MADE EASY

Leading Institute for ESE, GATE & PSUs

# 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 ☐ | |
| Pune ☐ | Kolkata ☐ | Hyderabad ☐ | |

### 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 | 22 |
| Q.2 | 40 |
| Q.3 | — |
| Q.4 | — |
| Section-B | |
| Q.5 | 44 |
| Q.6 | 38 |
| Q.7 | 35 |
| Q.8 | — |
| **Total Marks Obtained** | 179 |

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



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.

Do not write in this margin

## Section : A

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]**

**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]**

Ans

FCC ⇒ no of atoms = $8 \times \frac{1}{8} + 6 \times \frac{1}{2}$

= 1 + 3 = 4 atom

Na = 23 amu
Cl = 35 amu

2 Na and 2 Cl ⇒ Mass = 2 × 23 + 2 × 35

= 116 amu

$\rho = \frac{m}{V}$

$$\text{density} = \frac{\frac{116}{6.022 \times 10^{23}} \text{ gm}}{a^3} = 2.18 \text{ g/cm}^3$$

$a = 4.454 \times 10^{-8}$ cm

in FCC ⇒ $\sqrt{2}a = 4r$

$r = \frac{\sqrt{2}a}{4} = 1.5747 \times 10^{-8}$ cm

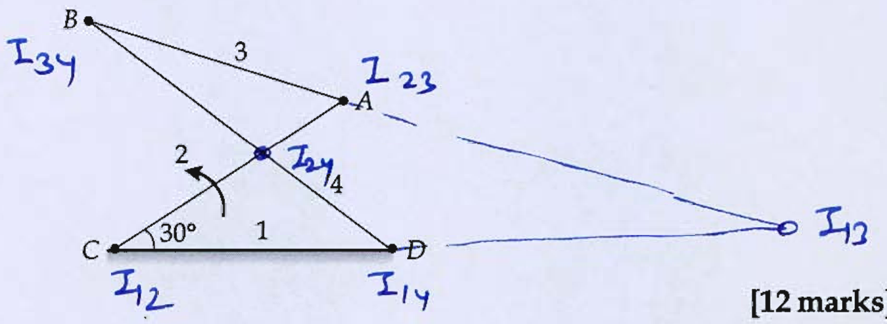
$r = 0.15747$ nm

Centre distance = 2r

= 0.3149 nm

3

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.



