MADE EASY

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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-8 : Full Syllabus Test **(Paper-II)**

Name : ....

Roll No :

Test Centres			**Student's Signature**
Delhi ☑	Bhopal ☐	Jaipur ☐	
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE	
Question No.	Marks Obtained
Section-A	
Q.1	29
Q.2	24
Q.3	—
Q.4	—
Section-B	
Q.5	34
Q.6	48
Q.7	40
Q.8	—
Total Marks Obtained	175

Signature of Evaluator .... Cross Checked by ....

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Well done! Keep it up.

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

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Section : A

Q.1 (a) A thick cylinder of 650 mm internal diameter is to be designed to sustain an internal pressure of 35 MPa. Assume an allowable stress of 180 MPa and poisson's ratio of 0.25. Determine the wall thickness by applying the below mentioned inertia of failure:

(i) Maximum principal stress theory.

(ii) Maximum shear stress theory.

[12 marks]

$R_i = 325 \text{ mm}$ $\quad t = R_o - R_i$

$R_o = ?$ $\quad \sigma_{per} = 180 \text{ MPa}$ $\quad \mu = 0.25$

$P_i = 35 \text{ MPa}$

$$\sigma_r = \frac{B}{r^2} - A$$

at $R = R_i$ $\quad \frac{B}{R_i^2} - A = P$

at $R = R_o$ $\quad \frac{B}{R_o^2} - A = 0$

$$P = B\left(\frac{1}{R_i^2} - \frac{1}{R_o^2}\right) = B\left[\frac{R_o^2 - R_i^2}{R_i^2 R_o^2}\right]$$

$$B = \frac{P R_i^2 R_o^2}{R_o^2 - R_i^2}$$

$$A = \frac{P R_i^2}{R_o^2 - R_i^2}$$

$$\sigma_h = \frac{B}{r^2} + A$$

$$(\sigma_h)_{R_i} = \frac{P(R_o^2 + R_i^2)}{(R_o^2 - R_i^2)} = \sigma_1$$

(i) MPST

$$\frac{P(R_o^2 + R_i^2)}{(R_o^2 - R_i^2)} = \sigma_1 \le \{\sigma_{per} = 180\}$$

$$\frac{35(R_o^2 + 325^2)}{R_o^2 - 325^2} \le 180$$

$R_o = 395.7478$

thickness acc. to MPST $= R_o - R_i = 70.7478$ mm

(ii) MSST

$$\left[\tau_{max} = \frac{(\sigma_h)_{Ri} - (-35)}{2}\right] \le \left(\frac{180}{2} = \tau_{per}\right)$$

$$\frac{\frac{35(R_o^2+325^2)}{(R_o^2-325^2)} + 35}{2} \le 90$$

$R_o = 415.7414$ mm

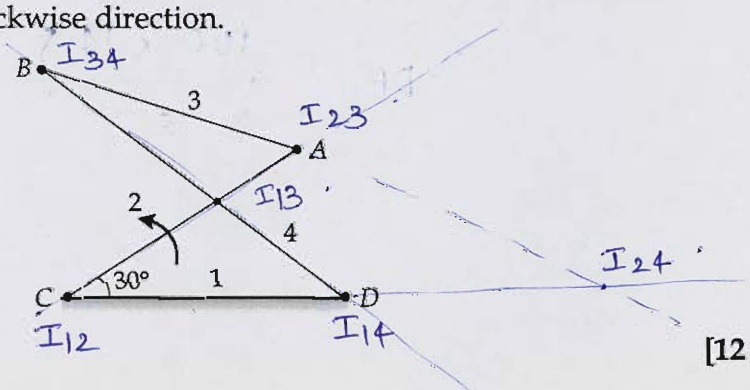
thickness acc. to MSST $= R_o - R_i = 90.7414$ mm

12

Q.1 (b) NaCl has face-centered cubic (FCC) crystal structure. Given its density is 2.18 g/cm^3, calculate the distance between two adjacent atoms in the crystal.

[12 marks]

Q.1 (c) Locate all the instantaneous centers for the crossed four bar mechanism as shown in figure. The dimensions of various links are : CD = 65 mm, CA = 60 mm, DB = 80 mm and AB = 55 mm. Find the angular velocities of the links AB and DB, if the crank CA rotates at 100 rpm in the anticlockwise direction.



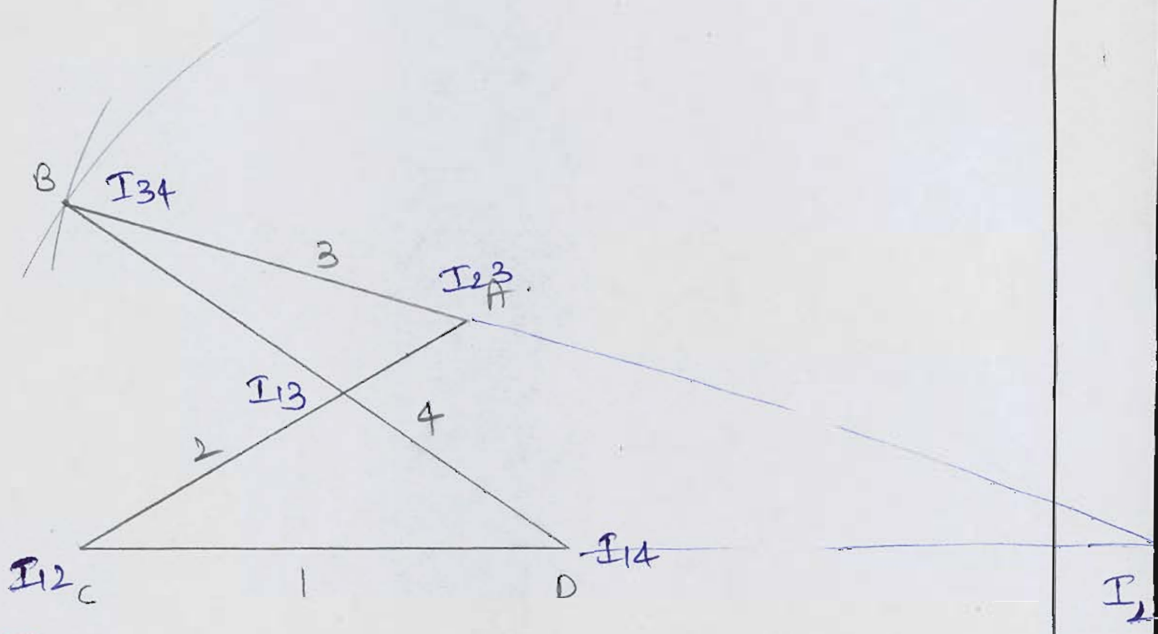
[12 marks]

