belt and pulley is comparatively large (always above 180º).
Length of the open belt is smaller as compared to cross belt.	For the same pulley diameter and same centre distance between driver and driven shaft, longer belt is required in cross belt drive.
Here belt remains in same plane in every rotation during its operation.	Here belt bends in two different planes in every rotation during its operation.
Here belt does not rub with itself. So belt life increases.	Here belt rubs with itself and thus life of the belt reduces.
Open belt drive is suitable when driving and driven shafts are in horizontal or little bit inclined.	Cross belt drive can be advantageously applied for horizontal, inclined and vertical positions of driving and driven shafts.
Power transmission capacity is small due to smaller wrap angle.	It can transmit more power as wrap angle is more.

Ratio of friction tensions:

Flexible Machine Elements Belt drives are called flexible machine elements. Flexible machine elements are used for a large number of industrial applications, some of them are as follows.

1. Used in conveying systems Transportation of coal, mineral ores etc. over a long distance

2. Used for transmission of power. Mainly used for running of various industrial appliances using prime movers like electric motors, I.C. Engine etc.

3. Replacement of rigid type power transmission system.

A gear drive may be replaced by a belt transmission system Flexible machine elements has got an inherent advantage that, it can absorb a good amount of shock and vibration. It can take care of some degree of misalignment between the driven and the driver machines and long distance power transmission, in comparison to other transmission systems, is possible. For the entire above reasons flexible machine elements are widely used in industrial application. Although we have some other flexible drives like rope drive, roller chain drives etc. we will only discuss about belt drives. Typical belt drives two types of belt drives; an open belt drive and a crossed belt drive are shown. In both the drives, a belt is wrapped around the pulleys. Let us consider the smaller pulley to be the driving pulley. This pulley will transmit motion to the belt and the motion of the belt in turn will give a rotation to the larger driven pulley. In open belt drive system the rotation of both the pulleys is in the same direction, whereas, for crossed belt drive system, opposite direction of rotation is observed.

Centrifugal tension in a belt:

centrifugal force tension on both side will be increased but at the same time normal reaction force in between belt and pulley surface will goes down so frictional tension will be decrease and ultimately power transmission efficiency will decrease. The belt continuously runs over both the pulleys.

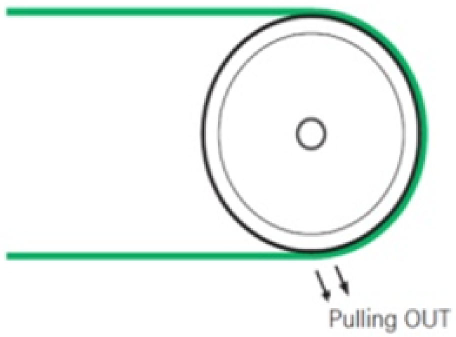
In tight side and slack side of belt tension is increased because of presence of centrifugal Tension in belt. At lower speeds centrifugal tension can be ignored but at the higher speed its effect is considered.

The tension caused in the running belt by the centrifugal force is known as centrifugal tension. Whenever particle of mass 'm' is rotated in circular path of radius 'r' at uniform velocity 'v', a centrifugal force is acting outward radially and its magnitude is equal to mv2/r

Centrifugal Tension in Belt

When the belt runs round the pulleys, a centrifugal force is produced on the belt. This force tends to **lift the belt from the pulley surface**, resulting in more tension on belt.

$$\frac{T_1}{T_2} = e^{\mu\theta}$$



Power transmitted by belts and ropes:

The following are the major types of power transmission.

1. 1 Belt drive,
2. 2 Rope drive,
3. 3 Chain drive,
4. 4 Gear drive

BELT DRIVE: - This type of drive is used when the power is to be transmitted from one shaft to other which is at a distance. Pulleys are mounted on the driver and driven/follower shafts and an endless belt are fitted tightly over these pulleys. The frictional resistance between these pulleys and belt is the reason for the power transmission, which depends on the velocity of belt, tension of the belt and arc of contact of the belt in the smaller pulley. There are flat belt and V- belt used for the power transmission.