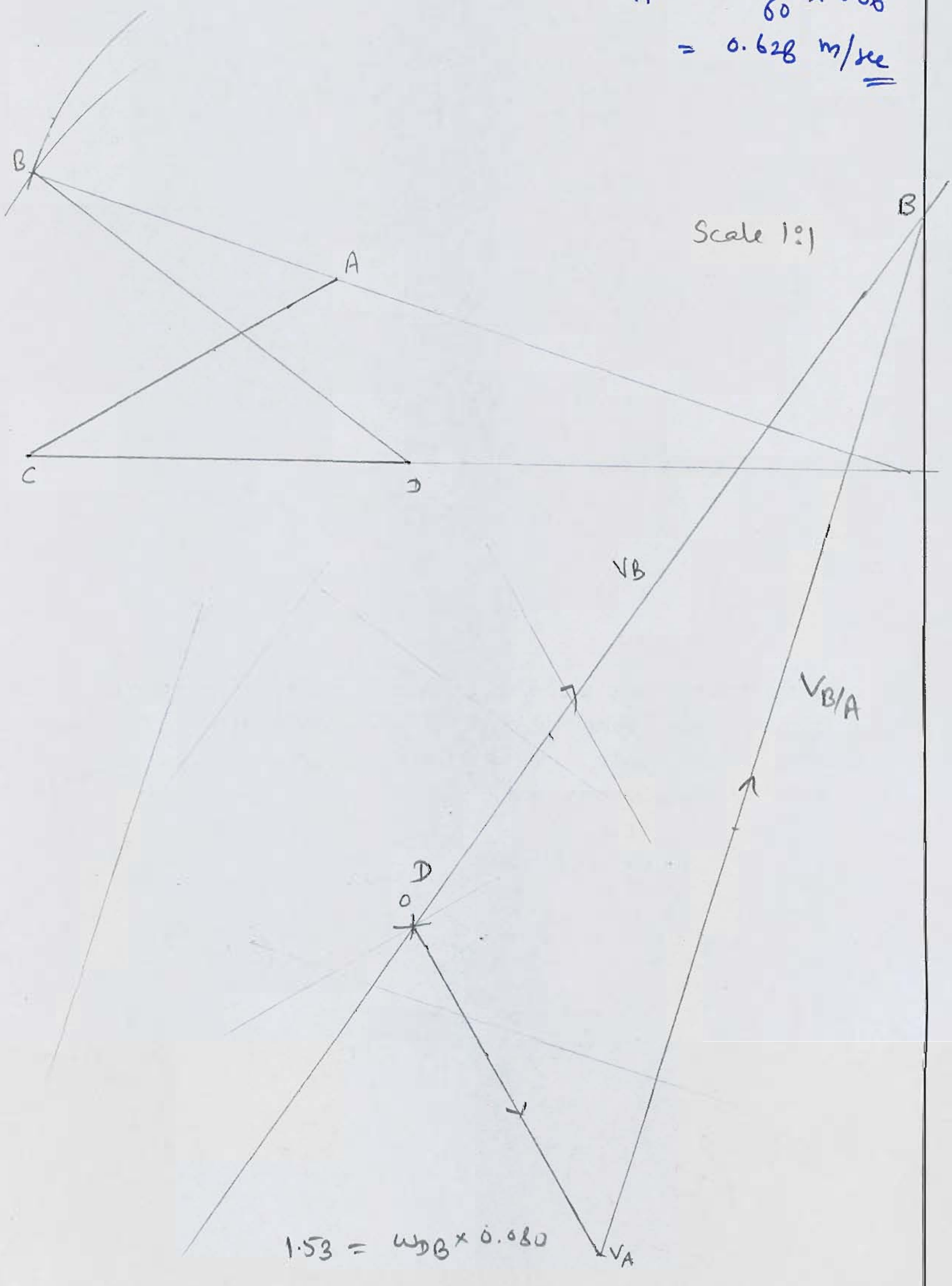

**[12 marks]**

7

?