$$\omega_2 (I_{23} I_{12}) = \omega_3 (I_{23} I_{13})$$

$$\omega_{AB} = \omega_3 = \frac{\omega_2 (I_{23} I_{12})}{(I_{23} I_{13})}$$

$$\omega_4 (I_{24} I_{14}) = \omega_2 (I_{24} I_{12})$$

$$\omega_4 = \frac{\omega_2 (I_{24} I_{12})}{(I_{24} I_{14})}$$



5

$$\omega_{AB} = \frac{100(55)}{20} = 275 \text{ rpm (ACW)}$$

$$\omega_{DB} = \frac{100 \times 145}{80} = 181.25 \text{ (ACW)}$$

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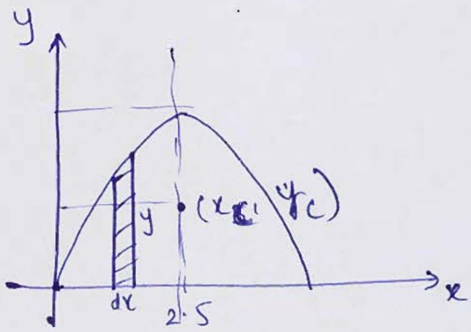
Q.1 (d) Determine the coordinates of the centroid of the area lying between the curve $y = 5x - x^2$ and the x-axis.

[12 marks]



$y = (5-x)x$

$\bar{x} = 2.5$ {since curve is symmetric about $x = 2.5$}

$$\bar{y} = \frac{\int_0^5 y\,dx\left(\frac{y}{2}\right)}{\int_0^5 (5x-x^2)\,dx} = \frac{\left(\frac{1}{2}\right)\int_0^5 y^2 \cdot dx}{\int_0^5 (5x-x^2)\,dx}$$

$$\bar{y} = \frac{5}{2} = 2.5$$

∴ coordinates of centroid of area lying b/w given curve and x-axis is (2.5, 2.5)

12

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Q.1 (e) A short column is of hollow circular section, the center of the inside hole being 6 mm eccentric to that of the outside. The outside diameter is 96 mm and the inside 48 mm. The line of action of the load intersects the cross-section at a point in line with the two centers. What are the limiting positions of the load for there to be no tensile stress set up?

[12 marks]

Q.2 (a) A machine of mass one tonne is acted upon by an external force of 2500 N at a frequency of 1440 rpm. To reduce the effects of vibration, an isolator of rubber having a static deflection of 2.5 mm under machine load and an estimated damping factor of 0.22 are used. Determine:

(i) The force transmitted to the foundation.

(ii) The amplitude of vibration of the machine.

(iii) The angle between the transmitted force and spring force.

[20 marks]

$m = 1000\ kg$.

$F_0 = 2500 N$ (external force).

$\omega = \frac{2\pi \times 1440}{60} = 150.7964\ rad/s$.

$\Delta = 2.5mm = 2.5 \times 10^{-3} m \implies \omega_n = \sqrt{\frac{g}{\Delta}} = \sqrt{\frac{s}{m}}$

$\omega_n = 62.64184\ rad/s$

$\xi = 0.22$.

$s = 3924000 \frac{N}{m}$

(i) ϵ = transmissivity $= \frac{F_t}{F_0} = \frac{\sqrt{1 + \left(\frac{2\xi\omega}{\omega_n}\right)^2}}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[\frac{2\xi\omega}{\omega_n}\right]^2}}$

$\frac{\omega}{\omega_n} = 2.4073 \quad \xi = 0.22.$

$\epsilon = 0.29664 = \frac{F_t}{F_0}$

$\boxed{F_t = 741.6006N}$ → force transmitted to the ground. (foundation.

(ii) $A = \frac{[F_0/S]}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[\frac{2\xi\omega}{\omega_n}\right]^2}}$

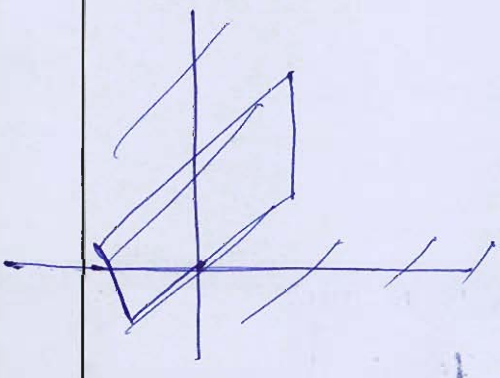
$A = \frac{2500/3924000}{\sqrt{\left(1-(2.4073)^2\right)^2 + \left[2\times0.22\times 2.4073\right]^2}}$

$A = 1.30265\times10^{-4}\,m.$

14

$\boxed{A = 0.13026\,mm.}$ → Amplitude of vibration of machine

(iii) Angle b/w F_t and F_s.



