



MADE EASY
Leading Institute for ESE, GATE & PSUs

Detailed Solutions

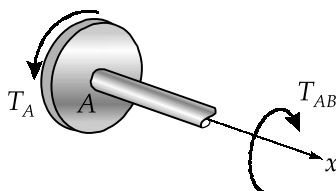
**ESE-2026
Mains Test Series**

**Mechanical Engineering
Test No : 15**

Section : A

1. (a) Solution:

Denoting by T_{AB} the torque in shaft AB , we pass a section through shaft AB and, for F.B.D. shown



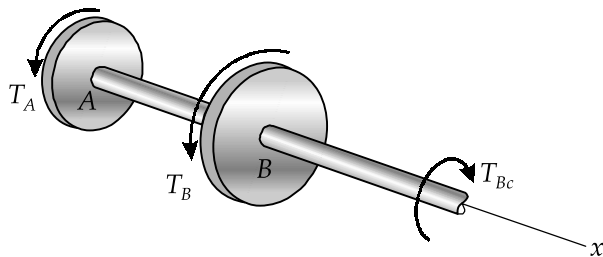
$$\sum M_x = 0$$

$$6 - T_{AB} = 0$$

\Rightarrow

$$T_{AB} = 6 \text{ kNm}$$

We now pass a section through shaft BC and, for the FBD shown



$$\sum M_x = 0$$

$$6 + 14 - T_{BC} = 0$$

$$\Rightarrow T_{BC} = 20 \text{ kNm}$$

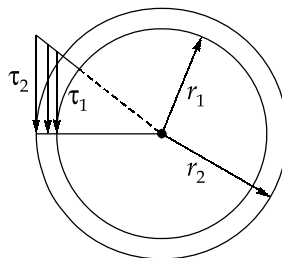
(i) **Shaft BC** : For hollow shaft we have

$$J = \frac{\pi}{32}(0.12^4 - 0.09^4) = 13.916 \times 10^{-6} \text{ m}^4$$

Maximum shearing stress : On the outer surface,

$$\begin{aligned} \tau_{\max} = \tau_2 &= \frac{T_{BC} \times \frac{d_2}{2}}{J} = \frac{20 \times 10^3 \times 0.060}{13.916 \times 10^{-6}} \\ &= 86.23 \text{ MPa} \end{aligned}$$

Minimum shear stress : We know that stresses are proportional to the distance from the axis of shaft.



$$\frac{\tau_{\min}}{\tau_{\max}} = \frac{D_1}{D_2}$$

$$\begin{aligned} \Rightarrow \tau_{\min} &= 86.23 \times \frac{90}{120} \\ \tau_{\min} &= 64.67 \text{ MPa} \end{aligned}$$

Shaft AB and CD : As we know that in both of these shafts the torque $T = 6 \text{ kNm}$ and $\tau_{\max \text{ per}} = 65 \text{ MPa}$.

$$\text{So, } \tau = \frac{T \times \frac{d}{2}}{J} \quad [\text{where } d = \text{diameter of these shafts}]$$

$$\text{So, } 65 = \frac{6 \times 10^3 \times 10^3 \times d}{2 \times \frac{\pi}{32} \times d^4}$$

$$d^3 = 470119.21 \text{ mm}^3$$

$$\Rightarrow \text{Required diameter, } d = 77.75 \text{ mm}$$

1. (b) Solution:

Given data : $C_s = 1.6\%$; $P = 50 \text{ kW}$; $N = 140 \text{ rpm}$; $\sigma = 3.8 \text{ MPa}$; $b = 3t$; $\rho = 7600 \text{ kg/m}^3$

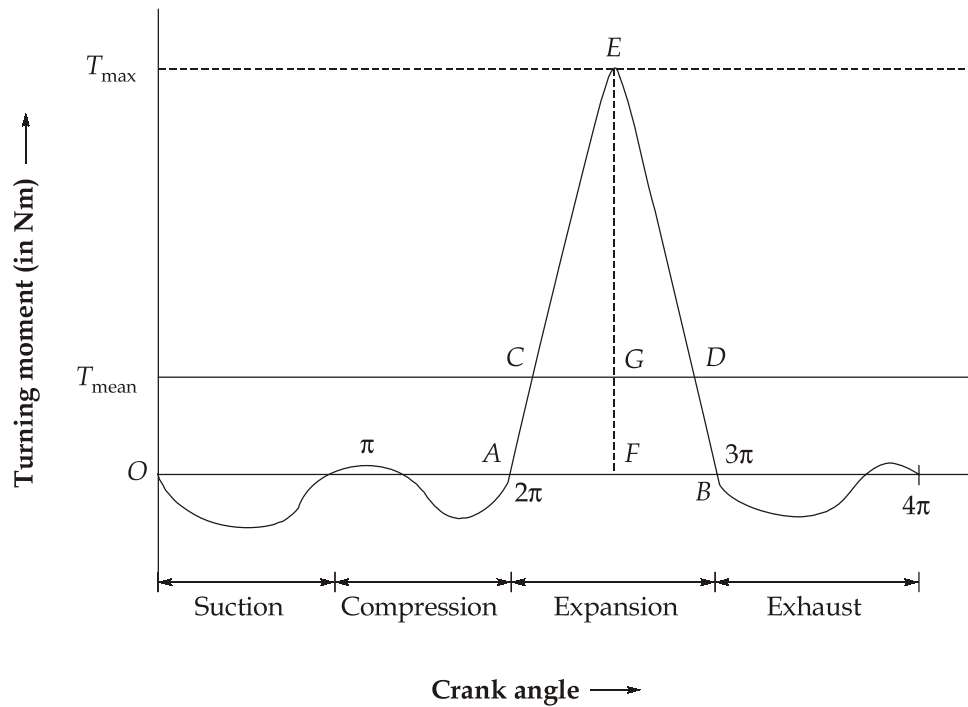
As the number of explosion are half the speed of engine, it is a four-stroke engine and the cycle is completed in 4π radians.

$$P = \frac{2\pi NT}{60}$$

$$50000 = \frac{2\pi \times 140 \times T_{\text{mean}}}{60}$$

$$T_{\text{mean}} = 3410.46 \text{ Nm}$$

The turning moment diagram is shown in the figure below.



$$\text{Energy produced per cycle} = 3410.46 \times 4\pi = 42857.14 \text{ Nm}$$

$$\begin{aligned} \text{Energy produced during expansion stroke} &= 42857.14 \times 1.5 \\ &= 64285.71 \text{ Nm} \end{aligned}$$

$$\text{The work done or energy produced during the power stroke} = \frac{T_{\text{max}} \times \pi}{2} = 64285.71$$

$$T_{\text{max}} = 40925.55 \text{ Nm}$$

$$\text{In triangle } ABE, \quad \frac{CD}{AB} = \frac{EG}{EF} = \frac{40925.55 - 3410.46}{40925.55} = 0.91666$$

or $CD = 0.91666 \times \pi$

$$CD = 2.8797 \text{ rad}$$

Maximum fluctuation of energy,

$$\begin{aligned} e &= \text{Area CDE} = \frac{CD \times EG}{2} \\ &= \frac{2.8797}{2} \times (40925.55 - 3410.46) = 54016.102 \text{ Nm} \end{aligned}$$

For strength consideration, the hoop stress,

$$\sigma = \rho v^2$$

or $3.8 \times 10^6 = 7600 \times v^2$

$$v = 22.36 \text{ m/s}$$

$$v = \frac{\pi d N}{60}$$

$$22.36 = \frac{\pi \times d \times 140}{60}$$

$$d = 3.05 \text{ m}$$

$$\text{Energy stored in the rim} = \frac{54016.102}{1.2} = 45013.418 \text{ Nm}$$

Now, $k = \frac{\text{Energy stored in the rim}}{I\omega^2} = \frac{\text{Energy stored in the rim}}{mk^2\omega^2}$

$$0.016 = \frac{45013.418}{m \left(\frac{3.05}{2} \right)^2 \times \left(\frac{2\pi \times 140}{60} \right)^2}$$

$$m = 5628.19 \text{ kg}$$

$$\text{Density} \times \text{Volume} = 5628.19 \text{ kg}$$

$$\rho \times \pi d \times t \times 3t = 5628.19$$

$$7600 \times \pi \times 3.05 \times 3 \times t^2 = 5628.19$$

$$t = 0.1605 \text{ m}$$

$$t = 160.506 \text{ mm}$$

$$b = 3t = 3 \times 160.506 = 481.52 \text{ mm}$$

Ans

1. (c) Solution:

Given : $m = 1800$ kg; $V = 2$ m/s; $\delta = 170$ mm; $c = 8$, $G = 82375$ MPa; $\tau = 200$ MPa

Wire diameter

The kinetic energy of the moving wagon is absorbed by the springs.

$$\begin{aligned} \text{K.E. of wagon} &= \frac{1}{2}mv^2 = \frac{1}{2} \times 1800 \times 2^2 \\ &= 3600 \text{ N-m} = 3600 \times 10^3 \text{ N-mm} \end{aligned}$$

Suppose P is the maximum force acting on each spring and causing it to compress by 170 mm.

The strain energy absorbed by two springs.

$$E = \frac{1}{2} \times 2 \times P \times \delta = 170PN\text{-mm}$$

The strain energy absorbed by two springs is equal to the kinetic energy of the wagon.

$$170P = 3600 \times 10^3$$

or,

$$P = 21176.4705 \text{ N}$$

$$K = \frac{4c-1}{4c-4} + \frac{0.615}{c} = \frac{4 \times 8 - 1}{4 \times 8 - 4} + \frac{0.615}{8} = 1.184$$

We know,

$$\tau = K \left(\frac{8Pc}{\pi d^2} \right)$$

$$200 = 1.184 \left(\frac{8 \times 21176.4705 \times 8}{\pi \times d^2} \right)$$

or,

$$d = 50.54$$

Ans.

$$\text{Mean coil diameter, } D = cd = 8 \times 50.54 = 404.32 \text{ mm}$$

Ans.

Number of active coils,

$$\text{We know, } \delta = \frac{8PD^3N}{Gd^4}$$

$$170 = \frac{8 \times 21176.4705 \times (404.32)^3 N}{(82375) \times (50.54)^4}$$

or

$$N = 8.16 \text{ or } 9 \text{ coils}$$

Ans.

1. (d) Solution:

Let us first find out the centre of gravity of the section.

Before finding C.G. let us name triangular section as (1) and rectangular section as (2).

As the section is symmetrical about YY-axis. Therefore C.G. will lie on this axis, let BC be the axis of reference.

$$\text{For triangular section, } A_1 = \frac{1}{2} \times 100 \times 90 = 4500 \text{ mm}^2$$

$$y_1 = \frac{90}{3} = 30 \text{ mm}$$

$$\text{For rectangular section, } A_2 = 30 \times 20 = 600 \text{ mm}^2$$

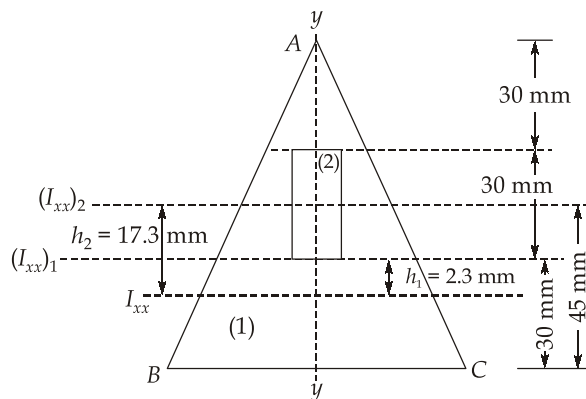
$$y_2 = 30 + 15 = 45 \text{ mm}$$

Distance between C.G. of section and base BC.

$$\bar{y} = \frac{A_1 y_1 - A_2 y_2}{A_1 - A_2} = \frac{(4500 \times 30) - (600 \times 45)}{4500 - 600}$$

$$\bar{y} = 27.6923 \text{ mm}$$

$$\bar{y} \approx 27.7 \text{ mm}$$



Moment of inertia (M.O.I.) of section (1) about its C.G.

$$(I_{XX})_1 = \frac{bh^3}{36} = \frac{100 \times 90^3}{36}$$

$$(I_{XX})_1 = 2025 \times 10^3 \text{ mm}^4$$

Distance between C.G. of triangular section and XX-axis

$$h_1 = 30 - 27.7 = 2.3 \text{ mm}$$

Distance between C.G. of rectangular section and XX-axis

$$h_2 = 15 + 2.3 = 17.3 \text{ mm}$$

$$\therefore \text{M.O.I. of section (1) about XX-axis} = (I_{XX})_1 + A_1 h_1^2 = 2025 \times 10^3 + 4500 \times 2.3^2 \\ = 2048805 \text{ mm}^4$$

$$\text{M.O.I. of section (2) about XX-axis} = (I_{XX})_2 + A_2 h_2^2 = \frac{20 \times 30^3}{12} + 600 \times (17.3)^2 \\ = 224574 \text{ mm}^4$$

M.O.I. of whole section about XX-axis

$$I_{XX} = (I_{XX})_1 - (I_{XX})_2 = 2048805 - 224574 = 1824231 \\ I_{XX} \approx 1.824 \times 10^6 \text{ mm}^4$$

Ans.