$V_A = 100 \times \frac{2\pi}{60} \times 0.06$

$= 0.628$ m/sec




$1.53 = \omega_{DB} \times 0.080$

$\omega_{DB} =$

19.125

$N_{DB} = 182.63$ rpm

$18.6 \times 10^{-2} \times 10^{-1} = \omega_{BA} \times 0.55$

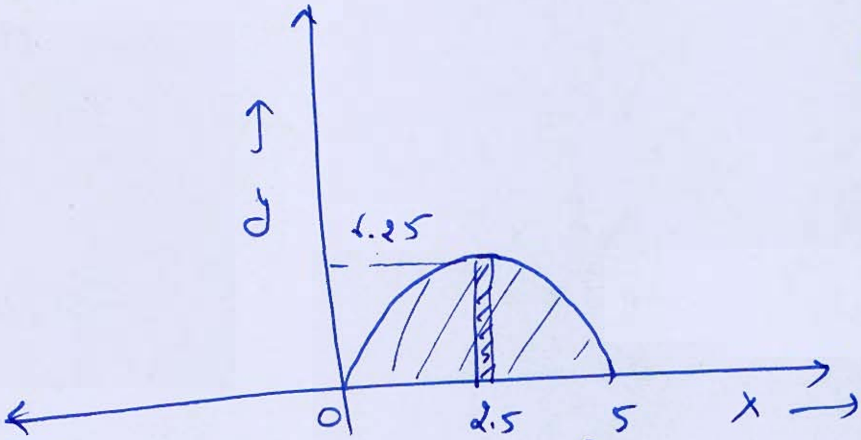
$\omega_{BA} = 33.81$ rad/sec

$N = 322.86$ rpm

Do not write in this margin

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

**[12 marks]**




$y = 0$

$(5 - x)x = 0$

$x = 0, 5$

$\frac{dy}{dx} = 5 - 2x$

$x = 2.5$

$$y_{cm} = \frac{\int \bar{y}\, dA}{\int dA} = \frac{\frac{1}{2}\int_0^5 (5x - x^2)^2 \cdot dx}{\int_0^5 (5x - x^2)\, dx} = \frac{\frac{1}{2} \times 625/6}{125/6}$$

$$y_{cm} = 5 \times \frac{1}{2} = 2.5 \text{ unit}$$

$$x_{cm} = \frac{\int_0^{6.25} \bar{x}\, dA}{\int_0^{6.25} dA} = \frac{\int 2\sqrt{6.25 - y}\,(2.5)\, dy}{\int 2\sqrt{6.25 - y}\, dy}$$

$$= 2.5 \text{ unit}$$

$5x - x^2 = y$

$-y = (x - 2.5)^2 - 2.5^2$

$2.5 \pm \sqrt{6.25 - y} = x$

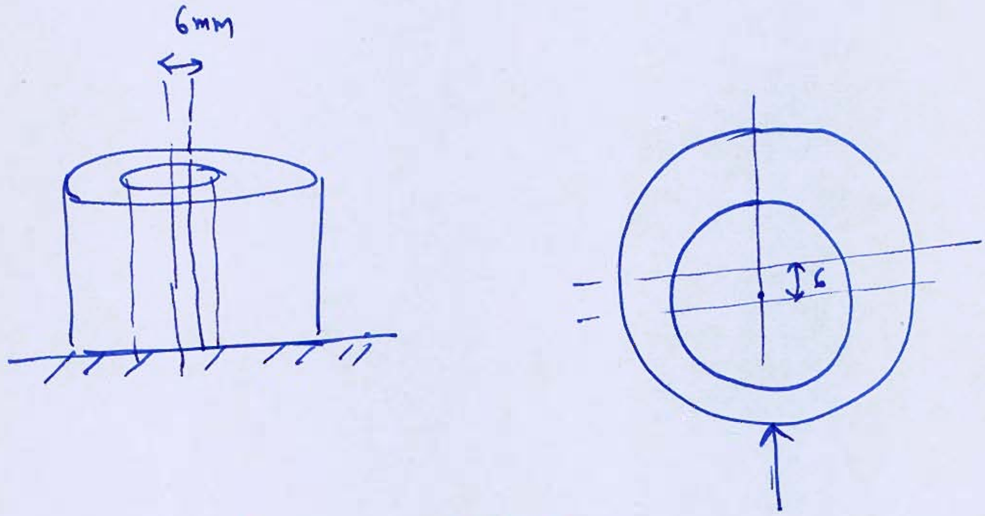
$X_{cm} = 2.5$

$Y_{cm} = 2.5$

12

(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]**



Do not write in this margin

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]**

Ans

$\omega = 150.796$ rad/sec $\quad \zeta = 0.22$

$F = 2500$ N

$\Delta = 2.5$ mm

$$\omega_n = \sqrt{\frac{g}{\Delta}} = \sqrt{\frac{9.81}{2.5\times10^{-3}}} = 62.642 \text{ rad/sec}$$

