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ESE – 2019
(MAINS)

Questions with Detailed Solutions

MECHANICAL ENGINEERING

PAPER – II

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MECHANICAL ENGINEERING

ESE _MAINS_2019_ (PAPER – II)

PAPER REVIEW

In this paper questions on Theory of Machines, Strength of materials, Engineering Mechanics, can be easily attempted.

Selection of Questions plays a vital role in securing a good score.

For example Section – B is relatively tougher than Section – A. So, choosing 3 questions from Section – A will fetch you a big advantage.

SUBJECT WISE REVIEW

	Subjects	Level	Marks
Section (A)	Mechanics	Easy	12
	Strength of Materials	Easy to moderate	62
	Theory of Machines	Easy	94
	Machine Design	Easy	72
Section (B)	Production	Easy to tough	66
	IM & OR	Easy	40
	Material Science	Easy to tough	52
	Mechatronics & Robotics	Easy to tough	72
	Maintenance Engineering	Easy	10

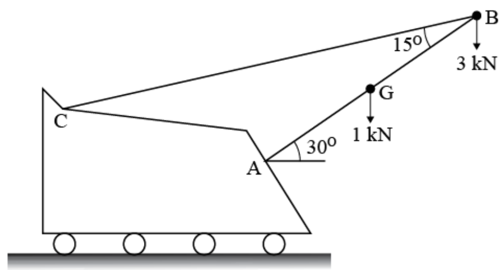
Subjects Experts,

ACE Engineering Academy

SECTION - A

01(a).

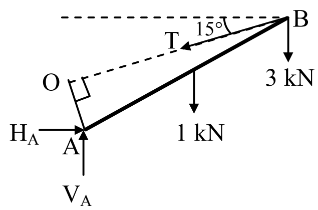
(i) A 10 m boom AB weighs 1 kN. The distance of centre of gravity is 5 m from A. For the position shown in the figure given below, determine the tension T in the cable and reaction at A:



(6 M)

Sol:

F.B.D of boom is shown below :



Taking moment about A,

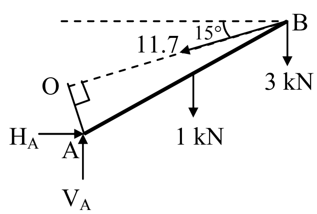
$T \times 2.59 = 1{\times}5 \cos30° + 3{\times}10 \cos30°$

$\Rightarrow T = 11.7$ kN

Final F.B.D

$\Sigma F_x = 0$

$\Rightarrow H_A = 11.7 \cos15° = 11.3$ kN



$\Sigma F_y = 0$

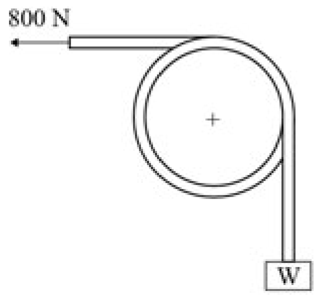
$\Rightarrow V_A = 3{+}1 + 11.7 \sin15° = 7.03$ kN

Net reaction,

$= \sqrt{7.03^2 + 11.3^2}$

$= 13.31$ kN

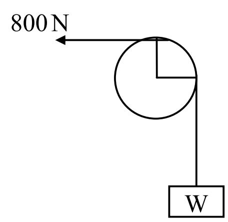
(ii) A rope making $1\frac{1}{4}$ turns around a stationary horizontal drum is used to support a weight as shown in the figure given below. If the coefficient of friction is 0.3, what range of weight can be supported by exerting an 800 N force at the end of the rope?



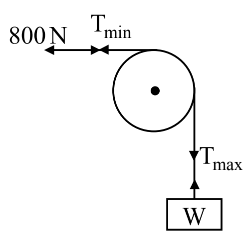
(6 M)

Sol: Angle of contact = $1^{1/4}$ turns

$$= 2\pi + \pi/2 = \frac{5\pi}{2}$$



Case (i): To hold W



$$\frac{T_{max}}{T_{min}} = e^{\mu\theta}$$

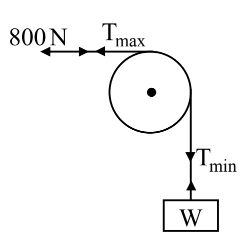
$$\frac{W}{800} = e^{\mu\theta}$$

$$W = e^{\left(\frac{5\pi}{2}\times 0.3\right)} \times 800$$

$$W = e^{2.35} \times 800$$

$$W = 8388.45\,\text{N}$$

Case (ii): To just lift the W



$$\frac{800}{W} = e^{\mu\theta}$$

$$W = \frac{800}{e^{\left(\frac{5\pi}{2}\times 0.3\right)}}$$

$$W = e^{\frac{800}{e^{2.35}}}$$

$$W = \frac{800}{10.48} = 76.33\ \text{N}$$

01(b). A steel tube of 100 mm internal diameter and 10 mm wall thickness in a plant is lined internally with well-fitted copper sleeve of 2 mm wall thickness. If the composite tube is initially unstressed, calculate the hoop stress set up assumed to be uniform throughout the wall thickness, in a unit length of each part of the tube due to an increase in temperature of 100 °C.

For steel, $E = 208\,\text{GPa}, \quad \alpha = 11\times10^{-6}/^\circ C$

For copper, $E = 104\,\text{GPa}, \quad \alpha = 18\times10^{-6}/^\circ C$. **(12 M)**

Sol:

For steel tube :

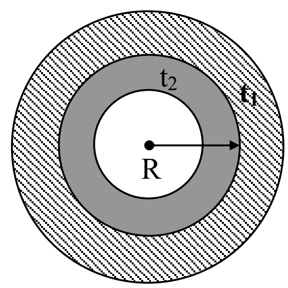
$d_i = 100$ mm, $t_1 = 10$ mm,

and $E = 208$ GPa, $\alpha = 11\times10^{-6}/^\circ C$

For Copper sleeve :

$d_o = 100$ mm, $t_2 = 2$ mm,

and $E = 104$ GPa, $\alpha = 18\times10^{-6}/^\circ C$



When temperature rises by 100°C, copper will try to expand faster than steel. Consequently, steel experiences tensile hoop stress whereas copper experiences compressive hoop stress.

Equilibrium gives $\rightarrow$ (For unit length)

$$\sigma_{st} \times 10 \times 1 = \sigma_{cu} \times 2 \times 1$$

$$\Rightarrow \quad \sigma_{cu} = 5\sigma_{st} \quad \text{--------(i)}$$

Compatibility condition $\rightarrow$ (At interface)

$$\alpha_{cu}(\pi\, d_{cu})\Delta T - \frac{\sigma_{cu}(\pi d_{cu})}{E_{cu}} = \alpha_{st}(\pi d_{st})\Delta T + \frac{\sigma_{st}(\pi d_{st})}{E_{st}}$$

$$\alpha_{cu}\Delta T - \frac{\sigma_{cu}}{E_{cu}} = \alpha_{st}\,\Delta T + \frac{\sigma_{st}}{E_{st}}$$

$$18\times10^{-6}\times100 - \frac{5\sigma_{st}}{104\times10^{3}} = 11\times10^{-6}\times100 + \frac{\sigma_{st}}{208\times10^{3}}$$

$$\frac{11\sigma_{st}}{208\times10^{3}} = 7\times10^{-4}$$

$$\Rightarrow \sigma_{st} = \frac{208\times10^{-1}\times7}{11} = 13.24 \text{ MPa}$$

01(c). (i) What is kinematic pair? How are kinematic pairs classified? Explain. (6 M)

Sol: Kinematic Pair:

Interconnection between two links that allows the relative motion between them is known as kinematic pair.

Classification of Kinematic pairs:

(a) Based on Degrees of Freedom:

- A kinematic pair allows few degrees of freedom and constraints some of them.
- A pair that constrains all the degrees of freedom of the second link relative to the first link is not considered as a kinematic pair, it is a rigid joint.
- On the basis of degrees of freedom there are following 6 pairs.

Pair	Symbol	Pair Variable	Degrees of Freedom	Relative motion
Revolute	R	$\Delta\theta$	1	Circular
Prismatic	P	Δs	1	Rectilinear
Helical	H	$\Delta\theta$ or Δs	1	Helical
Cylinder	C	$\Delta\theta$ and Δs	2	Cylindric
Sphere	S	$\Delta\theta$, $\Delta\phi$, $\Delta\psi$	3	Spheric
Flat	F	Δx, Δy, $\Delta\theta$	3	Planar

(b) Based on Nature of contact:

Based on the nature of contact between the two links the kinematic pairs are classified as *lower pairs and higher pairs*.

Lower pairs:

- When the two bodies have surface or area contact between them they are referred as lower pairs.
- The relative motion in a lower pair is either purely turning or sliding.

  Ex: Nut turning on screw, universal joint etc.

Higher pairs:

- When the contact between the bodies is a point or line contact they are referred as higher pairs.
- The relative motion in a higher pair is a combination of sliding and turning.

  Ex: Cam and Follower pair, ball and roller bearings and gears etc.

(c) Kinematic pair according to Mechanical construction.

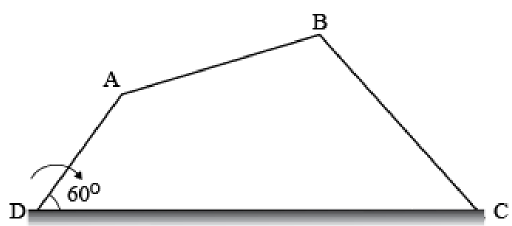
(i) Closed pair

(ii) Open pair

01(c).(ii) A four - bar mechanism has the following dimensions:

$$DA = 200\,\text{mm},\ CB = AB = 300\,\text{mm},\ DC = 500\,\text{mm}$$

The link DC is fixed and the angle ADC is 60°. The driving link DA rotates uniformly at a speed of 100 r.p.m. clockwise and constant driving torque has the magnitude of 50 N-m. Determine the velocity of point B and angular velocity of the driven link CB. If the efficiency is 70%, calculate also the resisting torque:



(6 M)

Sol: Given data,

DA = 500 mm

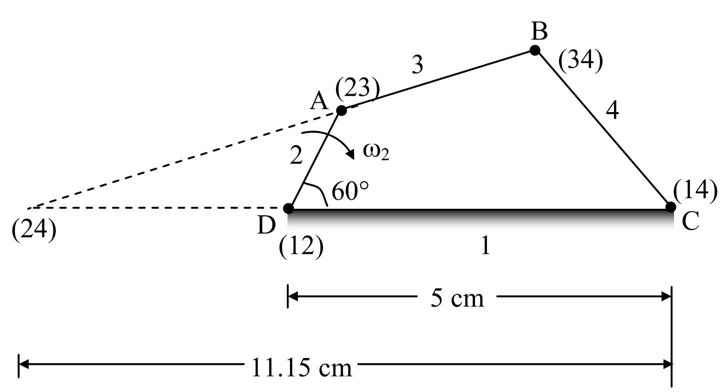
CB = AB = 300 mm

DC = 500 mm

$\angle ADC = 60°$

Let 1 cm = 100 mm

$\omega_2 = \omega_{DA} = 100$ rpm CW



$$\because\ V_{24} = I_{12}I_{24}.\omega_2 = I_{14}I_{24}.\omega_4$$

$$\Rightarrow \omega_4 = \frac{I_{12}I_{24}\times 100}{I_{14}I_{24}} = \frac{11.15\times 100}{6\times 100}\times 100 = 185.83 \text{ rpm}$$

$$V_B = CB.\omega_4 = 300 \times \frac{2\pi \times 185.83}{60} = 5838.12 \text{ mm/s}$$

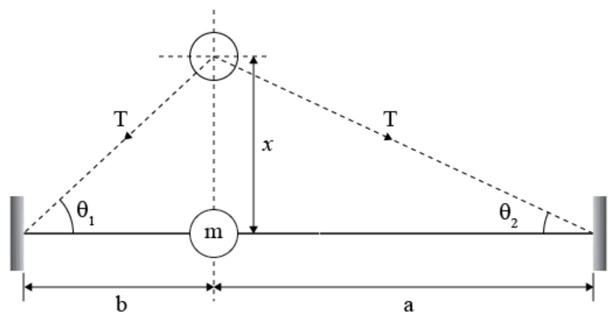
$$\because \quad \eta = 0.7 = \frac{\text{Power at output}}{\text{Power at input}}$$

$$0.7 = \frac{\tau_4.\omega_4}{\tau_2.\omega_2}$$

$$\tau_4 = \frac{0.7 \times 50 \times 100}{185.83} = 18.834 \text{ N-m}$$

01(d).

(i). The tension T in the spring as shown in the figure given below can be assumed to be constant for small displacements. Determine the natural frequency of the vertical vibrations of the spring and also show that the period of vibration is greatest when a = b;



(6 M)

Sol: $T\sin\theta_1 + T\sin\theta_2 = m\ddot{x}$

Newton's method

$$T\left(\frac{x}{b}\right) + T\left(\frac{x}{a}\right) = m\ddot{x}$$

$$\omega_n = \sqrt{T\left(\frac{1}{b} + \frac{1}{a}\right)}$$

$$\omega_n = \sqrt{T\left(\frac{a+b}{ab}\right)}$$

$$\omega_n = \sqrt{\frac{T.\ell}{a(\ell - a)}}$$

$a + b = \ell$

'T' will be maximum if ω_n is minimum.

$$\frac{d\omega_n}{da} = 0$$

$$\frac{d}{da}\left[a\ell - a^2\right] = 0 \Rightarrow \ell - 2a = 0$$

$$\Rightarrow a = \frac{\ell}{2} \qquad \text{i.e. } a = b = \frac{\ell}{2}$$

$$\omega_n = \sqrt{\frac{4T}{m\ell}}$$

01(d).(ii) A vibrating system has the following constants :

$$W = 19.62\,\text{kg}, K = 8\,\text{kg/cm}, C = 0.08\,\text{kg} - \text{s/cm}$$

Determine:

(1) damping factor;

(2) natural frequency of damped oscillations;

(3) logarithmic decrement.