$\theta = \tan^{-1}\left[\frac{F_s}{F_t}\right].$

$\theta = \tan^{-1}\left[\frac{SA}{F_t}\right].$

$\boxed{\theta = 34.5772^\circ}$

→ angle b/w F_t and F_s.

Q.2 (b) It is required to design a pair of spur gears with 20° full-depth involute teeth based on Lewis equation. The velocity factor is to be used to account for dynamic load. The pinion shaft is connected to a 10 kW, 1440 rpm motor. The starting torque of the motor is 150% of the rated torque. The speed reduction is 4:1. The pinion as well as the gear is made of plain carbon steel 40C8 (S_{ut} = 600 N/mm²). The factor of safety can be taken as 1.5. Design the gears, specify their dimensions and suggest suitable surface hardness for the gears.

Assume velocity factor, $C_V = \frac{3}{3+v}$; $\sigma_{\text{bending}} = \frac{\sigma_{ut}}{3}$; Width of tooth = 10 module.

Tooth form factor, $y = \left(0.154 - \left(\frac{0.912}{z}\right)\right)$

[20 marks]

$T_1 = \frac{10 \times 60 \times 10^6}{2\pi \times 1440} = 66314.5596$ N·mm (Rated Torque)

$[T_1]_{starting} = 150\%$ of T_1 (Rated)

$= 99471.8394$ N·mm (Design torque)

$G = 4$ $\quad S_{ut} = 600$ N/mm²

$N = 1.5$ $\quad \sigma_{bending} = \frac{600}{3} = 200$ N/mm² let $m = 1.26 \sqrt[3]{\frac{[T_1]}{[\sigma_b Y]_{WG} \psi z_1}}$

$\psi = 10$

$$\frac{99471.8394}{\left[\frac{m \times z_1}{2}\right] C_V} = [\sigma_b Y]_{w.g}\ b\ m.$$

$$\frac{99471.8394}{\left(\frac{m \times z_1}{2}\right) \times \frac{3}{3+\cdot}}$$

?

2

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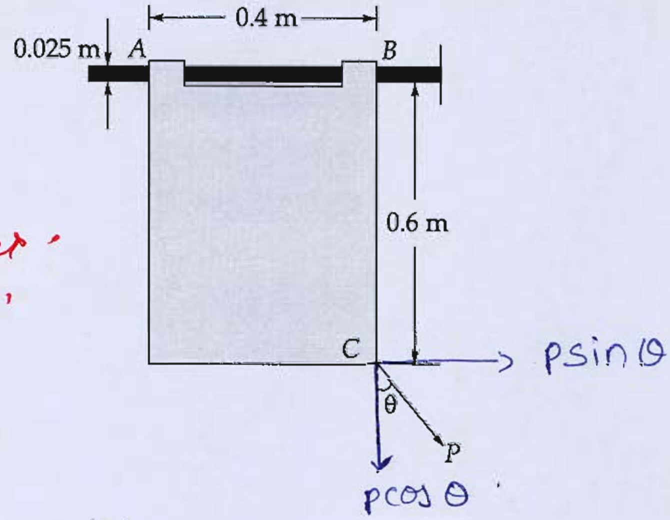
Q.2 (c) A light metal panel is welded to two short sleeves of 0.025 m inside diameter that can slide on a fixed horizontal rod. The coefficient of friction between the sleeves and the rod are $\mu_s = 0.4$ and $\mu_k = 0.3$. A cord attached to corner C is used to move the panel along the rod. Knowing that the cord lies in the same vertical plane as the panel, determine the range of values of θ for which the panel will be in impending motion to the right. Assume that sleeves make contact with the rod at the exterior points A and B.

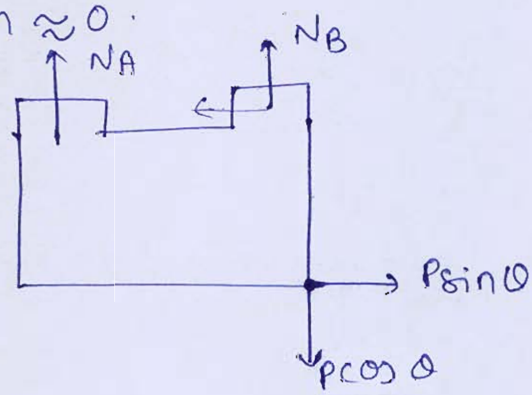


[20 Marks]

There are two cases. Refer to solution.

Light panel

$m \approx 0$.



$N_B + N_A = P\cos\theta$.

$\Sigma M_A = 0$

$N_B(0.4) - P\cos\theta(0.4) = 0$

$N_B = P\cos\theta$.

$N_A = 0$

$(f_B)_{max} = \mu_s N_B = 0.4(P\cos\theta)$

for impending motion

$(f)_{max} = 0.4(P\cos\theta) \geq P\sin\theta$

$0.4 \geq \tan\theta$.

$\theta = 21.8014^\circ$

8

Q.3 (a) Draw the profile of a cam operating a knife edge follower when the axis of the follower is offset 20 mm towards right from cam axis from the following data:

(i) Follower to move outwards through 40 mm during 60° of cam rotation.

(ii) Follower to dwell for the next 45°.

(iii) Follower to return to its original position during next 90°.

(iv) Follower to dwell for the rest of the cam rotation.

The displacement of the follower is to take place with SHM during both the outward and the return strokes. The least radius of cam is 50 mm. If the cam rotates at 300 rpm, determine the maximum velocity and acceleration of the follower during the outward stroke and return stroke.