M.O.I. of triangular section about its base BC,

$$I = \frac{bh^3}{12} = \frac{100 \times (90)^3}{12} \Rightarrow 6.075 \times 10^6 \text{ mm}^4$$

$$\text{M.O.I. of rectangular section about base BC} = (I_{XX})_2 + A_2 y_2^2 = \frac{20 \times 30^3}{12} + 600 \times (45)^2 \\ = 1.26 \times 10^6 \text{ mm}^4$$

$$\text{Moment of inertia of whole section about its base BC} = 6.075 \times 10^6 + 1.26 \times 10^6 \\ = 4.815 \times 10^6 \text{ mm}^4$$

Ans.

1. (e) Solution:

(i) Equation of motion can be written as

$$m\ddot{x} + c\dot{x} + kx = 0$$

and solution is given by, $x = e^{-\xi\omega_n t} [A \cos \omega_d t + B \sin \omega_d t]$... (i)

$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{3000}{20}} = 12.25 \text{ rad/s}$$

$$\xi = \frac{C}{2m\omega_n} = \frac{120}{2 \times 20 \times 12.25} = 0.245$$

$$\text{Damped frequency, } \omega_d = \omega_n \sqrt{1 - \xi^2} = 12.25 \sqrt{1 - 0.245^2} \\ = 11.88 \text{ rad/s}$$

Ans.

(ii) Substituting the values of ω_n , ω_d and ξ in equation (i), we get

$$x = e^{-0.245 \times 12.25 t} [A \cos(11.88t) + B \sin(11.88t)] \\ = e^{-3t} [A \cos(11.88t) + B \sin(11.88t)] \quad \dots \text{(ii)}$$

at $t = 0$, $x = 0$;

$$0 = e^{(0)} \{A \cos 0 + B \sin 0\}$$

$$\Rightarrow \begin{aligned} A &= 0 \\ x &= e^{-3t} \cdot B \sin(11.88t) \\ \dot{x} &= \left(\frac{dx}{dt} \right) = B \left[e^{-3t} \cos(11.88t) \times 11.88 - 3e^{-3t} \sin(11.88t) \right] \end{aligned}$$

$$\begin{aligned} \text{at } t = 0, \dot{x} &= 0.2 \text{ m/s} & 0.2 &= B[e^0 \cos(0) \times 11.88 - 3e^0 \sin 0] \\ & & B &= 0.0168 \end{aligned}$$

Displacement equations;

$$x = 0.0168 e^{-3t} \sin(11.88t) \Rightarrow f(t) \text{ only}$$

Velocity equations,

$$\dot{x} = 0.0168 e^{-3t} [11.88 \cos(11.88t) - 3 \sin(11.88t)]$$

(iii) $t = 0.5$ second

$$\begin{aligned} x &= 0.0168 e^{-3 \times 0.5} \sin(11.88 \times 0.5) \\ x \text{ at } 0.5 \text{ s} &= -1.261 \times 10^{-3} \text{ m} \end{aligned}$$

or 1.261 mm above mean position

Ans.

$$\begin{aligned} \text{(iv)} \quad \dot{x} \text{ at } 0.5 \text{ s} &= 0.0168 e^{-3 \times 0.5} [11.88 \cos(11.88 \times 0.5) - 3 \sin(11.88 \times 0.5)] \\ &= 0.046 \text{ m/s (in downward direction)} \end{aligned}$$

Ans.

2. (a) (i) Solution:

Given: $L = 1.2 \text{ m}$, $d = 80 \text{ mm}$, $t = 2 \text{ mm}$, $\Delta V = 20 \text{ cm}^3$.

$$\text{Volume} = \frac{\pi}{4} (d^2) L = \frac{\pi}{4} \times (80)^2 \times 1200 = 6031.9 \times 10^3 \text{ mm}^3$$

Let P be change in pressure.

$$\text{For tube, Hoop stress } (\sigma_h) = \frac{P \times d}{2t} = \frac{P(80)}{2 \times 2} = 20P \text{ (tensile)}$$

$$\text{Longitudinal stress } (\sigma_L) = \frac{P \times d}{4t} = \frac{20P}{2} = 10P \text{ (tensile)}$$

$$\text{Volumetric strain in tube, } \epsilon_V = \epsilon_l + 2\epsilon_D = \frac{1}{E} [\sigma_L - \mu \sigma_h] + 2 \frac{1}{E} [\sigma_h - \mu \sigma_L]$$

$$\epsilon_V = \frac{1}{E} [10P - 0.3 \times 20P] + \frac{2}{E} [20P - 0.3 \times 10P]$$

$$\epsilon_V = \frac{38P}{E} \text{ (increase)}$$

$$\text{Volumetric strain in water} = \frac{P}{K}$$

$$\frac{\Delta V}{V} = \frac{P}{K}$$

$$\text{Change in volume, } \Delta V = \frac{PV}{K}$$

Volume of the water pumped = Volumetric change in tube + Volumetric change in water

$$20 \times 1000 = \frac{38PV}{E} + \frac{PV}{K}$$

$$20 \times 1000 = P \times 6031.9 \times 10^3 \left[\frac{38}{1.02 \times 10^5} + \frac{1}{2.1 \times 10^3} \right]$$

$$P = 3.9066 \text{ N/mm}^2$$

Ans.

2. (a) (ii) Solution:

Given: $r_i = 100 \text{ mm}$, $r_o = 150 \text{ mm}$, $p_i = 60 \text{ MN/m}^2$, $p_o = 30 \text{ MN/m}^2$

For thick cylinder, using Lamé's equation,

$$\text{Radial stress, } \sigma_r = A - \frac{B}{r^2}$$

$$\text{Hoop stress, } \sigma_\theta = A + \frac{B}{r^2}$$

Using boundary conditions,

at $r = r_i = 100 \text{ mm}$,

$$\sigma_r = -p_i = -60$$

$$A - \frac{B}{100^2} = -60 \quad \dots \text{ (i)}$$

at $r = r_o = 150 \text{ mm}$,

$$\sigma_r = -p_o = -30$$

$$A - \frac{B}{150^2} = -30 \quad \dots \text{ (ii)}$$

On solving equation (i) and (ii)

$$B = 540000$$

$$A = -6$$

$$\text{Radial stress, } \sigma_r = -6 - \frac{540000}{r^2}$$

$$\text{Hoop stress, } \sigma_\theta = -6 + \frac{540000}{r^2}$$

where, σ is MN/m^2 , r in mm .

Stresses at inner surface, $r = 100$ mm

$$\text{Radial stress, } \sigma_r = -6 - \frac{540000}{10000} = -60 \text{ MN/m}^2$$

$$\text{Hoop stress, } \sigma_\theta = -6 + \frac{540000}{10000} = 48 \text{ MN/m}^2$$

Stress at outer surface, $r = 150$ mm

$$\text{Radial stress, } \sigma_r = -6 - \frac{540000}{150^2} = -30 \text{ MN/m}^2$$

$$\text{Hoop stress, } \sigma_\theta = -6 + \frac{540000}{150^2} = 18 \text{ MN/m}^2$$

Since, cylinder is closed at both ends, so longitudinal stress,

$$\sigma_L(r_o^2 - r_i^2) = p_i r_i^2 - p_o r_o^2$$

$$\sigma_L = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} = \frac{60 \times 100^2 - 30 \times 150^2}{150^2 - 100^2}$$

$$= -6 \text{ MN/m}^2$$

Ans.

2. (b) Solution:

Given data : $\phi = 20^\circ$; $G = 12$; $C = 325$ mm; $P = 380$ kW; $N_p = 1900$ rpm; $P = 1.2$ kN/mm of width

$$G = \frac{T_g}{T_p} = \frac{d_g}{d_p} = 12 \text{ or } d_g = 12 d_p \quad \dots(i)$$

$$C = \frac{d_p + d_g}{2} \text{ or } d_p + d_g = 2 \times 325$$

$$d_p + d_g = 650 \quad \dots(ii)$$

From (i) and (ii), $d_p = 50$ mm, $d_g = 600$ mm

Minimum number of teeth on gear wheel,

$$T_{\min} = \frac{2a_w}{\sqrt{1 + \frac{1}{G} \left(\frac{1}{G} + 2 \right) \sin^2 \phi} - 1}$$

$$= \frac{2 \times 1}{\sqrt{1 + \frac{1}{12} \left(\frac{1}{12} + 2 \right) \sin^2 20} - 1}$$

$$T_{\min} = 197.95 \text{ or } 198$$

$$(i) \text{ Number of teeth on pinion} = \frac{198}{12} = 16.5 \text{ or } 17$$

∴ Number of teeth on gear wheel = 17×12

$$T = 204 \text{ teeth}$$

$$(ii) \quad m = \frac{d_p}{t} = \frac{50}{17} = 2.941 \text{ say } 3$$

$$\text{Exact } d_p = m \times t = 3 \times 17 = 51 \text{ mm}$$

and

$$\text{Exact } d_g = m \times T = 3 \times 204 = 612 \text{ mm}$$

Exact centre distance,

$$C = \frac{d_g + d_p}{2} = \frac{51 + 612}{2} = 331.5 \text{ mm}$$

$$(iii) \quad P = \frac{2\pi NT}{60}$$

$$380 \times 10^3 = \frac{2\pi \times 1900 \times T}{60}$$

$$T = 1909.859 \text{ Nm}$$

$$\text{Tangential force} = \frac{1909.859 \times 10^3}{\frac{51}{2}} = 74896.44 \text{ N}$$

$$\text{Normal pressure on the tooth} = \frac{F}{\cos \phi} = \frac{74896.44}{\cos 20^\circ} = 79703.13 \text{ N}$$

$$\text{Width of pinion} = \frac{F_n}{\text{Limited normal pressure}}$$

$$w = \frac{79703.13}{1200} = 66.419 \text{ mm}$$

$$w = 66.419 \text{ mm}$$

Ans.

2. (c) Solution:

1. As the diameter of the journal (d) = 100 mm

Length of the journal (l) = $1.2d$

$$l = 1.2 \times 100 = 120 \text{ mm}$$

2. Bearing pressure, $p = \frac{W}{l \times d} = \frac{22000}{120 \times 100} = 1.83 \text{ N/mm}^2$

Since maximum bearing pressure for the pump is 3.50 N/mm^2 . therefore the above value of p is safe and hence dimensions of l and d are safe.

$$3. \quad \frac{Z.N}{p} = \frac{0.045 \times 850}{3.5} = 10.928$$

From table, we find the value of

$$\frac{Z.N}{p} = 12.8$$

that the minimum value of the bearing modulus at which the oil film will break is given by

$$3k = \frac{Z.N}{p}$$

$$k = \frac{1}{3} \left(\frac{Z.N}{p} \right) = \frac{1}{3} \times 12.8 = 4.26$$

Since the calculated value of bearing characteristics number $\left(\frac{Z.N}{p} = 10.928 \right)$ is more

than 4.26. Therefore the bearing will operate under hydrodynamic conditions.