Open belt drive: - for parallel shafts and to be rotated in the same direction as that of the driver shaft. The driver pulley pulls the belt from one side and delivers it to the other side. The tension in the former side will be larger and hence called tight side and the other side where the tension is less is called slack side.

Crossed belt drive: - when the driven shaft is to be rotated in the opposite direction as that of the driver shaft, the belt is to be arranged in a crossed manner as shown in the fig.

ROPE DRIVE: - cotton ropes of circular in cross section are used for power transmission. They are arranged in groves of the pulley. The grove angle varies from 40^0 to 60^0 . More than one drive can be taken is the main advantage. For transmitting large power wire ropes are used.

CHAIN DRIVES: -An endless chain running over toothed wheels mounted on the driver and driven shafts. The smaller wheel is called pinion and the other is called wheel. The chain consists of plates; pins and bushes made of high-grade steel. There are hoisting chains and pulling chains apart from the power transmitting chains. Roller chains and silent/inverted chains are the different types of power transmitting chains.

GEAR DRIVES: -Toothed wheel is the gear for transmitting power between two shafts, which are very closer. The teeth of the gear mounted on the shaft meshes each other during rotation. Gears are manufactured either by milling, by casting or by hobbling. Spur gear, helical gear, bevel gear, worm gear are different types.

Advantages of flat belt: -

1. Used for high speed transmission
2. Absorbs shock and vibration
3. Used in industrial purposes
4. Longer life when properly maintained
5. Used for very high speed ratio
6. Will not come out of grove
7. More drives can be taken from a single pulley

Advantages of rope drives

1. Smooth and silent
2. Less weight
3. Shock resistant
4. Longer life
5. High efficiency
6. Less maintenance cost
7. Very high accuracy

Advantages of chain drives

1. Zero slip
2. High efficiency
3. Occupies less space
4. Can be operated at adverse temp
5. less load on shaft
6. Can transmit power to several shafts

Disadvantages of chain drives

1. High cost
2. More weight
3. Velocity fluctuation due to change in length
4. Need accurate mounting and maintenance

Initial tensions in the belt:

When a belt is wound round the two pulleys (i.e. driver and follower), its two ends are joined together ; so that the belt may continuously move over the pulleys, since the motion of the belt from the driver and the follower is governed by a firm grip, due to friction between the belt and the pulleys.in order to increase this grip, the belt is tightened up. At this stage, even when the pulleys are stationary, the belt is subjected to some tension, called **initial tension**.

When the driver starts rotating, it pulls the belt from one side (increasing tension in the belt on this side) and delivers it to the belt is called tension in tight side and the decreased tension in the other side of the belt is called tension in the slack side.

Let T0T0= Initial tension in the belt,
T0T0= Tension in the tight side of the belt,
T2T2=Tension in the slack side of the belt , and
A = Coefficient of increase of the belt length per unit force.

A little consideration will show that the increase of tension in the tight side

= T1T1 – T0T0
And increase in the length of the belt on the tight side

= α(T1−T0)α(T1−T0) …..(i)
Similarly, decrease in tension in the slack side

=T0T0 – T2T2
And decrease in the length of the belt on the slack side

= α(T0−T2)α(T0−T2) …..(ii)
Assuming that the belt material is perfectly elastic such that the length of the belt remains constant, when it is at rest or in motion, therefore increase in length on the tight side is equal to decrease in the length on the slack side. Thus equating equations (i) and (ii),

α(T1−T0)α(T1−T0)=α(T0−T2)α(T0−T2) or T1−T0=T0−T2T1−T0=T0−T2
T0=(T1+T2)2T0=(T1+T2)2 …(Neglecting centrifugal tension)
= (T1+T2+2TC)2(T1+T2+2TC)2 …(Considering centrifugal tension)

Gear train

It is a mechanical system formed by mounting gears on a frame so the teeth of the gears engage.

Gear teeth are designed to ensure the pitch circles of engaging gears roll on each other without slipping, providing a smooth transmission of rotation from one gear to the next.[1]

The transmission of rotation between contacting toothed wheels can be traced back to the Antikythera mechanism of Greece and the south-pointing chariot of China. Illustrations by the Renaissance scientist Georgius Agricola show gear trains with cylindrical teeth. The implementation of the involute tooth yielded a standard gear design that provides a constant speed ratio.

