MADE EASY

Leading Institute for ESE, GATE & PSUs

Detailed Solutions

ESE-2026 Mains Test Series

Mechanical Engineering Test No : 6

Section A : Renewable Sources of Energy + Industrial and Maintenance Engineering [All topics]
Section B : Production Engineering & Material Science-1 [Part Syllabus]
Theory of Machines-2 [Part Syllabus]

Section A : Renewable Sources of Energy + Industrial and Maintenance Engg.

1. (a) Solution:

Given data : Motor output = 2 hp

$$\eta_m = 0.90$$

$$\eta_{cell} = 0.14$$

$$\text{Cell size} = 135 \times 135 \text{ mm}$$

$$\text{Motor power output} = 2 \text{ hp} = 2 \times 746 = 1492 \text{ W} \qquad [\because\ 1 \text{ H.P.} = 746 \text{ Watt}]$$

$$\text{Electrical power required by the motor} = \frac{1492}{0.9} = 1657.777 \text{ W}$$

$$\text{Cell area in one module} = 9 \times 4 \times 135 \times 135 \times 10^{-6} \text{ m}^2 = 0.6561 \text{ m}^2$$

Let, N number of module be required

Solar radiation incident on panel = 1 kW/m^2 = 1000 W/m^2

$$\text{Cell efficiency} = 0.14$$

$$\text{Output of solar array} = 1000 \times 0.6561 \times N \times 0.14 = 91.854 \times N$$

The output of solar array is the input to the motor,

$$91.854 \times N = 1657.777$$

$$N = 18.047 \simeq 18$$

Therefore, 18 modules are required in panel.

1. (b) Solution:

Gas required for cooking for the family = 5 × 0.227 = 1.135 m^3/day

Gas required for lighting = 0.126 × 3 × 5 = 1.89 m^3/day

Total daily gas required of the family = (1.135 + 1.89) m^3/day = 3.025 m^3/day

Let, n be the number of cows,

Cow dung produced = $10n$ kg/day

Collectable cow dung (70%) = $7n$ kg/day

Weight of dry solid mass (18%) in cow dung = 0.18 × $7n$ kg/day

$$\text{Gas production per day} = 0.34 \times 0.18 \times 7 \times n \text{ m}^3/\text{day}$$
$$= 0.4284n \text{ m}^3/\text{day}$$

Also, Gas production = Gas required

$$0.4284n = 3.025$$
$$n = 7.061 = 8 \text{ cows}$$ **Ans.**

Thus, 8 cows are required to feed the plant,

Daily feeding of cow dung = 7 × 8 = 56 kg

This will be mixed with equal quantity of water make the slurry.

Thus, daily feed of slurry = 56 × 2 = 112 kg

$$\text{Volume of slurry} = \frac{m}{\rho} = \frac{112}{1090} = 0.10275 \text{ m}^3$$

For a 50 days retention time, volume of slurry in the digester

$$= 50 \times 0.10275 = 5.1376 \text{ m}^3$$

As about 90% volume is occupied by slurry, the required volume of the digester

$$= \frac{5.1376}{0.9} = 5.708 \text{ m}^3$$ **Ans.**

1. (c) (i) Solution:

Inventory should be maintained for the following reasons.

1. It helps in smooth and efficient running of an enterprise.
2. It provides service to customers at a short notice.
3. Maintaining inventory may earn price discount due to bulk purchasing.
4. It act as buffer stock when raw materials are received late and shop rejections are too many.

5. It helps in maintaining economy by absorbing some of the fluctuations when demand of an item fluctuates or is seasonal.
6. Inventory can play a part in strategic planning, as a company can choose to enlarge the inventory in anticipation of rising vendor prices.

Need for optimisation of order quantity

We need to optimize the order quantity as there are optimum or Economic Order Quantity (EOQ) sizes at which inventory cost is minimum. These are the costs related to storing and maintaining its inventory over a certain period of time.

1. (c) (ii) Solution:

Given data:

$$\text{Annual demand: } D = 10000 \text{ units/yr.}$$

$$\text{Procurement Cost: } C_0 = 100 \text{ Rs/procurement}$$

$$\text{Holding Cost: } C_h = 2.5 \text{ per unit/year}$$

Instantaneous replacement implies infinite rate of replenishment and also since these should not be any shortages hence classical EOQ Model is to be used.

(i)
$$\text{EQO} = Q^* = \sqrt{\frac{2DC_0}{C_h}} = \sqrt{\frac{2 \times 10000 \times 100}{2.5}}$$

$$= 894.4272 \text{ units/procurement} \simeq 895 \text{ unit/procurement}$$

(ii)
$$\text{Number of orders (N)} = \frac{D}{Q^*}$$

$$N = \frac{10000}{894.4272} \simeq 11.18 \text{ orders/ year}$$

$$\text{Time between orders } (t) = \frac{1}{N} = \frac{1}{11.18} = 0.08944 \text{ year per order}$$

$$t = 1.0733 \text{ months per order}$$

(iii) Total cost per year if the cost of one unit is Rs 1.

$$\text{Total cost (TC)} = \text{DC} + \text{TIC}$$

$$= 10000 \times 1 + \sqrt{2 \times 2.5 \times 100 \times 10000}$$

$$= \text{Rs. } 12236.06798 \text{ per year}$$

1. (d) Solution:

Given data : $\phi = 27°10'\text{N} = 27.166°$; $n = 16 + 31 = 47$; $\overline{n} = 8 \text{ hours}$;

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284+n)\right]$$

$$\delta = 23.45\sin\left[\frac{360}{365}(284+47)\right]$$

$$\delta = -12.954°$$

Hour angle, $\omega_s = \cos^{-1}[-\tan\phi\tan\delta]$

$$\omega_s = \cos^{-1}[-\tan(27.166)\tan(-12.954)]$$

$$\omega_s = 83.2204°$$

$$\omega_s = 1.4524 \text{ radians}$$

Day length, $\overline{N} = \frac{2}{15} \times \omega_s$

$$\overline{N} = \frac{2}{15} \times 83.2204 = 11.096 \text{ hour}$$

Using, $\overline{H}_0 = 3600 \times \frac{24}{\pi} \times I_{sc}\left[1+0.033\cos\left(\frac{360n}{365}\right)\right][\cos\phi\cos\delta\sin\omega_s + \omega_s\sin\phi\sin\delta]$

$$\overline{H}_0 = 3600 \times \frac{24}{\pi} \times 1.367 \times \left[1+0.033\cos\left(\frac{360\times 47}{365}\right)\right]\begin{bmatrix}\cos(27.166)\cos(-12.954)\sin(83.2204) \\ +1.4524\sin(27.166)\sin(-12.954)\end{bmatrix}$$

$\overline{H}_0 = 27390.17$ kJ/m^2-day

Now, $\frac{\overline{H}_g}{\overline{H}_0} = a + b\left(\frac{\overline{n}}{\overline{N}}\right)$

$$\overline{H}_g = 27390.17\left(0.25 + 0.57 \times \frac{8}{11.096}\right)$$

$\overline{H}_g = 18103.77$ kJ/m^2-day **Ans.**

1. (e) Solution:

Basic purpose of Production Planning and Control (PPC) :

Production planning and control (PPC) includes the investigation, coordination and evaluation of manufacturing capabilities and requirements that ensure timely production through efficient and optimum use of facilities i.e. men, machines, money and materials (the four M's of production)

Objectives of production - planning and control.

There are two major and important objectives of PPC:

1. Planning the activities of production .

Objectives of Production planning.

(i) To operate the plant at a predetermined level of efficiency.
(ii) To ensure a prescribed level of profit.
(iii) To utilize available plant facilities.
(iv) To reduce manufacturing cost through R and D.

2. Controlling the production activities.

Objectives of production control.

(i) To get out the desired products economically on time.
(ii) To minimize idleness of man and machine.
(iii) To meet promises to customers.
(iv) To maximize inventory turnover.
(v) To improve quality of the product.

Production Planning and Control Functions

Planning Functions: Routing and scheduling

Control Functions: Dispatching, Follow up.

Routing: It includes planning of what work shall be done on the material to produce the product or part, where and by whom the work shall be done.

It also includes the determination of path that the work shall follow and the necessary sequence of operations which must be done on the material to make the product.

Scheduling : It consists of putting the production plan into the time frame of the calendar. It sets the starting and completion dates for processing products for manufacturing so that congested manufacturing conditions at one time and idle machines at another time may be prevented.

Dispatching : After the schedule has been completed, the production planning and control department makes a master manufacturing order with complete informations including Routing and desired completion dates within each department or on each machine and the engineering drawings.

From this master manufacturing orders, departmental manufacturing orders can be made up giving only the information necessary for each individual foreman. These include inspection tickets and authorization to move the work from one department to the next when each department's work is completed. When a foreman of a particular department receives the manufacturing order, he is authorized to begin production in his department. The dispatching of these orders and instructions at the proper time to the proper people is usually done by a person known as "Dispatcher".

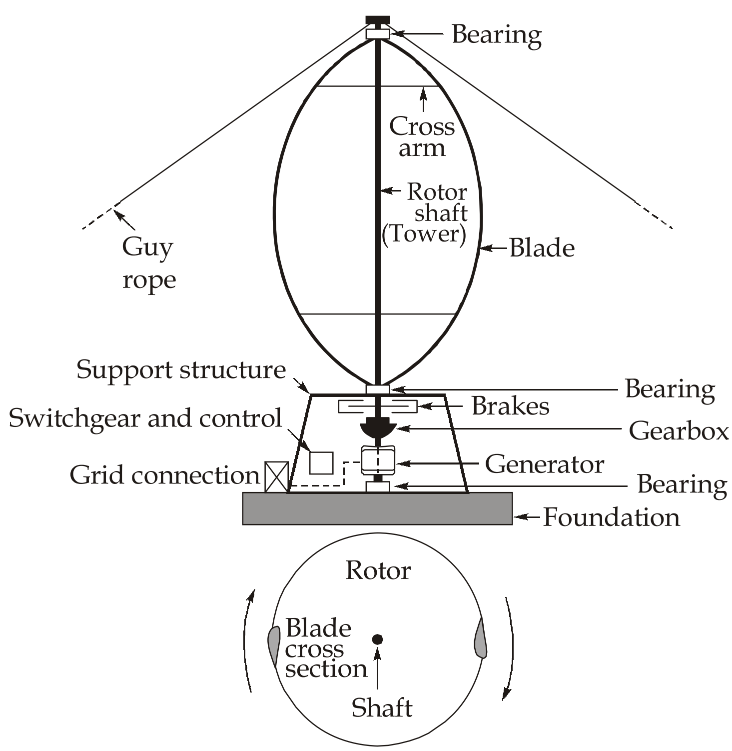
Progress Report and Follow up: Shortage of parts and failure of production foremen to meet production schedule are common. There are numerous reasons for these occurrences for example errors in routing, scheduling and despatching, lack of material, labour difficulties, breakdown of equipments, lack of proper tools or jigs & fixtures and excessive rejections etc. They cannot be pinpointed on any one individual but rather on built up system failures and lack of communication or follow through.

Progress reporting is essential to prevent these delays when the manufacturing within a department is completed, an inspection is made to check the quality and conformity within engineering specifications.

Follow-up : Progress reports prompt use of follow-up men also known as stock chasers or expeditors to locate lost jobs and push late jobs through to completion.

2. **(a) (i) Solution:**

The constructional details of a vertical axis wind turbine (Darrieus type rotor) are shown in figure below. The details of main components are as follows:



Vertical axis wind (Darrieus) turbine

(a) **Tower (or Rotor Shaft):** The tower is a hollow vertical rotor shaft, which rotates freely about vertical axis between top and bottom bearings. It is installed above a support structure. In the absence of any load at the top, a very strong tower is not required, which greatly simplifies its design. The upper part of the tower is supported by guy ropes. The height of the tower of a large turbine is around 100 m.

(b) **Blades** : It has two or three thin, curved blades shaped like an eggbeater in profile, with blades curved in a form that minimizes the bending stress caused by centrifugal forces-the so-called 'Troposkien' profile. The blades have airfoil cross-section with constant chord length. The pitch of the blades cannot be changed. The diameter of the rotor is slightly less than the tower height. The first large Darrieus type, Canadian machine has rotor height as 94 m and diameter as 65 m with a chord of 2.4 m.

(c) **Support Structure :** Support structure is provided at the ground to support the weight of the rotor. Gearbox, generator, brakes, electrical switchgear and controls are housed within this structure.

VAWTs are in the development stage and many models are undergoing field trial.

Main advantages of a VAWT are:

(i) it can accept wind from any direction, eliminating the need of yaw control.

(ii) gearbox, generator etc. are located at the ground, thus eliminating the heavy nacelle at the top of the tower. This simplifies the design and installation of the whole structure, including tower.

(iii) the inspection and maintenance also gets easier and

(iv) it also reduces the overall cost.