[20 marks]

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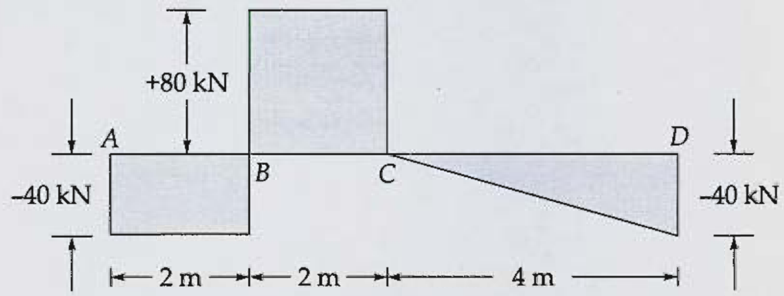
Do not write in this margin

Q.3 (b) A beam *ABCD*, 8 metres long, supported over a length of 6 metres at points *B* and *D* has the shear force diagram as shown below. Determine the various loads acting on the beam and draw the bending moment diagram and find:

(i) Magnitude and position of the maximum bending moment.

(ii) Position of the point of contraflexure, if any.



[20 marks]

Q.3 (c) In a winch, the rope supports a load W and is wound round a barrel 450 mm diameter. A differential band brake acts on a drum 800 mm diameter which is keyed to the same shaft as the barrel. The two ends of the bands are attached to pins on opposite sides of the fulcrum of the brake lever and at distance of 25 mm and 100 mm from the fulcrum. The angle of lap of the brake band is 250° and the co-efficient of friction is 0.25. What is the maximum load W which can be supported by the brake when a force of 750 N is applied to the lever at a distance of 3000 mm from the fulcrum?

[20 marks]

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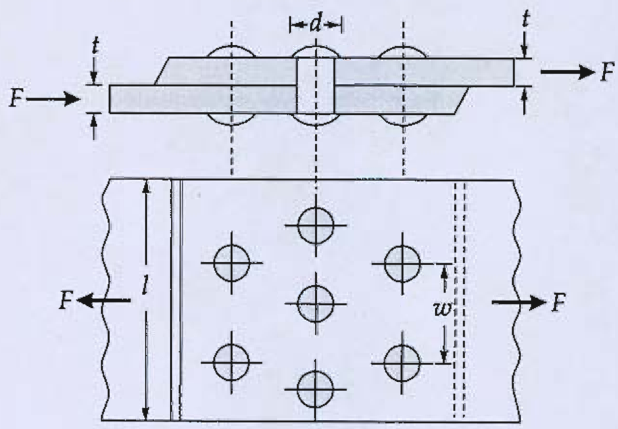
Q.4 (a) Two steel plates with a dimension of $l \times t$ is 180 mm × 12 mm are joined by rivets as shown in the figure. The diameter of the rivets, d is 18 mm and the pitch is w is 50 mm. The allowable tensile stress of the plate, allowable shear stress of the rivet and allowable bearing stress between the rivet and plate are 200 MPa, 150 MPa and 300 MPa respectively. Check the strength of the rivet joint if a force of 200 kN is applied. If the strength is deficient, how can the design be improved?



[20 marks]

Q.4 (b) Define the terms effort and power of a governor. Also derive the expressions for effort and power in the case of a porter governor.

[20 marks]

Q.4 (c) A "0° - 60° - 120°" strain gauge rosette is bonded to the surface of a thin steel plate. Under a loading condition, the strain measurements are $\in_A = 60\ \mu\in$, $\in_B = 135\ \mu\in$, $\in_C = 264\ \mu\in$. Find the principal strains, their orientations, and the principal stress. Take $E = 210$ GPa and $\nu = 0.3$.

[20 marks]

Section : B

Q.5 (a) What are the desirable properties of moulding sand. Name and explain different additives used to achieve these properties.

[12 marks]

Desirable properties of moulding sand

1. Refractoriness.
2. Permeability.
3. Flowability.
4. Adhesiveness
5. cohesiveness
6. strength
7. Hardness
8. collapsibility.

6

Different additives used:-

1. $CaCO_3$
2. malasses.
3. linseed oil
4. saw dust (wood flour)
5. ~~charcoal~~ Graphite powder.

Explain

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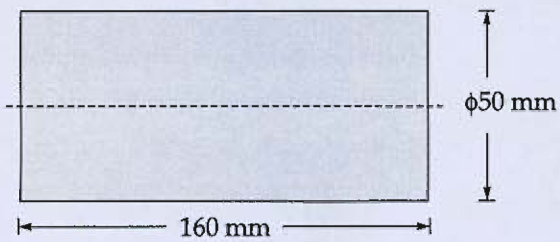
Q.5 (b) Estimate the actual machining time required for the component (C40 steel) shown in figure below. The available spindle speeds are 80, 120, 180, 290, 430, 700, 1200, 1800 and 3000 rpm. Use a roughing speed of 36 m/min and finish speed of 60 m/min. The feed of roughing is 0.36 mm/rev while that for finishing is 0.2 mm/rev. The maximum depth of cut for roughing is 2 mm. Finish allowance may be taken as 0.8 mm. Blank to be used for machining is 60 mm in diameter. Take overtravel allowance as 2 mm.