Features of gears and gear trains include:

- The ratio of the pitch circles of mating gears defines the speed ratio and the mechanical advantage of the gear set.
- A planetary gear train provides high gear reduction in a compact package.
- It is possible to design gear teeth for gears that are non-circular, yet still transmit torque smoothly.
- The speed ratios of chain and belt drives are computed in the same way as gear ratios. See bicycle gearing.

Classification of gears:

The most common way to classify gears is by category type and by the orientation of axes. Gears are classified into 3 categories; parallel axes gears, intersecting axes gears, and nonparallel and nonintersecting axes gears. Spur gears and helical gears are parallel axes gears. Bevel gears are intersecting axes gears. Screw or crossed helical, worm gear and hypoid gears belong to the third category. Table 1.1 lists the gear types by axes orientation.

Types of Gears and Their Categories

- Categories of Gears
  Parallel AxesGears
- Types of Gears
  Spur Gear
  Spur rack
  Internal gear
  Helical gear
  Helical rack
  Double helical gear
- Efficiency (%)
  98.0 – 99.5

- Categories of Gears
  Intersecting AxesGears
- Types of Gears
  Straight bevel gear
  Spiral bevel gear
  Zerol bevel gear
- Efficiency (%)
  98.0 – 99.0

- Categories of Gears
  Nonparallel and Nonintersecting
- Types of Gears
  Screw gear (Efficiency 70.0 – 95.0 %)
  Worm gear (Efficiency 30.0 – 90.0 %)

Also, included in table 1.1 is the theoretical efficiency range of various gear types. These figures do not include bearing and lubricant losses.

Since meshing of paired parallel axis gears or intersecting axis gears involves simple rolling movements, they produce relatively minimal slippage and their efficiency is high. Nonparallel and nonintersecting gears, such as screw gears or worm gears, rotate with relative slippage and by power transmission, which tends to produce friction and makes the efficiencylowerwhen compared to other types of gears.
Efficiency of gears is the value obtained when the gears are installed and working

accurately. Particularly for bevel gears, it is assumed that the efficiency will decrease if improperly mounted from off-position on the cone-top.

(1) Parallel Axes Gears

1 Spur Gear

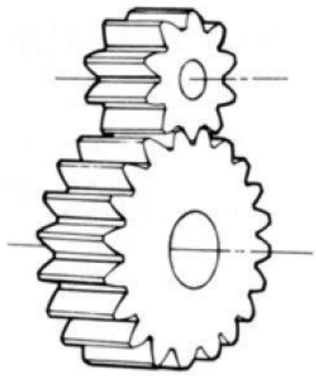
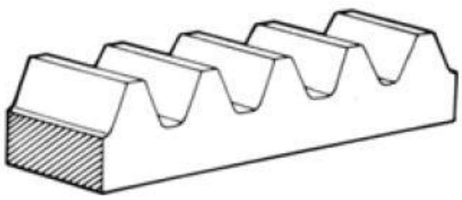


Fig. 1.1 Spur Gear

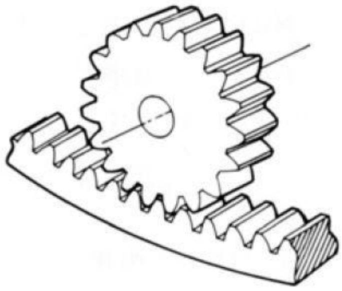
This is a cylindrical shaped gear, in which the teeth are parallel to the axis. It is the most commonly used gear with a wide range of applications and is the easiest to manufacture.

2.GearRack



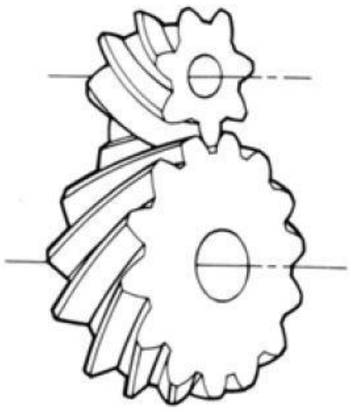
This is a linear shaped gear which can mesh with a spur gear with any number of teeth. The gear rack is a portion of a spur gear with an infinite radius.