2. (a) (ii)

From given data : $U_4 = 15$ m/s; $H = 10$ m; $Z = 120$ m; $\rho = 1.23$ kg/m^3; $\alpha = 0.15$; $D = 85$ m;

$A_1 = \dfrac{\pi \times (85)^2}{4} = 5674.5 \text{ m}^2$; $U_1 = 0.75U_0$; $\eta_{gen} = 0.9$

$$U_z = U_H\left(\frac{Z}{H}\right)^{\alpha} = 15 \times \left(\frac{120}{10}\right)^{0.15} = 21.775 \text{ m/s} = U_0$$

$$U_1 = 0.75U_0 = 0.75 \times 21.775 = 16.33 \text{ m/s}$$

and

(i) $$\frac{P_0}{A} = \frac{1}{2}\rho U_0^3$$

$$P_0 = 5674.5 \times \frac{1}{2} \times 1.23 \times (21.775)^3$$

$$P_0 = 36.031 \text{ MW}$$

(ii) The interference factor, $a = \frac{(U_0 - U_1)}{U_0} = \frac{21.775 - 16.33}{21.775} = 0.25$

The power coefficient, $c_p = 4a(1-a)^2$

$$= 4 \times 0.25(1 - 0.25)^2 = 0.5625$$

(iii) Electrical power generated = 0.9 × 0.5625 × 36.031 = 18.241 MW

(iv) Axial thrust on the turbine

$$F_A = 4a(1-a)\left(A_1 \frac{\rho U_0^2}{2}\right)$$

$$= 4 \times 0.25(1-0.25)\left(5674.5 \times 1.23 \times \frac{(21.775)^2}{2}\right)$$

$$= 12.41 \times 10^5 \text{ N}$$

(v) Maximum axial thrust occurs when

$$a = 0.5 \text{ and } c_p = 1$$

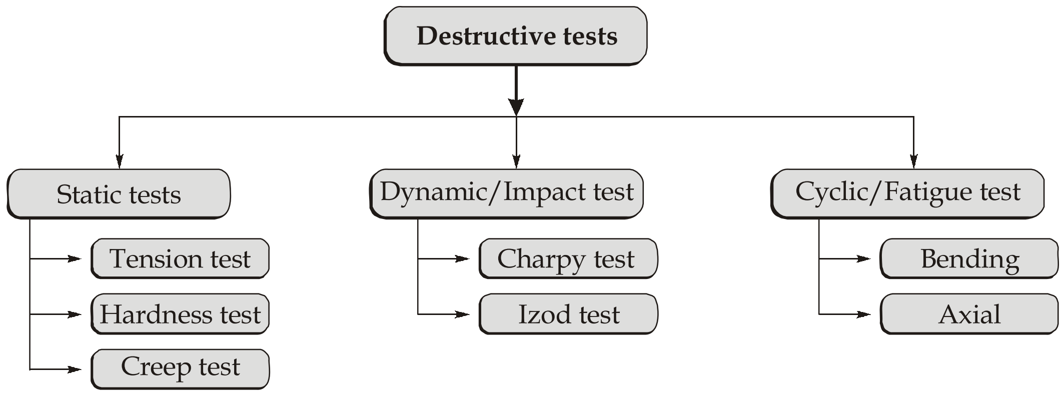
$$F_{A,\max} = A_1 \frac{\rho U_0^2}{2}$$

$$= 5674.5 \times 1.23 \times \frac{(21.775)^2}{2}$$

$$= 16.55 \times 10^5 \text{ N}$$

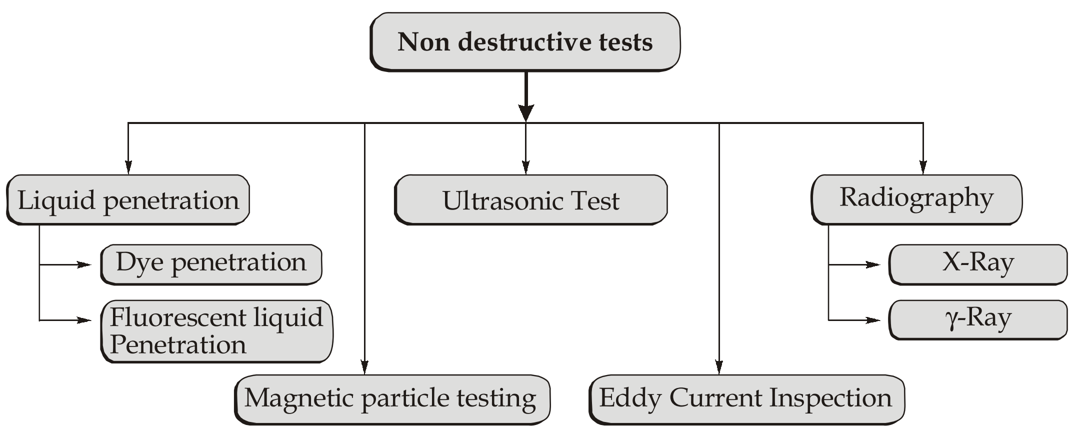
2. (b) Solution:

Destructive Tests: These tests are done to evaluate material properties by forcing samples to fail or undergo permanent damage. There are numerous destructive tests known for the machine parts subjected to any deterioration due to stress, impact, creep, fatigue & thermal loads.



Non-Destructive Tests: These tests are used to assess component without any considerable damage to the component.

Commonly used non-destructive testing technique in engineering application are as



Difference between Destructive Testing (DT) and Non-destructive Testing (NDT)

Feature	Destructive Testing (DT)	Non-Destructive Testing (NDT)
Impact on sample	Damages the component	Component is intact if usable
Primary Goal	Determines material properties	Detects flaws, cracks, etc.
Cost of Testing	Generally higher	Generally lower
Scope of Test	Sample based	Can test 100% of production
Data obtained	Quantitative (Numerical value)	Qualitative (presence of defects)
Component condition	Non usable after testing	Usable after testing
Examples	Tensile Test, Hardness test, Impact test, creep test	Ultrasound test, Radiography, Liquid penetration test

Various Non-destructive tests used in engineering applications are:

Liquid Penetration Inspection

This method is used to detect surface defect such as large cracks or openings.

There are two types of liquid penetration inspections:

(i) Dye penetration inspection

- Liquid dye penetrant is sprayed on to the clean surface.
- Excess amount of dye is removed.
- Surface is washed with water and dried.
- Then developer is sprayed on the surface.
- This brings out the colour in the dye penetrant that has penetrated into cracks or pinholes. As a result the surface crack can be identified.

(ii) Fluorescent - liquid penetration inspection.

- Fluorescent - liquid is applied to the surface.
- Excess liquid is removed.
- Surface is washed & dried.
- Then the surface is viewed under black-light (Ultra-Violet light) whose wavelength lies between visible region and ultraviolet region.

Magnetic Particle Testing

- Part is magnetised using external magnetic yoke-coils or passing current.
- Inspection medium is applied on the part.
- In dry method of inspection a special fine-ferromagnetic powder is applied on the surface by means of hand shaker or vibratory-screen so that the powder is uniformly distributed on the surface.
- A liquid like kerosene containing suspended fine ferromagnetic particles is sprayed or brushed.
- Due to the formation of magnetic-poles at the cracks or flaws, the powder concentrates in that area.

Eddy current inspection

Eddy current testing is one of the methods of detecting discontinuities.

This method is based on the principle that when the AC current carrying conductor coil is brought near a metallic/conductive specimen, eddy currents are induced in the specimen due to electromagnetism. These eddy currents produce their own magnetic field that opposes the field of current carrying conductor coil thereby increasing the impedance. Coil impedance can be measured whose variation indicates presence of a the crack or flaw.

Ultrasonic Inspection

This method is fast and reliable NDT technique. This employs electronically produced high frequency sound waves that will penetrate metals, liquids and many other materials at speed of several thousand feet per second. Piezoelectric-materials like quartz are used to produce ultrasonics waves. These materials undergo a change in physical dimension when subjected to electric field.

Radiography (X-Ray and γ-Ray)

Radiography is also one of the most practically-useful NDT methods, which can be applied for inspection of cracks, porosity, blowholes, etc. in welds of all types and thickness ranging from minute welds in electronic components to welds upto half a meters thick employed in heavy fabrications.

The principle of technique is based on exposing the component to short wavelength radiation in the form of X-Ray and γ-Ray.

2. (c) (i) Solution:

Techniques of Condition Monitoring:

1. Visual monitoring
2. Vibration monitoring
3. Wear Debris monitoring
4. Performance and behaviour monitoring
5. Corrosion monitoring

Vibration-Monitoring: The noise and vibration are the most important parameters to monitor a machine, particularly in the moving parts such as shaft, rotors, cutting tools, gears, etc. The vibration level is recorded using transducer-like velocity probe, accelerometer or proximity probe attached to the machine.

Noise-Monitoring: A non-contact/remote technique using microphones at a distance.

It is highly effective for detecting high frequency.

All operating machines generate a characteristic "acoustic-signature". When internal components (like bearings, gears or rotors) begin to fail, they produce abnormal sound frequencies or increased noise levels.

Noise-monitoring involves capturing these airborne sound waves using microphones and analyzing them to identify deviations from a "healthy baseline".

Wear Debris Monitoring:

This works on the principle that the working surface of a machine are washed by the lubricating oil, and any damage to them should be detectable from particles of wear debris in the oil.

If the debris consists of relatively large ferrous lumps such as those generated by fatigue of rolling element bearings and gears or the pitting of cams and taproots, these can be picked up by removable magnetic plugs inserted in the coil return-lines.

For small debris particle, spectrographic analysis or microscopic examination of oil samples after magnetic separation are commonly used techniques. Another popular technique is "SOAP - analysis" for Debris-monitoring.

2. (c) (ii) Solution:

Flexible Manufacturing System (FMS):

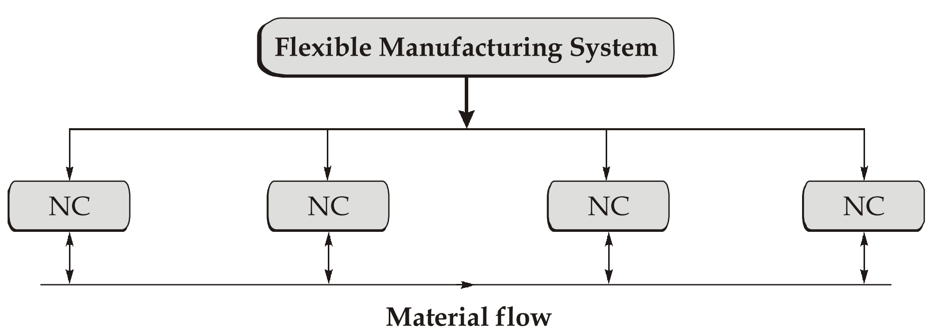
A production method that is designed to adapt easily the changes in the type and quantity of products being manufactured.

FMS is an automated-production-method using interconnected CNC machines, robots and computer-control to produce varied, small-batch products efficiently.

FMS is critical for enhancing flexibility, quality and adaptability to market demands.

Key Components of FMS :

- Workstations.
- Material handling systems.
- Computer control systems.



- Automated guided vehicles are used for transportation.
- Several manufacturing machines are grouped without mutual dependence of their activity.

Importance and advantages in manufacturing and automation

- Increased productivity
- Enhanced flexibility
- Improved quality
- Customization

3. (a) Solution:

Assumption:

(i) For simple analysis, a smooth laminar flow with perturbations is assumed.

(ii) Most commonly used horizontal axis wind turbine is considered.

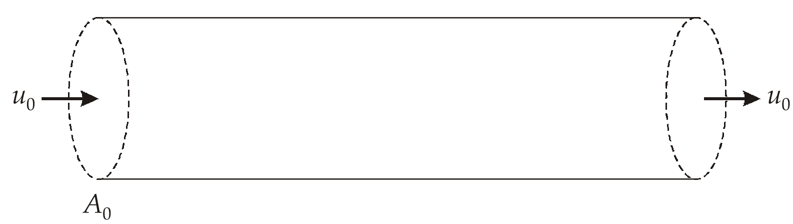
(iii) Rotor may be considered as an actuator disk across which there is reduction of pressure as energy is extracted.

(iv) Mass flow rate of air is assumed to be same everywhere within the stream tube.