4. From table, we find that for pumps, the clearance ratio (c/d)

$$= 0.0010$$

$$5. \quad \text{Coefficient of friction, } \mu = \frac{33}{10^8} \left(\frac{Z.N}{p} \right) \times \frac{d}{c} + 0.002$$

$$= \frac{33}{10^8} \times 10.928 \times \frac{1}{0.001} + 0.002 = 0.0056$$

$$\text{Heat generated, } Q_g = \mu Wv = 0.0056 \times 22000 \times \left(\frac{\pi \times 0.1 \times 850}{60} \right)$$

$$= 548.3126 \text{ W}$$

$$\text{Heat dissipated, } Q_d = CA(t_b - t_a) \quad [A = l \times d]$$

where

$$t_b - t_a = \frac{1}{2}(t_0 - t_a) = \frac{1}{2}(55 - 15.5) = 19.75^\circ \text{C}$$

$$= 1332 \times 0.12 \times 0.10 \times 19.75 = 315.684 \text{ W}$$

Since $Q_g > Q_d$

$$\text{Excess heat} = Q_g - Q_d = 548.3126 - 315.684$$

$$\Delta Q = 232.6286 \text{ W}$$

Mass of lubricating oil required for artificial cooling.

$$\begin{aligned}
 Q_t &= \Delta Q \\
 \dot{m} \times S_{\text{oil}} \times \Delta t &= \Delta Q \\
 \dot{m} \times 2000 \times 15 &= 232.6286 \\
 \dot{m} &= 7.75429 \times 10^{-3} \text{ kg/s} \\
 &= 0.465 \text{ kg/min} \\
 &= 27.9154 \text{ kg/hr}
 \end{aligned}$$

3. (a) (i) Solution:

As per given data,

$$\begin{aligned}
 \sigma_{yt} &= 450 \text{ MPa} \\
 \sigma_e &= 280 \text{ MPa} \\
 (\sigma_x)_{\min} &= 75 \text{ MPa}, (\sigma_x)_{\max} = 120 \text{ MPa} \\
 (\sigma_y)_{\min} &= 20 \text{ MPa}, (\sigma_y)_{\max} = 100 \text{ MPa} \\
 (\tau_{xy})_{\min} &= 10 \text{ MPa}, (\tau_{xy})_{\max} = 60 \text{ MPa} \\
 (\sigma_x)_m &= \frac{(\sigma_x)_{\min} + (\sigma_x)_{\max}}{2} = \frac{75 + 120}{2} = 97.5 \text{ MPa} \\
 (\sigma_x)_a &= \frac{(\sigma_x)_{\max} - (\sigma_y)_{\min}}{2} = \frac{120 - 75}{2} = 22.5 \text{ MPa} \\
 (\sigma_y)_m &= \frac{(\sigma_y)_{\max} + (\sigma_y)_{\min}}{2} = \frac{100 + 20}{2} = 60 \text{ MPa} \\
 (\sigma_y)_a &= \frac{(\sigma_y)_{\max} - (\sigma_y)_{\min}}{2} = \frac{100 - 20}{2} = 40 \text{ MPa} \\
 (\tau_{xy})_m &= \frac{(\tau_{xy})_{\max} + (\tau_{xy})_{\min}}{2} = \frac{60 + 10}{2} = 35 \text{ MPa} \\
 (\tau_{xy})_a &= \frac{(\tau_{xy})_{\max} - (\tau_{xy})_{\min}}{2} = \frac{60 - 10}{2} = 25 \text{ MPa}
 \end{aligned}$$

From Distortion Energy theory

$$\begin{aligned}
 \sigma^2 &= \frac{1}{2} [(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)] \\
 \sigma_z &= \tau_{yz} = \tau_{zx} = 0 \\
 \sigma^2 &= \frac{1}{2} [(\sigma_x - \sigma_y)^2 + (\sigma_y)^2 + (\sigma_x)^2 + 6\tau_{xy}^2]
 \end{aligned}$$

For equivalent mean stress :

$$\sigma_m^2 = \frac{1}{2}[(\sigma_{xm} - \sigma_{ym})^2 + (\sigma_{my})^2 + (\sigma_{xm})^2 + 6(\tau_{xym}^2)]$$

$$\sigma_m^2 = \frac{1}{2}[(97.5 - 60)^2 + (60)^2 + (97.5)^2 + 6 \times 35^2]$$

$$\sigma_m = 104.55 \text{ MPa}$$

Equivalent amplitude stress

$$\sigma_a^2 = \frac{1}{2}[(\sigma_{xa} - \sigma_{ya})^2 + (\sigma_{ya})^2 + (\sigma_{xa})^2 + 6 \times \tau_{xya}^2]$$

$$\sigma_a^2 = 0.5 \times [(22.5 - 40)^2 + (40)^2 + (22.5)^2 + 6 \times 25^2]$$

$$\sigma_a = 55.509 \text{ MPa}$$

From Soderberg equation,

$$\frac{\sigma_a}{\sigma_e} + \frac{\sigma_m}{\sigma_{yt}} = \frac{1}{N}$$

$$\frac{55.509}{280} + \frac{104.55}{450} = \frac{1}{N}$$

$$N = 2.322$$

3. (a) (ii) Solution:

Assume old clutch (UWT)

n = No. of contact surfaces = 2 (i.e., effective on both sides)

N_1 = Driver shaft speed = 260 rpm

μ = 0.20

R_i = Inner radius of friction lining = 70 mm

R_o = Outer radius of friction lining = 140 mm

P_{per} = 140 kPa = 0.14 MPa

I = M.O.I. of rotating parts = 9 kg.m²

(1) As per uniform wear theory,

$$(T_f)_{\text{UWT}} = [n \cdot \pi \cdot \mu \cdot P_{\text{per}} R_i (R_o^2 - R_i^2)]$$

$$= 2 \times \pi \times 0.20 \times 0.14 \times 70 (140^2 - 70^2)$$

$$(T_f)_{\text{UWT}} = 181.031 \times 10^3 = 181.031 \text{ N.m}$$

$$T_f = I \cdot \alpha$$

$$\alpha = \frac{T_f}{I} = \frac{181.031}{9} = 20.1145 \text{ rad/s}^2$$

$$(\omega_2)_f = (\omega_2)_i + \alpha t$$

$$\frac{2\pi N_1}{60} = 0 + (20.1145)t$$

$$\frac{2\pi \times 260}{60} = 20.1145 \times t$$

⇒

$$t = 1.3536 \text{ sec}$$

Ans.

$$\theta_1 = \omega_1 t = \frac{2\pi N_1}{60} t = \frac{2\pi \times 260}{60} \times 1.3536$$

$$\theta_1 = 36.854 \text{ rad}$$

$$\theta_2 = \frac{1}{2} \alpha t^2 = \frac{1}{2} \times 20.1145 \times 1.3536^2$$

$$\theta_2 = 18.427 \text{ rad}$$

$$\text{Energy lost during slipping} = T_f(\theta_1 - \theta_2)$$

$$= 181.031(36.854 - 18.427)$$

$$\Delta E = 3335.817 \text{ N.m or } 3.34 \text{ kJ}$$

Ans.

3. (b) (i) Solution:

Given :

$$PF = DF = 300 \text{ mm}$$

$$BF = 80 \text{ mm}; m = 10 \text{ kg}, M = 100 \text{ kg}$$

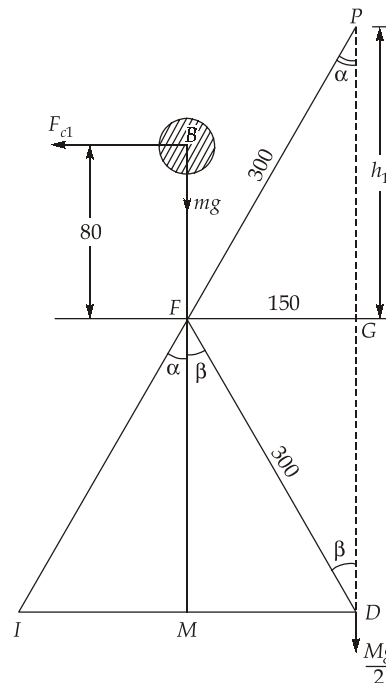
$$r_1 = 150 \text{ mm}; r_2 = 200 \text{ mm}$$

First of all, let us find the minimum and maximum speed of governor.

$$h_1 = PG = \sqrt{(PF)^2 - (FG)^2}$$

$$= \sqrt{(300)^2 - (150)^2} = \sqrt{0.3^2 - 0.15^2}$$

$$= 0.26 \text{ m}$$



$$FM = GD = PG = 260 \text{ mm} = 0.26 \text{ m}$$

∴

$$BM = BF + FM = 80 + 260 = 340 \text{ mm} = 0.34 \text{ m}$$

We know that

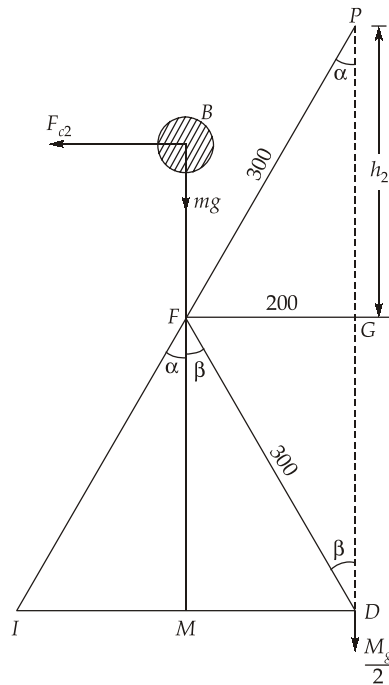
$$(N_1)^2 = \frac{FM}{BM} \left(\frac{m+M}{m} \right) \times \frac{895}{h_1} \quad (\because \alpha = \beta \text{ or } k = 1)$$

$$= \frac{0.26}{0.34} \left(\frac{10+100}{10} \right) \times \frac{895}{0.26} = 28956$$

$$N_1 = 170.15 \text{ rpm} \approx 170 \text{ rpm}$$

Now at maximum position

$$\begin{aligned} h_2 = PG &= \sqrt{(PF)^2 - (FG)^2} \\ &= \sqrt{(300)^2 - (200)^2} \\ &= 224 \text{ mm} = 0.224 \text{ m} \end{aligned}$$



and

$$FM = GD = PG = 224 \text{ mm} = 0.224 \text{ m}$$

$$BM = BF + FM = 80 + 224 = 304 \text{ mm} \\ = 0.304 \text{ m}$$

$$(N_2)^2 = \frac{FM}{BM} \left(\frac{m + M}{m} \right) \times \frac{895}{h_2} = \frac{0.224}{0.304} \left(\frac{10 + 100}{10} \right) \times \frac{895}{0.224}$$

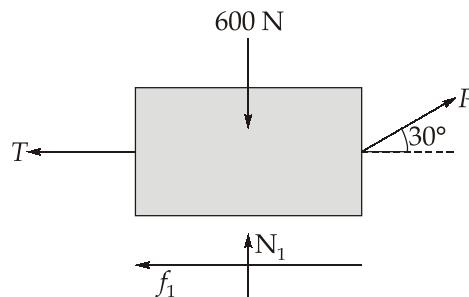
$$\Rightarrow N_2 = 179.95 \approx 180 \text{ rpm}$$

We know that range of speed

$$= N_2 - N_1 = 180 - 170 = 10 \text{ rpm}$$

3. (b) (ii) Solution:

FBD of 600 N block:



$$\Sigma F_H = 0$$

$$\Rightarrow P \cos 30^\circ - T - \mu N_1 = 0 \quad \dots(i)$$

$$\Sigma F_V = 0$$

$$\Rightarrow P \sin 30^\circ + N_1 - 600 = 0 \quad \dots(ii)$$

FBD of 800 N block:

$$\Sigma F \text{ normal to the inclined plane} = 0$$

$$\Rightarrow N_2 = 800 \cos 60^\circ = 400 \text{ N}$$

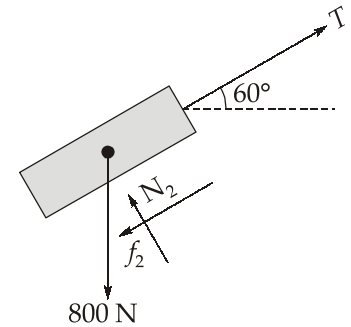
$$\Sigma F \text{ along the inclined plane} = 0$$

$$\Rightarrow T - f_2 - 800 \sin 60^\circ = 0$$

$$\Rightarrow T = 800 \sin 60^\circ + 0.25 \times N_2$$

$$= 800 \sin 60^\circ + 0.25 \times 400$$

$$= 792.82 \text{ N}$$



So, from equation (i)

$$P \times \frac{\sqrt{3}}{2} - 792.82 - 0.25 N_1 = 0$$

$$\Rightarrow \frac{\sqrt{3} P}{2} - 0.25 N_1 = 792.82 \quad \dots(iii)$$

From equation (ii)

$$\frac{P}{2} + N_1 = 600 \quad \dots(iv)$$

On solving equation (iii) and (iv), we get

$$P = 951.358 \text{ N and } N_1 = 124.32 \text{ N} \quad \text{Ans.}$$

3. (c) Solution:

Given:

The distributed torque function $T(x)$ using a linear relation:

$$T(x) = mx + c$$

At $x = 0 \text{ m}$, $T(0) = 200$ so, $c = 200 \text{ N-m}$

At $x = 2 \text{ m}$, $T(2) = 440$

$\therefore 440 = m(2) + 200 \Rightarrow m = 120 \text{ N}$

Hence, the torque function is

$$T(x) = 120x + 200(\text{N-m})$$

The internal torque at any section vis obtained by integrating the distributed torque

from that section to the free end:

$$T(x) = \int_x^2 (120x + 200) dx$$

$$\Rightarrow T(x) = [60x^2 + 200x]_x^2$$

$$\Rightarrow T(x) = 60(2)^2 + 200(2) - (60x^2 + 200x)$$

$$\Rightarrow T(x) = 640 - 200x - 60x^2 \text{ (N-m)}$$

The differential angle of twist is

$$d\phi = \frac{T(x)}{JG} dx$$

The total angle of twist at the free end is

$$\phi_B = \int_0^2 \frac{T(x)}{JG} dx$$

$$\Rightarrow \phi_B = \frac{1}{JG} \int_0^2 (640 - 200x - 60x^2) dx$$

$$\Rightarrow \phi_B = \frac{1}{JG} [640(2) - 100(2)^2 - 20(2)^3]$$

$$\Rightarrow \phi_B = \frac{720}{JG} \text{ radians}$$

Hence, the angle of twist at the free end is

$$\phi_B = \frac{720}{JG} \text{ radian}$$

4. (a) (i) Solution:

Given: Stress in x -direction (σ_x) = -100 MPa, Stress in y -direction (σ_y) = 25 MPa, Shear stress (τ_{xy}) = 40 MPa

For clockwise rotation of 20° .

$$\begin{aligned} \sigma_{x'} (\sigma_n)_{\theta x} &= \left(\frac{\sigma_x + \sigma_y}{2} \right) + \left(\frac{\sigma_x - \sigma_y}{2} \right) \cos 2\theta + \tau_{xy} \sin 2\theta \\ &= \left(\frac{-100 + 25}{2} \right) + \left(\frac{-100 - 25}{2} \right) \cos(40^\circ) + 40 \sin 40^\circ \\ \sigma_{x'} &= -59.67 \text{ MPa} \end{aligned}$$

Stress perpendicular to x face after rotation = -59.67 MPa

For finding stress on y face after rotation of 20° .

$$\Rightarrow \theta_y = 20 + 90 = 110^\circ$$

$$\begin{aligned} \sigma_{y'}(\sigma_n)_{\theta_y} &= \left(\frac{\sigma_x + \sigma_y}{2}\right) + \left(\frac{\sigma_x - \sigma_y}{2}\right)\cos 2\theta + \tau_{xy}\sin 2\theta \\ &= \left(\frac{-100 + 25}{2}\right) + \left(\frac{-100 - 25}{2}\right)\cos(2 \times 110) + 40\sin(2 \times 110) \end{aligned}$$

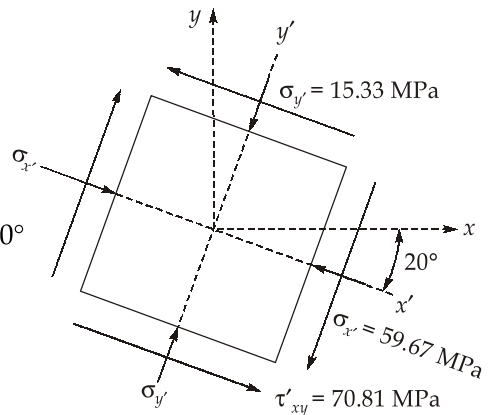
$$\sigma_{y'} = -\frac{75}{2} - \frac{125}{2}\cos 220^\circ + 40\sin 220^\circ$$

$$\sigma_{y'} = -15.33 \text{ MPa}$$

For shear stress on element rotated at 20° .

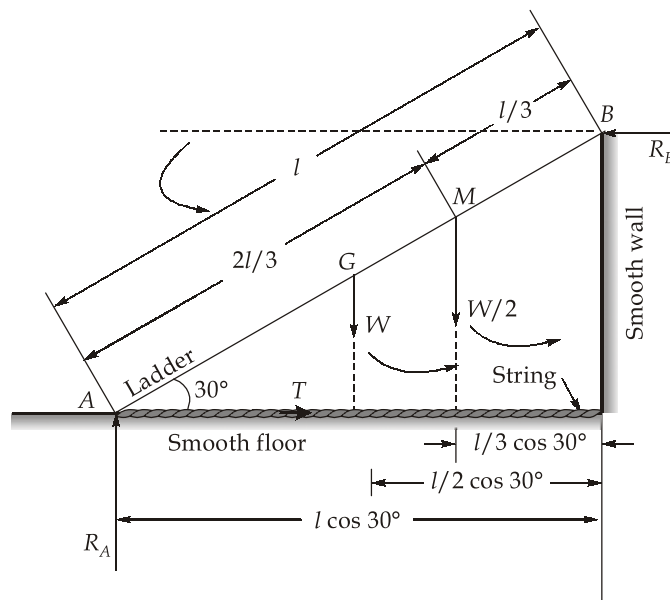
$$\begin{aligned} (\tau_s)_\theta &= -\left(\frac{\sigma_x - \sigma_y}{2}\right)\sin 2\theta + \tau_{xy}\cos 2\theta \\ &= -\left(\frac{-100 - 25}{2}\right)\sin 40 + 40\cos 40^\circ \end{aligned}$$

$$(\tau_s)_\theta = 70.816 \text{ MPa}$$



4. (a) (ii) Solution:

The ladder is in equilibrium under the action of the following forces:



Let the, weight of ladder be W

Reaction of wall be R_B

Weight of the man be $W/2$

Reaction of floor be R_A

Tension in the string be T

Considering horizontal equilibrium, $\Sigma H = 0$

$$R_B = T \quad \dots \text{(i)}$$

Considering vertical equilibrium,

$$R_A = W + \frac{W}{2} = \frac{3W}{2} \quad \dots \text{(ii)}$$

Also, $\Sigma M = 0$

Taking moments about B , we get

$$R_A \times (l \cos 30^\circ) = W \times \frac{l}{2} \cos 30^\circ + \frac{W}{2} \times \frac{l}{3} \cos 30^\circ + T \times l \sin 30^\circ$$

$$\frac{3W}{2} \times \cos 30^\circ = \frac{W}{2} \cos 30^\circ + W \times \frac{1}{6} \cos 30^\circ + T \sin 30^\circ$$

$$T \sin 30^\circ = \frac{W}{2} \left[3 \cos 30^\circ - \cos 30^\circ - \frac{1}{3} \cos 30^\circ \right]$$

$$T = 1.443W \text{ N}$$

4. (b) Solution:

$$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 600}{60} = 62.83 \text{ rad/s}$$

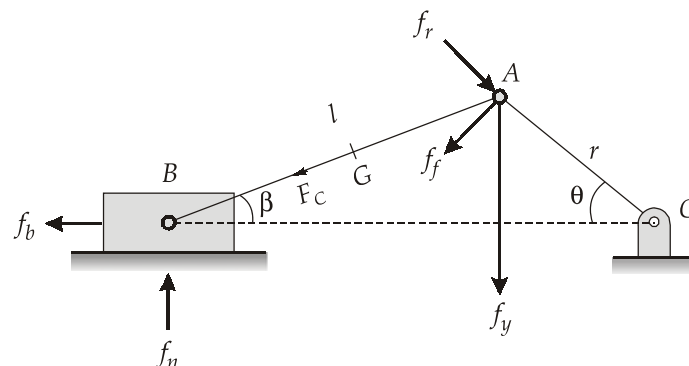
$$n = \frac{l}{r} = \frac{500}{100} = 5$$

Divide the mass of connecting rod into two parts

$$\text{Mass at crank pin, } m_a = 100 \times \left[\frac{500 - 200}{500} \right] = 60 \text{ kg}$$

$$\text{Mass of gudgeon pin, } m_b = 100 - 60 = 40 \text{ kg}$$

$$\text{Total mass of reciprocating parts, } m = 150 + 40 = 190 \text{ kg}$$



Acceleration of reciprocating parts,

$$a = r\omega^2 \left[\cos\theta + \frac{\cos 2\theta}{n} \right]$$

$$a = 0.1 \times (62.83)^2 \left[\cos 38 + \frac{\cos(2 \times 38)}{5} \right]$$

$$a = 330.17 \text{ m/s}^2$$

Inertial force, $f_b = ma$

$$= 190 \times 330.17$$

$$= 62733.45 \text{ N}$$

Inertia torque due to reciprocating parts = Turning moment on crank shaft

$$T_b = F \times r \left[\sin\theta + \frac{\sin 2\theta}{2\sqrt{n^2 - \sin^2\theta}} \right]$$

$$T_b = 62733.45 \times 0.1 \times \left[\sin 38 + \frac{\sin(2 \times 38)}{2\sqrt{5^2 - \sin^2 38}} \right]$$

$$T_b = 4475.62 \text{ Nm} \quad (\text{Counter clockwise})$$

Now, correction torque due assumed second mass of connecting rod at A;

$$b = 500 - 200 = 300 \text{ mm}$$

$$l = 500 \text{ mm}$$

$$L = b + \frac{k^2}{b} = 300 + \frac{160^2}{300} = 385.33 \text{ mm}$$

$$\alpha_c = -\omega^2 \sin\theta \left[\frac{n^2 - 1}{(n^2 - \sin^2\theta)^{3/2}} \right]$$

$$\alpha_c = -62.83^2 \times \sin 38 \times \left[\frac{5^2 - 1}{(5^2 - \sin^2 38)^{3/2}} \right]$$

$$\alpha_c = -477.45 \text{ rad/s}^2$$

Now, correcting torque, $\Delta T = m\alpha_c b (l - L)$

$$\Delta T = \frac{-100 \times 477.45 \times 300 \times [500 - 385.33]}{10^6}$$

$$\Delta T = -1642.483 \text{ Nm} \quad (\text{Clockwise})$$

\therefore Correction torque on crank shaft,

$$T_c = \frac{\Delta T \cos\theta}{\sqrt{n^2 - \sin^2\theta}} = \frac{-1642.483 \times \cos 38^\circ}{\sqrt{5^2 - \sin^2 38^\circ}}$$

$$T_c = -285.91 \text{ Nm} \quad (\text{Clockwise})$$

Torque due to weight of mass at A,

$$T_a = (m_a g) r \cos \theta = 60 \times 9.81 \times 0.10 \times \cos 38^\circ$$

$$T_a = 46.38 \text{ Nm} \quad (\text{Counter clockwise})$$

\therefore Total inertia torque on crankshaft

$$= T_b - T_c + T_a$$

$$= 4475.62 - (-285.91) + 46.38$$

$$= 4807.91 \text{ Nm} \quad (\text{Counter clockwise})$$

4. (c) Solution:

As per given information

$$\sigma_{ut} = S_{ut} = 600 \text{ N/mm}^2$$

$$\sigma_{yt} = S_{yt} = 380 \text{ N/mm}^2$$

$$P_{\max} = 150 \text{ N}$$

$$P_{\min} = -50 \text{ N}$$

Notch sensitivity, $q = 0.9$

Surface finish factor, $K_a = 0.78$

Size factor, $K_b = 0.85$

Reliability factor, $K_c = 0.897$

Load Factor, $K'_c = 1$

Theoretical stress concentration factor,

$$K_t = 1.35$$

$$\sigma_e^* = 0.5 S_{ut} = 0.5 \times 600 = 300 \text{ N/mm}^2$$

$$\text{FOS}, N = 2$$

Actual stress concentration factor

$$K_f = 1 + q(K_t - 1)$$

$$= 1 + 0.9(1.35 - 1)$$

$$K_f = 1.315$$

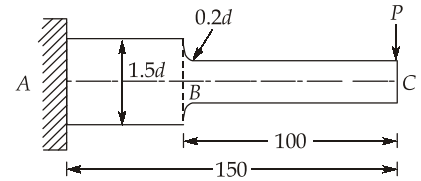
$$\sigma_e = \sigma_e^* K_a \cdot K_b \cdot K_c \cdot K'_c$$

$$\sigma_e = 300 \times 0.78 \times 0.85 \times 0.897 \times 1$$

$$\sigma_e = 178.4133 \text{ N/mm}^2$$

At the fillet cross-section

$$(M_B)_{\max} = 150 \times 100 = 15000 \text{ N.mm}$$



$$(M_B)_{\min} = -50 \times 100 = -5000 \text{ N.mm}$$

$$\begin{aligned} (M_B)_{\text{mean}} &= \frac{(M_b)_{\max} + (M_B)_{\min}}{2} \\ &= \frac{15000 + (-5000)}{2} = 5000 \text{ N.mm} \end{aligned}$$

$$\sigma_m = \frac{32(M_B)_{\text{mean}}}{\pi d^3}$$

$$\sigma_m = \frac{32 \times 5000}{\pi d^3}$$

$$\begin{aligned} (M_B)_{\text{variable}} &= \frac{(M_B)_{\max} - (M_B)_{\min}}{2} \\ &= \frac{15000 - (-5000)}{2} = 10000 \text{ N.mm} \end{aligned}$$

$$\sigma_v = \frac{32(M_B)_{\text{variable}}}{\pi d^3}$$

$$= \frac{32 \times 10000}{\pi d^3}$$

As the beam is made of ductile material, so Soderberg equation should be used for calculating safe dimension.