3. Internal Gear



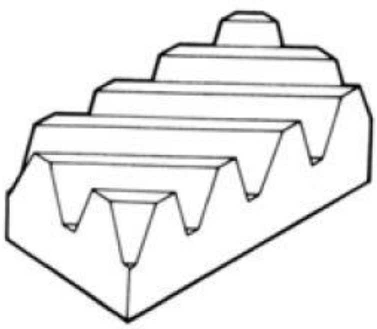
This is a cylindrical shaped gear, but with the teeth inside the circular ring. It can mesh with a spur gear. Internal gears are often used in planetary gear systems.

4 Helical Gear



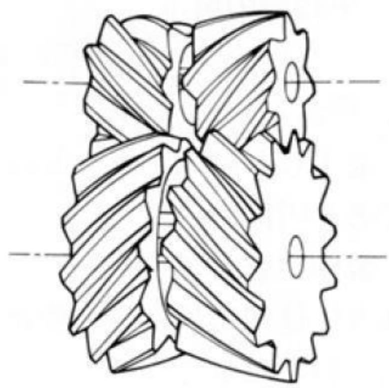
This is a cylindrical shaped gear with helicoid teeth. Helical gears can bear more load than spur gears, and work more quietly. They are widely used in industry. A disadvantage is the axial thrust force caused by the helix form.

5 Helical Rack



This is a linear shaped gear that meshes with a helical gear. A Helical Rack can be regarded as a portion of a helical gear with infinite radius.

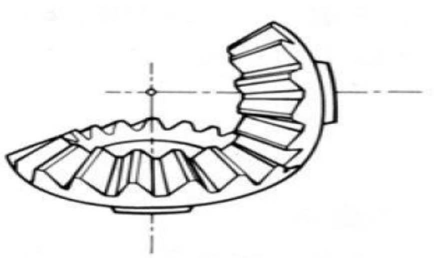
6 Double Helical Gear



A gear with both left-hand and right-hand helical teeth. The double helical form balances the inherent thrust forces.

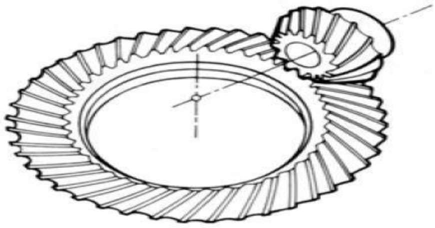
(2) Intersecting Axes

1. Straight Bevel Gear



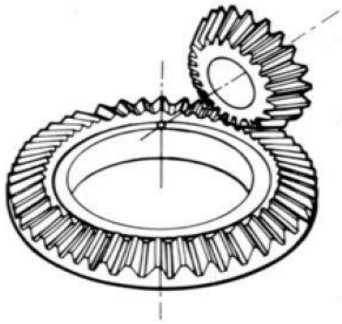
This is a gear in which the teeth have tapered conical elements that have the same direction as the pitch cone base line (generatrix). The straight bevel gear is both the simplest to produce and the most widely applied in the bevel gear family.

2. Spiral Bevel Gear



This is a bevel gear with a helical angle of spiral teeth. It is much more complex to manufacture, but offers higher strength and less noise.

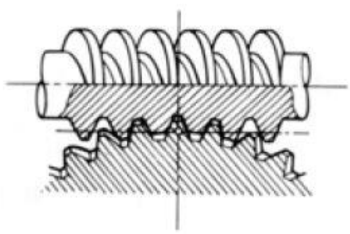
4. Zerol Bevel Gear



This is a special type of spiral bevel gear, where the spiral angle is zero degree. It has the characteristics of both the straight and spiral bevel gears. The forces acting upon the tooth are the same as for a straight bevel gear.