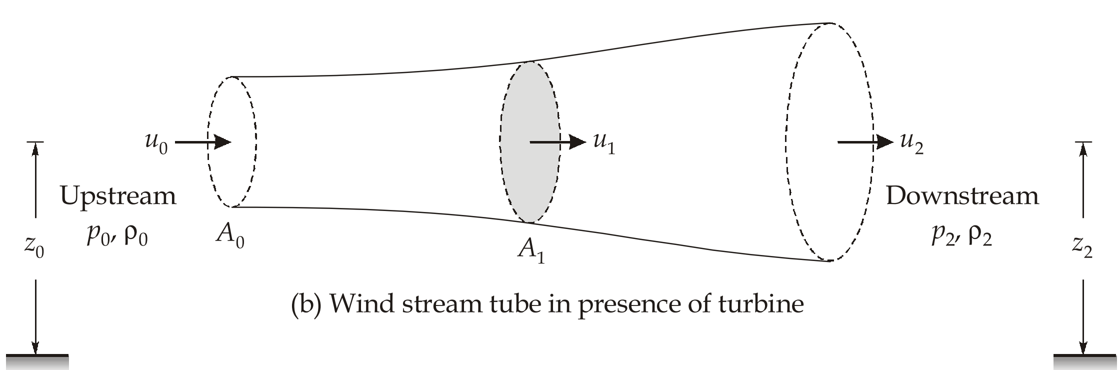
(v) Density of Air will remain constant.

The stream tube area of constant air mass is A_0 upstream, which expands to A_1 while passing through the rotor and becomes A_2 downstream. The wind speed is u_0 upstream, which reduces to u_1 while passing through the rotor and becomes u_2 downstream. The air-mass flow rate remains same throughout the stream tube. Therefore,

$$\dot{m} = \rho A_0 u_0 = \rho A_1 u_1 = \rho A_2 u_2 \quad \text{...(i)}$$



(a) Unperturbed wind stream tube in absence of turbine



(b) Wind stream tube in presence of turbine

Betz model of expanding air-stream tube

If u_0 and u_2 are wind speeds upstream and downstream respectively, the force or thrust on the rotor is equal to the reduction in momentum per unit time from the air mass flow rate $\dot{m}$ is given as :

$$F = \dot{m}u_0 - \dot{m}u_2$$

This force is applied by the air at uniform air-flow speed of u_1, passing through the actuator disk (turbine). The power extracted by the turbine is:

$$P_T = Fu_1 = \dot{m}(u_0 - u_2)u_1 \quad \text{...(i)}$$

The power extracted from wind is also equal to loss in KE per unit time. Thus,

$$P_w = \frac{1}{2}\dot{m}\left(u_0^2 - u_2^2\right) \quad \text{...(ii)}$$

Equating (i) and (ii), we have

$$u_1 = \frac{u_0 + u_2}{2} \quad \text{...(iii)}$$

As an extreme case, considering u_2 to be zero (which is not practical downstream air must have some kinetic energy to leave the turbine region), $u_1 = \frac{u_0}{2}$. Thus, according to this linear momentum theory, the air speed through the actuator disk cannot be less than half the speed of upstream air.

An interference factor, 'a' is defined as fractional wind speed decrease at the turbine thus:

$$a = \frac{(u_0 - u_1)}{u_0} \quad \text{...(iv)}$$

or $$u_1 = (1 - a)u_0$$

or $$a = \frac{(u_0 - u_2)}{2u_0} \quad \text{...(v)}$$

a is also know as the induction of perturbation factor.

Using equation (ii), (iii), (iv) and (v), power extracted by the turbine may be written as

$$P_T = 4a(1-a)^2\left(\frac{1}{2}\rho A_1 u_0^3\right)$$

$$P_T = C_p P_0 \qquad [P_0 \text{ is the energy available initially}]$$

where C_p is the fraction of available power in the wind that can be extracted and is known as power coefficient, C_p is given as

$$C_p = 4a(1 - a)^2$$

When no load is coupled to the turbine, the blades just freewheel. There is no reduction of wind speed at the turbine, therefore, $u_1 = u_0$ and the value of a is zero. The turbine does not generate any power and $C_p = 0$. The air just passes through the turbine without any reduction of speed.

For maximum power extraction at turbine

$$P_T = 4a(1-a)^2 \times \frac{1}{2}\rho A u_0^3$$

$$P_T = f(a)$$

For maximum power

$$\frac{dP_T}{da} = 0$$

$$\frac{d}{da}\left[4a(1-a)^2\right] = 0$$

On solving, $a = 1/3$, $a = 1$

For $a = 1$, P_T becomes zero, so $a \neq 1$.

For $\quad P_T \to P_{T,max}$, $a = 1/3$

$$C_{p,\max} = 4a(1-a)^2$$

$$= 4 \times \frac{1}{3} \times \left(1 - \frac{1}{3}\right)^2 = \frac{16}{27} = 0.593 \text{ it is called Betz limit}$$

Also, $\quad u_1 = (1 - a)u_0$

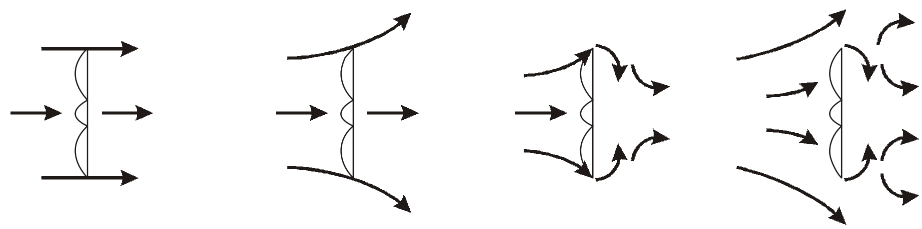
$$u_1 = \frac{2}{3}u_0$$

Maximum value of C_p (i.e. $C_{p,\max} = \frac{16}{27} = 0.593$) occurs at $a = \frac{1}{3}$. At this condition,

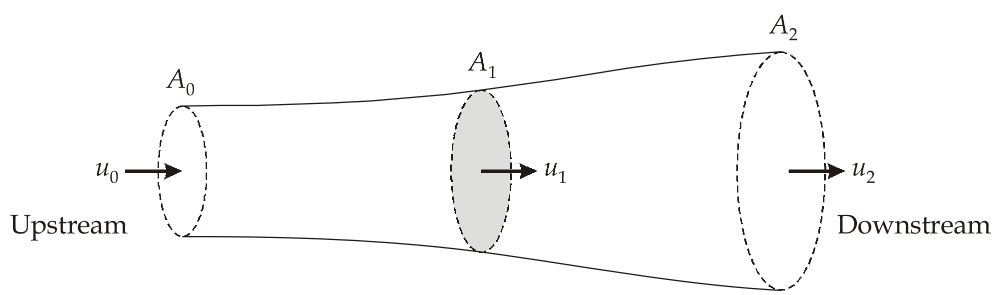
$$u_1 = \frac{2}{3}u_0 \text{ and } u_2 = \frac{1}{3}u_0$$

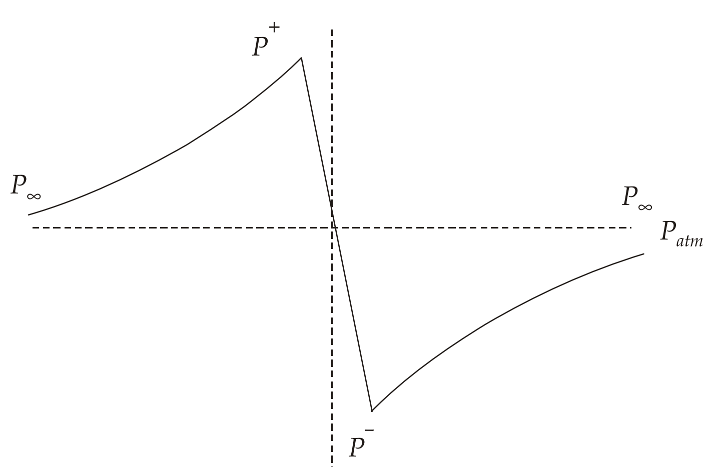
This applies to an ideal case. For a commercial wind turbine, however, maximum power coefficient is less than ideal value.

When $u_2 = 0$, $a = 0.5$ and the simple model breaks down as no wind is predicted to be leaving downstream. In practice, this is equivalent to the onset of a turbulence downstream. Power extraction decreases due to mismatch of rotational frequency and wind speed and partial stalling begins. The turbine blades will still be turning, causing extensive turbulence in the air stream, leading to more losses. When the wind speed at the turbine is reduced to zero (i.e., $u_1 = 0$), 'a' becomes unity and no power is extracted. This state is known as (complete) stall state of blades.



$u_1 = u_0$ $u_2 = u_0$ No power generation $a = 0$	$u_1 = (2/3)u_0$ $u_2 = (1/3)u_0$ Max power generation $a = 1/3$	$u_1 = (1/2)u_0$ $u_2 = 0$ Turbulent Downstream $a = 1/2$	$u_1 = 0$ Stall condition $a = 1$





Applying Bernoulli's equation for upstream and downstream

$$P_\infty \to P^+$$

$$\frac{1}{2}\rho u_0^2 + P_\infty = \frac{1}{2}\rho u_1^2 + P^+ \quad \text{...(vi)}$$

$$P^- \to P_\infty$$

$$\frac{1}{2}\rho u_1^2 + P^- = \frac{1}{2}\rho u_2^2 + P_\infty \quad \text{...(vii)}$$

Adding (vi) and (vii)

$$\Delta P = P^+ - P^- = \frac{1}{2}\rho\left(u_0^2 - u_2^2\right)$$

$$\text{Axial thrust, } F_A = \frac{1}{2}\rho\left(u_0^2 - u_2^2\right)A_1$$

Maximum possible thrust, $F_{A,\max} = A_1 \times \frac{1}{2}\rho u_0^2$ when $u_2 = 0$

Axial thrust can also be expressed as

$$F_A = \dot{m}\left(u_0 - u_2\right)$$

$$F_A = \dot{m}u_0 - \dot{m}(1-2a)\dot{u}_0 = \dot{m}u_0(2a)$$

$$F_A = 2au_0\left(\rho A_1 u_1\right) = 2au_0\left(\rho A_1(1-a)u_0\right)$$

$$F_A = 2a(1-a)\rho A_1 u_0^2$$

$$F_A = 4a(1-a)\times\frac{\rho A_1 u_0^2}{2}$$

$$F_A = C_f \times F_{A,\max}$$

where, C_f is the thrust coefficient, $C_f = 4a(1-a)$

at Betz limit $a = \frac{1}{3}$

$$C_f = 4\times\frac{1}{3}\times\left(1-\frac{1}{3}\right) = \frac{8}{9}$$

$$F_A = \frac{8}{9}F_{A,\max}$$ **Ans.**

3. (b) Solution:

Classification of a fuel cells:

(a) Based on the type of electrolyte

(i) PEMFC (Polymer electrolytic membrane fuel cell) or SPFC (Solid polymer fuel cell) or PEMFC (Proton exchange membrane fuel cell).

(ii) PAFC (Phosphoric Acid fuel cell)

(iii) AFC (Alkaline fuel cell)

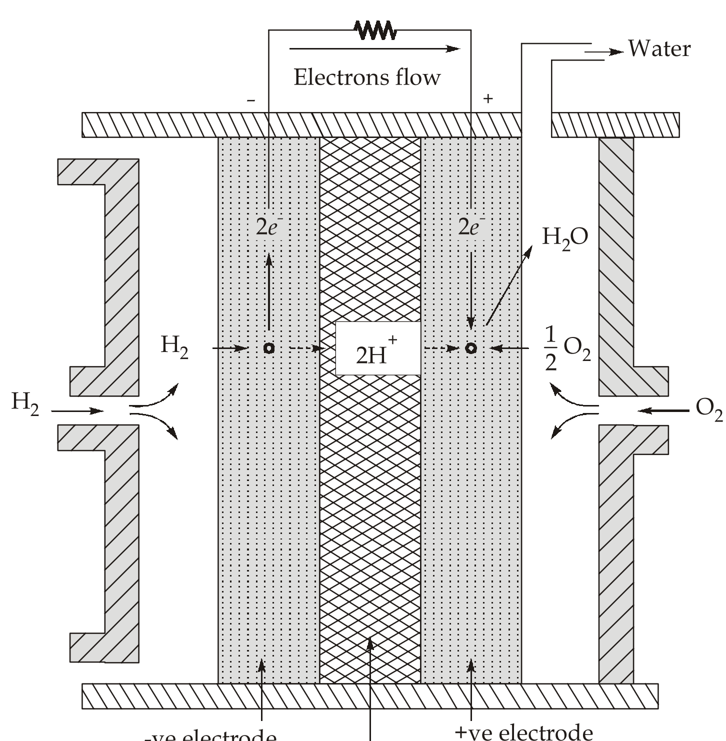
(iv) MCFC (Molten carbonate fuel cell)
(v) SOFC (Solid oxide fuel cell)

(b) Based on chemical nature of electrolyte
(i) Acidic electrolyte type
(ii) Neutral electrolyte type
(iii) Alkaline electrolyte type

(c) Based on operating temperature
(i) Low temperature fuel cell (below 150°C)
(ii) Medium temperature fuel cell (below 150°C to 250°)
(iii) High temperature fuel cell (250°C to 800°)
(iv) Very high temperature fuel cell (800°C to 1100°C)

Proton electrolyte membrane fuel cell (PEMFC)

A solid membrane of organic material (such as polystyrene sulphonic acid) that allows H^+ ions to pass through it is used as an electrolyte. The desired properties of the membrane are: (i) high ionic conductivity, (ii) non permeable (ideally) to reactant gases, i.e. hydrogen and oxygen, (iii) low degree of electro-osmosis (motion of liquid induced by applied potential across membrane), (iv) high resistance to dehydration, (v) high resistance to its oxidation or hydrolysis, and (vi) high mechanical stability.