Here, W = weight of mass, K = Spring stiffness, C = Damping coefficient. (6 M)

Sol: m = 19.62 kg ,

k = 8 kg/cm = 8×9.81×10^2 N/m = 7848 N/m,

c = 0.08 kg-sec/cm = 0.08×9.81×100 = 78.48 N-sec/m

Natural un-damped frequency,

$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{7848}{19.62}} = 20 \text{ rad/sec}$$

(i) Damping factor, $\xi = \dfrac{c}{2m\omega_n} = \dfrac{78.48}{2 \times 19.62 \times 20} = 0.1$

(ii) Natural frequency of damped oscillations, $\omega_d = \omega_n\sqrt{1-\xi^2}$

$$= 20 \times \sqrt{1-(0.1)^2}$$

$$= 19.899 \text{ rad/sec}$$

(iii) Logarithmic decrement, $\delta = \dfrac{2\pi\xi}{\sqrt{1-\xi^2}} = \dfrac{2\pi \times 0.1}{\sqrt{1-(0.1)^2}} = 0.6314$

01(e). Differentiate between 'shaft' and 'axle'. A solid shaft of diameter d is used in power transmission. Due to the modification of existing transmission system, the solid shaft is required to be replaced by a hollow shaft of the same material and equally strong in torsion. The weight of the hollow shaft per unit length is to be half of the solid shaft. Determine the outer diameter of the hollow shaft in terms of d. (12 M)

Sol: **Shaft:** A shaft is a rotating or stationary member, usually of circular cross-section, that supports transmission elements like gears, pulleys and sprockets and transmits power.

Shafts may be subjected to bending, axial, torsional loads acting single or in combination with one another.

Axle: An axle is a shaft, either stationary or rotating, not subjected to a torsion load.

Ex: Rear axle of railway wagon.

Outer diameter of hollow shaft in terms of solid shaft diameter, d

As both the shafts are equally strong in torsion,

$$T = \frac{\pi}{16}\tau d^3 = \frac{\pi}{16}\tau\left[\frac{d_o^4 - d_i^4}{d_o}\right]$$

d_o = outer diameter, d_i = inner diameter

$$\therefore\ d_i^4 = d_o^4 - d^3 d_o \qquad \text{..........(1)}$$

As the hollow shaft weighs half of solid shaft for same material and length,

$$\frac{\pi}{4}\left(d_o^2 - d_i^2\right) = \frac{1}{2}\frac{\pi}{4}d^2$$

$$d_i^2 = d_o^2 - \frac{d^2}{2} \qquad \text{.........(2)}$$

Eliminating d_i from equation 1 and 2

$$d^2 d_o^2 - d^3 d_o - \frac{d^4}{4} = 0 \text{..........(3)}$$

$$\therefore d_o = \frac{d + \sqrt{2}d}{2}$$

(Considering the positive root of equation 3)

02(a). The turbine rotor of a ship has a mass of 3000 kg. It has a radius of gyration of 0.45 m and a speed of 2000 r.p.m clockwise when looking from stern. Determine the gyroscopic couple and its effect on the ship

(i) When the ship is steering to the left on a curve of 100 m radius at a speed of 30 km/hr;

(ii) When the ship is pitching in a simple harmonic motion, the bow falling with its maximum velocity. The period of pitching is 40 seconds and the total angular displacement between the two extreme positions of pitching is 12 degrees. (20 M)

Sol: m = 3000 kg, k = 0.45 m

N = 2000 rpm CW when looked from stern.

(i) Ship is steering to left

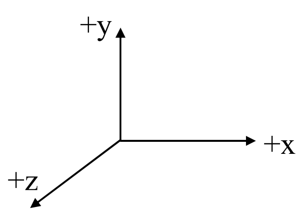
V = 30 km/hr

R = 100 m

Gyroscopic couple, $C = I\omega.\omega_p = mk^2 \times \frac{2\pi N}{60} \times \frac{V}{R}$

$$= 3000(0.45)^2 \times \frac{2\pi \times 2000}{60} \times \frac{30 \times 1000}{100 \times 3600}$$

$$= 10602.87 \text{ N-m}$$



Axis

Spin	+x	$+\hat{i}$
Process	+y	$+\hat{j}$
Reactive Gyroscopic couple	+z	$+\hat{k}$

Bow will raise and stern moves down.

(ii) Ship is pitching in simple harmonic motion (Bow is falling)

Let the displacement equation be, $\theta = \theta_o \sin \omega t$

Velocity, $\dot{\theta} = \theta_o \omega \cos \omega t$

T = 40 s

$$\theta_o = \frac{12^o}{2} = 6^o$$

Gyroscopic couple, $C = I\omega.\omega_p = mk^2 \times \frac{2\pi N}{60} \times \theta_o \omega$

$$= mk^2 \times \frac{2\pi N}{60} \times \left(6^o \times \frac{\pi}{180^o}\right) \times \frac{2\pi}{T}$$

$$T = 3000(0.45)^2 \times \frac{2\pi \times 2000}{60} \times \frac{\pi}{30^o} \times \frac{2\pi}{40} = 2092.92 \text{ N-m}$$

	Axis	
Spin	+x	$+\hat{i}$
Precession	–z	$-\hat{k}$
Reactive Gyroscopic couple	+y	$+\hat{j}$

∴ Ship will turn towards portside or left turn.

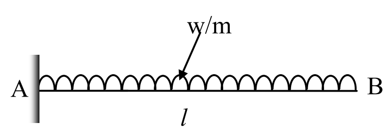
02(b). A steel cantilever of length 2 m of circular cross-section, 50 mm in diameter, carries uniformly distributed load of intensity w. What is the maximum value of w so that deflection at free end is not a exceed 1 mm? Find out the slope at free end. Take E = 200 GPa.

(20 M)

Sol: Given data:

$\ell = 2$ m; d = 50 mm = 0.050 m; E = 200 × 10^9 N/m^2

y_{max} = 1 mm = 1 × 10^{-3} m



$$y_B = \frac{w\ell^4}{8EI} = 1 \times 10^{-3} \text{ m}$$

$$= \frac{w \times 2^4}{8 \times 200 \times 10^9 \times \frac{\pi}{64} \times 0.05^4} = 1 \times 10^{-3}$$

w = 30.67 N/m

$$\theta_B = \frac{\omega\ell^3}{6EI} = \frac{30.67 \times 2^3}{6 \times 200 \times 10^9 \times \frac{\pi}{64} \times 0.05^4} = 0.667 \times 10^{-3} \text{ radians}$$

02(c). A thick cylinder is subjected to both internal and external pressure. The internal diameter of the cylinder is 200 mm and the external diameter is 250 mm. If the maximum permissible stress is 30 N/mm^2 and the external pressure is 8 N/mm^2, determine the intensity of internal radial pressure. (20 M)

Sol: Given data:

$d_i = 200$ mm $\Rightarrow$ $r_i = 100$ mm

$d_0 = 250$ mm $\Rightarrow$ $r_0 = 125$ mm

$\sigma_{max} = 30$ N/mm^2, $p_{x = 125\text{ mm}} = 8$ N/mm^2

Lami's equations:

$$p_x = \frac{b}{x^2} - a \text{ .... (1)}$$

$$\sigma_x = \frac{b}{x^2} + a \text{ .... (2)}$$

At $x = 125$ mm $p_x = 8$ N/mm^2

$$\therefore \quad 8 = \frac{b}{125^2} - a \text{ .... (3)}$$

At $x = 100$ mm; $\sigma_x = 30$ N/mm^2

$$\therefore \quad 30 = \frac{b}{100^2} + a \text{ .... (4)}$$

Solving the above two equations, we get

$a = 29.415$; $b = 5.85 \times 10^5$

$$\therefore \quad p_x = \frac{5.85 \times 10^5}{x^2} - 29.415 \text{ (from (1))}$$

$$\sigma_x = \frac{5.85 \times 10^5}{x^2} + 29.415 \text{ (from (2))}$$

At $x = 100$ mm,

$$p_{100} = \frac{5.85 \times 10^5}{100^2} - 29.415 = 29.085 \text{ N/mm}^2$$

Result: $p_{x = 100\text{ mm}} = 29.085$ N/mm^2

03(a). A horizontal gas engine running at 200 r.p.m. has a bore of 200 mm and a stroke of 400 mm. The connecting rod is 900 mm long and the reciprocating parts weigh 20 kg. When the crank has turned through an angle of 30° from the inner dead centre, the gas pressures on the cover and the crank sides are 500 kN/m² and 60 kN/m² respectively. The diameter of the piston rod is 40 mm. Determine

(i) turning moment on the crankshaft;

(ii) thrust on the bearings;

(iii) acceleration of the flywheel which has a mass of 8 kg and radius of gyration of 600 mm while the power of the engine is 22 kW. (20 M)

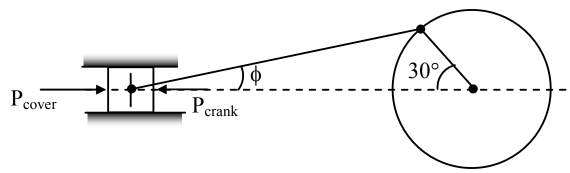
Sol: Speed $N = 200$ rpm

$D = 200 \text{ mm} = 0.2 \text{ m}$

Stroke length = 400 mm

$\Rightarrow$ Crank radius = 200 mm = 0.2 m

$\ell = 900$ mm



$m_{rec} = 20$ kg

$\theta = 30°$

$P_{cover} = 500 \text{ kN/m}^2$

$P_{crank} = 60 \text{ kN/m}^2$

$D_{piston\ rod} = 40$ mm

Gas force, $F_{gas} = (P_{cover}.\ A_{cover}) - (P_{crank\ side}.A_{crank\ side})$

$$= 500 \times \frac{\pi}{4}(0.2)^2 - 60 \times \frac{\pi}{4}\left(0.2^2 - 0.04^2\right)$$

$$= \left[500 \times (0.2)^2 - 60\left(0.2^2 - 0.04^2\right)\right]\frac{\pi}{4}$$

$$= (20 - 2.304) \times \frac{\pi}{4}$$

$$= 13.898 \text{ kN}$$

Inertia force $F_i = m r \omega^2\left[\cos\theta + \frac{\cos 2\theta}{n}\right]$

$$n = \frac{\ell}{r} = \frac{900}{200} = 4.5$$

$$F_i = 20 \times 0.2 \times \left(\frac{2\pi \times 200}{60}\right)^2 \left[\cos 30^\circ + \frac{\cos 60^\circ}{4.5}\right]$$

$F_i = 1714.48$ N

Piston effort

$F_p = F_{gas} - F_i = 13.898 \times 10^3 - 1714.48 = 12183.52$ N

$\therefore \ \sin\beta = \dfrac{\sin\theta}{n} \Rightarrow \beta = 6.379^\circ$

(i) Turning moment on crankshaft

$$T = \frac{F_p}{\cos\beta} \times r \times \sin(\theta + \beta)$$

$$= \frac{12183.52}{\cos 6.379^\circ} \times 0.2 \times \sin(30^\circ + 6.379^\circ) = 1454.27 \text{ N-m}$$

(ii) Thrust force on bearing = $F_p.\cos(\theta + \beta)$

$= 12183.52\cos(30^\circ + 6.379^\circ) = 9809.09$ N

(ii) Mass of flywheel = 8 kg,

k = 600 mm,

Power = 22 kW

$\because \ P = \dfrac{2\pi N T_m}{60}$

$$T_m = \frac{60 \times 22 \times 10^3}{2\pi \times 200} = 1050.42 \text{ N-m}$$

$T_{supply} = 1454.27$ N-m

$T_{fly} = T_{supply} - T_{load}$

and $T_{load} = T_{mean}$

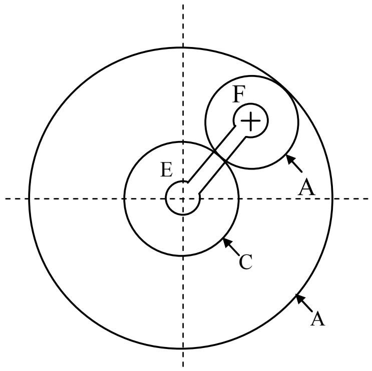
$T_{fly} = 1454.27 - 1050.42$

$I_{fly}.\alpha_{fly} = 403.8473$ N-m

$mk^2.\alpha_{fly} = 403.8473$

$$\alpha_{fly} = \frac{403.8473}{8 \times 0.6^2} = 140.224 \text{ rad/s}^2$$

03(b). An epicyclic gear consists of three gears A, B and C as shown in the figure given below. The gear A has 72 internal teeth and gear C has 32 external teeth. The gear B meshes with both A and C and is carried on an arm EF which rotates about the centre of A at 20 r.p.m. If the gear A is fixed, determine the speed of gears B and C:



(20 M)

Sol:

Condition	Arm	32 Gear C	20 Gear B	72 Gear A
Arm EF is fixed, Gear C is rotating with +x rpm cw.	0	+x	$-x.\frac{32}{20}$	$-x.\frac{32}{20}\times\frac{20}{72}$
Arm is rotating with +y rpm cw	+y	y+x	$y-x\times\frac{8}{5}$	$y-x\times\frac{4}{9}$

$R_A = R_C + 2R_B \qquad (\because \quad m_A = m_C = m_B)$

$T_A = T_C + 2T_B$

$72 = 32 + 2T_B$

$T_B = 20$

Gear A is fixed,

$\omega_A = 0$

$$y - \frac{4x}{9} = 0$$

$$y = \frac{4x}{9} \Rightarrow x = \frac{9y}{4} = \frac{9\times 20}{4} = 45 \text{ rpm}$$

$$\omega_B = y - \frac{8x}{5} = 20 - \frac{8\times 45}{5} = -52 \text{ rpm CW} = 52 \text{ rpm CCW}$$

$\omega_C = y + x = 20 + 45 = 65$ rpm

03(c). A single-cylinder reciprocating engine has a speed of 300 r.p.m., stroke 300 mm, mass of reciprocating parts 50 kg, mass of revolving parts at 150 mm radius 37 kg. If two - thirds of the reciprocating parts and all the revolving parts are to be balanced, find:

(i) the balance mass required at a radius of 300 mm;

(ii) the residual unbalanced force when the crank has rotated 60° from top dead centre.