[12 marks]

60 mm → (Roughing ①) 56 mm → (Roughing ②) 52 mm → (Roughing ③) 50.8 mm → (④ Finishing) 50 mm

$V_R = 36 \text{ m/min}$, $s = 0.36 \frac{mm}{rev}$

$V_f = 60 \text{ m/min}$, $s = 0.2 \text{ mm/rev}$

① Roughing.

$$t_m = \frac{160\,mm + 2\,mm}{0.36\frac{mm}{rev} \times N} = \frac{162}{0.36 \times 180} = 2.5 \text{ min}$$

$$36 \frac{m}{min} = \frac{\pi \times D\,N}{1000} \quad (D \to 60) \implies N = 190 \approx 180 \text{ available}$$

②③ Roughing

$$2 t_m = \frac{160+2}{0.36 \times N} = \left(\frac{162}{0.36 \times 290}\right) 2 = 3.1035 \text{ min}$$

$$36 = \frac{\pi \times D N}{1000}$$

Finishing

$$60 = \frac{\pi \times 50.8 \times N}{1000} \implies N = 430 \text{ rpm}$$

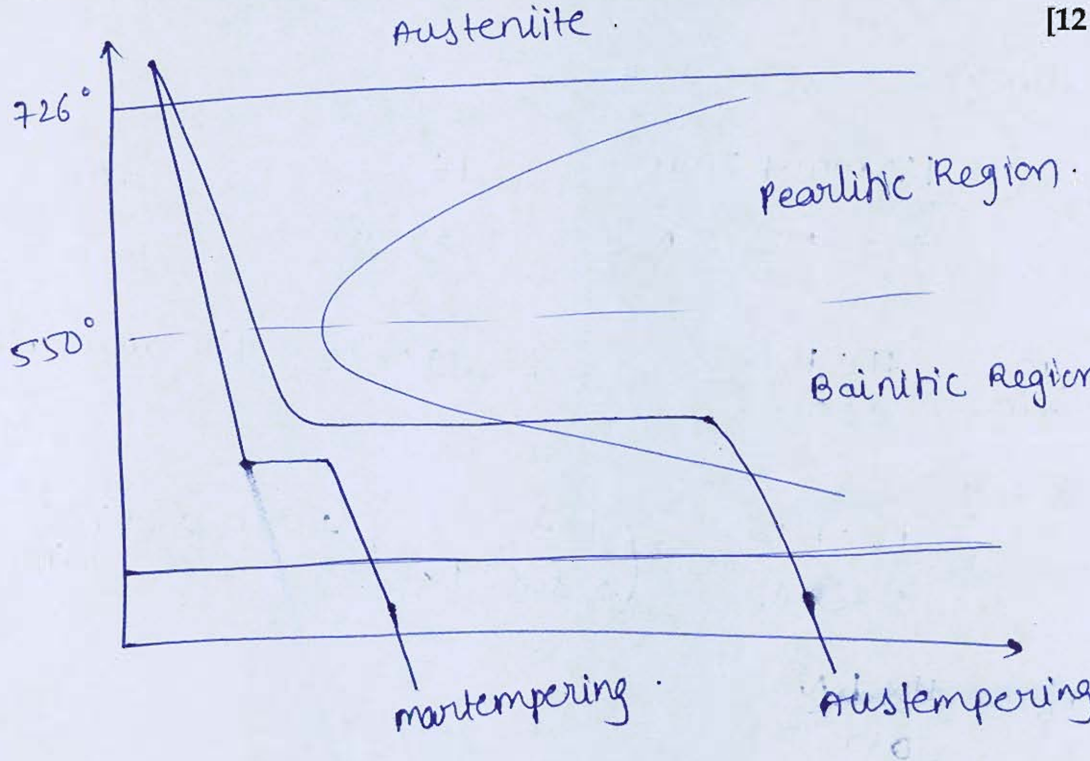
$$t_m = \frac{162}{0.2 \times 430} = 1.8837 \text{ min}$$

Total time ≈ 7.4872 min

(8)

Q.5 (c) Explain austempering and martempering process with suitable sketch.

[12 marks]



Austempering is a process where austenit is cooled from above 726°C ~~and~~ to below 550°c and held at a temperature giving it enough time so that bainite is formed. Bainite is much tougher than martension with slightly lesser hardness.

<u>Martempering</u> :-

It is also called as stepped quenching, It not only provides good hardness but also retains better toughness than quenched martensite.

Austenite $\xrightarrow{\text{martempering}}$ Martensite.

Austenite $\xrightarrow{\text{Austempering}}$ Bainite.

8

Q.5 (d) A point $P[7, 3, 1]^T$ is attached to a frame F_{noa} and is subjected to the following transformations:

(i) Rotation of 90° about the z-axis.

(ii) Followed by a rotation of 90° about the y-axis.

(iii) Followed by a translation of [4, –3, 7].

Find the coordinate of the point relative to the reference frame at the conclusion of transformations.

[12 marks]

$P\begin{bmatrix}7\\3\\1\end{bmatrix}$ } in F_{noa}

Transformations are about fixed coordinate system

i.e premultiplication to be done.

$$Rot(90°, z) = \begin{bmatrix} c90 & -s90 & 0 & 0 \\ s90 & c90 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$Rot(90°, y) = \begin{bmatrix} c90 & 0 & s90 & 0 \\ 0 & 1 & 0 & 0 \\ -s90 & 0 & c90 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$trans[4, -3, 7] = \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & 7 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & 7 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 7 \\ 3 \\ 1 \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & 7 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -3 \\ 7 \\ 1 \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & 7 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 7 \\ 3 \\ 1 \end{bmatrix} = \begin{bmatrix} 5 \\ 4 \\ 10 \\ 1 \end{bmatrix}$$

final coordinates = $\begin{bmatrix} 5 \\ 9 \\ 10 \\ 1 \end{bmatrix}$

12

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Q.5 (e) A pump acting as hydraulic actuator supplies oil at 0.002 m^3/s to a 50 mm diameter double acting cylinder and a rod diameter is 20 mm. If the load is 6000 N both in extending and retracting.

Find

(i) Piston velocity during the extension stroke and retraction stroke.

(ii) Pressure during the extension stroke and retraction stroke.

(iii) Power during the extension stroke and retraction stroke.