From Soderberg equation,

$$\left(\frac{\sigma_m}{\sigma_{yt}} \right) + K_f \left(\frac{\sigma_v}{\sigma_e} \right) = \frac{1}{N}$$

$$\left(\frac{32 \times 5000}{\pi d^3 \times 380} \right) + 1.315 \left(\frac{32 \times 10000}{\pi d^3 \times 178.4133} \right) = \frac{1}{2}$$

$$\frac{1}{d^3} (134.0252 + 750.755) = \frac{1}{2}$$

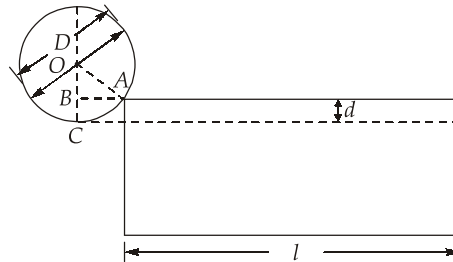
$$d = \sqrt[3]{1769.56178}$$

$$d = 12.095 \text{ mm} = 14 \text{ mm}$$

Section : B

5. (a) Solution:

Given, $D = 120$ mm, $l = 150$ mm, $d = 20$ mm, $z = 10$ teeth, $f = 0.20$ mm per teeth,
 $V = 40$ m/min



$$\text{Compulsory approach, } AB = \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d\right)^2} = \sqrt{60^2 - (60 - 20)^2}$$

$$AB = 44.72 \text{ mm}$$

$$\text{Cutting velocity, } V = \frac{\pi DN}{1000}$$

$$40 = \frac{\pi \times 120 \times N}{1000}$$

$$N = 106.10 \text{ rpm}$$

$$\text{Table feed} = f \times z \times N = 0.20 \times 10 \times 106.10 = 212.2 \text{ mm/min}$$

$$\begin{aligned} \text{Total cutter travel} &= \text{Length of workpiece} + \text{Compulsory approach} \\ &= 150 + 44.72 = 194.72 \text{ mm} \end{aligned}$$

$$\begin{aligned} \text{Slot cutting time, } T &= \frac{\text{Total cutter travel}}{\text{Table feed}} = \frac{194.72}{212.2} \\ &= 0.9176 \text{ minutes} \simeq 55.05 \text{ s} \end{aligned}$$

5. (b) Solution:

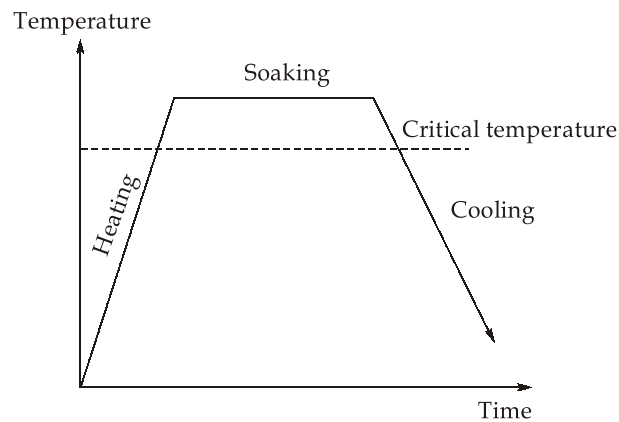
Stages of heat Treatment: Heat-treating is accomplished in three major stages:

- **Stage 1 – heating** the metal slowly to ensure a uniform temperature
- **Stage 2 – soaking** (holding) the metal at a given temperature for a given time and cooling the metal to room temperature.
- **Stage 3 – cooling** the metal to room temperature.

Heating Stage: The primary objective in the heating stage is to maintain uniform temperatures. If uneven heating occurs, one section of a part can expand faster than another and result in distortion or cracking. Slow heating attains uniform temperatures.

The heating rate of a part depends on several factors. One important factor is the heat conductivity of the metal. A metal with a high-heat conductivity heats at a faster rate than one with a low conductivity. Also, the condition of the metal determines the rate at which it may be heated. The heating rate for hardened tools and parts should be slower than un-stressed or untreated metals. Finally, size and cross section figure into the heating rate. Parts with a large cross section require slower heating rates to allow the interior temperature to remain close to the surface temperature that prevents warping or cracking. Parts with uneven cross sections experience uneven heating; however, such parts are less apt to be cracked or excessively warped when the heating rate is kept slow.

Soaking Stage: After the metal is heated to the proper temperature, it is held at that temperature until the desired internal structural changes take place. This process is called SOAKING. The length of time held at the proper temperature is called the SOAKING PERIOD. The soaking period depends on the chemical analysis of the metal and the mass of the part.



During the soaking stage, the temperature of the metal is rarely brought from room temperature to the final temperature in one operation; instead, the steel is slowly heated to a temperature just below the point at which the change takes place and then it is held at that temperature until the heat is equalized throughout the metal. We call this process PREHEATING. Following preheat, the metal is quickly heated to the final required temperature.

When a part has an intricate design, it may have to be preheated at more than one temperature to prevent cracking and excessive warping. For example, assume an intricate part needs to be heated to 1500°F for hardening. This part could be slowly heated to 600°F, soaked at this temperature, then heated slowly to 1200°F, and then soaked at that temperature. Following the final preheat, the part should then be heated quickly to the hardening temperature of 1500°F.

Note: Non-ferrous metals are seldom preheated, because they usually do not require it, and preheating can cause an increase in the grain size in these metals.

Cooling Stage: After a metal has been soaked, it must be returned to room temperature to complete the heat-treating process. To cool the metal, you can place it in direct contact with a COOLING MEDIUM composed of a gas, liquid, solid, or combination of these. The rate at which the metal is cooled depends on the metal and the properties desired. The rate of cooling depends on the medium; therefore, the choice of a cooling medium has an important influence on the desired properties.

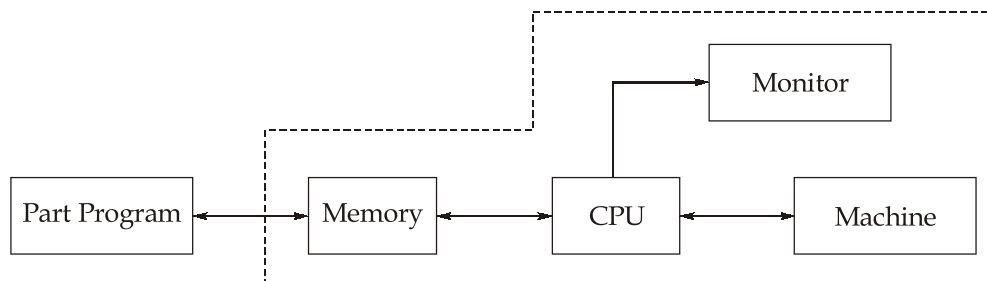
5. (c) Solution:

CNC Machine: This type of machine generally use a tape reader for storing and inputting the program into the memory of the NC machine too. Due to unreliability the tape reader as well as the low speed of operation, NC machine effort were being applied for searching for a suitable alternative. Instead the part program is transmitted to the MCU directly from the computer. NC machine encountering the such difficulties are overcome using CNC machine. The change in trend from hardware to software has increased productivity and flexibility in manufacturing. A CNC machine basically a NC machine with a dedicated computer as its integral part.

A CNC machine does not have those limitation which are inherent to a NC machine. This development became very popular with NC machine user due to various significance application:

1. The computer can be used for editing the program.
2. Since the computer has large memories there was no limitation in the number of size of program stored.
3. Copy program to and from the floppy disc.
4. Editing the existing program or create a new program.
5. Eliminating the need for paper tape in the old generation of NC machine.

Features of CNC Machine:



DNC Machine: Early NC machine used to tape reader of storing and inputting the program into memory of NC machine tool. Due to unreliability of tape reader as well as low speed of operation, NC machine effort were being applied for searching. For suitable

alternative several clones of APT languages were introduced in 80s to automatically develop NC code from the geometric model of the component, now one can model, draft, analyse, modify, optimized and create the NC code.

Manufacturer a component and simulate the machining operation sitting at a computer workstation. In this system a number of machine were connected and controlled by a single computer. The central computer usually has large capacity and it can be main frame computer which can store program after processing, send the controlled signal to respective NC machine.

These are silent feature of DNC machine system which are given:

1. A single computer can be used to operate many machine in the shop floor.
2. A number of NC machine can be connected to single computer.
3. The DNC computer store all parts program and transfers the program to CNC machine in response to request to the operator.
4. The concept of intranet, internet and extranet has future enlarged the scope of distributed numerical control.
5. DNC system are generally designed for 4, 8 and 16 CNC machine. However with the wide spread acceptance of local area network concept, the possibility of connecting more CNC machine in a DNC network has become a reality.

5. (d) Solution:

$$4x_1 + 5x_2 \geq 50 \quad \dots (i)$$

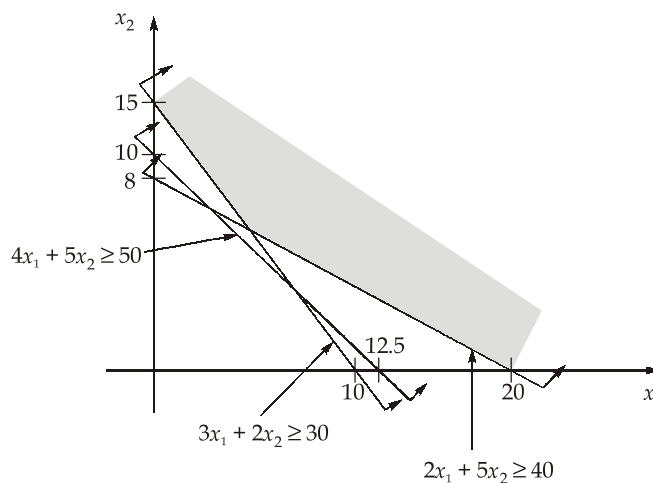
$$3x_1 + 2x_2 \geq 30 \quad \dots (ii)$$

$$2x_1 + 5x_2 \geq 40 \quad \dots (iii)$$

$$x_1, x_2 \geq 0$$

$$Z = 7x_1 + 12x_2$$

Minimize,



$$3x_1 + 2x_2 = 30$$

$$2x_1 + 5x_2 = 40$$

On solving (ii)nd and (iii)rd all inequality satisfied

$$x_1 = 6.3636$$

$$x_2 = 5.4545$$

So, minimum cost is ₹110.

because

$$Z_{(0, 15)} = 7 \times 0 + 12 \times 15 = 180$$

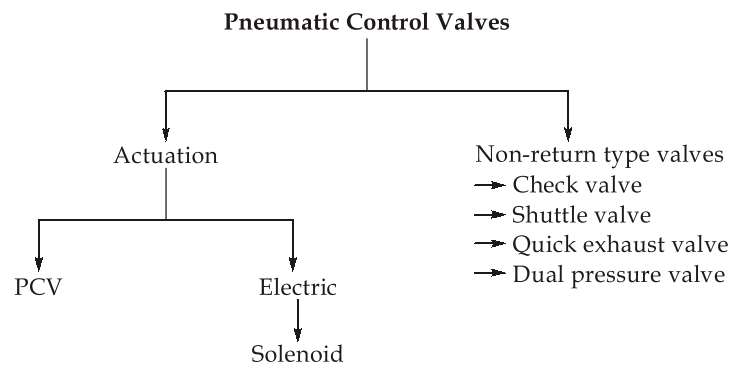
$$Z_{(20, 0)} = 20 \times 7 + 12 \times 0 = 140$$

$$Z_{(6.3636, 5.4545)} = 7 \times 6.3636 + 12 \times 5.4545 = 109.999 \simeq 110$$

5. (e) Solution:

Pneumatic Control Valve:

- These type of control valves are exclusively used in Pneumatic systems.
- Pneumatic control valves are used to regulate the quantity of air flow and also used to regulate the direction of air flow.
- Pneumatic control valves are classified based on the actuation method and on the type of opening the valve.

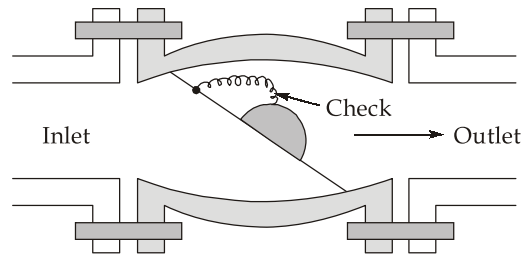


Non Return Type Control Valves:

- These types of valves are also called as direction control valves.

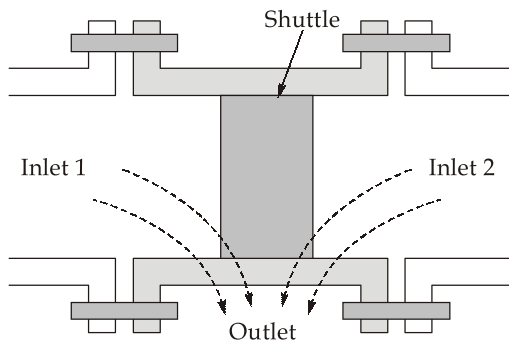
Check Valve:

1. It is basic type of non return type control valve.
2. If the inlet air pressure applies a force more than force offered by a internal spring, then the check will be lifted up such that it can allows the air flow in a particular direction.
3. Check valves offer minimum pressure drop compare to remaining non-return type control valves.



Shuttle Valve:

1. It is a dual check valve. It has two inlets and one outlet as shown in the figure.
2. The air flows through output channel if atleast air flows through one of the inlet.
3. These types of control valves are exclusively used in process industry as well as in chemical industries to mix two different gases.
4. Shuttle valve performs “OR’ operation in pneumatic systems.



Inlet 1	Inlet 2	Outlet
1	0	1
0	1	1
0	0	0
1	1	1

Shuttle valve perform OR Logic

6. (a) (i) Solution:

A cutting fluid is any liquid or gas that is applied directly to the machining operation to improve cutting performance.