(10 M)

Sol: Speed, $\omega = \frac{2\pi \times 300}{60}$ = 10π rad/s

Stroke length, $2r = 300$ mm

$r = 0.15$ m

$m_{recip} = 50$ kg

$m_{rotating} = 37$ kg

$\because$ $B.b = cm_{recip}.r + m_{rot}.r_{rot}$

$$B \times \frac{300}{1000} = \left(\frac{2}{3} \times 50 \times 0.15\right) + (37 \times 0.15)$$

$0.3B = 5 + 5.55$

Mass to the balance, $B = 35.16$ kg

Unbalanced force along the line of stroke

$F_x = (1 - c)\, mr\omega^2 \cos\theta$

$$F_x = \left(1 - \frac{2}{3}\right) \times 50 \times 0.15 \times \left(\frac{2\pi \times 300}{60}\right)^2 \times \cos 60^\circ = 1233.7 \text{ N}$$

Unbalanced force perpendicular to line of stroke,

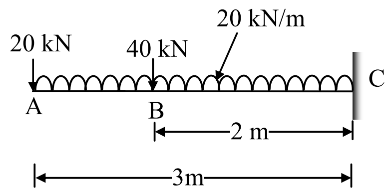
$F_y = c\, mr\omega^2 \sin\theta$

$$= \left(\frac{2}{3}\right) \times 50 \times 0.15 \times \left(\frac{2\pi \times 300}{60}\right)^2 \times \sin 60^\circ = 4273.67 \text{ N}$$

Resultant unbalanced force, $R = \sqrt{(F_x)^2 + (F_y)^2}$

$$= \sqrt{(1233.7)^2 + (4273.67)^2} = 4448.17 \text{ N}$$

03(d). Draw the shear force and bending moment diagram for the cantilever beam as shown in the figure given below:

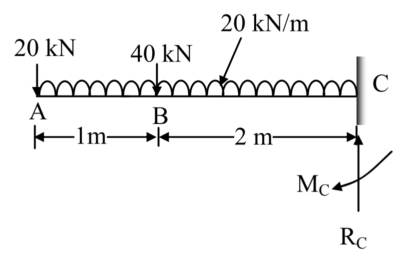


(10 M)

Sol: (+)↑ $\Sigma F_y = 0$

$R_C - 20 - 40 - 20 \times 3 = 0$

$R_C = 20 + 40 + 60 = 120$ kN



(+) ↺ $\Sigma M_C = 0$

$-20 \times 3 - 40 \times 2 - (20 \times 3)(1.5) + M_C = 0$

$M_C = 60 + 80 + 90 = 230$ kN-m

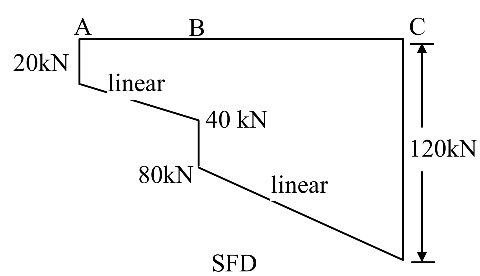
Shear force calculation

$F_A = -20$ kN

$F_{B,left} = -20 - (20 \times 1) = -40$ kN

$F_{B,right} = -40 - 40 = -80$ kN

$F_C = R_C = -120$ kN



Bending moment calculation

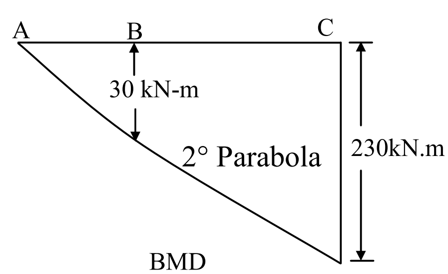
$M_A = 0$

$M_B = -20 \times 1 - (20 \times 1)(0.5)$

$= -20 - 10 = -30$ kN-m

$M_C = (-20 \times 3) - (40 \times 2) - (20 \times 3)(1.5)$

$= -230$ kN-m

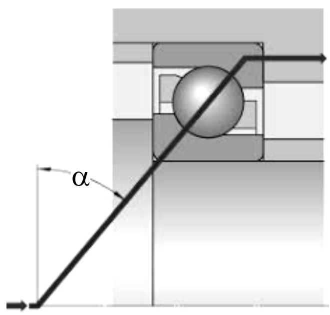


04(a).

(i) Describe angular contact bearings and taper roller bearings with the help of neat sketches. Also, cite at least two advantages and two disadvantages of each. (8 M)

Sol: Angular Contact Bearing:

In angular contact bearing, the grooves in inner and outer races are so shaped that the line of reaction at the contact between balls and races makes an angle with the axis of the bearing. This reaction has two components angular contact bearing can take radial and thrust loads.



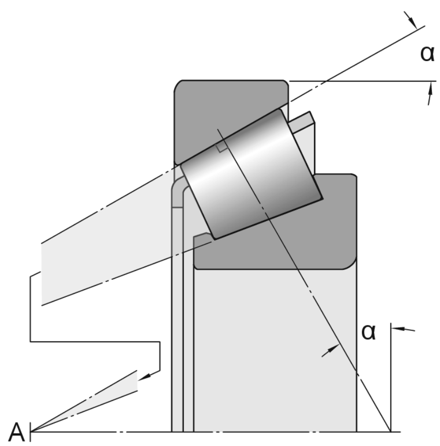
Advantages:

- Angular contact bearing can take both radial and thrust loads.
- In angular contact bearing, one side of the groove in the outer race is cut away to permit the insertion of larger number of balls than that of deep groove ball bearing. This permits the bearing to carry relatively large axial and radial loads. Therefore, the load carrying capacity of angular contact bearing is more than that of deep groove ball bearing.

Disadvantages:

- Two bearings are required to take thrust load in both directions.
- The angular contact bearing must be mounted without axial play.
- The angular contact bearing requires initial pre-loading.

Taper Roller Bearing: The taper roller bearing consists of rolling elements in the form of a frustum of cone. They are arranged in such a way that the axes of individual rolling elements intersect in a common apex point on the axis of the bearing. In kinematics analysis, this is the essential requirement for pure rolling motion between conical surfaces. In taper roller bearing, the line of resultant reaction through the rolling elements make an angle with the axis of the bearing. Therefore, taper roller bearing can carry both radial and axial loads.



Advantages:

- Taper roller bearing can take heavy radial and thrust loads.
- Taper roller bearing has more rigidity
- Taper roller bearing can be easily assembled and disassembled due to separate parts.

Disadvantages:

- It is necessary to use two taper roller bearings on the shaft to balance the axial force.
- It is necessary to adjust the axial position of the bearing with pre-load. This is essential to coincide the apex of the cone with the common apex of the rolling elements.
- Taper roller bearing cannot tolerate misalignment between the axes of the shaft and the housing bore.
- Taper roller bearings are costly.

04(a).

(ii) A pair of spur gears with 20° full-depth involute teeth consists of a 20 teeth pinion meshing with a 41 teeth gear. The module is 3 mm while the face width is 40 mm. The material for both the pinion and the gear is steel having an ultimate tensile strength of 660 N/mm^2. The gears are heat-treated to a surface hardness of 400 BHN. The pinion rotates at 1500 r.p.m. and the service factor is 2.0. Assume that the velocity factor accounts for the dynamic load and the factor of safety is 1.5. Determine the rated power that the gears can transmit. Assume a Lewis form factor of 0.32. (12 M)

Sol:

$\phi = 20^o$, $T_P = 20$, $T_G = 41$, $m = 3\,mm$,

$w = 40\,mm$, $S_{ut} = 660\,N/mm^2$, BHN = 400

$N_P = 1500\,rpm$, $c_s = 2.0$, F.s = 1.5, Power = ?, y = 0.32

Since, gear and pinion are made of same material, the design is based on pinion.

Dynamic load carrying capacity of pinion based on Lewis equation is

$$F_t = \frac{S_{ut}\ w\ m\ y\ c_v}{c_s} \qquad \text{[where } c_v \text{ is velocity factor]}$$

$$= \frac{660}{1.5} \times \frac{40 \times 3 \times 0.32}{2.0} \times c_v$$

$$V = \frac{\pi d_p N_p}{60} = \frac{\pi \times m T_P \times N_P}{1000 \times 60}$$

$$= \frac{\pi \times 3 \times 20 \times 1500}{1000 \times 60} = 4.712 \text{ m/s}$$

$\therefore$ Since, V < 10 m/s

Assuming, $c_v = \frac{3}{3+V} = \frac{3}{3+4.712} = 0.389$

$$F_t = \frac{660}{1.5} \times \frac{40 \times 3 \times 0.32 \times 0.389}{2} = 3.286 \text{ kN}$$

Load carrying capacity based on wear strength,

$$F_W = k d_p W Q$$

$$k = \frac{S_{ew}^2 \sin\phi}{1.4}\left(\frac{1}{E_p} + \frac{1}{E_G}\right)$$

$$S_{ew} = 2.76\,BHN - 70\,MPa$$

$$= 2.76 \times 400 - 70$$

$$= 1034 \text{ MPa}$$

$\therefore$ Dynamic load factor,

$$k = \frac{1034^2 \times \sin 20}{1.4}\left(\frac{1}{2 \times 10^5} + \frac{1}{2 \times 10^5}\right) = 2.6$$

$$E = 2 \times 10^5\ N/mm^2 \text{ for steel} \quad \text{(Assumed)}$$

Ratio factor,

$$Q = \frac{2T_G}{T_G + T_P} = \frac{2\times 41}{41+20} = 1.34$$

$$\therefore\ F_w = 2.6 \times mT_P \times w \times Q$$

$$= 2.6 \times 3 \times 20 \times 40 \times 1.34 \ = 8.361 \text{ kN}$$

Since $F_t < F_w$, design is based on F_t

Hence, the power transmitted is,

$$P = F_t \times V = 3.286 \times 4.712 \ = 15.48 \text{ kW}$$

04(b). What advantages do the welded joints offer in comparison to riveted joints? Neatly sketch the basic symbols used to specify the following types of weld:

(i) Fillet

(ii) Square butt

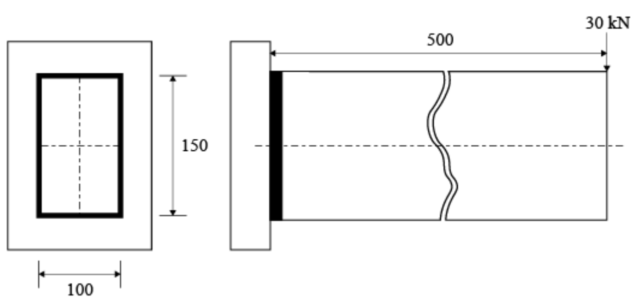
(iii) Single V-butt

(iv) Spot

(v) Seam

(vi) Projection

A beam of rectangular cross-section is welded to a support by means of fillet welds as shown in the figure given below. Determine the size of the welds if the permissible shear stress is 80 N/mm^2. (20 M)



Sol: Welded joints offer the following advantages compared with Riveted Joints:

(i) Riveted joints require additional cover plates, gusset plates, straps, clip angles and a large number of rivets, which increase the weight. Since there are no such additional parts, welded assembly results in light weight construction. Welded steel structures are lighter than corresponding iron castings lighter than the corresponding iron castings by 50% and steel castings by 30%.

(ii) Due to the elimination of these components, the cost of welded assembly is lower than that of riveted joints.

(iii) The design of welded assemblies can be easily and economically modified to meet the changing product requirements. Alternations and additions can be easily made in the existing structure by welding.

(iv) Welded assemblies are tight and leakproof as compared with riveted assemblies.

(v) The production time is less for welded assemblies.

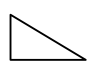
(vi) When two parts are joined by the riveting method, holes are drilled in the parts to accommodate the rivets. The holes reduce the cross-sectional area of the members and result in stress concentration. There is no such problem in welded connections.

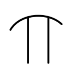
(vii) A welded structure has smooth and pleasant appearance. The projection of rivet head adversely affects the appearance of the riveted structure.

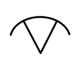
(viii) The strength of welded joint is high. Very often, the strength of the weld is more than the strength of the plates that are joined together.