Proton Electrolyte Membrane Fuel Cell

The basic components of cell are shown in figure. A thin layer (about 0.076 cm thickness) of the membrane is used to keep the internal resistance of the cell as low as possible. Finely divided platinum deposited on each surface of the membrane serves as electrochemical catalyst and current collector. Hydrogen enters a closed compartment, interacts with negative electrode and converted into H^+ ions and equal number of electrons (e^-) :

$$H_2 \rightarrow 2H^+ + 2e^-$$

The H^+ ions are transported to positive electrode through the membrane and electrons return to positive electrode through external resistance. At positive electrode, the ions, electrons and oxygen (O_2) interact to produce water.

$$\frac{1}{2}O_2 \rightarrow 2H^+ + 2e^- \rightarrow H_2O$$

Thus the overall reaction is:

$$H_2 \rightarrow \frac{1}{2}O_2 \rightarrow H_2O$$

On positive electrode the coolant tubes run through the ribs of current collectors. The current collectors also hold wicks, which absorb water, produced in electrochemical reaction and carry it over by capillary action. Water leaves the oxygen compartment through an exit. The advantageous feature of this membrane is that it retains only limited quantity of water and rejects excess water produced in the cell. The cell operates at 40-60°C. The ideal emf produced is 1.23V at 25°C.

3. (c) (i) Solution:

1. The reliability over a 30 days continuous period,

$$R(30 \times 24) = e^{-0.00034 \times 30 \times 24} = 0.78286$$

2. Reliability function for parallel system is : $2e^{-\lambda t} - e^{-2\lambda t}$

$$R(t) = 2e^{-0.00034t} - e^{-0.00068t}$$

Therefore reliability over a 30 day period is

$$R(720) = 2e^{-0.00034 \times 720} - e^{-0.00068 \times 720}$$

$$R(720) = 0.9528507$$

Its hazard function is given by

$$\lambda(t) = \frac{f(t)}{R(t)} = \left[\frac{\lambda(1-e^{-\lambda t})}{1-\frac{1}{2}e^{-\lambda t}}\right]$$

$$\lambda(t) = \frac{0.00034(1-e^{-(0.00034t)})}{1-0.5e^{-(0.00034)t}}$$

3. (c) (ii) Solution:

Let, x and y denote the number of old hens and young hens that must be bought. Objective is to maximize the profit per week.

Problem formulation :

$$x = \text{Number of old hens}$$
$$y = \text{Number of young hens}$$

Objective is to maximize profit per week

old hens : 3 eggs/ week

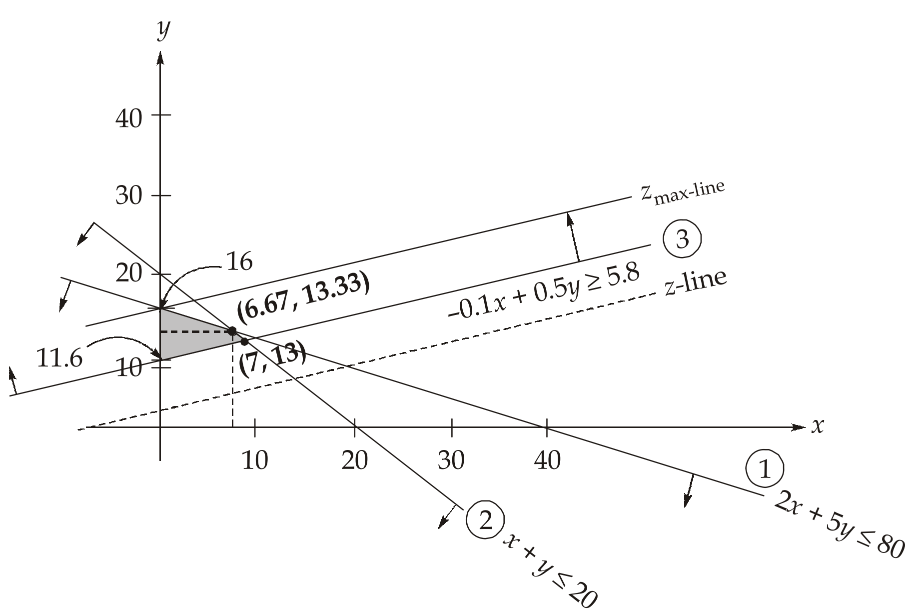
young hens : 5 eggs/ week

Total number of eggs/week = $3x + 5y$

Total earning/week = $[0.3(3x + 5y) - (x + y)]$

Thus objective function (z) is

$$\text{Max. } z = \text{Rs}[-0.1x + 0.5y]$$



Constraints:

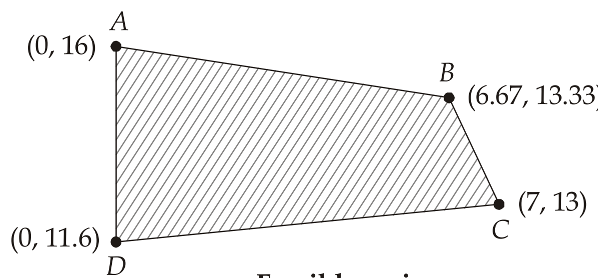
$$x, y \geq 0$$
$$2x + 5y \leq 80 \quad \text{...(i)}$$
$$x + y \leq 20 \quad \text{...(ii)}$$
$$-0.1x + 0.5y \geq 5.8$$

$$\Rightarrow \qquad y \geq 0.2x + 11.6 \qquad \text{...(iii)}$$

Intersection of lines (i) and (ii)

$$\left(\frac{20}{3}, \frac{40}{3}\right) = (6.67, 13.33)$$

Intersection of lines (i) and (iii)



Feasible region

$$\left(\frac{22}{3}, \frac{196}{15}\right) = (7.33, 13.067)$$

Intersection of lines (ii) and (iii)

$$(7, 13)$$

Objective function line parallel to (iii),

$$z_{(0,\ 11.6)} = 5.8$$

$$z_{(0,\ 16)} = 8$$

$$z_{(6.67,\ 13.33)} = -0.1(6.67) + 0.5(13.33) = 5.998$$

$$z_{(7,\ 13)} = -0.1(7) + 0.5(13) = 5.8$$

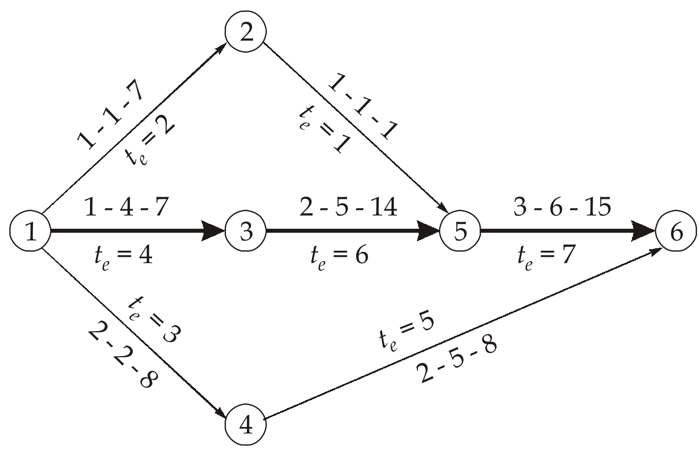
$$z_{max} = \text{Rs. } 8$$ **Ans.**

Since; the maximum of z is 8 which occurs at $A(0, 16)$ the solution to problem is

$$\left.\begin{matrix} x = 0 \\ y = 16 \end{matrix}\right\} z = \text{Rs.}8$$

4. (a) Solution:

(i)



(ii)

Activity	t_0	t_m	t_p	$t_e = \frac{t_0 + 4t_m + t_p}{6}$	$\sigma^2 = \left(\frac{t_p - t_0}{6}\right)^2$
1 - 2	1	1	7	2	1
1 - 3	1	4	7	4	1
1 - 4	2	2	8	3	1
2 - 5	1	1	1	1	0
3 - 5	2	5	14	6	4
4 - 6	2	5	8	5	1
5 - 6	3	6	15	7	4

Various paths through network are

1 - 2 - 5 - 6 : Length = 2 + 1 + 7 = 10

1 - 3 - 5 - 6 : Length = 4 + 6 + 7 = 17

1 - 4 - 6 : Length = 3 + 5 = 8

Since, 1 - 3 - 5 - 6 has the longest duration, it is the critical path of the network.

Hence; expected project length = 17 weeks

Variance of the project length is the sum of the variances of the activities of critical path.

$$V = V_{1-3} + V_{3-5} + V_{5-6} = 1 + 4 + 4 = 9$$ **Ans.**

$$V = \sigma^2_{1-3} + \sigma^2_{3-5} + \sigma^2_{5-6} = 1 + 4 + 4 = 9$$

$$\sigma = \sqrt{V} = \sqrt{9}$$

$\sigma = 3$ weeks **Ans.**

(iii)

Probability that the project will be completed at least 4 weeks earlier than expected time

$$\text{Expected time} = 17 \text{ Weeks } [T_e]$$

$$\text{Scheduled time} = 17 - 4 = 13 \text{ Weeks } [T_s]$$

$$\text{Standard normal variate} = z = \frac{T_s - T_e}{\sigma} = \frac{13-17}{3} = -1.33$$

$$P(z = -1.33) = 9.18\%$$ **Ans.**

Probability that the project will be completed no more than 4 weeks later than expected time.

$$\text{Expected time} = 17 \text{ weeks, schedule time} = 17 + 4 = 21 \text{ weeks}$$

$$z = \frac{21-17}{3} = 1.33$$

$$P(z = 1.33) = 90.82\%$$ **Ans.**

4. (b) Solution:

Step I : Prepare square matrix:

The problem involves a non-square 4 × 6 matrix.

As three-jobs can be performed internally

Jobs

Firms		1	2	3	4	5	6
	1	44	67	41	53	48	64
	2	46	69	40	45	45	68
	3	43	73	37	51	44	62
	I_1	50	65	35	50	46	63
	I_2	50	65	35	50	46	63
	I_3	50	65	35	50	46	63

Step II : Reduce the matrix

Performing row and column reductions

	1	2	3	4	5	6
1	3	26	0	12	7	23
2	6	29	0	5	5	28
3	6	36	0	14	7	25
I_1	15	30	0	15	11	28
I_2	15	30	0	15	11	28
I_3	15	30	0	15	11	28

Matrix after row reduction

→

	1	2	3	4	5	6	
1	[0]	~~0~~	~~0~~	7	2	~~0~~	
2	3	3	0	[0]	~~0~~	5	
3	3	10	[0]	9	2	2	
I_1	12	4	~~0~~	10	6	5	✓
I_2	12	4	~~0~~	10	6	5	✓
I_3	12	4	~~0~~	10	6	5	✓
			✓				

Matrix after column reduction (Initial basic feasible solution)

∵ Minimum number of lines covering all zeroes = 3

Order of matrix = 6

and 3 < 6 ⇒ Initial basic feasible solution is not optimal.

Row Reduction: Subtract minimum element of each row from all the elements of that row.

Column Reduction: It is performed when there is at least one column without atleast one zero.

Subtract the minimum element of the column not containing a zero element from rest element of respective column. The solution obtained from this is called "Initial Basic Feasible Solution".

Optimality check: Minimum no. of lines crossing all zeroes ≥ Order of matrix.

Step III: Iteration Towards Optimal Solution

Examine the elements that do not have line through them. Select the smallest of these elements and subtract it from all the elements that do not have a line through them. Add this smallest element to every element that lies at the intersection of two lines. Leave the remaining elements of matrix unchanged.

'2' is the smallest element of IBFS.

Jobs

Firms	1	2	3	4	5	6	
1	[0]	~~0~~	2	7	2	~~0~~	
2	3	3	2	[0]	~~0~~	5	
3	1	8	~~0~~	7	[0]	~~0~~	
I_1	10	2	[0]	8	4	3	✓
I_2	10	2	~~0~~	8	4	3	✓
I_3	10	2	~~0~~	8	4	3	✓
			✓				

Second basic feasible solution

→

Jobs

Firms	1	2	3	4	5	6	
1	[0]	~~0~~	4	7	2	~~0~~	
2	3	3	4	[0]	~~0~~	5	
3	1	8	2	7	[0]	~~0~~	
I_1	8	[0]	~~0~~	6	2	1	✓
I_2	8	~~0~~	[0]	6	2	1	✓
I_3	8	~~0~~	~~0~~	6	2	1	✓
		✓	✓				

Third basic feasible solution

Since third basic feasible solution is also not optimum.