Purposes of cutting fluid to improve machinability

- **Act as lubricant:** Reduce friction and wear by acting as a film and hence also reduce welding tendency.
- **Act as coolant:** Cooling of cutting zone and hence increasing tool life & improving dimensional stability, Reducing the temperature of the workpart for easier handling.
- Reduce forces and energy consumption.
- Flush away the chips from the cutting zone to avoid interference in cutting.
- Protect the machined surface from environmental corrosion (weakening and depletion of surface by deposition of other matter like rust) & contamination by the gases like SO₂, O₂, H₂S, and N_xO_y present in the atmosphere.

Properties of workpiece material that affect Machinability

1. **Nature-Brittle/Ductile:** Brittle materials are easy to machine as the chip separation is due to brittle fracture requiring lesser energy of chip formation and further shorter chips causing lesser frictional force and heating at the rake surface. Ductile materials like mild steel produce better surface finish but BUE, if formed, may worsen the surface finish. Also cutting forces increase with the increase in yield shear strength, T_s of the work material.
 2. **Microstructure-Coarse/ Fine:** The value of shear strength and hence shear force of a given material depends on its microstructure. Coarse microstructure leads to lesser value of T_s . Therefore, T_s can be desirably reduced by either proper heat treatment like annealing of steels or controlled addition of materials like Sulphur (S), lead (Pb), Tellurium etc. leading to free cutting of soft ductile metals and alloys.
 3. **Hardness, hot strength and hot hardness and work hardening:** Harder materials are obviously more difficult to machine for increased cutting forces and tool damage. Usually, with the increase in cutting velocity the cutting forces decrease to some extent making machining easier through reduction in TS and also chip thickness. TS decreases due to softening of the work material at the shear zone due to elevated temperature. Such benefits of increased temperature and cutting velocity are not attained when the work materials are hot strong and hard like Ti and Ni based superalloys and work hardenable like high manganese steel, Ni- hard, Hadfield steel etc.
 4. **Stickiness/Self Lubricity:** Sticking of the materials (like pure copper, aluminium and their alloys) and formation of BUE at the tool rake surface also hamper machinability by increasing friction, cutting forces, temperature and surface roughness.
 5. **Thermal Conductivity:** Lower thermal conductivity of the work material affects their machinability by raising the cutting zone temperature and thus reducing tool life.
6. (a) (ii) **Solution:**

For material A:

$$v_1 = 100 \text{ m/min}, v_2 = 150 \text{ m/min}, T_1 = 25 \text{ min}, T_2 = 10 \text{ min.}$$

$$\text{As we know, } \log v + n \log T = \log C$$

On substituting the above value, we get

$$\log 100 + n \log 25 = \log C \quad \dots(i)$$

$$\log 150 + n \log 10 = \log C \quad \dots(ii)$$

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

$$n = 0.443 \text{ and } C = 416.2$$

Hence, tool life equation becomes.

$$vT^{0.443} = 416.2 \tag{iii}$$

To find speed at $T = 60 \text{ min}$

Substituting, $T = 60 \text{ min}$ in (iii), we get $v_{60} = 67.85 \text{ m/min}$.

For material B:

$v_1 = 200 \text{ m/min}$, $v_2 = 250 \text{ m/min}$, $T_1 = 40 \text{ min}$, $T_2 = 20 \text{ min}$.

As we know, $\log v + n \log T = \log C$

On substituting the above value, we get

$$\log 200 + n \log 40 = \log C \tag{iv}$$

$$\log 250 + n \log 20 = \log C \tag{v}$$

Solving equation (iv) and (v), we get

$$n = 0.322 \text{ and } C = 655.98$$

Hence, tool life equation becomes.

$$vT^{0.322} = 655.98 \tag{vi}$$

To find speed at $T = 60 \text{ min}$

Substituting, $T = 60 \text{ min}$ in (vi), we get $v_{60} = 175.52 \text{ m/min}$.

$$\begin{aligned} \text{Relative machinability} &= \left[\frac{v_{60} \text{ for test material}}{v_{60} \text{ for standard material}} \right] \times 100 \\ &= \frac{175.52}{67.85} \times 100 = 258.68\% \end{aligned}$$

Ans.

6. (b) Solution:

(i) According to shortest processing time, sequence is 3 - 1 - 5 - 2 - 4.

Job	t_i	C_j or F_j	D_j	$L_j = C_j - D_j$	T_j
3	3	3	20	-17	0
1	4	7	7	0	0
5	5	12	15	-3	0
2	8	20	10	10	10
4	8	28	18	10	10
$\Sigma C_j = 70$				$\Sigma T_j = 20$	

$$\text{Mean job flow time} = \frac{\Sigma C_j}{n} = \frac{70}{5} = 14 \text{ days}$$

$$\text{Average tardiness per job} = \frac{\Sigma T_j}{n} = \frac{20}{5} = 4 \text{ days}$$

$$\text{Number of tardy jobs} = 2$$

(ii) According to earliest due date rule, sequence is 1 - 2 - 5 - 4 - 3

Job	t_j	C_j	D_j	$L_j = C_j - D_j$	T_j
1	4	4	7	-3	0
2	8	12	10	2	2
5	5	17	15	2	2
4	8	25	18	7	7
3	3	28	20	8	8

$$\Sigma C_j = 86$$

$$\Sigma T_j = 19$$

$$\text{Mean job flow time} = \frac{\Sigma C_j}{n} = \frac{86}{5} = 17.2 \text{ days}$$

$$\text{Average tardiness per job} = \frac{\Sigma T_j}{n} = \frac{19}{5} = 3.8 \text{ days}$$

$$\text{Number of tardy jobs} = 4$$

6. (c) (i) Solution:

Controllability of a System : A state x_1 of a system is “controllable” if all initial conditions x_0 at any previous time t can be transferred to x_1 in a finite time by some control function $u(t, x_0)$.

- If all the states are controllable then the system is completely controllable.
- If controllability is restricted to depend upon ‘ t_0 ’ then the system is controllable at time ‘ t_0 ’.

The controllability matrix for a system (A, B) is defined as

$$Q_c = [B \quad AB \quad A^2B \quad \dots \quad A^{n-1}B]$$

where, state equation

$$\dot{x}(t) = Ax(t) + Bu(t)$$

$$[A]_{n \times n} = \text{system matrix}, [B]_{n \times m} = \text{input matrix}$$

The system is fully controllable if Rank $[Q_c] = n$.

Observability of a system : A state $x_1(t)$ at some given time is 'observable' if knowledge of the input $u(t)$ and output $y(t)$ over a finite segment of time completely determines $x_1(t)$.

The observability matrix for a system is defined as

$$D^T = [C^T \quad C^T A^T \quad \dots \quad C^T (A^{n-1})^T]$$

The system is fully observable if Rank $[D^T] = n$ where output equation $y(t) = Cx(t) + Du(t)$.

6. (c) (ii) Solution:

Controllability :

$$\dot{x} = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} x + \begin{bmatrix} 1 \\ -1 \end{bmatrix} u$$

$$\dot{x}(t) = Ax(t) + Bu(t)$$

$$A = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix}, B = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

$$AB = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} \begin{bmatrix} 1 \\ -1 \end{bmatrix} = \begin{bmatrix} -1 \\ 1 \end{bmatrix}$$

$$Q_c = [B \quad AB]$$

$$Q_c = \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$|Q_c| = \begin{vmatrix} 1 & -1 \\ -1 & 1 \end{vmatrix} = 0$$

As determinant of Q_c is zero, so rank is not equal to 'n', i.e., 2. So system is not controllable.

Observability, $C^T = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$

$$A^T C^T = \begin{bmatrix} 0 & -2 \\ 1 & -3 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} -2 \\ -2 \end{bmatrix}$$

$$Q_o = [C^T \quad A^T C^T]$$

$$= \begin{bmatrix} 1 & -2 \\ 1 & -2 \end{bmatrix}$$

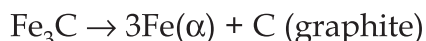
$$|Q_o| = \begin{vmatrix} 1 & -2 \\ 1 & -2 \end{vmatrix} = 0$$

As determinant of Q_o is zero, hence rank is not equal to n , i.e., 2. So, system is not observable.

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

Cast Irons: Generally, cast irons are a class of ferrous alloys with carbon contents above 2.14 wt%; in practice, however, most cast irons contain between 3.0 and 4.5 wt% C and, in addition, other alloying elements. The iron-iron carbide phase diagram reveals that alloys within this composition range become completely liquid at temperatures between approximately 1150°C and 1300°C, which is considerably lower than for steels. Thus, they are easily melted and amenable to casting. Furthermore, some cast irons are very brittle, and casting is the most convenient fabrication technique.

Cementite (Fe_3C) is a metastable compound, and under some circumstances it can be made to dissociate or decompose to form α -ferrite and graphite, according to the reaction



This tendency to form graphite is regulated by the composition and rate of cooling. Graphite formation is promoted by the presence of silicon in concentrations greater than about 1 wt%. Also, slower cooling rates during solidification favor graphitization (the formation of graphite). For most cast irons, the carbon exists as graphite, and both microstructure and mechanical behavior depend on composition and heat treatment. The most common cast iron types are gray, nodular, white, malleable, and compacted graphite.

Gray Iron: The carbon and silicon contents of gray cast irons vary between 2.5 and 4.0 wt% and 1.0 and 3.0 wt%, respectively. For most of these cast irons, the graphite exists in the form of flakes (similar to corn flakes), which are normally surrounded by an α -ferrite or pearlite matrix; the microstructure of a typical gray iron is shown in figure. Because of these graphite flakes, a fractured surface takes on a gray appearance – hence its name.

Mechanically, gray iron is comparatively weak and brittle in tension as a consequence of its microstructure; the tips of the graphite flakes are sharp and pointed and may serve as points of stress concentration when an external tensile stress is applied. Strength and ductility are much higher under compressive loads. Typical mechanical properties and compositions of several common gray cast irons are listed. Gray irons have some desirable characteristics and are used extensively. They are very effective in damping

vibrational energy; this is represented, which compares the relative damping capacities of steel and gray iron. Base structures for machines and heavy equipment that are exposed to vibrations are frequently constructed of this material. In addition, gray irons exhibit a high resistance to wear. Furthermore, in the molten state they have a high fluidity at casting temperature, which permits casting pieces that have intricate shapes; also, casting shrinkage is low. Finally, and perhaps most important, gray cast irons are among the least expensive of all metallic materials.

Ductile (or Nodular) Iron: Adding a small amount of magnesium and/or cerium to the gray iron before casting produces a distinctly different microstructure and set of mechanical properties. Graphite still forms, but as nodules or sphere like particles instead of flakes. The resulting alloy is called ductile or nodular iron. The matrix phase surrounding these particles is either pearlite or ferrite, depending on heat treatment; it is normally pearlite for an as-cast piece. However, a heat treatment for several hours at about 700°C yields a ferrite matrix, as in this photomicrograph. Casting having this microstructure is stronger and more ductile than gray iron; the mechanical properties ductile iron has tensile strengths between 380 and 480 MPa and ductilities (as percent elongation) from 10% to 20%. Typical applications for this material include valves, pump bodies, crankshafts, gears, and other automotive and machine components.

White Iron and Malleable Iron: For low-silicon cast irons (containing less than 1.0 wt% Si) and rapid cooling rates, most of the carbon exists as cementite instead of graphite. A fracture surface of this alloy has a white appearance, and thus it is termed white cast iron. An optical photomicrograph showing the microstructure of white iron is presented in figure. Thick sections may have only a surface layer of white iron that was “chilled” during the casting process; gray iron forms at interior regions, which cool more slowly. As a consequence of large amounts of the cementite phase, white iron is extremely hard but also very brittle, to the point of being virtually unmachinable. Its use is limited to applications that necessitate a very hard and wear-resistant surface, without a high degree of ductility—for example, as rollers in rolling mills. Generally, white iron is used as an intermediary in the production of yet another cast iron, malleable iron.

Heating white iron at temperatures between 800°C and 900°C for a prolonged time period and in a neutral atmosphere (to prevent oxidation) causes a decomposition of the cementite, forming graphite, which exists in the form of clusters or rosettes surrounded by a ferrite or pearlite matrix, depending on cooling rate. The microstructure is similar to that of nodular iron), which accounts for relatively high strength and appreciable ductility or malleability. Representative applications include connecting rods, transmission gears, and differential cases for the automotive industry, and also flanges, pipe fittings, and valve parts for railroad, marine, and other heavy-duty services.

7. (a) (ii) Solution:

Glass Fiber - Reinforced Polymer (GFRP) composites: Fiberglass is simply a composite consisting of glass fibers, either continuous or discontinuous, contained within a polymer matrix; this type of composite is produced in the largest quantities. The composition of the glass that is most commonly drawn into fibers (sometimes referred to as E-glass); fiber diameters normally range between 3 and 20 μm . Glass is popular as a fiber reinforcement material for several reasons:

1. It is easily drawn into high-strength fibers from the molten state.
2. It is readily available and may be fabricated into a glass-reinforced plastic economically using a wide variety of composite-manufacturing techniques.
3. As a fiber it is relatively strong, and when embedded in a plastic matrix, it produces a composite having a very high specific strength.
4. When coupled with the various plastics, it possesses a chemical inertness that renders the composite useful in a variety of corrosive environments.