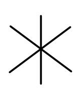
(ix) Machine components of certain shape, such as circular steel pipes, find difficulty in riveting. However, they can be easily welded.

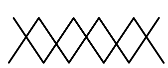
The basic Symbols used to specify the following types of weld :

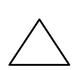
(i) Fillet 

(ii) Square Butt 

(iii) Single V-Butt 

(iv) Spot 

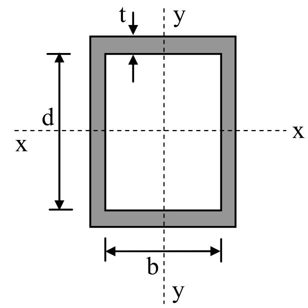
(v) Seam 

(vi) Projection 

Given,

P = 30 kN,

$$\frac{S_{sy}}{FS} = 80\,\text{MPa}$$



Total area of weld

$$A = 2(100t + 150t) = 500\,t\,\text{mm}^2$$

Primary shear stress,

$$\tau_1 = \frac{P}{A} = \frac{30000}{500\,t}\,\text{N/mm}^2 = \frac{60}{t}\,\text{N/mm}^2$$

Moment of inerita of weld about x-axis,

$$I_{xx} = 2\left[\frac{1}{12}\times bt^3 + bt\times\left(\frac{d}{2}\right)^2\right] + 2\left(\frac{td^3}{12}\right)$$

Since, b and d are very large compared to 't', t^3 terms are neglected.

$$I_{xx} = bt\times\frac{d^2}{2} + \frac{td^3}{6}$$

$$= t\left[\frac{bd^2}{2} + \frac{d^3}{6}\right]$$

$$\therefore I_{xx} = t\left[\frac{100\times150^2}{2} + \frac{150^3}{6}\right] = 75\times150^2\times t\,\text{mm}^4$$

Bending stress,

$$\sigma_b = \frac{M}{I_{xx}}\times y$$

$$= \frac{30000\times500}{75\times150^2\,t}\times75 = \frac{666.66}{t}\,\text{N/mm}^2$$

$\therefore$ Maximum shear stress,

$$\tau_{max} = \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau_1^2}$$

$$= \sqrt{\left(\frac{666.66}{2t}\right)^2 + \left(\frac{60}{t}\right)^2} = \frac{338.69}{t}\,\text{N/mm}^2$$

According maximum shear stress theory,

$$\tau_{max} = \frac{S_{sy}}{FS}$$

$$\frac{338.69}{t} = 80$$

$\therefore$ t = 4.23 mm

$$\therefore \text{ Size of weld, } s = \frac{t}{0.707} = \frac{4.23}{0.707} = 5.98\,\text{mm} \approx 6\,\text{mm}$$

04(c). A shaft is subjected to a maximum torque of 10 kN-m and a maximum bending moment of 7.5 kN-m at a particular section. If the allowable equivalent stress in simple tension is 160 MN/m^2, find the diameter of the shaft according to (i) maximum shear stress theory, (ii) strain energy theory and (iii) shear strain energy theory. Take Poisson's ratio as 0.24.

(20 M)

Sol: Given:

$T = 10\,\text{kN} - \text{m},$

M = 7.5 kN-m,

$S_{yt} = 160\,\text{N/mm}^2,$ d = ?

(i) Maximum shear stress theory:

Equivalent torque,

$$T_{eq} = \sqrt{M^2 + T^2} = \sqrt{7.5^2 + 10^2} = 12.5\,\text{kN} - \text{m}$$

Maximum shear stress,

$$\tau_{max} = \frac{16T_{eq}}{\pi d^3} = \frac{16 \times 12.5 \times 10^6}{\pi \times d^3}\,\text{N/mm}^2 = \frac{63.66 \times 10^6}{d^3}\,\text{N/mm}^2$$

According to maximum shear stress theory,

$$\tau_{max} = S_{sy} = \frac{S_{yt}}{2}$$

$$\frac{16 \times 12.5 \times 10^6}{\pi d^3} = \frac{160}{2} \Rightarrow d \geq 92.66\,\text{mm}$$

(ii) Maximum strain energy theory:

$$\text{Let } \alpha = \frac{16}{\pi d^3}$$

$$\sigma_1 = \alpha\left(M + \sqrt{M^2 + T^2}\right) = 20 \times 10^6\,\alpha$$

$$\sigma_2 = \alpha\left(M - \sqrt{M^2 + T^2}\right) = -5 \times 10^6\,\alpha$$

Now, $\sigma_1^2+\sigma_2^2-2\mu\sigma_1\sigma_2 \le S_{yt}{}^2$

$$\alpha^2\left[(20\times10^6)^2+(5\times10^6)^2+2\times0.24\times100\times10^{12}\right]\le160^2$$

$$\alpha^2\times473\times10^{12}\le160^2$$

$$\Rightarrow \alpha\le\frac{160}{\sqrt{473\times10^{12}}}$$

$$\Rightarrow \alpha\le7.3563\times10^{-6}$$

$$\Rightarrow \frac{16}{\pi d^3}\le7.356\times10^{-6}$$

$$\Rightarrow d\ge88.48 \text{ mm}$$

(iii) Shear strain energy theory or von-Mises theory:

$$\sigma_1^2+\sigma_2^2-\sigma_1\sigma_2\le S_{yt}{}^2$$

$$\frac{10^6}{d^3}\sqrt{101.855^2+25.4^2+101.855\times25.4}\le160$$

$$d \ge 90 \text{ mm}$$

SECTION - B

05(a). Describe the following microconstituents of iron-carbon alloys in relation to the phases present, arrangement of phases and their relative mechanical properties:

(a) Spheroidite

(b) Pearlite

(c) Bainite

(d) Martensite **(12 M)**

Sol: Phase transformations and mechanical properties for iron–carbon alloys

Several different microstructures that may be produced in iron–carbon alloys depending on heat treatment. Figure summarizes the transformation paths that produce these various microstructures. Here, it is assumed that Pearlite, Bainite, and Martensite result from continuous-cooling treatments; furthermore, the formation of Bainite is possible only for alloy steels (not plain carbon ones).

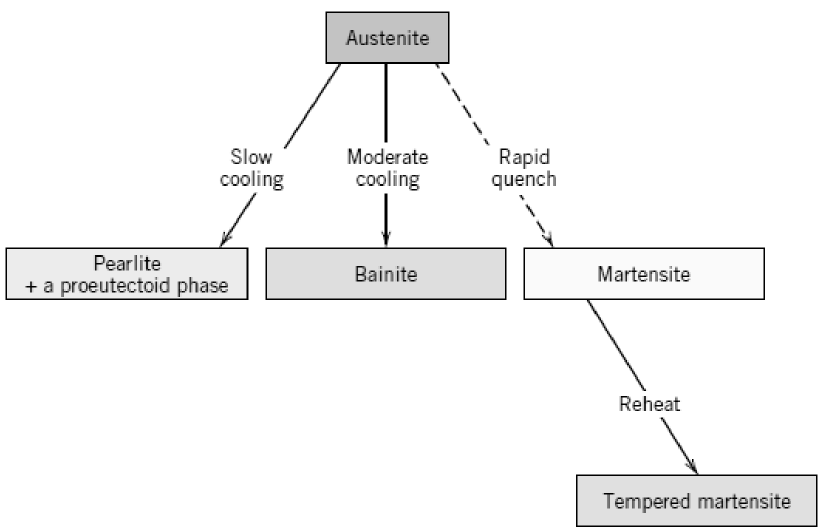


Figure *Possible transformations involving the decomposition of austenite. Solid arrows, transformations involving diffusion; dashed arrow, diffusionless transformation.*

Microstructural characteristics and mechanical properties of the several microconstituents for iron–carbon alloys are summarized in Table.

Microconstituent	*Phases Present*	*Arrangement of Phases*	*Mechanical Properties (Relative)*
Spheroidite	α-Ferrite + Fe_3C	Relatively small Fe_3C spherelike particles in an α-ferrite matrix	Soft and ductile
Coarse pearlite	α-Ferrite + Fe_3C	Alternating layers of α-ferrite and Fe_3C that are relatively thick	Harder and stronger than spheroidite, but not as ductile as spheroidite
Fine pearlite	α-Ferrite + Fe_3C	Alternating layers of α-ferrite and Fe_3C that are relatively thin	Harder and stronger than coarse pearlite, but not as ductile as coarse pearlite
Bainite	α-Ferrite + Fe_3C	Very fine and elongated particles of Fe_3C in an α-ferrite matrix	Harder and stronger than fine pearlite; less hard than martensite; more ductile than martensite
Tempered martensite	α-Ferrite + Fe_3C	Very small Fe_3C spherelike particles in an α-ferrite matrix	Strong; not as hard as martensite, but much more ductile than martensite
Martensite	Body-centered, tetragonal, single phase	Needle-shaped grains	Very hard and very brittle

Table: Microstructures and Mechanical Properties for Iron–Carbon Alloys

05(b). In an orthogonal cutting operation, the cutting speed is 2.5 m/s, rake angle is 6° and the width of cut is 10 mm. The underformed chip thickness is 0.2 mm. 13.36 grams of steel chips with total length of 50 cm are obtained. The tool post dynamometer gives cutting and thrust forces as 1134 N and 453.6 N respectively. Find

(i) shear plane angle;

(ii) friction energy at tool-chip interface as percentage of total energy;

(iii) specific cutting energy.

Assume density of steel = 7.8 grams/cm^3. **(12 M)**

Sol: Given data:

Orthogonal cutting operation:

Cutting speed $(V) = 2.5$ m/sec

Rake angle $(\alpha) = 6°$

Width of cut $(W) = 10$ mm

Uncut chip thickness $(t_1) = 0.2$ mm

Mass (or) weight of chip obtained (Wt) = 13.36 grams

l_c = chip length = 50 cm

Density of steel $(\rho) = 7.8$ grams/cm^3

Cutting force $(F_C) = 1134$ N

Thrust force $(F_T) = 453.6$ N

Find:

(i) Shear plane angle (ϕ)

(ii) friction energy at tool chip interface as % of total energy

(iii) specific cutting energy

Density of steel (ρ) = Mass / Volume = 7.8 grams/cm^3

$\therefore$ Volume = W t_2 l_C = Mass / Density = $\dfrac{13.36}{7.8}$ = 1.713 cm^3

$\therefore$ W t_2 l_C = 1.713

$t_2 = 1.713 \times 10^3 / 10 \times (50 \times 10) = 0.343$ mm

$\therefore$ t_1 = 0.2 mm, t_2 = 0.343 mm

$r = t_1 / t_2 = 0.2 / 0.343 = 0.584$

Chip thickness ratio (or) cutting ratio (r) = 0.584

(i) Shear plane angle $\phi = \tan^{-1}\left(\dfrac{r\cos\alpha}{1 - r\sin\alpha}\right)$

$\therefore$ $\phi = \tan^{-1}\left(\dfrac{0.584\ \cos 6^\circ}{1 - 0.584\ \sin 6^\circ}\right)$

$\phi = 31.74°$

Total energy ($P_{cutting}$) = $F_c.V = 1134 \times 2 = 2268$ Watt

Chip thickness ratio (r) = $\dfrac{V_c}{V}$

V_c (chip flow velocity) = r.V = 0.584×2 = 1.168 m/sec

$F = F_T\cos\alpha + F_c\sin\alpha$ (From Merchant's circle)

Friction force (F) = 453.6 cos 6° + 1134 sin 6°

F = 569.65 N

Friction energy ($P_{friction}$) = $F.V_c$ = 569.65×1.168 = 665.35 Watt

(ii) $\dfrac{P_{friction}}{P_{total}} = \dfrac{665.35}{2268} = 0.293$

$\therefore$ 29.3% of total energy is used as friction energy.

(ii) Specific cutting energy $= \dfrac{P_{cutting}}{MRR}$

$$= \frac{F_c.V}{wt_1 V} = \frac{F_c}{wt_1} = \frac{1134}{10 \times 0.2}$$

Specific cutting energy = 567 N/mm^2

05(c). Describe four tests of flexibility that an automated manufacturing system should satisfy to qualify as being flexible. Also list the application areas where FMS technology is successfully employed. (12 M)

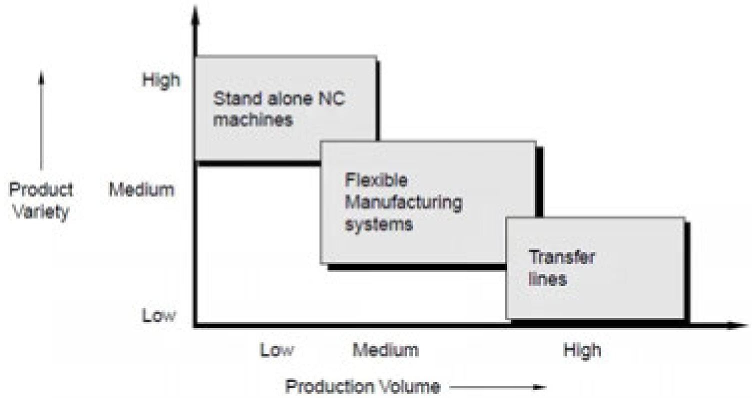
Sol: To qualify as being flexible, an automated manufacturing system should satisfy the following four tests of flexibility:

1. *Part-variety test.* Can the system process different part or product styles in a mixed model (non-batch) mode?
2. *Schedule-change test.* Can the system readily accept changes in production schedule, that is, changes in part mix and/or production quantities?
3. *Error-recovery test.* Can the system recover gracefully from equipment malfunctions and breakdowns, so that production is not completely disrupted?
4. *New-part test.* Can new part designs be introduced into the existing part mix with relative ease if their features qualify them as being members of the part family for which the system was designed? Also, can design changes be made in existing parts without undue challenge to the system?