Hence,

Jobs

Firms	1	2	3	4	5	6
1	[0]	1	5	7	2	~~0~~
2	3	4	5	[0]	~~0~~	5
3	1	9	3	7	[0]	~~0~~
I_1	7	[0]	~~0~~	5	1	~~0~~
I_2	7	~~0~~	[0]	5	1	~~0~~
I_3	7	~~0~~	~~0~~	5	1	[0]

Number of assignments = Order of matrix

$\Rightarrow$ Solution is optimum

$$T_{C,\ \min} = (1 \times C_{I,1}) + (1 \times C_{I_1 2}) + (1 \times C_{I_2 3}) + (1 \times C_{24}) + (1 \times C_{35}) + (1 \times C_{I_3 6})$$

Minimum cost = 44 + 45 + 44 + 65 + 35 + 63

= 296 Thousand

= 2.96 lakh **Ans.**

4. (c) Solution:

Tidal power plants are broadly classified into the following four categories:

(i) Single-basin single-effect plant

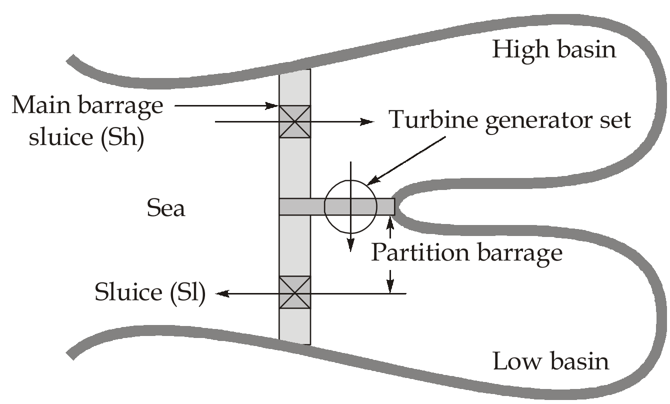
(ii) Single-basin double-effect plant

(iii) Double-basin with linked-basin operation

(iv) Double-basin with paired-basin operation

Double-basin with Linked-basin Operation

In this arrangement a large basin is converted into two basins of suitable dimensions; one which is at a higher level is called the high basin and the other low basin. The scheme consists of three barrages, one separating the high basin from the sea and containing the filling gates, another separating the low basin from the sea and containing the emptying gates. The third barrage separates the high basin from the low basin and contains the powerhouse as shown in figure.



Double Basin with Linked Basin Operation

The upper basin filling gates are opened only during the time when the sea level is higher than the upper basin water level. The emptying gates of the lower basin are opened only when the sea level is lower than the lower basin water level. The head on the turbine is the difference in elevation between the upper and lower basins.

The two-basin scheme may be economically viable where power demand is less than the guaranteed output as determined by the tide cycle. Alternatively, the two-basin system can be operated by retaining water in high basin and releasing it to meet peak demands only.

There are three important components of a tidal plant are :

(i) A barrage to form a basin

(ii) Sluice gates in the barrage for flow of water from the sea to the basin and vice-versa

(iii) A powerhouse equipped with turbines, each coupled to a generator along with auxiliary equipment

Barrage (Dam or Dyke) : The barrage should be constructed by the material available at site or from a nearby place. Barrages for tidal power projects have to withstand the force of sea waves, so the design should be suitable to site conditions and to economic aspect of development. The rockfill dams or barrages are preferred due to their stability against flows. The dyke (barrage) crest and slopes should be armoured for protection against waves.

Sluices : Tidal power plants operate on the continuously varying difference in level at which the basin must be filled from the sea or emptied to the sea, as required by the operating regime of the power plant. This requires suitable sluice ways equipped with gates which can be operated quickly. These are required to be operated two or more times a day.

Turbines : The energy potential in tidal power development is exploited from low to very low heads, for which large size turbines are required. If the water head is more than 8 metres, a propeller type turbine is quite suitable because the angle of blades can be changed to obtain maximum efficiency while the water is falling. These are also called as variable head turbines.

Generally three types of turbines can be used; the selection is made according to the suitability. These turbines are:

(i) Bulb turbine

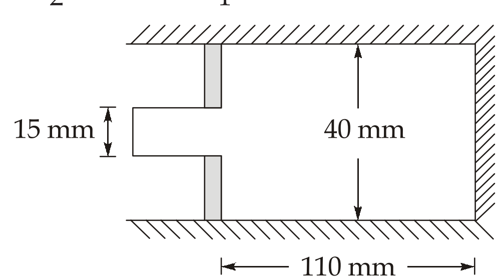
(ii) Tube turbine

(iii) Straight flow rim type turbine.

Section B : Production Engineering & Material Science-1 + Theory of Machines-2

5. (a) Solution:

Given data : d_1 = 40 mm; d_2 = 15 mm; l_1 = 110 mm; a = 0.8; b = 1.5; k = 800 MPa; n = 0.17



Assuming no change in volume.

$$V_1 = V_2 \qquad [\because \text{ Material is incompressible}]$$

$$\Rightarrow \quad \frac{\pi}{4} d_1^2 l_1 = \frac{\pi}{4} d_2^2 l_2$$

$$\Rightarrow \quad l_2 = \left(\frac{d_1}{d_2}\right)^2 l_1 = \left(\frac{40}{15}\right)^2 \times 110 = 782.222 \text{ mm}$$

$$\text{Engineering strain; } \in_E = \frac{l_f - l_i}{l_i} = \frac{782.222 - 110}{110} = 6.111$$

$$\text{True extrusion strain, } \in_T = \ln(1 + \in_E) \simeq 1.96166 \qquad \textbf{Ans.}$$

$$\text{Extrusion ratio, } R = \frac{A_i}{A_f} = \left(\frac{d_1}{d_2}\right)^2 = \left(\frac{40}{15}\right)^2 = 7.111 \qquad \textbf{Ans.}$$

$$\text{Mean flow stress, } \sigma_0 = \frac{k \in_T}{n+1}$$

$$\sigma_0 = \frac{800 \times (1.96166)^{0.17}}{1.17} = 766.743 \text{ MPa}$$

Stress according to Johnson's relation.

$$\sigma_d = \sigma_0 (a + b \ln R) = 766.743 (0.8 + 1.5 \ln(7.11))$$

$$\sigma_d = 2869.526 \text{ MPa}$$

$$\therefore \quad \text{Ram force} = \sigma_d (\text{Ram Area})$$

$$= \sigma_d \times \frac{\pi}{4}(d_1^2 - d_2^2)$$

$$= 3.09885 \text{ MN} \qquad \textbf{Ans.}$$

5. (b) (i) Solution:

Given data : Gating ratio = 1 : 2 : 3; t = 12 mm; h_s = 200 mm; m = 30 kg; ρ = 7900 kg/m^3;

$t_p = k\sqrt{w}$, $k = 2.3$ for $t = 12$ mm

$$t_p = 2.3\sqrt{30} = 12.597 s$$

$$Q = C_d A V$$

$$\Rightarrow \quad \frac{m}{\rho\, t_p} = C_d A_s \sqrt{2gh_s}$$

$$\Rightarrow \quad \frac{30}{7900 \times 12.597} = 0.9 A_s \sqrt{2 \times 9.81 \times 0.2}$$

$$\text{Sprue base area, } A_s = 1.69 \times 10^{-4} \text{ m}^2$$

$$\text{Diameter of sprue base, } d_s = \sqrt{\frac{4A_s}{\pi}} = 0.02074 = 20.745 \text{ mm}$$

$$\text{Area of runner, } A_r = 2A_s$$

$$= 2 \times 1.69 \times 10^{-4}$$

$$= 3.38 \times 10^{-4} \text{ m}^2$$

$$\text{Diameter of runner, } d_r = \sqrt{\frac{4A_r}{\pi}} = 0.02074 \text{ m} = 20.745 \text{ mm}$$ **Ans.**

$$\text{Area of Gate, } A_g = 3A_g = 3 \times 1.69 \times 10^{-4} = 5.07 \times 10^{-4} \text{ m}^2$$

$$\text{Diameter of gate, } d_g = \sqrt{\frac{4 \times A_g}{\pi}} = 0.025407 \text{ m or } 25.407 \text{ mm}$$

5. (b) (ii) Solution:

Given data : $a = 0.28$ nm; $\lambda = 0.18$ nm; n(order of reflection) = 1; $h = 2$, $k = 2$, $l = 0$

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}} = \frac{0.28}{\sqrt{2^2 + 2^2 + 0^2}}$$

$$= 0.098995 \text{ nm}$$

Using Bragg's law:

$$n\lambda = 2d_{hkl} \cdot \sin\theta$$

$$\theta = \sin^{-1}\left[\frac{n\lambda}{2 \cdot d_{hkl}}\right] = \sin^{-1}\left[\frac{1 \times 0.18}{2 \times 0.098995}\right]$$

$$\theta = 65.3864°$$

Differaction angle is 2θ

$$2\theta = 130.772°$$ **Ans.**

5. (c) Solution:

Pb-Sn alloy consists of two-phases.

By using lever-rule to find alloy composition.

$$W_\alpha = \frac{C_\beta - C_1}{C_\beta - C_\alpha} = \frac{98 - 40}{98 - 10} = 0.659$$

$$W_\beta = \frac{C_1 - C_\alpha}{C_\beta - C_\alpha} = \frac{40-10}{98-10} = 0.341$$

To compute volume fraction it is necessary to determine the density of each phase.

$$\rho_\alpha = \frac{100}{\dfrac{C_{Sn(\alpha)}}{\rho_{Sn}} + \dfrac{C_{Pb(\alpha)}}{\rho_{Pb}}} = \frac{100}{\dfrac{10}{7.24} + \dfrac{90}{11.23}} = 10.64 \text{ g/cm}^3$$

$$\rho_\beta = \frac{100}{\dfrac{C_{Sn(\beta)}}{\rho_{Sn}} + \dfrac{C_{Pb(\beta)}}{\rho_{Pb}}} = \frac{100}{\dfrac{98}{7.24} + \dfrac{2}{11.23}} = 7.29 \text{ g/cm}^3$$

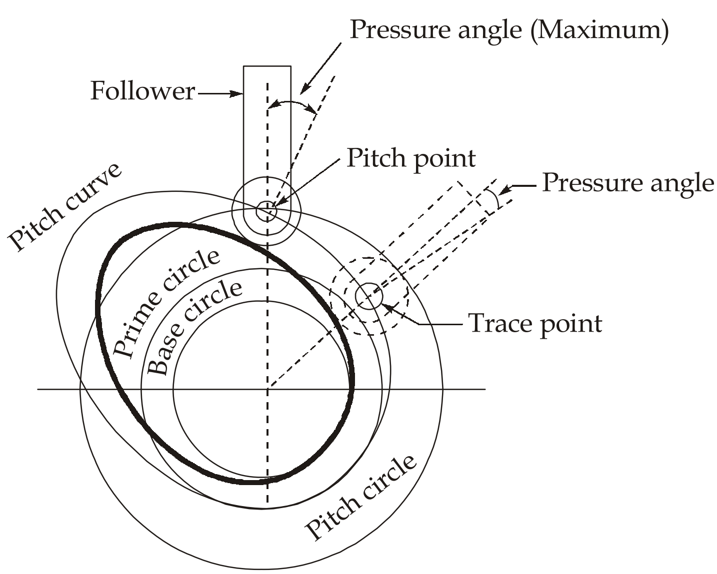
Now; calculating volume fraction of each phase.

$$V_\alpha = \frac{\dfrac{W_\alpha}{\rho_\alpha}}{\dfrac{W_\alpha}{\rho_\alpha} + \dfrac{W_\beta}{\rho_\beta}} = \frac{\dfrac{0.659}{10.64}}{\dfrac{0.659}{10.64} + \dfrac{0.341}{7.29}} = 0.569$$

Ans.

$$V_\beta = \frac{\dfrac{W_\alpha}{\rho_\beta}}{\dfrac{W_\alpha}{\rho_\alpha} + \dfrac{W_\beta}{\rho_\beta}} = \frac{\dfrac{0.341}{7.29}}{\dfrac{0.659}{10.64} + \dfrac{0.341}{7.29}} = 0.430$$

5. (d)



- **Base circle :** It is the smallest circle tangent to the cam profile (contour) drawn from the centre of rotation of a radial cam.

- **Trace point:** It is a reference point on the follower to trace the cam prifile such as knife-edge of a knife edge follower and centre of the roller of a roller follower.
- **Pitch curve :** It is the curve drawn by the trace point assuming that the cam is fixed, and the trace point of the follower rotates around the cam.
- **Pressure angle :** It is the angle between the normal to the pitch curve at a point and the direction of the following motion.