The surface characteristics of glass fibers are extremely important because even minute surface flaws can deleteriously affect the tensile properties. Surface flaws are easily introduced by rubbing or abrading the surface with another hard material. Also, glass surfaces that have been exposed to the normal atmosphere for even short time periods generally have a weakened surface layer that interferes with bonding to the matrix. Newly drawn fibers are normally coated during drawing with a size, a thin layer of a substance that protects the fiber surface from damage and undesirable environmental interactions. This size is ordinarily removed before composite fabrication and replaced with a coupling agent or finish that produces a chemical bond between the fiber and matrix.

There are several limitations to this group of materials. In spite of having high strengths, they are not very stiff and do not display the rigidity that is necessary for some applications (e.g., as structural members for airplanes and bridges). Most fiberglass materials are limited to service temperatures below 200°C (400°F); at higher temperatures, most polymers begin to flow or to deteriorate. Service temperatures may be extended to approximately 300°C (575°F) by using high-purity fused silica for the fibers and high-temperature polymers such as the polyamide resins.

Many fiberglass applications are familiar: automotive and marine bodies, plastic pipes, storage containers, and industrial floorings. The transportation industries are using increasing amounts of glass fiber-reinforced plastics in an effort to decrease vehicle weight and boost fuel efficiencies.

Carbon Fiber - Reinforced Polymer (CFRP) composites: Carbon is a high-performance fiber material that is the most commonly used reinforcement in advanced (i.e., non fiberglass) polymer–matrix composites. The reasons for this are as follows:

1. Carbon fibers have high specific moduli and specific strengths.
2. They retain their high tensile modulus and high strength at elevated temperatures; high-temperature oxidation, however, may be a problem.
3. At room temperature, carbon fibers are not affected by moisture or a wide variety of solvents, acids, and bases.
4. These fibers exhibit a diversity of physical and mechanical characteristics, allowing composites incorporating these fibers to have specific engineered properties.
5. Fiber and composite-manufacturing processes have been developed that are relatively inexpensive and cost effective.

Manufacturing techniques for producing carbon fibers are relatively complex. However, three different organic precursor materials are used: rayon, polyacrylonitrile (PAN), and pitch. Processing them vary from precursor to precursor, as do the resultant fiber characteristics.

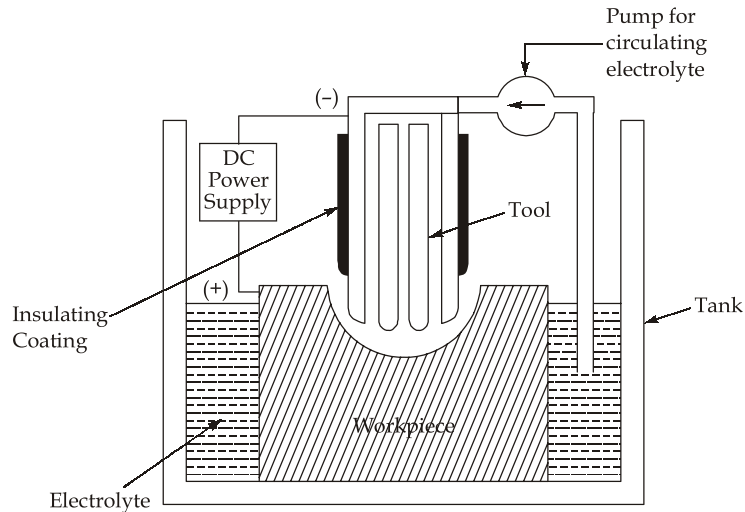
One classification scheme for carbon fibers is by tensile modulus; on this basis, the four classes are standard, intermediate, high, and ultrahigh moduli. Fiber diameters normally range between 4 and 10 μm ; both continuous and chopped forms are available. In addition, carbon fibers are normally coated with a protective epoxy size that also improves adhesion with the polymer matrix.

Carbon-reinforced polymer composites are currently being used extensively in sports and recreational equipment (fishing rods, golf clubs), filament-wound rocket motor cases, pressure vessels, and aircraft structural components—both military and commercial, both fixed-wing aircraft and helicopters (e.g., as wing, body, stabilizer, and rudder components).

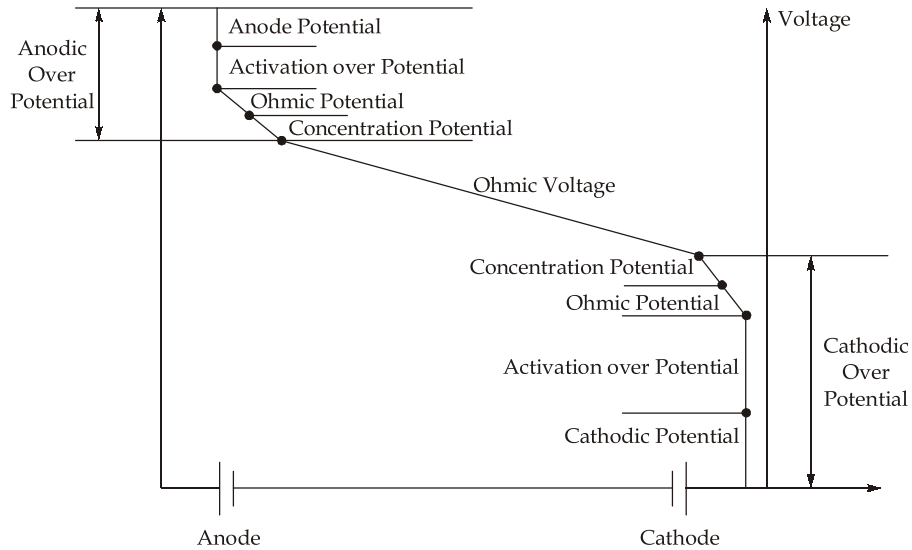
Q.7 (b) (i) Solution:

- Electrochemical Machining Process (ECM) can be thought of a controlled anodic dissolution at atomic level of a workpiece that is electrically conductive by a shaped tool due to flow of high current at relatively low potential difference through an electrolyte which is quite often water based neutral salt solution.
- An electrolyte acts as current carrier and high rate of electrolyte movement in the tool-workpiece washes metal ions away from the workpiece (anode) before they have a chance to plate onto the tool (cathode).

- As the material removal takes place due to atomic level dissociation, the machined surface is of excellent surface finish and stress free and without any thermal damage.



- MRR of ECM process does not depend on atomic mechanical and physical properties of work material.
- Total potential drop in ECM cell.**



Application :

- Die sinking
- Grinding
- Profiling and contouring
- Drilling

- Trepanning
- Micromachining

Q.7 (b) (ii) Solution:

Given : $f = 0.25 \text{ mm/min} = \frac{0.25 \text{ mm}}{60 \text{ s}}, l = 2 \text{ mm}, V_o = 2.5 \text{ V}$

$r = 50 \text{ }\Omega\text{m}, A = 56, z = 2, \rho = 7.8 \text{ gm/cc}$

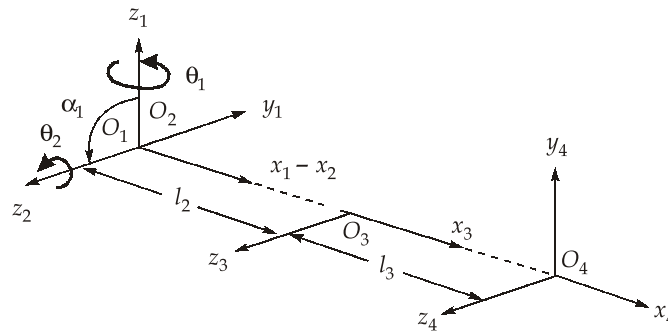
$$f = \frac{\text{MRR}}{\text{Area}} = \frac{A \left(\frac{I}{\text{Area}} \right)}{\rho Z F} = \frac{A \left(\frac{V_s - V_o}{rl} \right)}{\rho Z F}$$

$$V_s - 2.5 = \frac{f}{A} (\rho Z F)(rl) = \frac{0.25}{60 \times 56} \times 7.8 \times 10^{-3} \times 2 \times 96500 \times 50 \times 2$$

$$V_s = 11.2 + 2.5$$

$$V_s = 13.7 \text{ volts}$$

7. (c) Solution:



Link	Pair/joint	Link parameters				Pair/joint variable	cos θ_i	sin θ_i	cos α_i	sin α_i
		a_i	α_i	θ_i	d_i		(C $_i$)	(S $_i$)		
2	1	0	90°	θ_1	0	θ_1	C $_1$	S $_1$	0	1
3	2	l_2	0°	θ_2	0	θ_2	C $_2$	S $_2$	1	0
4	3	l_3	0°	θ_3	0	θ_3	C $_3$	S $_3$	1	0

$${}^1T_2 = \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos 30^\circ & -\sin 30^\circ & 0 & 0 \\ \sin 30^\circ & \cos 30^\circ & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 0.866 & -0.5 & 0 & 0 \\ 0.5 & 0.866 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^2T_3 = \begin{bmatrix} C_2 & -S_2 & 0 & l_2C_2 \\ S_2 & C_2 & 0 & l_2S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos 60^\circ & -\sin 60^\circ & 0 & 1\cos 60^\circ \\ \sin 60^\circ & \cos 60^\circ & 0 & 1\sin 60^\circ \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^2T_3 = \begin{bmatrix} 0.5 & -0.866 & 0 & 0.5 \\ 0.866 & 0.5 & 0 & 0.866 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^3T_4 = \begin{bmatrix} C_3 & -S_3 & 0 & l_3C_3 \\ S_3 & C_3 & 0 & l_3S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos 45^\circ & -\sin 45^\circ & 0 & 0.7\cos 45^\circ \\ \sin 45^\circ & \cos 45^\circ & 0 & 0.7\sin 45^\circ \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^3T_4 = \begin{bmatrix} 0.707 & -0.707 & 0 & 0.495 \\ 0.707 & 0.707 & 0 & 0.495 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^2T_4 = {}^2T_3 {}^3T_4 = \begin{bmatrix} 0.5 & -0.866 & 0 & 0.5 \\ 0.866 & 0.5 & 0 & 0.866 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.707 & -0.707 & 0 & 0.495 \\ 0.707 & 0.707 & 0 & 0.495 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 0.5 \times 0.707 - 0.866 \times 0.707 & -0.5 \times 0.707 - 0.866 \times 0.707 & 0 & 0.31883 \\ 0.965762 & -0.258762 & 0 & 1.54217 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} -0.258762 & -0.965762 & 0 & 0.31883 \\ 0.965762 & -0.258762 & 0 & 1.54217 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

8. (a) (i) Solution:

Width, $w = 275$ mm, Initial thickness, $h_0 = 30$ mm, Final thickness, $h_1 = 25$ mm

Roll radius, $R = 350$ mm, Roll speed, $N = 120$ rpm

True stress strain relation, $\sigma = 200\epsilon^{0.22}$ MPa.