If the answer to all of these questions is "yes" for a given manufacturing system, then the system is flexible. The most important tests are (1) and (2). Test (3) is applicable to multi-machine systems but in single-machine systems when the one machine breaks down it is difficult to avoid a halt in production. Test (4) would seem to not apply to systems designed for a part family whose members are all known in advance. However, such a system may have to deal with design changes to members of that existing part family.

Applications of Flexible Manufacturing Systems

Flexible manufacturing systems are typically used for mid-volume, mid-variety production. If the part or product is made in high quantities with no style variations, then a transfer line or similar dedicated production system is most appropriate. If the parts are low volume with high variety, then numerical control, or even manual methods would be more appropriate. These application characteristics are summarized in Figure below.



Application characteristics of FMS

Flexible machining systems comprise the most common application of FMS technology. Owing to the inherent flexibilities and capabilities of computer numerical control, it is possible to connect several CNC machine tools to a small central computer, and to devise automated methods for transferring workparts between the machines.

In addition to machining systems, other types of flexible manufacturing systems have also been developed, although the state of technology in these other processes has not permitted the rapid implementation that has occurred in machining. The other types of systems include assembly, inspection, sheet-metal processing (punching, shearing, bending, and forming), and forging. Most of the experience in flexible manufacturing systems has been gained in machining applications.

05(d). Describe at least five main functions carried out by coating on electrode in electric arc welding process. Also, list the constituents of coating and their purpose. (12 M)

Sol: Function of coating on electrodes

(1) The coatings produce a reducing or nonoxidizing atmosphere around the arc; thus, preventing the contamination of the metal in the arc by oxygen and nitrogen from the air.

(2) The coatings reduce impurities such as oxides, sulphur, and phosphorous so that these impurities will not impair the weld deposit.

(3) They provide substance to the arc, which tend to increase its stability, so that the arc can be maintained without excessive spattering and which can initiate the arc easily

(4) Coatings converges the arc and reduce convective heat transfer from the arc

(5) They controls the fluidity of the molten metal and slag.

(6) On melting they form the slag a bad conductor of heat and prevents hardening of weld bead.

Constituents of coating and their purpose

Various constituents of electrode coating are cellulose, calcium fluoride, calcium carbonate, titanium dioxide, clay, talc, iron oxide, asbestos, potassium / sodium silicate, iron powder, ferro-maganese, powdered alloys, silica etc. Each constituent performs either one or more than one functions.

Electrode metallic core wire is the same but the coating constituents give the different characteristics to the welds. Based on the coating constituents, structural steel electrodes can be classified in the following classes;

1. *Cellulosic Electrodes*

Coating consists of high cellulosic content more than 30% and TiO_2 up to 20%. These are all position electrodes and produce deep penetration because of extra heat generated during burning of cellulosic materials. However, high spatter losses are associated with these electrodes.

2. *Rutile Electrodes*

Coating consists of TiO_2 up to 45% and SiO_2 around 20%. These electrodes are widely used for general work and are called general purpose electrodes.

3. *Acidic Electrodes*

Coating consists of iron oxide more than 20%. Sometimes it may be up to 40%, other constituents may be TiO_2 10% and $CaCO_3$ 10%. Such electrodes produce self detaching slag and smooth weld finish and are used normally in flat position.

4. *Basic Electrodes*

Coating consist of $CaCO_3$ around 40% and CaF_2 15-20%. These electrodes normally require baking at temperature of approximately 250°C for 1-2 hrs or as per manufacturer's instructions. Such electrodes produce high quality weld deposits which has high resistance to cracking. This is because hydrogen is removed from weld metal by the action of fluorine i.e. forming HF acid as CaF_2 generates fluorine on dissociation in the heat of arc.

The major constituents and their functions are listed here under

Coating Constituent	Purpose	Function
Cellulose	Gas former	Coating Strength and Reducing agent
Calcium Fluoride (CaF_2)	Slag basicity and metal fluidity, H_2 removal	Slag former
Clay (Aluminum Silicate)	Slag former	Coating strength
Talc (Magnesium Silicate)	Slag former	Arc stabilizer
Rutile (TiO_2)	Arc stabilizer, Slag former, Fluidity	Slag removal and bead appearance
Iron Oxides	Fluidity, Slag former	Arc Stabilizer, improved metal transfer,
Calcium Carbonate	Gas former, Arc stabilizer	Slag basicity, Slag former
Asbestos	Coating strength	Slag former
Quartz (SiO_2)	Slag fluidity, Slag former	Increase in current carrying capacity.
Sodium Silicate / Potassium Silicate	Binder, Arc stabilizer	Slag former
FeMn / FeSi	Deoxidizer	-
Iron Powder	Deposition Rate	-
Powdered Alloys	Alloying	-

05(e). Explain the distinction between the following using block diagrams and examples:

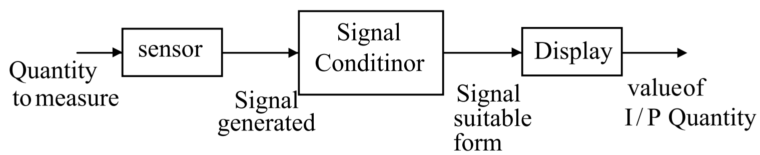
(i) Measurement systems and Control systems

(ii) Open-loop systems and Closed-loop systems. (6 +6 = 12 M)

Sol:

(i) Distinction between measurement systems and control systems.

Measurement system consist of three basic elements as shown block diagram



(i) Sensor: Measure the input quantity and generate output signal related to input quantity.

Ex: Thermo couple, Input quantity is temperature, output is emf (voltage),

(ii) Signal conditioner is a circuit manipulate into suitable form for display.

Ex: amplifier circuit, amplify small voltage (mv (or) µv) to large value (volts)

(iii) Display: Indicator (or) digital display of output.

Ex: Pointer moving on scale for Analog display,7-segment display for digital display.

So example of measurement system is digital thermometer, measure temperature and display its value.

Control system includes measurement system and controller and other necessary parts for control some variable at set value.

Ex: Temperature is controlled in central air conditioning system at set value.

Control system also used to control sequence of events.

Ex: Washing machine,

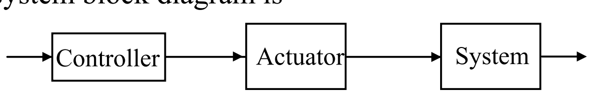
Pre wash cycle → main wash cycle → rinse cycle → spinning

In conclusion: Measurement system is a part of control system.

(ii) Open loop systems and closed loop systems.

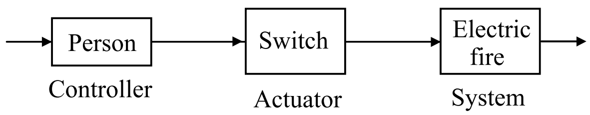
Control systems are mainly two basic types as (i) open loop systems (ii) closed loop systems to control any parameter at particular set value.

Open loop system block diagram is



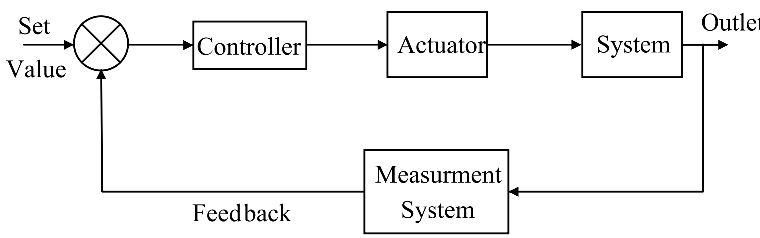
Ex: domestic toaster

Bread is toasted by setting a timer, how much time to toast the bread. In this no feed back and measurement. So, it is simple, with low cost;



Ex: Heating room with open-loop system.

→ Closed loop system block diagram is



Several examples in industries as control of temperature, pressure in boiler and so on.

Closed loop systems are more accurate, and preferable when load changes are frequent. But it is complex and costly compared with open loop systems.

06(a).

(i) In an open die forging, a strip 150 mm wide, 400 mm long and 10 mm thick is compressed in plane strain such that the dimension 400 remains same. The yield strength of material in uniaxial compression is equal to 200 N/mm^2. Find the minimum, average and maximum die pressures at the beginning of plastic deformation if the coefficient of friction on the interface between the die and the material is equal to 0.l. (10 M)

Sol: Given data :

Open die forging

Strip size = 150 mm × 4 mm × 10 mm

Yield strength $(\sigma_y) = 200\ \text{N/mm}^2$

Coefficient of friction $(\mu) = 0.1$

Length of outer edge from centre of strip, $(L) = \dfrac{b}{2} = \dfrac{150}{2} = 75\ \text{mm}$

Sticking zone length, $(x_s) = L - L - \dfrac{h}{2\mu}\ell n\left(\dfrac{1}{2\mu}\right)$

$$x_s = 75 - \frac{10}{2\times0.1}\ell n\left(\frac{1}{2\times0.1}\right)$$

x_s = –5.47 (so there is only sliding zone)

Sliding zone $0 \le x \le 75$ mm

Pressure variation in sliding zone is given by, $P = 2ke^{\frac{2\mu}{n}(L-x)}$

Where $k = \frac{\sigma_y}{\sqrt{3}}$ (from von Mises theory)

$$k = \frac{200}{\sqrt{3}} = 115.47\ \text{N/mm}^2$$

$P_{max} = 2\times115.47e^{\frac{2\times0.1}{10}\times75} = 1035\ \text{N/mm}^2$

Minimum pressure is at x = L, i.e.,

$P_{min} = 2ke^{o} = 2k = 230.94\ \text{N/mm}^2$

$P_{min} = 230.94\ \text{N/mm}^2$

Mean pressure (P_{mean}):

$$P_{mean}\times L = \int_o^L P dx$$

$$P_{mean}\times75 = \int_0^{75} 2ke^{\frac{2\mu}{h}(L-x)} = 40203.06$$

$P_{mean} = 536.04\ \text{N/mm}^2$

06(a). (ii) For a product, the purchase prices are given below :

Sl. No.	**Order Quantity (Q_i)**	**Unit Prices (Rs)**
1	**$Q_1 < 500$**	**10.00**
2	**$500 \le Q_2 < 750$**	**9.25**
3	**$Q_3 \ge 750$**	**8.75**

Determine the optimum purchase quantity if the annual demand of the product is 2400 units. The cost of ordering is Rs.100 and the inventory carrying charge is 24% of the purchase price per year. (10 M)

Sol: Annual demand (D) = 2400 units

Order cost (C_o) = Rs. 2100

Carrying cost (C_c) = 24% of unit cost per year

Let C_u = Rs. 8.75

$$EOQ\Big|_{C_u=8.75} = \sqrt{\frac{2DC_o}{C_c}} = \sqrt{\frac{2\times2400\times100}{0.24\times8.75}} = 478 \text{ units}$$

The calculated 'EOQ' does not satisfy the quantity range. Hence, this value is discarded.

$$TC\Big|_{\substack{Q_3=750\\C_u=8.75}} = \frac{Q_3}{2}\times C_c + \frac{D}{Q_3}\times C_o + D\times C_u$$

$$= \frac{750}{2}\times0.24\times8.75 + \frac{2400}{750}\times100 + 2400\times8.7 = 22107.50$$

Let $C_u = 9.25$

$$EOQ\Big|_{C_u=9.25} = \sqrt{\frac{2\times2400\times100}{0.24\times9.25}} = 464.9 \text{ units}$$

The EOQ does not satisfy the quantity range

$$TC\Big|_{\substack{Q_2=500\\C_u=9.25}} = \frac{500}{2}\times0.24\times9.25 + \frac{2400}{500}\times100 + 2400\times9.25 = \text{Rs. } 23235/-$$

Let $C_u = 10$

$$EOQ\Big|_{C_u=10} = \sqrt{\frac{2\times2400\times100}{0.24\times10}} = 447.2 \text{ units}$$

$$TC\Big|_{\substack{EOQ=447.2\\C_u=10}} = \sqrt{2DC_oC_c} + D\times C_u$$

$$= \sqrt{2\times2400\times100\times0.24\times10} + 2400\times10 = \text{Rs. } 25073/-$$

Order Quantity	**Total cost**
Q = 750	22107/-
Q = 500	23235/-
EOQ = 447.2	25073/-

Optimum (Best) order quantity = 750 units.

06(b). What is a eutectoid reaction? Explain the development of microstructure in iron-carbon alloys of hypoeutectoid, eutectoid and hypereutectoid compositions when they are cooled from high temperature with the help of neatly labelled diagrams indicating the phases present. (20 M)

Sol: Eutectoid reaction: A reaction in which, upon cooling, one solid phase transforms isothermally and reversibly into two new solid phases that are intimately mixed.

DEVELOPMENT OF MICROSTRUCTURE IN IRON–CARBON ALLOYS

An alloy of *eutectoid composition* (0.76 wt% C) as it is cooled from a temperature within the γ-phase region, say, 800°C —that is, beginning at point *a* in Figure 1 and moving down the vertical line *xx′*.