(i)

$$\text{transmissibility } \epsilon = \frac{\sqrt{1+\left(2\zeta\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2+\left(\frac{2\zeta\omega}{\omega_n}\right)^2}}$$

$$= \frac{1.4567}{4.9105} = 0.2966$$

$\omega_n = \sqrt{\frac{k}{m}}$

$62.642 = \sqrt{\frac{k}{1000}}$ $\quad k = 3.924 \times 10^6 \ N/m$

force transmitted $= \epsilon F_0$

$= 0.2966 \times 2500$

$= 741.5 \ N$

(2) Amplitude of vibration of M/c

$$= \frac{F_0/k}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(\frac{2\zeta\omega}{\omega_n}\right)^2}}$$

$$= \frac{2500/3.924 \times 10^6}{4.9105}$$

$= 1.2974 \times 10^{-4}$

$= 0.1297 \ mm$

(3)

Spring force amplitude $= kA = 3.924 \times 10^6 \times 1.2974 \times 10^{-4}$

$= 509.0997 \ N$

damper force amplitude $= c\omega A = \frac{~~23.792~~ \times 10^3}{27.562} \times 150.796 \times 0.1297 \times 10^{-3}$

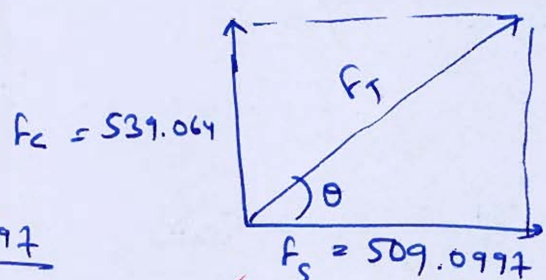
$=$ ~~465.329 N~~

$= 539.064 \ N$

$\zeta = \frac{c}{2\sqrt{mk}}$

$c = \frac{~~23.792~~ \times 10^3}{27.562}$

20




$\cos\theta = \frac{509.0997}{741.5}$

$\boxed{\theta = 46.64^\circ}$

Do not write in this margin

**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/mm$^2$). 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]**

Ans

$$\text{Torque} = \frac{15\times10^3}{1440 \times \frac{2\pi}{60}} = 66.314 \text{ N-m}$$

$$T_{starting} = 1.5\,T_{rated} = 99.4718 \text{ N-m} \qquad b = 10m$$

Bending

$$\text{gear strength} = \sigma Y m b$$

$$= \left(\frac{S_{ut}}{3}\right) \times \left(0.154 - \frac{0.912}{z}\right) \pi \times m \times 10m$$

$$\text{dynamic load} = C_v\, C_s\, F_{static}$$

$$= \left(\frac{3+V}{3}\right) \times 1 \times \frac{F_t}{} \leftarrow \text{design for pinion}$$

assume $z_1 \rightarrow$ no of teeth in pinion

$$V = \left(\frac{m z_1}{2}\right) \times \omega = 75.398\, m z_1$$

$$\text{min no of teeth for gear} = \frac{2}{\sqrt{1+\frac{1}{4}\left(\frac{1}{4}+2\right)\sin^2\phi} - 1} = 61.77$$

$z_2 = 62$ pinion $= z_1 = 15.5$ X

$$\left.\begin{array}{l} z_1 = 16 \\ z_2 = 64 \end{array}\right\}$$

$V = 1206.368\, m$

$$\left(\frac{3 + 1206.368 m}{3}\right) \times 1 \times \frac{99.4718}{\left(\frac{m \times 16}{2}\right)} \times (fos = 1.5)$$

$$= \frac{600 \times 10^6}{3} \times \left(0.154 - \frac{0.912}{16}\right) \times \pi \times 10 m^2$$

$m = 4.39 \times 10^{-3}$ m

$m = 4.39$ mm

(2)

taking standard module $= 5$ mm

$$F_d = \left(\frac{3+V}{3}\right) \times 1 \times F_t = 7.4867 \text{ kN}$$

$$K\phi = \frac{2G_i R}{G_i R + 1}$$

$K\phi = 1.6$

wear $\Rightarrow$

$F_d \times fos = D B Q k$

for pinion

$$7.4867 \times 1.5 \times 10^3 = \frac{(0.005 \times 16)}{1} \times 10 \times 0.005 \times Q \times 1.6$$