Length of arc of contact, $L_p = \sqrt{R\Delta h} = \sqrt{350(30-25)} = 41.833$ mm

$$\text{True strain, } \epsilon = \ln\left(\frac{h_0}{h_1}\right) = \ln\left(\frac{30}{25}\right) = 0.18232$$

We know that, Avg. flow stress, $\bar{\sigma}_f = \frac{K\epsilon^n}{n+1} = \frac{200 \times (0.18232)^{0.22}}{0.22+1}$

$$\bar{\sigma}_f = 112.734 \text{ MPa}$$

$$\begin{aligned} \text{Projected area, } A_p &= L_p \times w && \text{[where, } w \text{ is width]} \\ &= 41.833 \times 275 \\ &= 11504.075 \text{ mm}^2 \end{aligned}$$

$$\begin{aligned} \text{Roll separating force, } F &= \bar{\sigma}_f \times A_p \\ &= 112.733 \times 11504.075 \times 10^{-6} = 1.2968 \text{ MN} \end{aligned}$$

$$\begin{aligned} \text{Torque per roller} &= F \times 0.5 L_p && \text{[for hot rolling]} \\ &= 27.126 \times 10^{-3} \text{ MN-m} = 27.126 \text{ kN-m} \end{aligned}$$

$$\text{Power per roller, } P = T \times \left(\frac{2\pi N}{60}\right) = 340.856 \text{ kW}$$

$$\text{Total power, } 2P = 681.7134 \text{ kW}$$

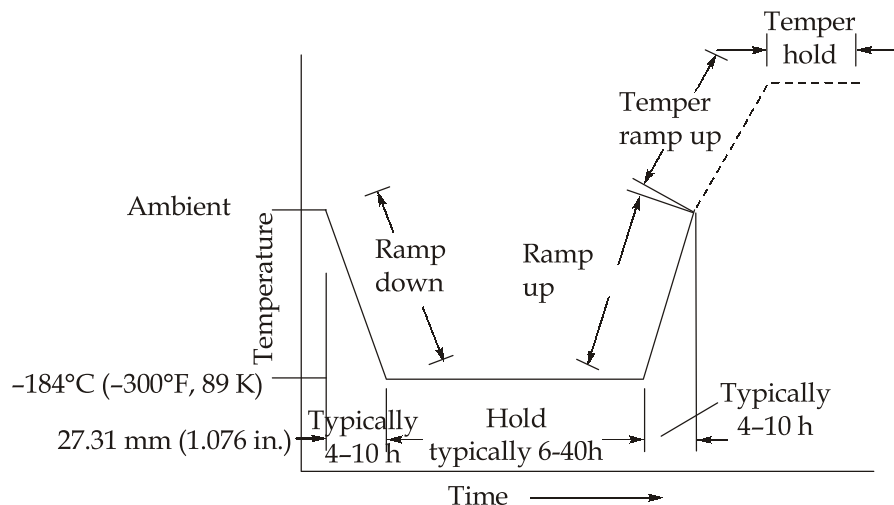
8. (a) (ii) Solution:

A cryogenic treatment is the process of treating workpiece to cryogenic temperatures (i.e. below -190°C) in order to remove residual stresses and improve wear resistance on steels. In addition to seeking enhanced stress relief and stabilization, or wear resistance, cryogenic treatment is also sought for its ability to improve corrosion resistance by precipitating micro-fine eta carbides, which can be measured before and after in a part using a quantimeter. The process has a wide range of applications from industrial tooling

to the improvement of musical signal transmission. Some of the benefits of cryogenic treatment include longer part life, less failure due to cracking, improved thermal properties, better electrical properties including less electrical resistance, reduced coefficient of friction, less creep and walk, improved flatness, flatness, and easier machining.

Cryogenic treatment is an add-on process to conventional heat treatment process in material processing technology. It is a one-time permanent treatment which affects the whole section of the component. It is not like the coatings of superior materials over other metal surfaces that only affects the surface of components. Cryogenic treatments are proved to be a good way to reduce the retained austenite content and improve the performance of materials by improving its martensite structure. Objectives of cryogenic treatment are to increase material's strength, hardness, to improve machinability, cutting properties of tools, to improve surface properties, electrical properties and magnetic properties.

While steel was one of the first materials to undergo cryogenic treatment and the use of this technique to increase the lifetime of machine tools is one of its major applications- cryogenic treatment has been applied to a wide range of materials including aluminium, brass, titanium, nickel alloys, some plastics and even carbon nanotubes.



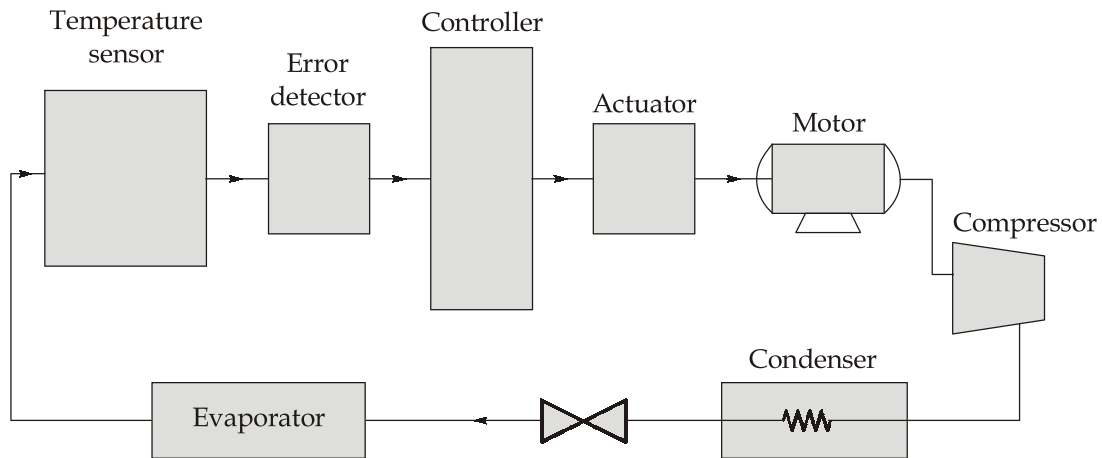
Typical cryogenic treatment cooling curve

8. (b) (i) Solution:

Non destructive inspection techniques are necessary for creating a confidence when using a cast product. Some techniques used for testing the various kinds of defects are listed below.

1. **Visual inspection:** Common defects such as rough surfaces (fused sand), obvious shifts, omission of cores, and surface cracks can be detected by a visual inspection of casting. Cracks may also be detected by hitting the casting with a mallet and listening to the quality of the tone.
2. **Pressure test:** The pressure test is conducted on a casting to be used as a pressure vessel. In this, first all the flanges and ports are blocked. Then, the casting is filled with water, oil or compressed air. Thereafter, the casting is submerged in a soap solution when any leak will be evident by the bubbles that come out.
3. **Magnetic particle inspection:** The magnetic particle test is conducted to check for very small voids and cracks at or just below the surface of a casting of a ferromagnetic material. The test involves inducing a magnetic field through the section under inspection. The powdered ferromagnetic material is spread out onto the surface. The presence of voids or cracks in the section results in a change in the permeability of the surface; this, in turn, cause a leakage in the magnetic field. The powdered particles offer a low resistance path to the leakage. Thus, the particles accumulate on the disrupted magnetic field, outlining the boundary of discontinuity.
4. **Dye penetrant inspection:** The dye-penetrant method is used to detect invisible surface defects in a nonmagnetic casting. The casting is brushed with, sprayed with, or dipped into a dye containing a fluorescent material. The surface to be inspected is then wiped, dried and viewed in darkness. The discontinuities in the surface will then be readily visible.
5. **Radiographic examination:** The radiographic method is expensive and is used only for subsurface exploration. In this, both X- and γ -ray are used. With γ -rays, more than one film can be exposed simultaneously; however, X-ray pictures are more distinct. Various defects, e.g., voids, nonmetallic inclusions, porosity, cracks and tears can be detected by this method. On the exposed film, the defects, being less dense, appear darker in contrast to the surrounding.
6. **Ultrasonic inspection:** In the ultrasonic method, an oscillator is used to send an ultrasonic signal through the casting. Such a signal is readily transmitted through a homogeneous medium. However, on encountering a discontinuity, the signal is reflected back. This reflected signal is then detected by an ultrasonic detector. The time interval between sending the signal and receiving its reflection determines the location of the discontinuity. The method is not very suitable for a material with a high damping capacity (e.g., cast iron) because in such a case the signal gets considerably weakened over some distance.

8. (b) (ii) Solution:



In a refrigeration system, temperature is maintained automatically using a closed-loop control mechanism.

Working Principle:

- The **temperature sensor** continuously measures the temperature inside the evaporator.
- This measured temperature is compared with the desired (reference) temperature.
- The difference between these two values forms the **error signal (trimming signal)**.
- The error signal is sent to the **controller**, which determines the required action.

Control Action:

- If the measured temperature is **higher than the reference temperature**:
- The controller sends a signal to the actuator to **switch ON the motor**.
- The motor drives the **compressor**, increasing refrigeration effect.
- Cooling is produced in the evaporator, reducing temperature.
- If the measured temperature **reaches the desired value**:
- The controller sends a signal to **switch OFF the motor**.
- The compressor stops, maintaining uniform temperature.

Component-wise Function:**1. Temperature Sensor:**

- Senses actual temperature and converts it into electrical signal.

2. Error Detector:

- Compares measured temperature with reference value.

3. Controller:

- Generates ON/OFF control signal based on error.

4. Actuator:

- Operates the motor (switching action).

5. Motor and Compressor:

- Compressor circulates refrigerant to produce cooling effect.

6. Condenser:

- Rejects heat and converts refrigerant from vapor to liquid.

7. Solenoid Valve:

- Controls flow and expansion of refrigerant.

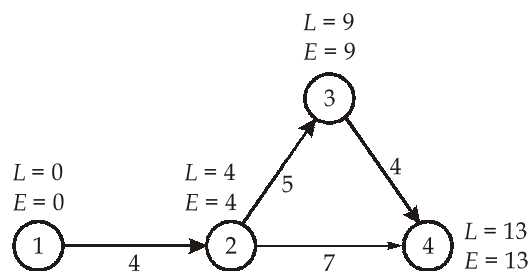
8. Evaporator:

- Absorbs heat from surroundings, producing cooling.

8. (c) Solution:

Given :

Activity	Normal		Crash		$\Delta C/\Delta T$
	Time (Days)	Cost (₹)	Time (Days)	Cost (₹)	
1 - 2	4	4000	2	12000	4000
2 - 3	5	3000	2	7500	1500
2 - 4	7	3600	5	6000	1200
3 - 4	4	5000	2	10000	2500



So, the critical path is 1 - 2 - 3 - 4

Normal duration of the project,

$$T_E = 4 + 5 + 4 = 13 \text{ days}$$

Direct cost of the project will be equal to the sum of the normal cost of all the activities.

$$\therefore \text{Direct cost, D.C.} = 4000 + 3000 + 3600 + 5000 = ₹15600$$

$$\text{Indirect cost} = 13 \times 3000 = ₹39000$$

$$\text{Total cost} = 15600 + 39000 = ₹54600$$

First stage crashing:

We have to crash the minimum cost-slope activity along the critical path. So, we have to choose amongst 1 - 2, 2 - 3 and 3 - 4. It is activity 2 - 3 which has minimum cost slope of 1500 per day. Let us crash this first. Its crash period is 2 days, i.e., $\Delta T = 5 - 2 = 3$ days. However, crashing it by 3 days will affect the critical path. So, let us restrict our crashing to 2 days only.

$$\text{New duration of the project} = 13 - 2 = 11 \text{ days}$$

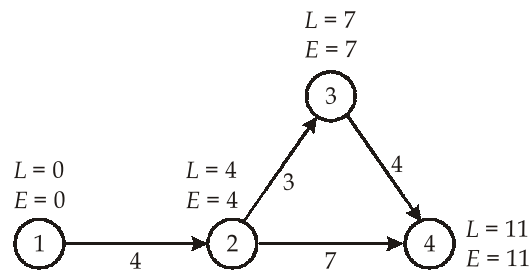
$$\text{Extra cost of crashing activity 2 - 3 by 2 days} = 1500 \times 2 = ₹3000$$

$$\text{Reduction in overhead cost} = 2 \times 3000 = ₹6000$$

$$\therefore \text{Overall reduction} = 6000 - 3000 = ₹3000$$

$$\begin{aligned} \text{Total cost after first crashing} &= 54600 - 3000 \\ &= ₹51600 \end{aligned}$$

The network diagram will become like shown below:



Now, the network has two critical paths and crashing can be done in the following three ways:

- Crashing activity 1 - 2 having a cost-slope of ₹4000 per day.
- Crashing activities 2 - 3 and 2 - 4 simultaneously, having a combined cost slope of $(1500 + 1200) = ₹2700$ per day.
- Crashing activities 3 - 4 and 2 - 4 simultaneously, having a combined cost slope of $(1200 + 2500) = ₹3700$ per day.

Out of these, the second alternative has minimum cost-slope i.e., ₹2700 per day.

Second stage crashing:

Let us crash activities 2 - 3 and 2 - 4 by one day.

Extra cost of crashing activities 2 - 3 and 2 - 4 simultaneously by 1 day is ₹2700.

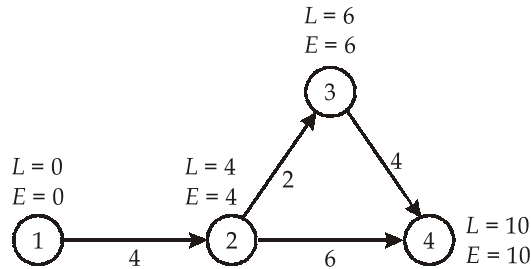
Reduction in the overhead cost = ₹3000

Overall reduction = ₹3000 - ₹2700 = ₹300

Total cost after second crashing = 51600 - 300 = ₹51300

In this step, activity 2 - 3 has been crashed to its fullest extent.

Network diagram after second crashing:



New duration of the project = 10 days.

Third stage crashing:

Now crashing can be done in two ways:

- (a) Crashing activity 1 - 2 having a cost-slope of ₹4000 per day.
- (b) Crashing activities 3 - 4 and 2 - 4 simultaneously having a combined cost-slope of ₹3700 per day.

Out of these, minimum cost-slope is ₹3700 per day. So, let us crash activities 3 - 4 and 2 - 4 simultaneously by 1 day.

Then extra cost of crashing = ₹3700

Reduction in overhead cost = ₹3000

So, there is a net increase of ₹700 due to crashing. So, we stop here.

Therefore, optimum project duration = 10 days

Corresponding cost = ₹51300

Ans.

Ans.