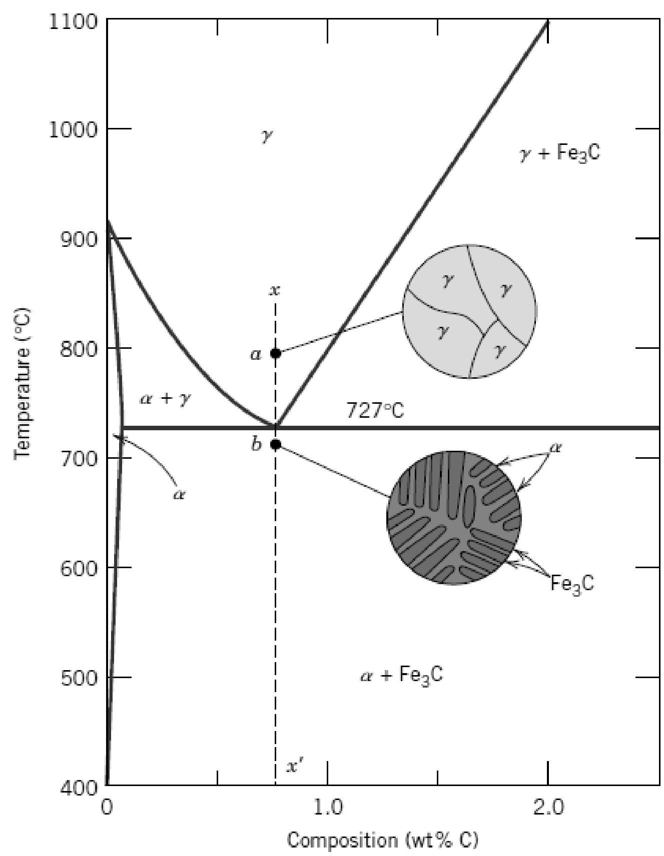


Figure 1: *Schematic representations of the microstructures for an iron– carbon alloy of eutectoid composition (0.76 wt% C) above and below the eutectoid temperature.*

Initially, the alloy is composed entirely of the austenite phase having a composition of 0.76 wt% C and corresponding microstructure, also indicated in Figure 1. As the alloy is cooled, no changes occur until the eutectoid temperature (727°C) is reached. Upon crossing this temperature to point *b* the austenite transforms.

The microstructure for this eutectoid steel that is slowly cooled through the eutectoid temperature consists of alternating layers or lamellae of the two phases (α and Fe_3C) that form simultaneously during the transformation. In this case, the relative layer thickness is approximately 8 to 1. This microstructure, represented schematically in Figure 1, point *b*, is called **pearlite** because it has the appearance of mother-of pearl when viewed under the microscope at low magnifications.

Hypoeutectoid Alloys :

Consider a composition C_0 to the left of the eutectoid, between 0.022 and 0.76 wt% C; this is termed a **hypoeutectoid** ("less than eutectoid") **alloy.** Cooling an alloy of this composition is represented by moving down the vertical line *yy′* in Figure. At about 875°C, point *c*, the microstructure consists entirely of grains of the γ phase, as shown schematically in the figure.

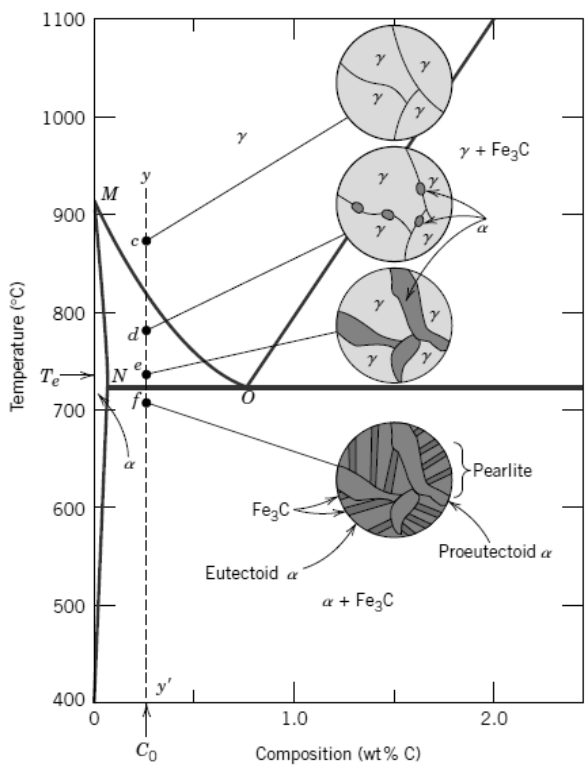


Figure : *Schematic representations of the microstructures for an iron– carbon alloy of hypoeutectoid composition C_0 (containing less than 0.76 wt % C) as it is cooled from within the austenite phase region to below the eutectoid temperature.*

In cooling to point *d*, about 775°C, which is within the $\alpha + \gamma$ phase region, both these phases coexist as in the schematic microstructure. Most of the small α particles form along the original γ grain boundaries. The compositions of both α and γ phases may be determined using the appropriate tie line; these compositions correspond, respectively, to about 0.020 and 0.40 wt % C.

While cooling an alloy through the $\alpha + \gamma$ phase region, the composition of the ferrite phase changes with temperature along the $\alpha - (\alpha + \gamma)$ phase boundary, line *MN*, becoming slightly richer in carbon. However, the change in composition of the austenite is more dramatic, proceeding along the $(\alpha + \gamma) - \gamma$ boundary, line *MO*, as the temperature is reduced.

Cooling from point *d* to *e*, just above the eutectoid but still in the $\alpha + \gamma$ region, produces an increased fraction of the α phase and a microstructure similar to that also shown: the α particles will have grown larger. At this point, the compositions of the α and γ phases are determined by constructing a tie line at the temperature T_e; the α phase contains 0.022 wt % C, whereas the γ phase is of the eutectoid composition, 0.76 wt % C. As the temperature is lowered just below the eutectoid, to point *f*, all of the γ phase that was present at temperature T_e (and having the eutectoid composition) transforms into pearlite. There is virtually no change in the α phase that existed at point *e* in crossing the eutectoid temperature—it is normally present as a continuous matrix phase surrounding the isolated pearlite colonies. The microstructure at point *f* appears as the corresponding schematic inset of Figure 2.

Thus the ferrite phase is present both in the pearlite and as the phase that formed while cooling through the $\alpha + \gamma$ phase region. The ferrite present in the pearlite is called *eutectoid ferrite,* whereas the other, which formed above T_e, is termed **proeutectoid** (meaning “pre- or before eutectoid”) **ferrite,** as labeled in Figure 4.

Hypereutectoid Alloys :

Analogous transformations and microstructures result for **hypereutectoid alloys** those containing between 0.76 and 2.14 wt % C—that are cooled from temperatures within the γ-phase field.

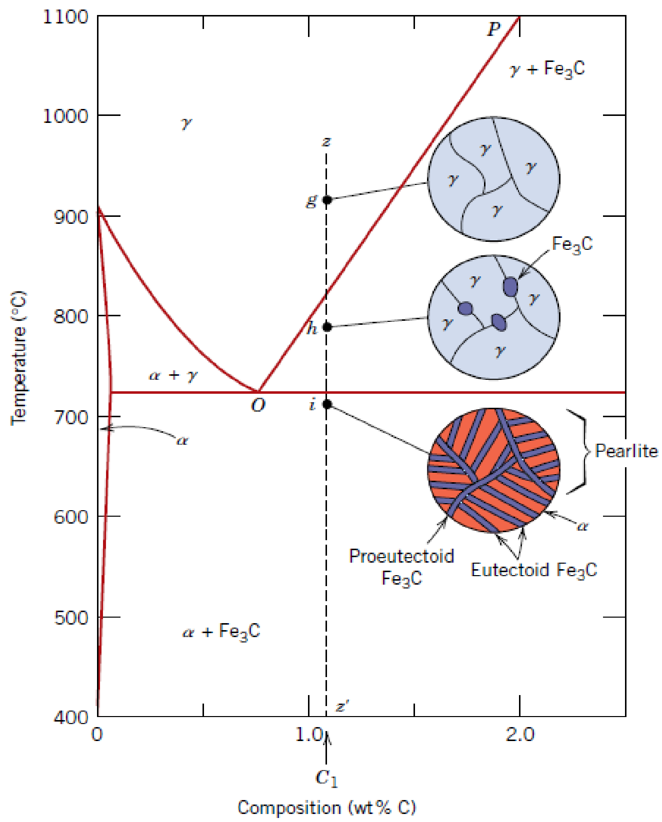


Figure 3: *Schematic representations of the microstructures for an iron–carbon alloy of hypereutectoid composition C_1 (containing between 0.76 and 2.14 wt % C) as it is cooled from within the austenite-phase region to below the eutectoid temperature.*

Consider an alloy of composition C_1 in Figure that, upon cooling, moves down the line *zz′*. At point *g*, only the γ phase is present with a composition of C_1; the microstructure appears as shown, having only γ grains. Upon cooling into the $\gamma + Fe_3C$ phase field - say, to point *h* - the cementite phase begins to form along the initial γ grain boundaries, similar to the a phase in Figure, point *d*. This cementite is called **proeutectoid cementite** that which forms before the eutectoid reaction. The cementite composition remains constant (6.70 wt % C) as the temperature changes.

However, the composition of the austenite phase moves along line *PO* toward the eutectoid. As the temperature is lowered through the eutectoid to point *i*, all remaining austenite of eutectoid composition is converted into pearlite; thus, the resulting microstructure consists of pearlite and proeutectoid cementite as microconstituents .

06(c).

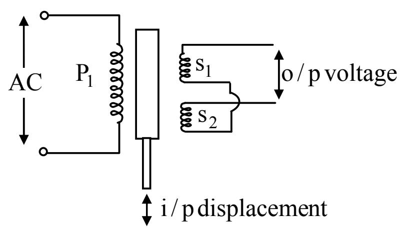
(i) Describe, with neat sketches, the working principle of

(1) linear variable differential transformer (LVDT);

(2) Hall effect sensor. **(5 + 5 = 10 M)**

Sol:

1. ***Linear Variable Differential Transformer (LVDT):*** It is a electrical passive transducer, used to measure small Linear displacements.

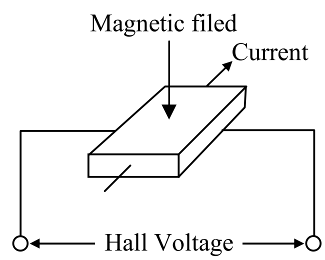


It consist of 3 coils (1 Primary coil, excited with AC voltage) & (2 secondary coils, connected in opposition and generate output voltage) and magnetic core.

When Input displacement applied to magnetic core it induces voltages in two secondary coils (S_1) & (S_2).

The difference between two secondary coils (S_1 & S_2) is proportional to input displacements upto small displacements (± 5 mm ......). Its operating range is ± 2 mm to ± 400 mm displacements.

2. ***Hall effect sensors:*** It is proximity sensor, used to detect position (or) displacement of moving object without any contact.



If a thin strip of current carrying material, subjected to transverse magnetic field, then Hall voltage generated between opposite edges of strip.

So generated voltage output.

$$V_\mu = K_\mu \frac{I.B}{t},$$

V_μ = Hall voltage output generated,

K_H is Hall coefficient, depends on selected strip material,

I is constant current

B is majestic flux density at rigid Angles to the strip plate.

t is thickness of plate.

The sensor is available in Integrated Circuit (IC) form. Its output Hall voltage is proportional to majestic flux density, which depends on input position (or) displacement of moving object.

(ii) A measurement system consists of a cylindrical load cell of diameter 2.5 mm. The material of the cell is steel with modulus of elasticity, E = 210 GPa and Poisson's ratio, γ = 0.3. This carries four strain gauges each with gauge factor 2.1. Two of them are mounted longitudinal and other two are transverse. The resistances of the gauges are 120 Ω. This load cell is required to yield a voltage through the bridge of strain gauges with bias 10 V. If the maximum load sustained by the cell is –2500 N, what is the corresponding voltage across the bridge?

(10 M)

Sol: Measurement system consist of

→ Cylindrical load cell of diameter = 2.5 mm,

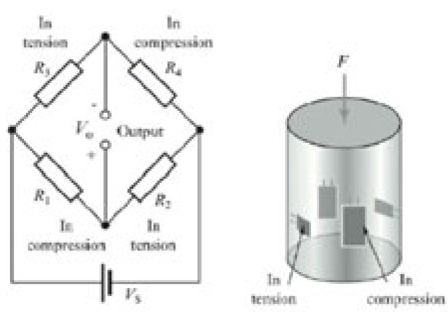
→ Steel with E = 210 GPa, γ = 0.3

→ 4 strain gauges with G.F = 2.1, R = 120 Ω,

→ 2 longitudinal direction and 2 transverse direction.

→ Excitation = 10 V, max load = 2500 N,

What is V_0 (output voltage)?



Its output voltage $V_0 = (1+\nu)\dfrac{G_f.\varepsilon.V}{2}$

With Young's modulus

$$E = \frac{\text{Stress}}{\text{Strain}(\varepsilon)} = \frac{F/A}{\varepsilon}$$

So strain (ε) = $\dfrac{F}{A} \times \dfrac{1}{E}$

$$= \frac{2500}{\pi(1.25\times10^{-3})^2} \times \frac{1}{250\times10^9}$$

$\varepsilon = 2.037 \times 10^{-3}$

Then, $V_0 = (1+\nu)\dfrac{G_f.\varepsilon.V}{2}$

ν = Poisson's ratio = 0.3

G_f = Gauge factor = 2.1

ε = strain = 2.037×10^{-3}

V = excitation = 10 V

$$V_0 = \frac{(1+0.3)(2.1)(2.037\times10^{-3})(10\,V)}{2} = 0.0278 \text{ Volt}$$

07(a).