$Q = 1.754$ MPa

surface hardness for pinion

Pinion ⇒ no of teeth = 16

$m = 5$

$b = 5 \times 10 = 50$ mm

$d = m z_1 = 80$ mm

Hardness = 1.754 MPa

Gear → no of teeth = 64

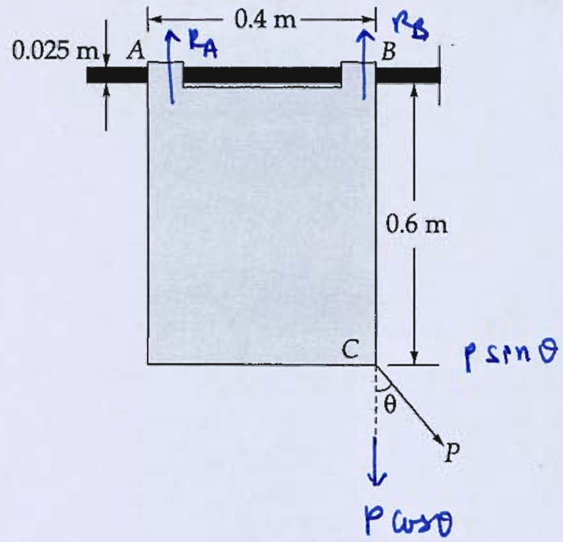
$m = 5$

$b = 50$ mm

$d = m z_2 = 64 \times 5 = 320$ mm

Hardness = 1.754 MPa

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]**

~~Normal~~

$N = R_A + R_B = P\cos\theta$

$\Sigma M_A = 0$ $R_B \times 0.4 + P\sin\theta \times 0.6 = P\cos\theta \times 0.4$

$$R_B = \frac{P(0.4\cos\theta - 0.6\sin\theta)}{0.4}$$

$$R_B = P[\cos\theta - 1.5\sin\theta]$$

$$R_A = 1.5P\sin\theta$$

friction $= \mu_s|R_A| + \mu_s|R_B|$ max friction

$$f = 0.4\left|\left[P(\cos\theta - 1.5\sin\theta)\right]\right| + 0.4\left|(1.5P\sin\theta)\right|$$

for motion

$$f \leq P\sin\theta$$

$$0.4\left|P(\cos\theta - 1.5\sin\theta)\right| + 0.4\left|1.5P\sin\theta\right| \leq P\sin\theta$$

$$\left|\cos\theta - 1.5\sin\theta\right| + 1.5\left|\sin\theta\right| \leq 2.5\sin\theta$$

$\theta = 21.8°$, $-10.3$, $-21.8$, ~~$\cos\theta = 5.5\sin\theta$~~ $10.3° \times$

+, +, −, +, −, −, + −

8

~~θ = 0 to 21.8~~

$\theta = 0$ to $21.8^\circ$ ⇒ It will have impending motion

$21.8^\circ \leq \theta \leq 32.61^\circ$

.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.