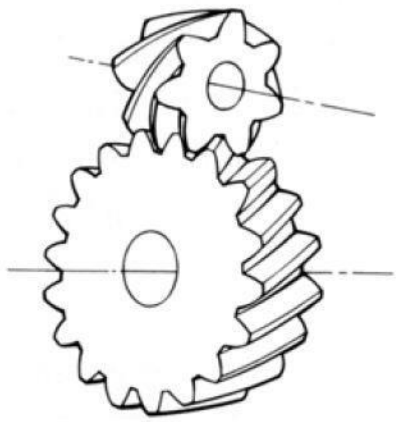
(3) Nonparallel and Nonintersecting Axes Gears

1 Worm Gear Pair



Worm gear pair is the name for a meshed worm and worm wheel. An outstanding feature is that it offers a very large gear ratio in a single mesh. It also provides quiet and smooth action. However, transmission efficiency is poor.

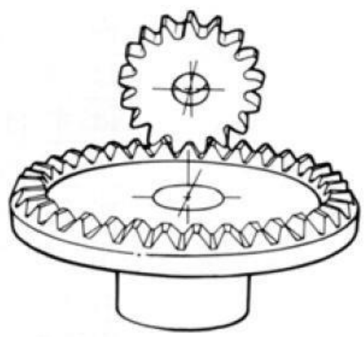
2 Screw Gear (Crossed Helical Gear)



A pair of cylindrical gears used to drive non-parallel and nonintersecting shafts where the teeth of one or both members of the pair are of screw form. Screw gears are used in the combination of screw gear / screw gear, or screw gear / spur gear. Screw gears assure smooth, quiet operation. However, they are not suitable for transmission of high horsepower.

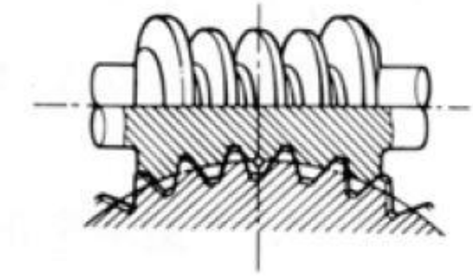
(4) Other Special Gears

1 Face Gear



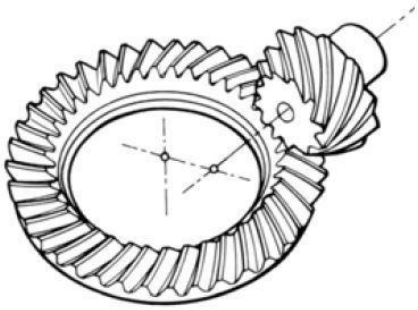
A pseudo bevel gear that is limited to 90° intersecting axes. The face gear is a circular disc with a ring of teeth cut in its side face; hence the name Face Gear.

2 Enveloping Gear Pair



This worm set uses a special worm shape that partially envelops the worm gear as viewed in the direction of the worm gear axis. Its big advantage over the standard worm is much higher load capacity. However, the worm gear is very complicated to design and produce.

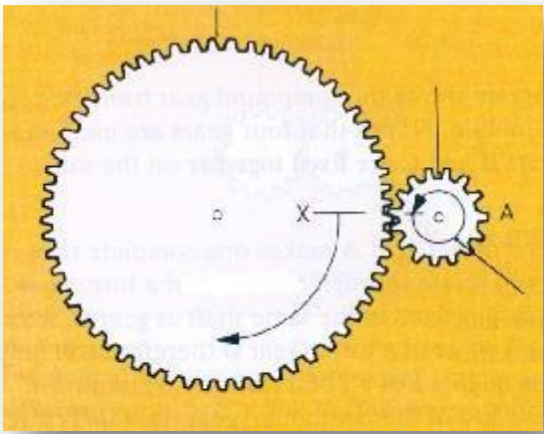
3 Hypoid Gear



This gear is a slight deviation from a bevel gear that originated as a special development for the automobile industry. This permitted the drive to the rear axle to be nonintersecting, and thus allowed the auto body to be lowered. It looks very much like the spiral bevel gear. However, it is complicated to design and is the most difficult to produce on a bevel gear generator.