(i). On the basis of microstructure, briefly explain why gray iron is brittle and weak in tension. Compare gray and malleable cast irons with respect to (1) composition and heat treatment, (2) microstructure and (3) mechanical properties. (10 M)

Sol: Gray iron is weak and brittle in tension because the tips of the graphite flakes act as points of stress concentration.

This question asks us to compare various aspects of gray and malleable cast irons.

(a) With respect to composition and heat treatment:

Gray iron: 2.5 to 4.0 wt% C and 1.0 to 3.0 wt% Si. For most gray irons there is no heat treatment after solidification.

Malleable iron: 2.5 to 4.0 wt% C and less than 1.0 wt% Si. White iron is heated in a non-oxidizing atmosphere and at a temperature between 800 and 900°C for an extended time period.

(b) With respect to microstructure:

Gray iron: Graphite flakes are embedded in a ferrite or pearlite matrix.

Malleable iron: Graphite clusters are embedded in a ferrite or pearlite matrix.

(c) With respect to mechanical characteristics:

Gray iron: Relatively weak and brittle in tension; good capacity for damping vibrations.

***Malleable iron*:** Moderate strength and ductility.

(ii) Cite three sources of internal residual stresses in metal components. What are two possible adverse consequences of these stresses? Describe the following heat treatment procedures for steels and for each, the intended final microstructure:

Full annealing, Normalizing, Tempering and Quenching. (10 M)

Sol: Three sources of residual stresses in metal components are plastic deformation processes, non-uniform cooling of a piece that was cooled from an elevated temperature, and a phase transformation in which parent and product phases have different densities.

Two adverse consequences of these stresses are distortion (or warpage) and fracture.

Full annealing: Heat to about 50°C above the A_3 line (if the concentration of carbon is less than the eutectoid) or above the A_1 line (if the concentration of carbon is greater than the eutectoid) until the alloy comes to equilibrium; then furnace cool to room temperature. The final microstructure is coarse pearlite.

Normalizing: Heat to at least 55°C above the A_3 line (if the concentration of carbon is less than the eutectoid) or above the A_{cm} line (if the concentration of carbon is greater than the eutectoid) until the alloy completely transforms to austenite, then cool in air. The final microstructure is fine pearlite.

Quenching: Heat to a temperature within the austenite phase region and allow the specimen to fully austenitize, then quench to room temperature in oil or water. The final microstructure is martensite.

Tempering: Heat a quenched (martensitic) specimen, to a temperature between 450 and 650°C, for the time necessary to achieve the desired hardness. The final microstructure is tempered martensite.

07(b).

(i) Why is unilateral tolerance preferred over bilateral tolerance? Find the limits of tolerance and allowance for a 25 mm H_8d_9 shaft and hole pair. The 25 mm shaft lies in the 18 - 30 diameter step. The fundamental tolerance can be computed using $i = 0.45\sqrt[3]{D} + 0.001D\,\mu m$.

For H_8 hole, the fundamental tolerance is 25i and for d_9 shaft, the fundamental tolerance is 40i. The fundamental deviation for the shaft can be computed using $-16D^{0.44}\mu m$. What type of fit is given by $H_8\,d_9$?

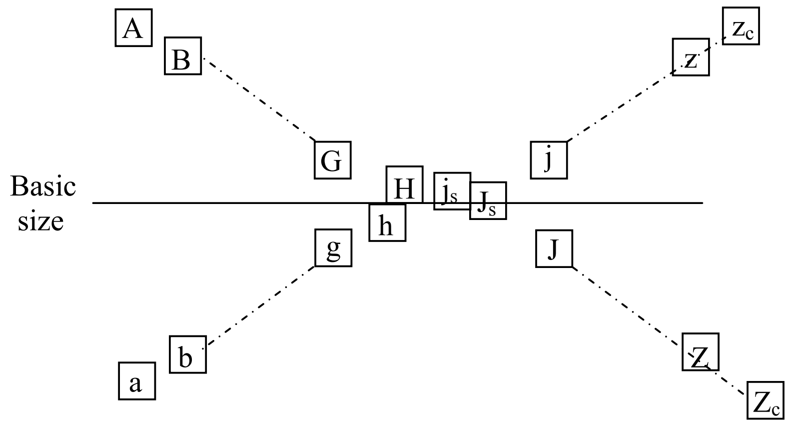
List the causes of getting primary texture and secondary texture in machined components. Further, list the three main methods of assessment of surface texture. (10 M)

Sol: Unilateral tolerance preferred over bilateral tolerance.

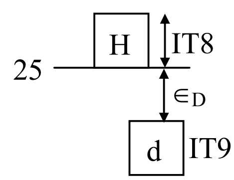
In Hole and Shaft assembly, unilateral tolerance are one sided to the basic size. i.e., either above or below the basic size or zero line as representing limits is convenient as per design criterion because both limits are either positive or negative.

In bilateral tolerance zone is across the basic size line bilateral tolerance is to make simplicity of representation for manufacturer as per I.S.O.

There are 25 types of tolerances for Hole and Shaft for Hole (A-G) above the zero line, "H" on the zero line, "J_s" across the zero line, (J-Z) below the zero line. For shaft (a-g) below the zero line, "h" on the zero line, "j_s" across the zero line, (j-z) above the zero line.



In this except J_s, j_s remaining all are unilateral tolerances i.e, (A-G), h, (J-Z) for Hole and (a-g), h, (j-z) for shaft $25H_8d_9$ fundamental deviation for shaft $(\in_D) = -16D^{0.44}$



25 mm lies in the range (18 - 30)

$\therefore\ D = \sqrt{D_1 D_2} = \sqrt{18\times 30} = 23.24$ mm

Initial tolerance (or) fundamental tolerance

$(i) = 0.45\sqrt[3]{D} + 0.001D$

$\therefore\ i = 0.45\ \sqrt[3]{23.24} + 0.001(23.24) = 1.3\mu$

IT8 = 25i = 25×1.3 = 33 μ = 0.033 mm

IT9 = 40i = 40×1.3 = 52 μ = 0.052 mm

$\in_D = -16D^{0.44} = -16(23.34)^{0.44} = 64\ \mu = 0.064$ mm

$\therefore$ Hole $25^{+0.033}_{+0.0}$ mm

Shaft $25^{-0.064}_{-0.116}$ mm

It is clearance fit with allowance = 0.064 mm

Primary and secondary texture in machined component. There are two types of irregularities on any machined surface. i.e., Roughness and waviness. Small wavelength fluctuations called primary texture (or) Roughness and large wave length fluctuations called secondary texture (or) waviness.

Roughness on machined surface mainly because of improper selection of cutting fluids, higher temperature on cutting zone and tool vibrations waviness or secondary texture is mainly due to machine and tool vibrations, work piece arrangements, guide way errors etc.

07(b).

(ii) Five jobs are to be processed on three machines. The processing time (in hours) is given in the following table. Find the optimal schedule so that the total elapsed time is minimized. Also, find the idle time on each machine:

Jobs

Machines		J_1	J_2	J_3	J_4	J_5
	M_1	8	10	6	7	11
	M_2	5	6	2	3	4
	M_3	4	9	8	6	5

(10 M)

Sol:

Job	M_1	M_2	M_3
J_1	8	5	4
J_2	10	6	9
J_3	6	2	8
J_4	7	3	6
J_5	11	4	5

Check the following conditions:

1. $\text{Max}\{t_{2j}\} \le \text{Min}\{t_{1j} \text{ or } t_{3j}\}$

   If the condition is satisfied then create two virtual machines viz., M/c G and M/c H

   Machine G processing time = $t_{1j} + t_{2j}$

   Machine H processing time = $t_{2j} + t_{3j}$

   Otherwise; the problem cannot be solved by means of Johnson's algorithm and one can conclude that the problem has no optimal solution (no guarantee for optimal values)

2. Get the optimum job sequence using algorithm, similar to n jobs & 2 machines

3. Calculate the make-span for the original data using the optimum job sequence.

Job	Machine G ($M_1 + M_2$)	Machine H ($M_2 + M_3$)
J_1	13	9
J_2	16	15
J_3	8	10
J_4	10	9
J_5	15	9

According to Johnson's rule the sequence is as follows:

M/c G **M/c H**

J_3	J_2	J_5	J_1	J_4

Job	**M_1**			**M_2**				**M_3**			
	In	PT	Out	In	PT	Out		I_4	PT	Out	
J_3	0	6	6	6	2	8		8	8	16	
J_2	6	10	16	16	6	22		22	9	31	
J_5	16	11	27	27	4	31		31	5	36	
J_1	27	8	35	35	5	40		40	4	44	
J_4	35	7	42	42	3	45		45	6	51	

Total elapsed time = 51

Total time on M_1 = 51 – 42 = 9 hrs

Idle time on M_2 = (0 - 6) + (8 - 16) + (22 - 27) + (31 - 35) + (40 - 42) + (45 - 51)

= 6 + 8 + 5 + 4 + 2 + 6 = 31 hrs

Idle time on M_3 = (0 - 8) + (16 - 22) + (31 - 31) + (36 - 40) + (44 - 45)

= 8 + 6 + 0 + 4 + 1 = 19 hrs

07(c).

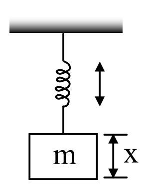
(i) What are natural and forced responses of a dynamic system? Derive the expression for dynamic natural response of a spring-mass system. (10 M)

Sol: ***Natural response of dynamic system:*** It is the response (or) output of dynamic system naturally without applying input and observing the changes of system naturally.

Forced response: It is the response (or) output of dynamic system with applied forced input and observing the changes with forced input.

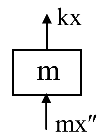
Expression for dynamic natural response of spring - mass system.

When mass is connected P end of spring, without damping, it oscillates freely without any input force, so its output is continuous oscillation.



Free body diagram of mass:

As per D Alembert's Principle



$$mx'' + kx = 0$$

$$m\frac{d^2x}{dt^2} + kx = 0$$

$$\frac{d^2x}{dt^2} + \frac{k}{m}x = 0,\ \text{ so it oscillates with undamped natural frequency of } \omega_n = \sqrt{\frac{k}{m}}$$

(ii) A vector 25i + 10j + 20k is translated by 8 units in X and 5 units in Y directions. Subsequent to this the vector is rotated by 60° about Z-axis and 30° about X-axis. Determine the final form of the vector. (10 M)

Sol: A vector $25i + 10j + 20k$

→ It is translated 8 units → x and 5 units → y

→ Then the resultant vector is

$$33i + 15j + 20k$$

→ Above vector rotated 60°, about z axis, then resultant vector is

$$\begin{bmatrix} c60^o & -s60^o & 0 \\ s60^o & c60^o & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 33 \\ 15 \\ 20 \end{bmatrix} = \begin{bmatrix} \dfrac{33-15\sqrt{3}}{2} \\ \dfrac{33\sqrt{3}+15}{2} \\ 20 \end{bmatrix}$$

$$c60^o = \frac{1}{2},\ s60^o = \frac{\sqrt{3}}{2}$$

Now above vector is further rotated by 30°, around x axis $R(x, 30^o)$.

$$\text{Then resultant vector is } = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sqrt{3}/2 & -1/2 \\ 0 & 1/2 & \sqrt{3}/2 \end{bmatrix}\begin{bmatrix} \dfrac{33-15\sqrt{3}}{2} \\ \dfrac{33\sqrt{3}+15}{2} \\ 20 \end{bmatrix} = \begin{bmatrix} \dfrac{33-15\sqrt{3}}{2} \\ \dfrac{99+15\sqrt{3}}{4} - 10 \\ \dfrac{33\sqrt{3}+15}{4} + 10\sqrt{3} \end{bmatrix}$$

Then the final form of vector after above translation and rotations is

$$= \left(\frac{33-15\sqrt{3}}{2}\right)i + \left(\frac{99+15\sqrt{3}}{4} - 10\right)j + \left(\frac{33\sqrt{3}+15}{4} + 10\sqrt{3}\right)k$$

08(a). (i) Explain briefly the following:

(1) Four configurations of Robot (2) Work volume

(3) Spatial resolution (4) Accuracy (5) Repeatability (10 M)

Sol:

(1) Four types of robot configurations

(a) Cartesian configuration

(b) Cylindrical configuration

(c) Spherical / polar configuration

(d) Jointed arm configuration

(2) *Work volume* is space (or) volume of all points reached by robot tool movement with all joints movements.

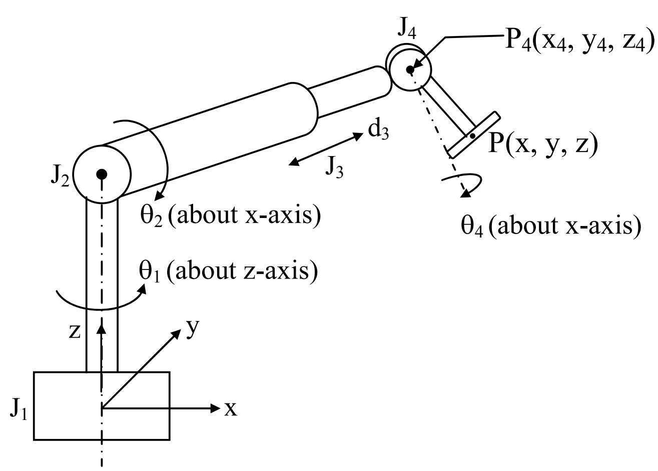
Ex: Cartesian configuration work volume is rectangular / cuboid. As its tool can move to any point in rectangular / cuboid work volume.