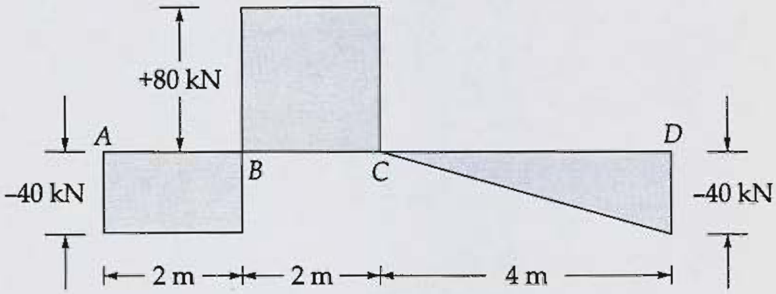
**[20 marks]**

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]**

Do not write in this margin

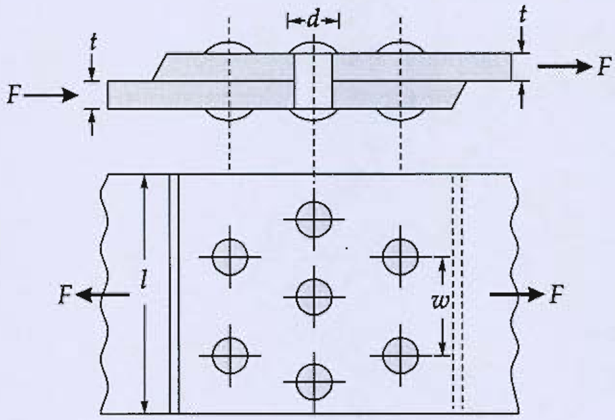
**Q.3 (c)** In a winch, the rope supports a load W and is wound round a barrel 450 mm diameter. A differential band brake acts on a drum 800 mm diameter which is keyed to the same shaft as the barrel. The two ends of the bands are attached to pins on opposite sides of the fulcrum of the brake lever and 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]**

Do not write in this margin

Do not write in this margin

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]**

Do not write in this margin

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]**

Do not write in this margin

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]**

Do not write in this margin

## 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]

Ans

Properties of moulding Sand →

① Permeability ⇒ to allow gases through it

② Refractoryness ⇒ withstand high temp without burning

③ flow ability ⇒ Reches at all the corener point.

④ Collapsibility ⇒ After casting done, It should be easily collapesable to get the casting without any damage.

⑤ Gree strength ⇒ Mould should ~~not~~ withstand its own load with collapsing

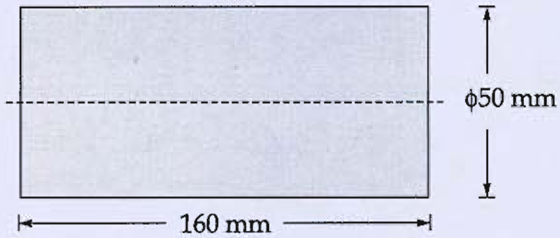
⑥ Hot strength ⇒ During pouring of molten meltal mould should not collapse

6

Do not write in this mar

Do not write in this margin

.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]**

Ans

dia $d_i = 60$ mm  $d_f = 50$ mm

2 pass of roughing ⇒ 8mm dia Reduction

$V = 36$ m/min $= \frac{\pi D N}{60}$

$D_1 = 60$ mm Roughing

$\frac{\pi \times 0.06 \times N_1}{60} = \frac{36}{60}$  $N_1 = 190.98$ rpm ⇓ having spindle Speed = 180 rpm

$t_1 = \frac{160+2}{180 \times 0.36}$

$= 2.5$ min

6

$D_2 = 56$ mm Roughing

$\frac{\pi \times 0.056 \times N_2}{60} = \frac{36}{60}$  $N_2 = 204.62$ ⇓ having spindle Speed = 180 rpm

$t_2 = \frac{160+2}{180 \times 0.36} = 2.5$ min

$D_3 = 52$ mm finishing

no of pass $= \frac{2}{1.6} = 1.25 = 2$ pass

2pass

$\frac{\pi \times 0.052 \times N_3}{60} = \frac{60}{60}$  $N_3 = 367.28$ ⇓ taking $N_3 = 290$ rpm

$t_3 = \frac{160+2}{290 \times 0.2} = 2.793$ min dia 50.4 $\frac{\pi \times 0.0504 \times N_4}{60} = \frac{60}{60}$ $N_4 = 378.94$ rpm