Gear trains velocity ratio:

The diagram below shows a simple gear train where A is the driver gear, and B is the driven gear. When A makes one complete turn, its 15 teeth move past point X on the diagram. Since the gears are meshed (and cannot slip), 15 teeth on the driven gear also pass point X. For each complete turn of the driver gear therefore, the driven gear only rotates through a quarter of a turn. Now, since the driven gear only rotates through a quarter of a turn for each complete turn of the driver gear, the driven gear will only rotate at a quarter of the speed (or velocity) of the driver gear.



The **velocity ratio** of the above system therefore (and gear ratio) is 4:1.

In other words, the driver gear revolves four times to make the driven gear revolve once.

To calculate the Velocity Ratio of a gear train.

VR = Number of teeth on DRIVEN gear ÷ Number of teeth on DRIVER gear.
Number of teeth on driven gear = 8 Number of teeth on driver gear = 24 RV = 8 / 24 = 1:3

In **Compound** gear systems to work out the overall Velocity ratio you have to know the velocity ratio of each pair of gears in the system and then multiply them together.Compound gear trains allows to achieve higher gear ratios without having the need for more number of shafts.

They could also be used to change the axis of input and output shafts say when they are perpendicular etc…Reverted gear trains are a type of compound gear trains where the input and the output shafts are co axial or parallely offset. Gear train is a combination of gears and used for transmitting motion and power from one shaft to another shaft. Gear trains are used to achieve large and different velocity ratio in small area or space. Gear trains are use for increasing or reducing speed of driven shaft. Examples of gear trains use in machines are lathe machine, milling machine, in watch and many others. Different types of gear trains are as follow.

Simple gear train

Simple gear train is a type of gear train. Gear train are use to obtain different velocity ratio or to transmit power from one shaft to another. In simple gear train multiple gears are used to obtain different velocity ratio. Only one gear is mounted on each shaft and these shafts are rigidly fixed or not movable. Simple gear train consist three major area or part and these are driving gear, driven gear and intermediate gears. In which driving gear is mounted on driving shaft and driven gear is mounted on driven shaft and these both gears are mesh with the help of intermediate gears. In simple gear train intermediate gears play major role and intermediate gears will be one or more in simple gear train depending upon design or application. To obtain different velocity ratio different size gears are used. In simple gear trains power and motion transmit from driving gear to intermediate gears and from intermediate gears to driven gears. In this way simple gear trains are work.

Compound gear train

Compound gear train is a type of gear train in which two intermediate gears (gears between driving gear and driven gear) are mounted on one shaft. Means only one gear on driving shaft and driven shaft, and intermediate shafts have two mounted gears. Compound gear trains are use to get large velocity ratio or different speed in a small area or space. Compound gear box is good example of compound gear trains.

Reverted gear train

Reverted gear trains are a special type of gear trains. In which driving gear shaft axis and driven gear shaft axis are in a line. In reverted gear train one gear is mounted on each driving and driven shaft and on intermediate shaft two gears are mounted, reverted gear train are arrange in this way that driving gear transmit motion and power to intermediate shaft gear and other gear of intermediate shaft transmit motion and power to driven gear. Reverted gear trains are use there, where velocity ratio required in small space. Watches are good example of reverted gear trains. In watches reverted gear trains are used, in which minute and hour hands of watches are on a same axis.

Epicyclic gear train

In above gear trains simple gear train, compound gear train and reverted gear train, gear shaft axis is fixed or not movable but in epicyclic gear trains, the shaft axes are not fixed means the shaft axis is movable. There is a relative motion between the gears axis. Epicyclic gear trains may consist of simple gear trains, compound gear trains and mixed simple and compound gear trains. The advantage of epicyclic gear train is that, it can get very high or very low velocity ratio compared to simple gear trains and compound gear trains. The common example of epicyclic gear train is differential gear box of automobile

These are the type gear trains are use in machine according to require velocity ratio, speed, space and application.

Important Questions:

1. Define Belt drive- Rope drive And Chain drive

2. Explain the types of Belt drive- Rope drive And Chain drive
3. Define the terms velocity ratio, slip, length of belt
4. Explain the open belt and cross belt drives
5. Explain ratio of friction tensions, centrifugal tension in a belt
6. Explain power transmitted by belts and ropes
7. Write about the Gear trains classification.
8. Define gear trains velocity ratio, simple, compound reverted and epicyclic gear trains