  It represents the steepness of the cam profile. It varies in magnitude at all instants of the follower motion.

5. (e) Solution:

Given : $\phi = 20°$; G = 2.4; m = 8 mm; N_P = 300 rpm; t = 20

$$T = G \times t$$
$$= 2.4 \times 20 = 48$$
$$R = \frac{mT}{2} = \frac{8 \times 48}{2} = 192 \text{ mm}$$
$$r = \frac{mT}{2} = \frac{8 \times 48}{2} = 80 \text{ mm}$$

Maximum addendum of the wheel (Gear),

$$a_{w,\max} = R\left[\sqrt{1 + \frac{1}{G}\left(\frac{1}{G} + 2\right)\sin^2\phi} - 1\right]$$
$$= 192\left[\sqrt{1 + \frac{1}{2.4}\left(\frac{1}{2.4} + 2\right)\sin^2 20} - 1\right]$$
$$= 10.993 \text{ mm}$$
$$a_{p,\max} = r\left[\sqrt{1 + G(G+2)\sin^2\phi} - 1\right]$$
$$= 80\left[\sqrt{1 + 2.4(2.4+2)\sin^2 20} - 1\right]$$
$$= 39.606 \text{ mm}$$

Path of contact when the interference is just avoided = Maximum length of path approach + Maximum length of path fo recess.

$$= r\sin\phi + R\sin\phi$$
$$= 80 \sin 20° + 192 \sin 20°$$
$$= 93.029 \text{ mm}$$ **Ans.**

Now, $$w_P = \frac{2\pi N_P}{60} = \frac{2\pi \times 300}{60} = 31.415 \text{ rad/s}$$

[Angular velocity of pinion]

$$w_g = \frac{w_P}{G} = \frac{31.415}{2.4} = 13.089 \text{ rad/s}$$

[Angular velocity of gear]

Velocity of sliding on one side $= (w_P + w_g) \times$ Path of approach

$= (31.415 + 13.089) \times 80 \sin 20$

$= 1217.72$ mm/s

Velocity of sliding on other side $= (w_P + w_g) \times$ Path of recess

$= (39.606 + 13.089) \times 192 \sin 20$

$= 2922.48$ mm/s **Ans.**

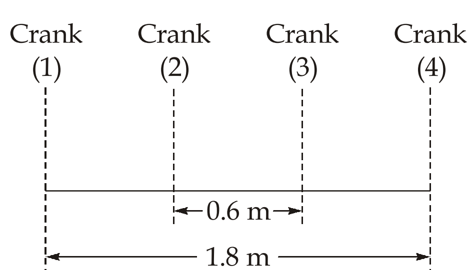
6. (a) Solution:

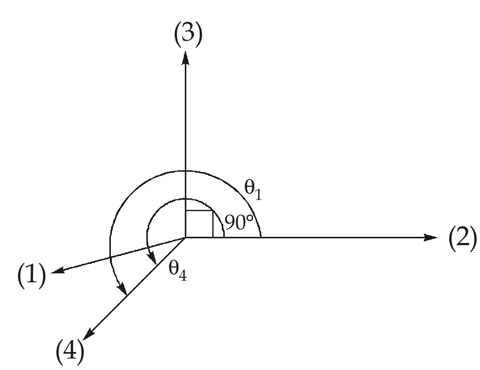
Given: $m_2 = m_3 = 400$ kg, $L = 0.9$ m, $r = 0.2$ m, $n = \dfrac{0.9}{0.2} = 0.45$

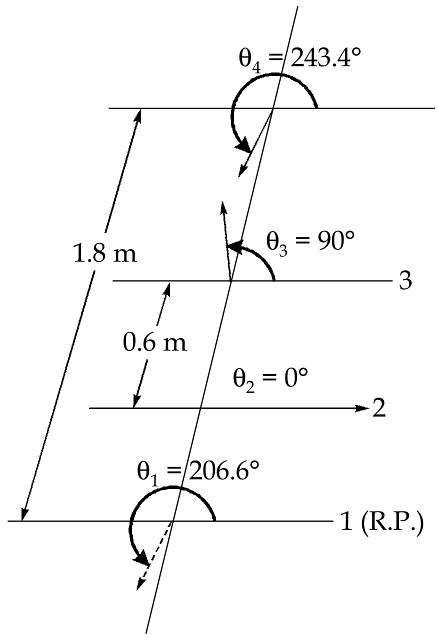
Arrangement the data in table as shown below:

Plane	Mass, M (kg)	Radius, (m)	Distance from reference (l, m)	mr(kg.m)	mrl(kg.m^2)	θ
Ref → 1	m_1	0.2	0	0.2 m_1	0	θ_1
2	400	0.2	0.6	80	48	0°
3	400	0.2	1.2	80	96	90°
4	m_4	0.2	1.8	0.2 m_4	0.36 m_4	θ_4

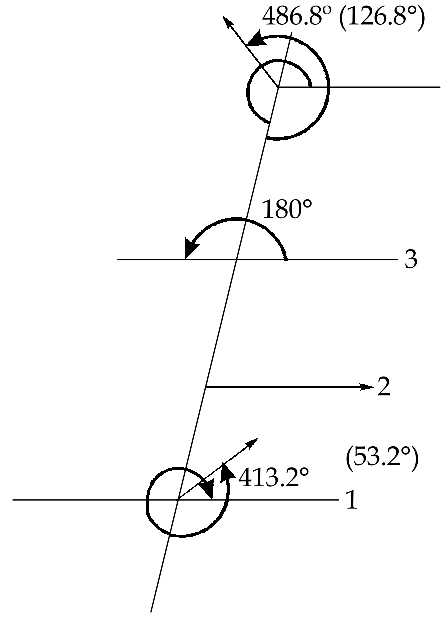
The engine is in complete primary balance.



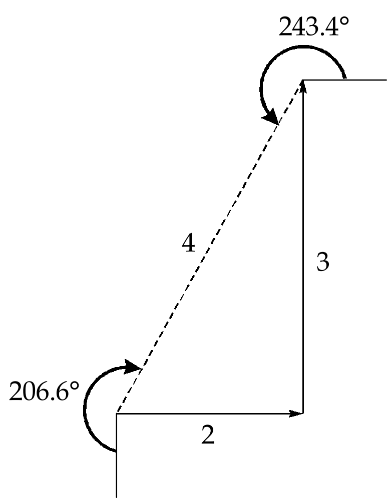




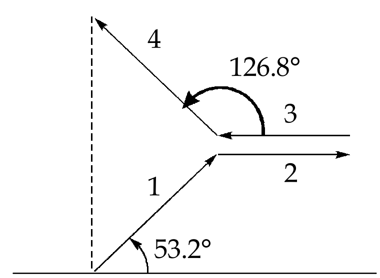
Primary cranks



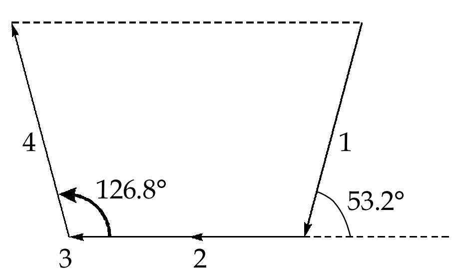
Secondary cranks



Primary couple



Secondary force



Secondary couple

For complete primary balance, moment balance

$48\cos 0° + 96\cos 90° + 0.36m_4\cos\theta_4 = 0$ ... (i)

$48\sin 0° + 96\sin 90° + 0.36m_4\sin\theta_4 = 0$ ... (ii)

Solving equation (i) and (ii), we get

$$0.36m_4 = \sqrt{48^2 + 96^2} = 107.33$$ **Ans.**

By symmetry, $m_1 = m_4 = 298.14$ kg **Ans.**

$$\tan\theta_4 = \frac{-96}{-48} = 2 \Rightarrow \theta_4 = 243.4°$$

and $$\tan\theta_1 = \frac{-48}{96} \Rightarrow \theta_1 = 206.6°$$ **Ans.**

Now, $$\omega = = \frac{2\pi \times 150}{60} = 15.7 \text{ rad/s}$$

For secondary forces and couples, crank angles will be doubled.

$$F_{sec} = \frac{r\omega^2}{n}\begin{bmatrix}\{298.14(\cos 53.2° + \cos 126.8°) + 400(\cos 0° + \cos 180°)\}^2 \\ +\{298.14(\sin 53.2° + \sin 126.8°) + 400(\sin 0° + \sin 180°)\}^2\end{bmatrix}^{1/2}$$

On solving, we get

or, $F_{sec} = 5230.62$ N **Ans.**

For secondary couple about the centreline,

$$M_{sec} = \begin{bmatrix}\{298.14(-0.9\cos 53.2° + 0.9\cos 126.8°) + 400(-0.3\cos 0° + 0.3\cos 180°)\}^2 \\ +\{298.14(-0.9\sin 53.2° + 0.9\sin 126.8°) + 400(-0.3\sin 0° + 0.3\sin 180°)\}^2\end{bmatrix}^{1/2}$$

On solving, we get

or, $$M_{sec} = \frac{0.2 \times 15.7^2}{4.5}[298.14 \times (-0.9\cos 53.2° + 0.9\cos 126.8°) \times 400(-0.6)]\, 5230.62 \text{ N}$$

$$M_{sec} = 6155 \text{ N.m}$$ **Ans.**

6. **(b) Solution:**

(i) Characteristics of Miller indices of planes:

1. When a plane is parallel to any axis, its miller index on that axis is zero.
2. Two parallel planes will have quantitatively the same miller indices. However they may differ in algebraic sign.

3. Two planes ($h_1\ k_1\ l_1$) and ($h_2\ k_2\ l_2$) will be perpendicular, if $h_1h_2 + k_1k_2 + l_1l_2 = 0$.
4. The angle 'θ' between intersecting planes ($h_1\ k_1\ l_1$) and ($h_2\ k_2\ l_2$) given by:

$$\cos\theta = \frac{h_1h_2 + k_1k_2 + l_1l_2}{\left(\sqrt{h_1^2 + k_1^2 + l_1^2}\right)\left(\sqrt{h_2^2 + k_2^2 + l_2^2}\right)}$$

5. Planes having low indices are far away from the origin than those having high indices.

Characteristics of Miller indices of direction:

1. When a direction vector is perpendicular to an axis its miller indices on that axis is zero.
2. Two parallel directions will have quantitatively same miller indices. However they may differ in the algebraic sign of non-zero index.
3. Two directions ($u_1v_1w_1$) and ($u_2v_2w_2$) will be perpendicular if $u_1u_2 + v_1v_2 + w_1w_2 = 0$
4. The angle 'θ' between intersecting directions: ($u_1\ v_1\ w_1$) and ($u_2\ v_2\ w_2$) given by:

$$\cos\theta = \frac{u_1u_2 + v_1v_2 + w_1w_2}{\left(\sqrt{u_1^2 + v_1^2 + w_1^2}\right)\left(\sqrt{u_2^2 + v_2^2 + w_2^2}\right)}$$

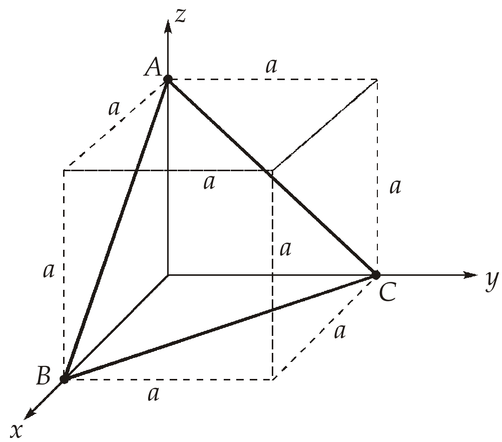
(ii) **Planar density:** Planar density is defined as the number of atoms whose centres are intersected per unit area of the plane under consideration.

$$\text{Planar density } (\rho_{PL}) = \frac{\text{Number of atoms}}{\text{Area of plane}}$$

Linear density: Linear density is defined as the number of atoms whose centres are intersected per unit length of a direction vector.

$$\text{Linear density } (\rho_l) = \frac{\text{Number of atoms}}{\text{Length of direction vector}}$$

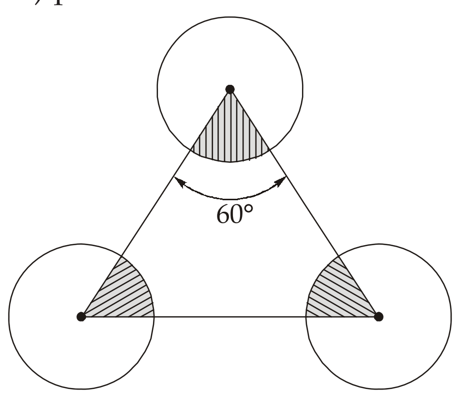
Planar density of (111) plane:



Plane ABC represents (111) plane.