⇓

taking $N_4 = 290$

time $= \frac{160+2}{290 \times 0.2}$

$= 2.793$

total M/c time $= 2.5 + 2.5 + 2.793 + 2.793$

$= 10.586$ min

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

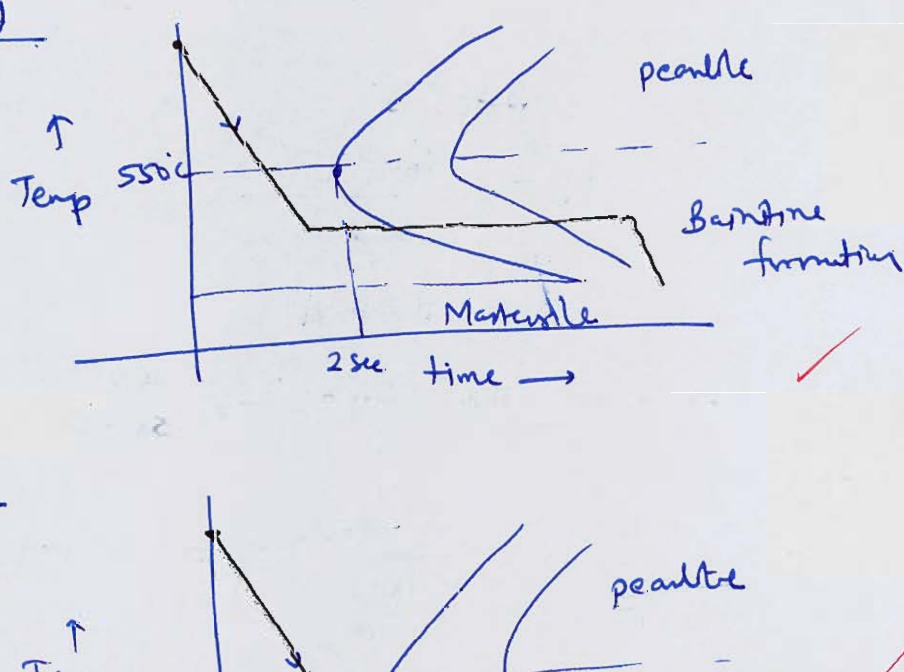
**[12 marks]**

Ans

Austempering

⇓

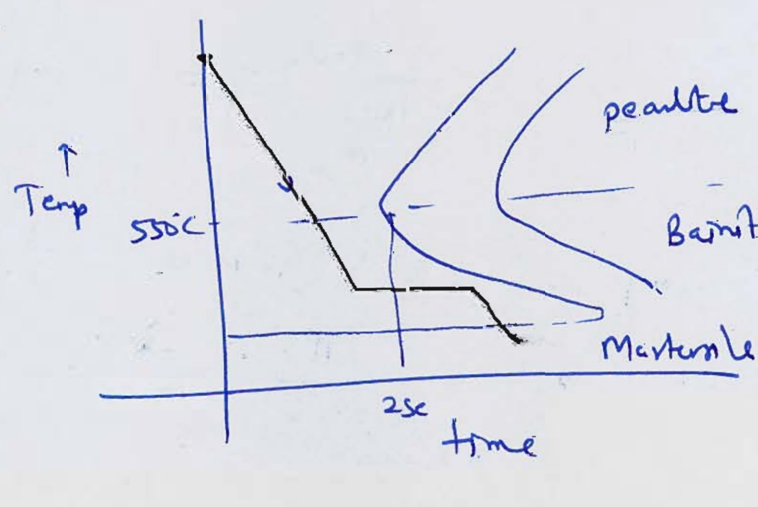
Bainite formation




Martempering

⇓

Martensite formation



Do not write in this margin

Austempering →
austenite is ~~cooling~~ cooled at cooling rate > critical cooling
and held at const temperature below
nose point than allow to form Bainite.

Martempering →
Austenite is cooled at cooling rate > CCR and
held at constant temp for grain growth ~~and~~
and than cooled to Martensite temp.

⇒ stresses are reduced by holding at ~~l~~
~~elem~~ ~~elevated~~ temp.