[12 marks]

Q.6 (a) The following are weekly sales data, in thousands of units, for micro-computer disks: 113, 101, 98, 107, 120, 132, 110, 117, 112 and 125 Use $\alpha = 0.2$, $\alpha = 0.5$ and $\alpha = 0.8$ to produce an exponential smoothing model for these data. Which value of α produces better forecasts, assuming the initial forecast as 108? Explain.

[20 marks]

for $\alpha = 0.2$

D_i	F_i	$e_i = D_i - F_i$	RSFE
113	108	5	5
101	109	−9	−4
98	107.2	−9.2	−13.2
107	105.36	1.64	11.56
120	105.688	14.312	2.752
132	108.5504	23.4496	26.2016
110	113.24032	−3.24032	22.96128
117	112.5922	4.4077	27.36898
112	113.4737	−1.4737	25.895
125	113.1789	11.821	37.71628

~~Absolute Deviation~~

$MAD = \frac{\Sigma|e_i|}{n}$

$MAD = \frac{83.5448}{10}$

$MAD = 8.3545$

$T.S = 4.5148$

$F_{i+1} = F_i + \alpha e_i$

$RSFE = 37.71628$

$Bias = \frac{RSFE}{10}$

$Bias = 3.7716$

$\alpha = 0.5$

D_i	F_i	e_i
113	108	5
101	110.5	-9.5
98	108.6	-10.6
107	103.3	3.7.
120	104.04	15.96
132	112.02	19.98
110	122.01	-12.01
117	116.005	0.995
112	116.5025	-4.5025
125	114.25125	10.74875

RSFE = 19.77125

Bias = 1.977125

$MAD = \frac{\Sigma |e_i|}{10}$

MAD = 6.8.976

TS = 2.8664

$\alpha = 0.8$

D_i	F_i	e_i
113	108	5
101	112	-11
98	103.2	-5.2
107	99.04	7.96
120	105.408	14.592
132	117.0816	14.9184
110	129.01632	-19.01632
117	113.8032	3.1967.
112	116.3606	-4.3605
125	112.87213	12.1279

RSFE = 18.21818.

$Bias = \frac{RSFE}{10}$

Bias = 1.8218

$MAD = \frac{97.37182}{10}$

MAD = 9.73718.

T.S = 1.871

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→ with respect to mean Absolute deviation (MAD)

$\alpha = 0.5$ produces the best forecast.

→ But bias is least in $\alpha = 0.8$

Traking signal = $\frac{RSFE}{MAD}$

→ with respect to tracking signal $\boxed{\alpha = 0.8}$ is

the better plan.

14

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Q.6 (b) A carbide tipped turning tool with designation 0 - 10 - 6 - 6 - 8 - 90 - 1 mm (ORS) is used for orthogonal turning of a mild steel piece of 80 mm diameter at a cutting speed of 280 m/min and feed 0.25 mm/rev. If the cutting force is 180 kg and feed force is 100 kg and chip thickness is 0.32 mm, find shear angle, shear force, normal force acting on shear plane, friction force, coefficient of friction, friction angle and velocity of chip flow.

[20 marks]

$\alpha_o = 10°$ $\quad \phi = 90°$

$V = 280 \, m/min$

$s = 0.25 \, mm/rev$ $\quad K = \frac{t_2}{t_1} = 1.28 = \frac{1}{r}$

$F_c = 1765.8 \, N$

$F_t = 981 \, N$ $\quad \tan\theta = \frac{\cos\alpha_o}{K - \sin\alpha_o}$

$t_2 = 0.32 \, mm$

$t_1 = s\sin\phi = 0.25 \, mm$

$\boxed{\theta = 41.6736°}$ → shear angle

$F_s = F_c \cos\theta - F_t \sin\theta$

$\boxed{F_s = 666.7014 \, N}$ → shear force acting on shear plane

$F_N = F_c \sin\theta + F_t \cos\theta$

$\boxed{F_N = 1906.8088 \, N}$ → Normal force acting on shear plane

merchants 2nd angle relation

$2\theta + \tau - \alpha = 90°$

$2(41.6736) + \tau - 10 = 90°$

$\boxed{\tau = 16.6528°}$ → friction Angle

$\mu = \tan(\tau)$

$\boxed{\mu = 0.2991 \approx 0.3}$ → coefficient of friction

$F = F_c S\alpha_0 + F_t \cos\alpha_0$

$F = (1765.8 \sin 10) + (981 \cos 10)$

$F = 1272.72\, N$ → friction force.

$V_{chip} = V \times r$

$V_{chip} = 280 \frac{m}{min} \times \frac{1}{1.28}$

$V_{chip} = 218.75\, m/min$

16

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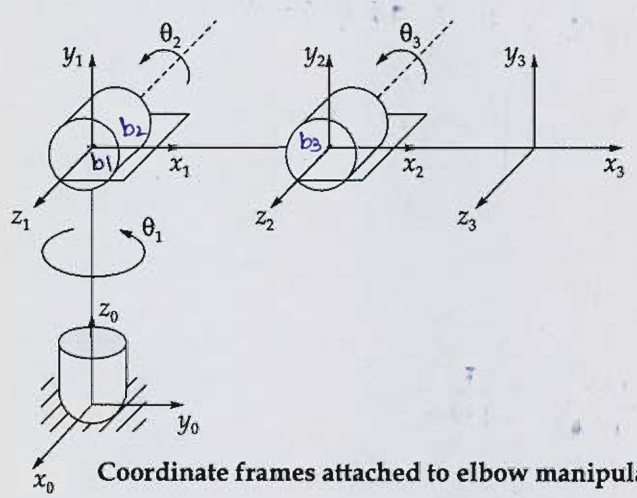
Q.6 (c) Consider frames attached to elbow manipulator as shown below. Manipulator has been pictured after rotation $(\theta_1, \theta_2, \theta_3) = (90°, 0, 0)$



Coordinate frames attached to elbow manipulator

Using forward-Kinematics:

(i) Set up a table of D-H parameters

(ii) Generate individual transformation matrices

(iii) Generate overall transformation matrix

Assume link lengths of a_2 and a_3 for links 2 and 3 respectively, and that the link 1 offset is d_1.