For BCC:

In BCC structure, the plane (111) will not intersect at the centre of the body centered atom. Hence body centered atom should not be considered in the calculation of planer density of (111) plane.



$\therefore$ Total, number of atoms on (111) plane

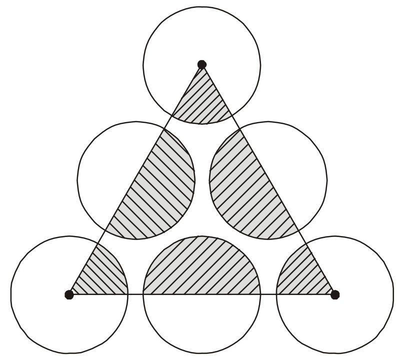
$$= \frac{60}{360} \times 3 = \frac{1}{2}$$

Length of each side of plane (111) = $\sqrt{2}a$

$$\therefore \quad \text{Area of plane (111)} = \frac{\sqrt{3}}{4} \times \left(\sqrt{2}a\right)^2 = \frac{\sqrt{3}}{2}a^2$$

$$\therefore \quad \text{Planar density} = \frac{1/2}{\frac{\sqrt{3}}{2}a^2}$$

For FCC:



$\therefore$ Total, number of atoms on (111) plane

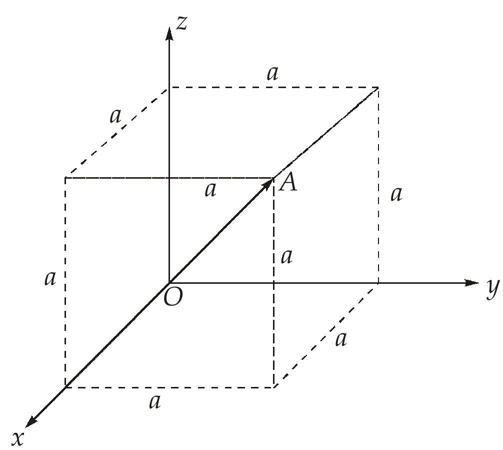
$$= \frac{1}{6} \times 3 + \frac{1}{2} \times 3 = \frac{1}{2} + \frac{3}{2} = 2$$

Length of each side of (111) plane = $\sqrt{2}a$

$$\therefore \quad \text{Area of plane (111)} = \frac{\sqrt{3}}{4} \times \left(\sqrt{2}a\right)^2 = \frac{\sqrt{3}}{2}a^2$$

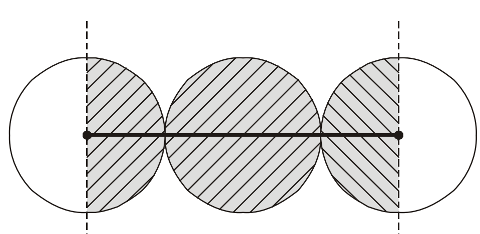
$$\therefore \quad \text{Planar density} = \frac{2}{\frac{\sqrt{3}}{2}a^2}$$

Linear density of [111] direction:



$\overrightarrow{OA}$ vector represents [111] direction vector.

For BCC:

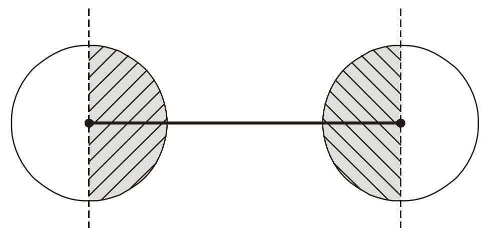


$$\text{Number of atoms} = \frac{1}{2}\times 2+1=2$$

$$\text{Length of the vector [111]} = \sqrt{3}a$$

$$\therefore \quad \text{Linear density} = \frac{2}{\sqrt{3}a}$$

For FCC:

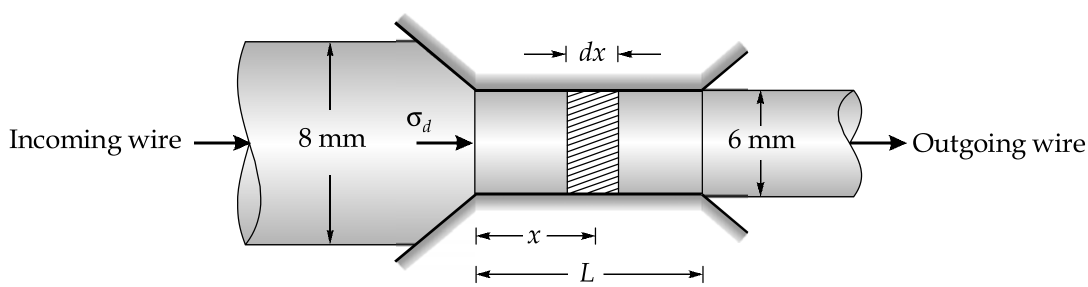


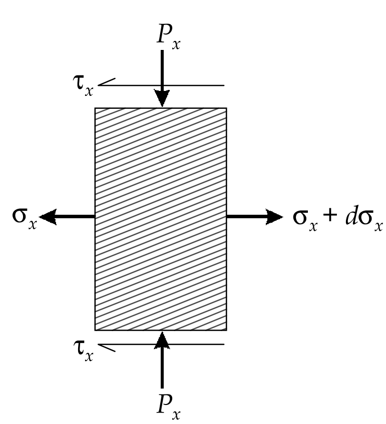
$$\text{Number of atoms} = \frac{1}{2}\times 2=1$$

$$\text{Length of vector [111]} = \sqrt{3}a$$

$$\therefore \quad \text{Linear density} = \frac{1}{\sqrt{3}a}$$

6. (c) Solution:





From equilibrium of forces in horizontal direction,

$$(\sigma_x + d\sigma_x)\pi r_f^2 - \sigma_x \pi r_f^2 - \tau(2\pi r_f dx) = 0$$

$$\Rightarrow \qquad d\sigma_x = \frac{2\tau}{r_f}dx = \frac{2(\mu P_x)}{r_f}dx \qquad \text{...(i)}$$

Considering σ_x and P_x, also due to spherical co-ordinate system both von-mises and tresca will lead to the same result.

$$\sigma_x + P_x = \sigma_o$$
$$P_x = \sigma_o - \sigma_x$$

From equation (i), we get

$$\int \frac{d\sigma_x}{\sigma_o - \sigma_x} = \int \frac{2\mu}{r_f}dx$$

$$\Rightarrow \qquad \ln(\sigma_o - \sigma_x) = \frac{-2\mu}{r_f}x + C_1 \qquad \text{...(ii)}$$

Boundary conditions,

at $x = 0$, $\sigma_x = \sigma_d$

$$\ln(\sigma_o - \sigma_d) = C_1$$

Putting in equation (ii), we get

$$\Rightarrow \qquad \ln(\sigma_o - \sigma_x) = \frac{-2\mu x}{r_f} + \ln(\sigma_o - \sigma_d)$$

$$\Rightarrow \qquad \left(\frac{\sigma_o - \sigma_x}{\sigma_o - \sigma_d}\right) = e^{-\frac{2\mu x}{r_f}}$$

$$\Rightarrow \qquad \sigma_o - \sigma_x = (\sigma_o - \sigma_d)e^{-\frac{2\mu x}{r_f}}$$

$$\Rightarrow \qquad \sigma_x = \sigma_o - (\sigma_o - \sigma_d)e^{-\frac{2\mu x}{r_f}}$$

and
$$\sigma_d = \sigma_o\left(\frac{1+B}{B}\right)\left(1 - \left(\frac{r_f}{r_i}\right)^{2B}\right)$$

Now, $\alpha = 8°$, $\mu = 0.05$, $\sigma_o = 30$ MPa, $r_i = 4$ mm, $r_f = 3$ mm, $L = 4$ mm

and
$$B = \mu\cot\alpha = 0.05\cot(8°) = 0.3557$$

So,
$$\sigma_d = 30\left(\frac{1+0.3557}{0.3557}\right)\left(1 - \left(\frac{3}{4}\right)^{2(0.3557)}\right)$$

$$\sigma_d = 21.1614 \text{ MPa}$$

So,
$$\sigma_x\big|_{x=L} = 30 - (30 - 21.1614)e^{\left(\frac{2\times 0.05\times 4}{3}\right)}$$

$$\sigma_L = 30 - (10.0992) = 19.900 \text{ MPa}$$

So, pull required to draw the wire is

$$= (19.900)\frac{\pi}{4}(6)^2 = 562.680 \text{ N}$$

7. (a) Solution:

The structure of all crystals can be described in terms of a lattice with a group of atoms attached to every lattice point. The group of atoms is called basis. When they are repeated in a space it forms the crystal structure. The basis consist of primitive cell, containing one single lattice point.

Different unit cells and space lattice under bravais crystal system:

Unit cell	Space lattice	Materials
(1) Cubic $a = b = c$ $\alpha = \beta = \gamma = 90°$	Simple cubic	Mn, NaCl
	BCC	Na, W
	FCC	Ni, Au, Ag
(2) Tetragonal $a = b \neq c$ $\alpha = \beta = \gamma = 90°$	Simple Tetragonal	Pb, In
	BCT	Martensite
(3) Orthorhombic $a \neq b \neq c$ $\alpha = \beta = \gamma = 90°$	Simple orthorhombic	As, Bi
	End centered orthorhombic	$MgSO_4$, KNO_3
	Body centered orthorhombic	Cementite
	Face centered orthorhombic	Ga
(4) Rhombohedral $a = b = c$ $\alpha = \beta = \gamma \neq 90°$	Simple Rhombohedral	$CaCO_3$, SiO_2
(5) Hexagonal $a = b \neq c$ $\alpha = \beta = 90°$ $\gamma = 120°$	Hexagonal closed packed	Cobalt, Zinc, Magnesium
(6) Monoclinic $a \neq b \neq c$ $\alpha = \gamma = 90° \neq \beta$	Simple monoclinic	
	End centered monoclinic	
(7) Triclinic $a \neq b \neq c$ $\alpha \neq \beta \neq \gamma \neq 90°$	Simple triclinic	$CuSO_4$

Given : Zn has HCP structure

For HCP, volume of unit cell,

$$V_C = 4.82185\, a^3$$

where, a = side of hexagon and $\frac{c}{a} = 1.856$

Also, $a = 2r$ (where, r = atomic radius of element)

and, $r = 0.133$ nm $= 1.33 \times 10^{-8}$ cm

$$\Rightarrow \quad V_C = 4.82185\,(2r)^3$$

$$= 38.575\, r^3$$

$$V_C = 38.575\,(1.33 \times 10^{-8})^3 = 90.753 \times 10^{-24}\ \text{cm}^3$$

$$N_A = \text{Avogadro's number} = 6.023 \times 10^{23}\ \text{atoms/mol}$$

Now,

$$\text{Density } (\rho) = \frac{nA_{zinc}}{V_C N_A}$$

$$= \frac{(6)(65.39)}{90.753 \times 10^{-24} \times 6.023 \times 10^{23}} \qquad [\because n = 6 \text{ for HCP}]$$

$$\rho_{zinc} = \frac{6 \times 65.39}{54.66} = 7.18\ \text{g/cc}$$

So, theoretical density of zinc is 7.18 g/cc.

7. (b) Solution:

Various Rapid prototyping techniques are:

1. Stereolithography
2. Selective Laser Sintering
3. Laminated object manufacturing (LOM)
4. Optical fabrication
5. Solid base curing
6. Fused deposition modelling (FDM)
7. 3-D printing
8. Ballistic particle manufacturing
9. Photo chemical machining

1. Stereolithography

- In this technique, a computer slices the computer generated design into cross-sections.

- A laser beam is guided by a moving-mirror (under Computer control) which traces each sections of the past to be finished, on the surface of a Vat of liquid resin. The laser radiation (UV light) causes the resin to set, producing a thin layer of the model.
- After one layer is completed, it drops slightly below the surface of the resin bath, so that the next layer can be built on top of it. Like this the complete model is fabricated.

Advantages:

(1) High and better dimensional accuracy as compared to other techniques.

(2) Best surface finish.

(3) Reliable technique since it is well proven.

Disadvantages:

(1) The technique requires support structures.

(2) The components can get warped.

(3) Resin is expensive and can be environmentally hazardous.

2. Selective Laser Sintering :

- Here discrete metal powders particles are joined together into a solid body by selective laser sintering.
- A computer controlled high powered laser beam based on a 3-D CAD programme of the part to be fabricated is focused on a layer of powder, tracing and sintering the defined shape into a solid section. The loose powder supports the sintered layer. The table is then lowered by exact amount and another layer of powder is then deposited on top and the cycle is repeated.
- A new layer of solid mass is produced which gets fused to the lower layers. In this way the entire 3-D model is slowly built-up. The completed part is recovered by shaking off the loose particles.