(3) *Spatial resolution* combines the control resolution of all motions and also considered the mechanical errors arises from backlash in gears, Hysteresis, Deflection of links and hydraulic leaks.

(4) *Accuracy* is ability of robot to position the tool (or) end of wrist at target point (or) location in the specified work volume.

(5) *Repeatability* is measure ability of robot for position an object (or) tool repeatedly at previously taught points in the specified work volume.

(ii) A 4 d-o-f manipulator of Maker Robot type is shown in the figure given below. Prepare a D-H parameter table for this configuration. Define the position of end wrist P in terms of joint lengths and angles:



(10 M)

Sol: DOF manipulator,

D – 4 parameter table for given configuration is

	a	α	θ	d		$C\alpha$	$S\alpha$
1	0	0	θ_1	0	→	1	0
2	0	$\pi/2$	θ_1	0	→	0	1
3	0	$\pi/2$	0	d_3	→	0	1
4	0	$\pi/2$	θ_4	0	→	0	1

To know the position of end wrist P

$${}_0T^4 = {}_0T^1 \cdot {}_1T^2 \cdot {}_2T^3 \cdot {}_3T^4$$

$$= \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_2 & 0 & S_2 & 0 \\ S_2 & 0 & -C_2 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_4 & 0 & S_4 & 0 \\ S_4 & 0 & C_4 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

After multiplication of above four matrices

$$= \begin{bmatrix} 124^1 & 0 & -S_{124^1} & S_{12}d_3 \\ 124^1 & 0 & C_{124^1} & -C_{12}d_3 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

So position of end wrist P in terms of joint lengths and angles is

$x = S_{12}d_3$,

$y = -C_{12}d_3$,

$z = 0$

Note: $S_{12} = \sin(\theta_1 + \theta_2)$

$C_{12} = \cos(\theta_1 + \theta_2)$

$C_{124}{}^1 = \cos(\theta_1 + \theta_2 - \theta_4)$

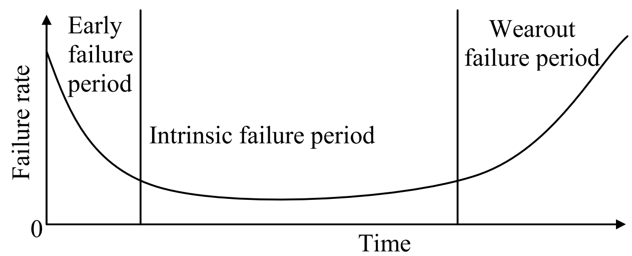
$S_{124}{}^1 = \sin(\theta_1 + \theta_2 - \theta_4)$

08(b).

(i) Draw the 'bathtub curve' and indicate various failure regions. List the major causes of failure in mechanical components/system. Draw the flowchart for failure modes and effects analysis (FMEA). (10 M)

Sol: Bathtub Curve:

The typical distribution of failure for a given product with time is important.



Early Failure or Infant Failure Period: Early life failures are often associated with fabrication issues, quality-control issues, or initial "shakedown" stresses, while age-related failure rates would increase with time.

Useful Life Period (Intrinsic Failure Period):

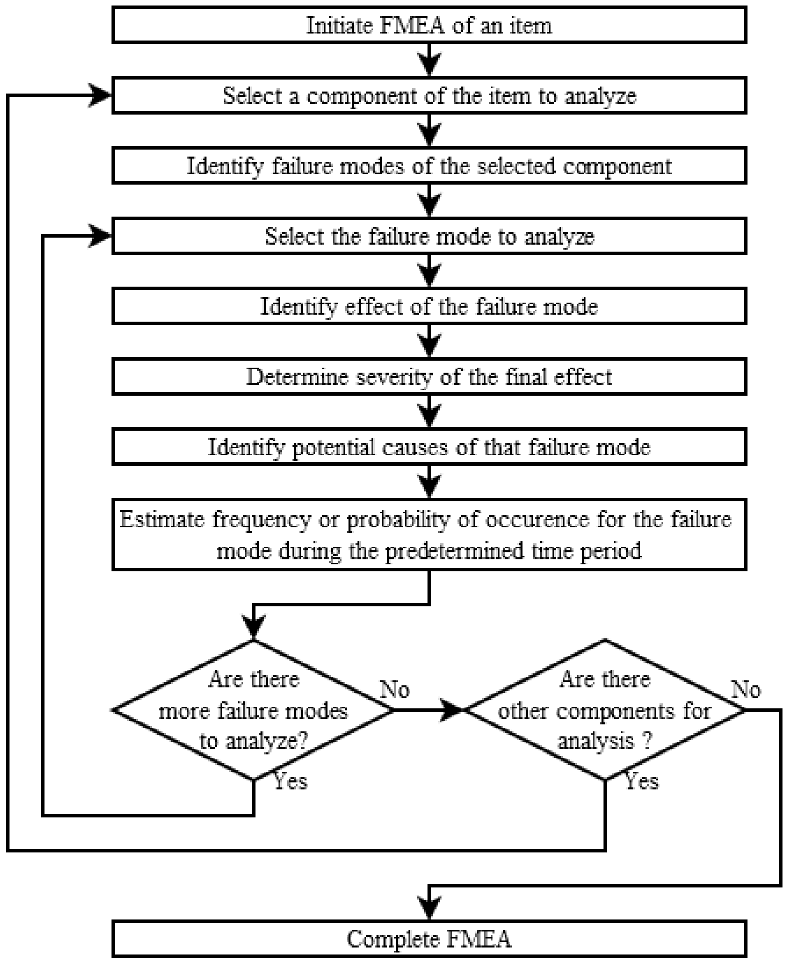
- As the product matures, the weaker units die off, the failure rate becomes nearly constant, and modules have entered into normal life period.
- It is characterized by a constant failure rate and the length of this period is referred to as the system life of a product or component. It is the period of time that the lowest failure rate occurs.
- The amplitude on the bathtub curve is at its lowest during this time. The useful life period is the most common time frame for making reliability predictions.

Wearout Failure Period: As components begin to fatigue or wearout, failures occur at increasing rates. Wearout in the rotating or sliding components are usually caused by the breakdown of system that is subject to physical wear, mechanical and thermal stress.

Major Causes of failures in mechanical components/systems: Most of the failures are caused by human errors, of which there are three general types:

- Errors of knowledge
- Errors of performance (which might be caused by negligence), or
- Errors of intent (which may come down to acts of greed)

FMEA Flow Chart :



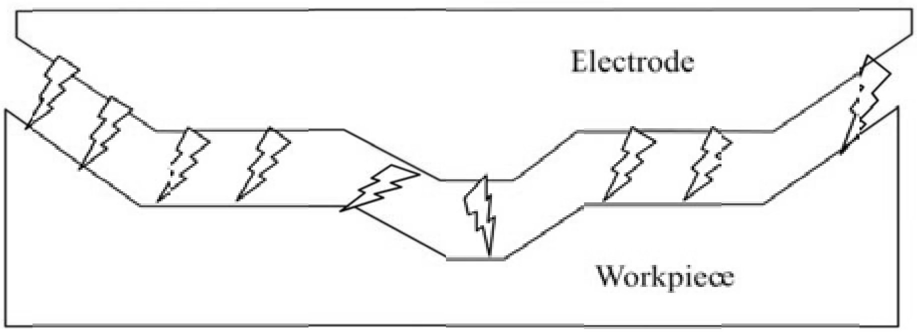
08(b).

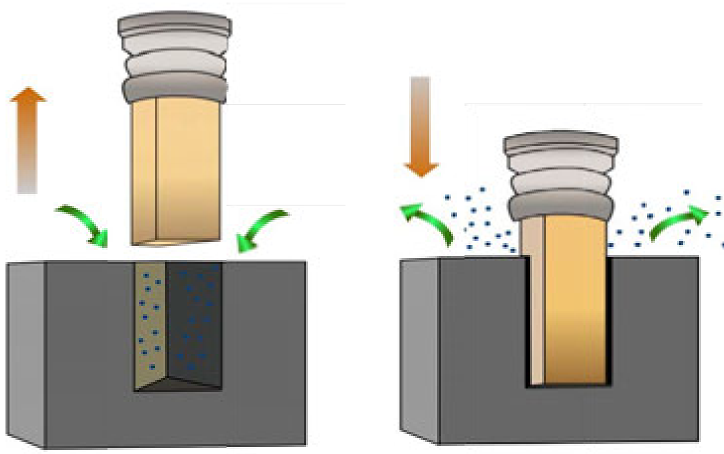
(ii) Explain the mechanism of metal removal in die-sinking EDM. State the three main advantages of electron-beam machining (EBM). (10 M)

Sol: Die-Sinker EDM is known by different names such as Ram EDM, sinker EDM, vertical EDM and plunge EDM. The process is generally used for producing blind cavities. In die-sinker EDM, the electrode and workpiece are submerged in an insulating liquid such as oil or other dielectric fluids. The electrode and workpiece are connected to a suitable power supply. An electrical potential is generated between the tool and the workpiece through the power supply. As the electrode approaches workpiece, the dielectric break down starts taking place in the fluid. Due to this activity, a plasma channel starts forming and sparks jump from the electrode to the workpiece leading to material removal from the workpiece. The principle of die-sinking EDM is shown in Fig.1 and the schematic of die-sinker EDM process is shown in Fig.2

The main components of Die-sinker EDM are:

- Power supply.
- Dielectric system.
- Electrode
- Servo system.





The main advantages of electron-beam machining (EBM)

- EBM provides very high drilling rates when small holes with large aspect ratio are to be drilled.
- It can machine almost any material irrespective of their mechanical properties.
- As it applies no mechanical cutting force, work holding and fixturing cost is very less. Further for the same reason fragile and brittle materials can also be processed.
- The heat affected zone in EBM is rather less due to shorter pulses.
- EBM can provide holes of any shape by combining beam deflection using electromagnetic coils and the CNC table with high accuracy.

08(c). A manufacturer of patient medicines is proposed to prepare a production plan for medicines A and B. There are sufficient ingredients available to make 20000 bottles of medicine A and 40000 bottles of medicine B. However, there are only 45000 bottles into which either of the medicines can be filled. Further, it makes three hours to prepare enough material to fill 1000 bottles of medicine A and one hour to prepare enough material to fill 1000 bottles of medicine B, and there are 66 hours available for this operation. The profit is ₹ 8 per bottle for medicine A and ₹ 7 per bottle for medicine B.

(i) Formulate this problem as linear programming problem.

(ii) How does the manufacturer schedule his production in order to maximize profit? Use graphical method. (10 M)

Sol: Let x_1 = No. of bottles of medicine 'A'

x_2 = No. of bottles of medicine 'B'

Maximum, $z = 8x_1 + 7x_2$

Constraints:

Ingredients: $x_1 \le 20000$

$x_2 \le 40000$

$x_1 + x_2 \le 45000$

Time: $1000A's \to 3$ hrs

$1A \to ?$

Time for 1 bottle 'A' = $\frac{3}{1000}$

1000 B's $\to 1$ hr

$1B \to ?$

Time for 1 bottle 'B' = $\frac{1}{1000}$

$$\frac{3}{1000}x_1 + \frac{1}{1000}x_2 \le 66$$

$\Rightarrow 3x_1 + x_2 \le 66000$

LP model:

Maximum, $z = 8x_1 + 7x_2$

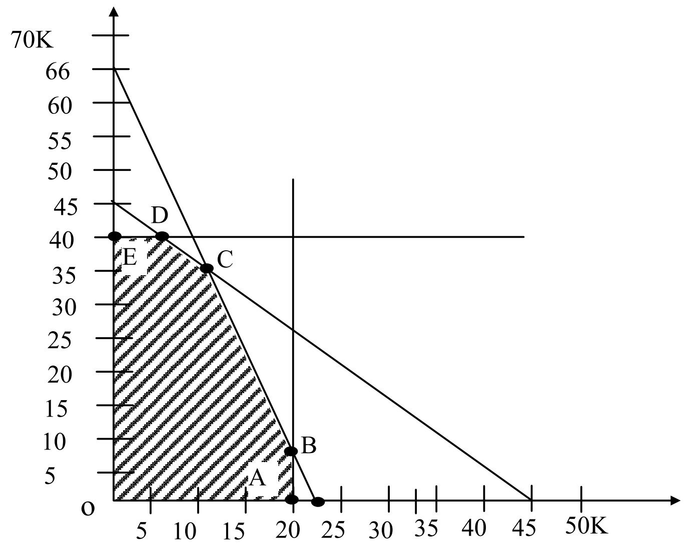
Subject to: $x_1 \leq 20000$

$x_2 \leq 40000$

$x_1 + x_2 \leq 45000$

$3x_1 + x_2 \leq 66000$

$x_1 \geq 0, \quad x_2 \geq 0$



$z_{max} = 8x_1 + 7x_2$

$z|_{(0,0)} = 0$

$z|_{(0,40000)} = 8(0) + 7(40000) = 2,80,000$

$z|_{(5000,40000)} = 8(5000) + 7(40000) = 3,20,000$

$z|_{(10500,34500)} = 8(10500) + 7(34500) = 3,25,500$

$z|_{(20000,6000)} = 8(20000) + 7(6000) = 2,02,000$

$z|_{(20000,0)} = 8(20000) + 7(0) = 1,,60,000$

No. of bottles of 'A' = 10500,

No. of bottles of 'B' = 34500

$z_{max} = 3,25,500$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