[20 marks]

(i) θ_K is angle b/w $\angle x_{K-1}, x_K$ about z_{K-1}

$\theta_1 \Rightarrow 90° + \theta_1$

$\theta_2 \Rightarrow 0° + \theta_2$

$\theta_3 \Rightarrow 0° + \theta_3$

consider point b_K which is intersection of x_K, z_{K-1}

$d_1 \Rightarrow$ distance b/w L_0, b_1 along z_0.

$d_1 = d_1$

$d_2 = 0$

$d_3 = 0$

$a_K \Rightarrow$ distance b/w L_K, b_K along x_K.

$a_1 \quad 0$

$a_2 \quad a_2$

$a_3 \quad a_3$

α_K is angle b/w $\angle Z_{K-1}, Z_K$ about X_K.

α_1 $90°$

α_2 $0°$

α_3 $0°$

DH Parameter table

θ	d	a	α
$90°+\theta_1$	d_1	0	90
$0°+\theta_2$	0	a_2	0
$0°+\theta_3$	0	a_3	0

At home position $(\theta_1\ \theta_2\ \theta_3) = (90°, 0°, 0°)$

(ii) $$_{K-1}T^K = \begin{bmatrix} C\theta_K & -C\alpha_K S\theta_K & S\alpha_K S\theta_K & a_K C\theta_K \\ S\theta_K & C\alpha_K C\theta_K & -S\alpha_K C\theta_K & a_K S\theta_K \\ 0 & S\alpha_K & C\alpha_K & d \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$_0T^1 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$_1T^2 = \begin{bmatrix} 1 & 0 & 0 & a_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$_2T^3 = \begin{bmatrix} 1 & 0 & 0 & a_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

} Individual Transformation matrices.

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

$${}_0T^3 = \begin{bmatrix}0&0&1&0\\1&0&0&0\\0&1&0&d_1\\0&0&0&1\end{bmatrix}\begin{bmatrix}1&0&0&a_2\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}1&0&0&a_3\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$$

$${}_0T^3 = \begin{bmatrix}0&0&1&0\\1&0&0&0\\0&1&0&d_1\\0&0&0&1\end{bmatrix}\begin{bmatrix}1&0&0&(a_2+a_3)\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$$

$${}_0T^3 = \begin{bmatrix}0&0&1&0\\1&0&0&(a_2+a_3)\\0&-1&0&d_1\\0&0&0&1\end{bmatrix}$$

→ overall transformation matrix

18

Q.7 (a) A small project involves 7 activities and their time estimates are listed in the following table. Activities are identified by their beginning (i) and ending (j) node numbers.

Activity (*i-j*)	Estimated Duration (Weeks)		
	Optimistic	Most likely	Pessimistic
1 - 2	1	1	7
1 - 3	1	4	7
1 - 4	2	2	8
2 - 5	1	1	1
3 - 5	2	5	14
4 - 6	2	5	8
5 - 6	3	6	15

(i) Draw the network diagram of the activities in the project.

(ii) Find the expected duration and variance for each activity. What is the expected project length?

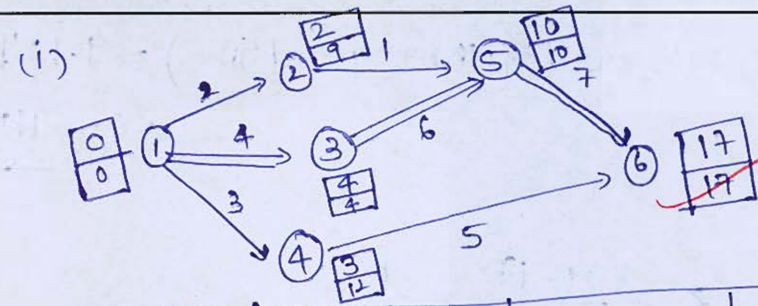
(iii) Calculate the variance and standard deviation of the project length. What is probability that the project will be completed:

1. at least 4 weeks earlier than expected time.
2. no more than 4 weeks later than expected time. Given:

Z	0.50	0.67	1.00	1.33	2.00
Prob.	0.6915	0.7486	0.8413	0.9082	0.9772

[20 marks]

(i)



(ii)

Activity	a	b	c	$t_e = \frac{a+4b+c}{6}$	$\sigma^2 = \left(\frac{b-a}{6}\right)^2$
1–2	1	1	7	2	$1^2 = 1$
1–3	1	4	7	4	$1^2 = 1$
1–4	2	2	8	3	$1^2 = 1$
2–5	1	1	1	1	$0 = 0$
3–5	2	5	14	6	$2^2 = 4$
4–6	2	5	8	5	$1^2 = 1$
5–6	3	6	15	7	$2^2 = 4$

t_e ↓ Expected duration of each activity

σ^2 ↓ Expected variance of each activity

t_E = Expected project length = 17 weeks

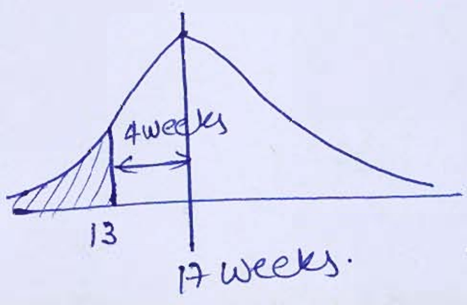
(iii)

$$\sigma^2 = \sigma_{13}^2 + \sigma_{35}^2 + \sigma_{56}^2$$

$$\sigma^2 = 1^2 + 2^2 + 2^2 = 9$$

$\sigma^2 = 9$ ⟶ variance of project.