Advantages:

1. Good range of materials can be used (e.g. polymer, wax etc.)
2. No post curing unless material is ceramic.
3. Relatively low cost of materials.

Disadvantages

1. Long time to heat up and cool down.
2. Porous component (unless copper is used).
3. High initial cost.

7. (c) (i) Solution:

Given : m = 200 kg; I_w = 1.3 kgm^2; r = 0.325 m; I_e = 0.2 kgm^2; R = 30 m;

$$v = \frac{50 \times 1000}{3600} = 13.88 \text{ m/s} ; G = \frac{\omega_e}{\omega_w} = 6; h = 0.59 \text{ m}$$

$$\text{Total gyroscopic couple, } C_G = (2I_w + GI_e)\frac{v^2}{rR}\cos\theta$$

$$C_G = (2 \times 1.3 + 6 \times 0.2)\frac{13.88^2}{0.325 \times 30}\cos\theta$$

$$C_G = 75.085 \cos\theta$$

$$\text{Centrifugal couple, } C_C = \frac{mv^2}{R}h\cos\theta = 200 \times \frac{13.88^2}{30} \times 0.59 \times \cos\theta$$

$$= 757.77 \cos\theta$$

$$\text{Total overturning couple} = (75.085 + 757.77)\cos\theta$$

$$= 832.85 \cos\theta$$

$$\text{Rightening couple} = mgh\sin\theta$$

$$= 200 \times 9.81 \times 0.59 \sin\theta$$

$$= 1157.58 \sin\theta$$

$$\therefore \quad 1157.58 \sin\theta = 832.85 \cos\theta$$

$$\tan\theta = \frac{832.85}{1157.58}$$

$$\theta = 35.734° \quad \textbf{Ans.}$$

7. (c) (ii) Solution:

Given : T_B = 24; T_{c_i} = 30; T_D = 44; T_{c_e} = 36

Action	a/S_1	B/S_2	C	D
'a' is fixed, B is +1 rev	0	1	$\frac{T_B}{T_{C_i}}$	$\frac{T_B}{T_{C_i}} \times \frac{T_{C_e}}{T_D}$
'a' fixed B is $+x$ rev	0	x	$\frac{T_B}{T_{C_i}}x$	$\frac{T_B}{T_{C_i}} \times \frac{T_{C_e}}{T_D} \times x$
Add y	y	$y+x$	$y+\frac{T_B}{T_{C_i}}x$	$y+\frac{T_B}{T_{C_i}} \times \frac{T_{C_e}}{T_D} \times x$

(i) From the given conditions,

$$N_D = y + \frac{24}{30} \times \frac{36}{44} x = 0$$

$$y + \frac{36}{55} x = 0$$

$$y = -\frac{36}{55} x$$

$$\frac{N_{S_1}}{N_{S_2}} = \frac{N_a}{N_B} = \frac{y}{y+x} = \frac{y}{y - \frac{55y}{36}} = -\frac{36}{19} = -1.895$$

(ii)
$$\frac{N_{S_1}}{N_D} = \frac{N_a}{N_D} = \frac{y}{y + \frac{36}{55} x}$$

$$N_B = y + x = 0$$

$$y = -x$$

$\therefore$
$$\frac{N_{S_1}}{N_D} = \frac{-x}{-x + \frac{36}{55} x} = \frac{55}{19} = 2.895$$

If T denotes the torque, so we can written : $\Sigma T.N = 0$

$$T_{S_1} N_{S_1} + T_{S_2} N_{S_2} + T_D N_D = 0$$

or
$$T_{S_2} = -\frac{T_{S_1} N_{S_1}}{N_{S_2}} = + \frac{300 \times 36}{19}$$

$$T_{S_2} = 568.42 \text{ Nm}$$

As number external torque,

So, $\Sigma T = 0$

Also, $T_{S_1} + T_{S_2} + T_D = 0$

$$300 + 568.42 + T_D = 0$$

$$T_D = 868.42 \text{ Nm}$$ **Ans.**

8. (a) Solution:

Given data : M_1 = 5 kg; r_1 = 70 mm; M_2 = 6 kg; r_2 = 80 mm; M_3 = 5 kg; r_3 = 40 mm

Plane	M (kg)	r (m)	mr	θ	Distance from reference plane l (m)	mrl
M_1	5	0.07	0.35	45	0.1	0.035
M_2	6	0.08	0.48	150	0.4	0.192
M_3	5	0.04	0.20	230	0.7	0.140
B_1 (RP)	B_1	0.08	$0.08B_1$	θ_1	0	0
B_2	B_2	0.08	$0.08B_2$	θ_2	0.8	$0.064B_2$

Moment equation,

$$\Sigma m_i r_i l_i \cos\theta_i = 0$$

$$0.035\cos45 + 0.192\cos150 + 0.140\cos230 + 0 + 0.064B_2\cos\theta_2 = 0$$

$$B_2\cos\theta_2 = +3.6174 \quad \text{...(i)}$$

$$\Sigma m_i r_i l_i \sin\theta_i = 0$$

$$0.035\sin45 + 0.192\sin150 + 0.140\sin230 + 0 + 0.064B_2\sin\theta_2 = 0$$

$$B_2\sin\theta_2 = -0.211 \quad \text{...(ii)}$$

Square and add equation (i) and (ii),

$$B_2 = \sqrt{3.6174^2 + 0.211^2} = 3.6235 \text{ kg}$$

Equation (ii) / (i), $\tan\theta_2 = -\dfrac{0.211}{3.6174}$

IVth quadrant, $\theta_2 = 356.66°$ [As cosθ is positive and sinθ is negative]

Force equation, $\Sigma m_i r_i \cos\theta_i = 0$

$$0.35\cos45 + 0.48\cos150 + 0.20\cos230 + 0.08B_1\cos\theta_1 + 0.08 \times 3.6235 \times \cos 356.66 = 0$$

$$B_1\cos\theta_1 = 0.09218 \quad \text{...(iii)}$$

$$\Sigma m_i r_i \sin\theta_i = 0$$

$$0.35\sin45 + 0.48\sin150 + 0.20\sin230 + 0.08B_1\sin\theta_1 + 0.08 \times 3.6235 \times \sin 356.66 = 0$$

$$B_1\sin\theta_1 = -3.9677 \quad \text{...(iv)}$$

Square and add equation (iii) and (iv),

$$B_1 = \sqrt{0.09218^2 + 3.9677^2}$$

$$B_1 = 3.968 \text{ kg}$$

Equation (iv)/(iii), $\tan\theta_1 = -\dfrac{3.9677}{0.09218}$ [As cosθ is positive and sinθ is negative]

IVth quadrant $\theta_1 = 271.33°$

8. **(b) Solution:**

For a continuous and oriented fiber reinforced composite,

(i) Moduli of elasticity in longitudinal direction:

Let, E_m = Modulus of elasticity of matrix phase

E_f = Modulus of elasticity of fiber phase

E_{ct} = Modulus of elasticity of transverse direction

E_{cl} = Modulus of elasticity of longitudinal direction

We know, $V_m + V_f = 1$

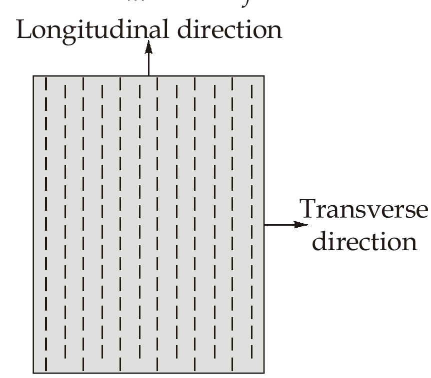
$$V_m = 1 - V_f$$

So,

$$E_{cl} = (1 - V_f)\,E_m + V_f\,E_f$$

$$33 = (1 - 0.3)E_m + 0.3E_f$$

$$33 = 0.7E_m + 0.3E_f \quad \text{... (i)}$$



Continuous and aligned fiber reinforced composites

(ii) Moduli of elasticity in transverse direction:

When a continuous and oriented fiber reinforced composite is loaded in transverse direction, the stress σ to which the composite as well as both phases (matrix and fiber) are exposed is the same.

So, $\sigma_c = \sigma_m = \sigma_f = \sigma$

It is termed as the isostress state. The strain or the deformation of the entire composite ϵ_c is given by

$$\in_c = \in_m V_m + \in_f V_f \quad \text{... (ii)}$$

Where,

$\in_m$ = Strain in the matrix phase

$\in_f$ = Strain in the fiber phase

V_f = Volume fraction of fiber phase

V_m = Volume fraction of matrix phase

We know that, $\in = \dfrac{\sigma}{E}$

From equation (ii), we get

$$\frac{\sigma_c}{E_{ct}} = V_m\left(\frac{\sigma_m}{E_m}\right) + V_f\left(\frac{\sigma_f}{E_f}\right)$$

and $\sigma_c = \sigma_m = \sigma_f = \sigma$

$$\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$$

$$E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m}$$

$$3.65 = \frac{E_m E_f}{(1 - V_f)E_f + V_f E_m}$$

$$3.65 = \frac{E_m E_f}{(1 - 0.3)E_f + 0.3E_m}$$

$$3.65 = \frac{E_m E_f}{0.7E_f + 0.3E_m} \quad \text{... (iii)}$$

From equation (i), we have,

$$0.7E_m + 0.3E_f = 33$$

$$0.3E_f = 33 - 0.7E_m$$

$$E_f = \frac{10}{3}(33 - 0.7E_m)$$

Putting value of E_f is equation (iii), we get

$$3.65 = \frac{E_m\left[\frac{10}{3}(33 - 0.7E_m)\right]}{0.7\left[\frac{10}{3}(33 - 0.7E_m)\right] + 0.3E_m}$$

$$3.65\left(77 - \frac{49}{30}E_m + \frac{3}{10}E_m\right) = 110E_m - \frac{7}{3}E_m^2$$

$$\frac{7}{3}E_m^2 - 114.867E_m + 281.05 = 0$$

$$E_m = 46.64 \text{ GPa}, 2.58 \text{ GPa}$$

When, $E_m = 46.64$ GPa

$$E_f = \frac{10}{3}(33 - 0.7 \times 46.64) = 1.173 \text{ GPa}$$

and when $E_m = 2.58$ GPa,

$$E_f = \frac{10}{3}(33 - 0.7 \times 2.58) = 103.98 \text{ GPa}$$

Modulus of elasticity of matrix phase,

$$E_m = 2.58 \text{ GPa or } E_m = 46.64 \text{ GPa}$$

Modulus of elasticity of fiber phase,

$$E_f = 103.98 \text{ GPa or } E_m = 103.98 \text{ GPa}$$

8. (c) Solution:

Non-Ferrous materials are also used in engineering applications for their specific and special properties compared to Ferrous alloys inspite of their generally high cost.

Desired mechanical properties can be obtained in these alloys by work-hardening, age hardening etc, but not through normal heat treatment processes used for ferrous alloys.

(1) **Aluminium** of all the non-ferrous alloys, aluminium and its alloys are the most important because of their excellent properties. Some properties of pure aluminium for which it is used in engineering industry are

(i) Excellent thermal conductivity and electrical conductivity

(ii) Low mass - density (2.7g/cm^3)

(iii) Low melting point.

(iv) Excellent corrosion resistance, aluminium - oxide protects parent aluminium from further oxidation.

(v) Non-toxic

(vi) Highly reflective

(vii) Highly ductile.

Applications: Duralumin is used in forged pistons and general purpose aerospace engineering.

(2) Copper:

(i) High electrical and excellent thermal conductivity

(ii) Comparatively high mass density (8.96 g/cm^3)

(iii) Resists corrosion

(iv) It can be joined together by brazing.

(v) Applications: Used to manufacture electrical wires, bus-bars, transmission cable, refrigerator tubing & pipes.

Copper alloys

Gun Metal: Used in bearings, bushes

Admiralty Brass: Used in heat exchangers.

(3) Zinc :

- Zinc is principally used in engineering because of its low melting temperature (419°C) and higher corrosion resistance, which increases with purity of zinc. The corrosion resistance is caused by the formation of a protective oxide coating on the surface.
- Principal applications of zinc are in galvanising to protect steel from corrosion, in printing industry and for die casting.
- The disadvantages of zinc are the strong anisotropy exhibited under deformed conditions, lack of dimensional stability under ageing conditions, a reduction in impact strength at lower temperatures and the susceptibility to intergranular corrosion. It cannot be used for service above a temperature of 95°C because it will cause substantial reduction in tensile strength and hardness.
- Its widespread use in die casting because it requires lower pressure, which results in higher life of die.

(4) Magnesium:

(i) Light weight and good mechanical strength.

(ii) Used in aerospace industries where low density to strength ratio is required.

(iii) For same stiffness, magnesium alloys require only 37.2% of the weight of C25 steel.

(iv) Two principal alloying elements used are aluminium and zinc.

Applications: Used for making automobile wheels, crank cases etc.