$\sigma = \sqrt{9} = 3$ ⟶ standard deviation of project.



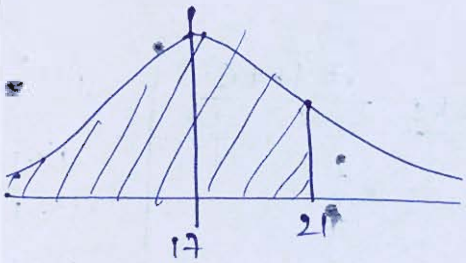
$$Z = \frac{T_S - T_E}{\sigma} = \frac{13-17}{3}$$

$$Z = \frac{-4}{3}$$

$$p(Z) = 0.091211$$

P(atleast 4 weeks earlier than expected time) = 9.1211 %

= 0.09121



$z = \frac{21-17}{3} = \frac{4}{3}$

$P(z) = 90.82\%$

P(No more than 4 weeks later than expected time) = 90.82%

20

Q.7 (b) The following Taylor tool life equation for carbide tool, steel work piece pair is obtained experimentally $VT^{0.2} = 600$ where V is in m/min and T is in min. A batch of 1200 steel parts, each 100 mm in diameter and 200 mm in length, is to be rough turned using a feed of 0.15 mm/rev. If the cost per edge of the throw away carbide insert is ₹60, time required to reset the cutting edge is 1 min and the total machining cost (including operator cost) is ₹360 per hour, calculate

(i) optimum cutting speed for minimum cost.

(ii) the corresponding tool life.

(iii) total production cost if time taken to load and unload the component is 3 min, and the initial setup time is 2 hours, and

(iv) total production time for the given batch.

[20 marks]

$n = 0.2$ $\quad D = 100$ mm, $L = 200$ mm } each part.

$C = 600$

1200 parts in each batch.

$S = 0.15$ mm/rev.

TCT = 1 min (tool change time)

$Z_2 = ₹60$ / piece.

6

$Z_1 = 360 \times 60$ ₹/min.

(i) Optimum cutting speed for minimum cost.

$$V = \frac{C}{\left[\left(\frac{1}{n}-1\right)\left(TCT + \frac{Z_2}{Z_1}\right)\right]^n}$$

$$V = \frac{600}{\left[\left(\frac{1}{0.2}-1\right)\left(1 + \frac{60}{360 \times 60}\right)\right]^{0.2}}$$

$$\boxed{V = 454.46 \text{ m/min}}$$

$V = \frac{\pi D N}{1000} \Rightarrow N = 1446.59$ rpm

(ii) tool life $= \left(\frac{1}{n}-1\right)\left(TCT+\frac{t_2}{z_1}\right)$

tool life = 4.0111 minutes.

(iii) Total Production cost

= (machining cost) + (initial setup time cost)

+ (loading and unloading component)

+ (Tool change cost).

$t_m = \frac{L}{SN} = \frac{0.2\,m}{\frac{0.15}{1000} \times 1446.59} = 0.9217\,min.$

No of tool failures $= \frac{1200 \times 0.9217\,min}{4.0111\,min}$

$= 275.747$

(iv) Total time = (2 hrs) [setup] + (1200 × 0.9217 min) [m/cing time]

+ (1200 × 3 min) [load and unload component] + (275.747 × 1 min) [tool change time]

Total time per batch = 5101.8147 min.

(iii) Total production cost = (360×60) × (total production time)

+ (No of tool failures) × (Regrinding cost)

Total cost = 110.2157 × 10^6 ₹

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Q.7 (c) Define corrosion. Write names of different type of corrosion. Briefly explain selective leaching. Name different type of methods to control corrosion and explain cathodic protection.

[20 marks]

Corrosion

It is defined as the electrochemical spontaneous reaction in which a pure metal gets converted in to its ore form. [i.e high energy state to a low energy state].

Types of corrosion

1. Dry corrosion
   (a) oxidation (in presence of O_2, moisture)
   (b) In presence of H_2, H_2S
2. Wet corrosion
   (a) Galvanic cell corrosion
   (b) concentration cell corrosity (Crevice corrosion)
3. stress corrosion.

methods to control corrosion :-

1. Never leave metal surface wet, i.e no droplets of any liquid on it as it can cause pitting corrosion.
2. Use techniques like cathodic protection. (Impressed current cathodic Protection) (ICCP)

Cathodic Protection :-

Consider an asembly of two different metal. Naturally due to their respective electro chemical potentials on becomes anode and other becomes cathode. As soon as an electrolyte gets available anodic dissolution takesplace. That means, anode gets disappeared slowly.

This can be achieved by three techniques

cathodic protection

- Sacrificial anode type by bring a more anodic material in contact
- Impressed current cathodic protection. (Externally supplying current to make it less anodic)

14

Q.8 (a) Explain development of microstructure in isomorphous alloys for non equilibrium cooling.

[20 marks]

Q.8 (b) A shopkeeper estimates the annual requirement of an item as 2,000 units. He buys it from his supplier at a cost of Rs. 10 per item and the cost of ordering is Rs 50 each time he orders. If the stockholding costs are 25 per cent per year of stock value, how frequently should he replenish his stocks? Further, suppose the supplier offers a 10 per cent discount on orders between 400 and 699 items, and a 20 per cent discount on orders exceeding or equal to 700. Can the shopkeeper reduce his costs by taking advantage of either of these discounts?

[20 marks]

Q.8 (c) Explain the following NDT techniques:

(i) Vibration Monitoring

(ii) Wear debris analysis

(iii) Thermography

(iv) Visual inspection

[20 marks]

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Space for Rough Work

Space for Rough Work