8

Do not write in this margin

**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]**

Ans

① 90° rotation z

$$T_1 = \begin{bmatrix} C90 & -S90 & 0 & 0 \\ S90 & C90 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

② 90° rotation y

$$T_2 = \begin{bmatrix} C90 & 0 & S90 & 0 \\ 0 & 1 & 0 & 0 \\ -S90 & 0 & C90 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

③ Translation [4, -3, 7]

$$T_3 = \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & 7 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Do not write in this margin

$$P^* = T_3 T_2 T_1 P$$

$$P^* = \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & 7 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 7 \\ 3 \\ 1 \\ 1 \end{bmatrix}$$

$$P^* = \begin{bmatrix} 5 \\ 4 \\ 10 \\ 1 \end{bmatrix}$$

12

Do not write in this margin

**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

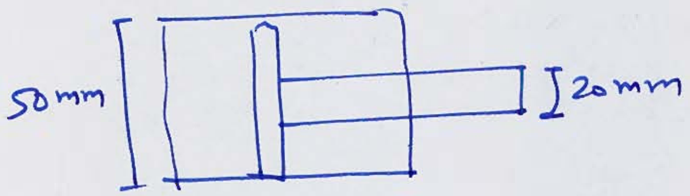
(i) Piston velocity during the extension stroke and retraction stroke.

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

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

**[12 marks]**

Ans




① Piston velocity

$$V_1 = \frac{Q}{A} = \frac{0.002}{\pi \times 0.025^2} = 1.0185 \text{ m/sec}$$

$$V_2 = \frac{Q}{A} = \frac{0.002}{\pi \times (0.025^2 - 0.010^2)}$$

$$= 1.2126 \text{ m/sec}$$

② pressure

$$P_1 = F/A = \frac{6000 \text{ N}}{\pi \times 0.025^2} = 3.056 \text{ MPa}$$

$$P_2 = F/A = \frac{6000}{\pi \times (0.025^2 - 0.01^2)} = 3.638 \text{ MPa}$$

③ power

$$P_1 = F \times V_1 = 6000 \times 1.0165 = 6111 \text{ N}$$

$$P_2 = F \times V_2 = 6000 \times 1.2126 = 7275.6 \text{ N}$$

12

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 $\alpha$ produces better forecasts, assuming the initial forecast as 108? Explain.

[20 marks]

| $\alpha=0.2$ | units | $F_t$ (108) | D−F |
|---|---|---|---|
| 1 | 113 | 109 | 4 |
| 2 | 101 | 109.8 | −8.8 |
| 3 | 98 | 108.04 | −10.04 |
| 4 | 107 | 106.032 | 0.968 |
| 5 | 120 | 106.1936 | 13.8064 |
| 6 | 132 | 108.955 | 23.045 |
| 7 | 110 | 113.564 | −3.564 |
| 8 | 117 | 112.85 | 4.15 |
| 9 | 112 | 113.68 | −1.68 |
| 10 | 125 | 113.34 | 11.66 |

$F_t = F_{t-1} + \alpha(D_{t-1} - F_{t-1})$

initial value = 108

Do not write in this margin

$\alpha = 0.5$

| | | F ~~(108)~~ | D − F |
|---|---|---|---|
| 1 | 113 | ~~112.5~~ 108 | 5 |
| 2 | 101 | 110.5 | −9.5 |
| 3 | 98 | 105.75 | −7.75 |
| 4 | 107 | 101.875 | 5.125 |
| 5 | 120 | 104.4375 | 15.56 |
| 6 | 132 | 112.21 | 19.79 |
| 7 | 110 | 122.105 | −12.105 |
| 8 | 117 | 116.05 | 0.95 |
| 9 | 112 | 116.525 | −4.525 |
| 10 | 125 | 114.2625 | 10.7375 |

10

$$F_t = F_{t-1} + \alpha (D_{t-1} - F_{t-1})$$

?

1

Do not write in this margin

**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]**

Ans

$\lambda = 0 \rightarrow$ orthogonal cutting

$\alpha = 10°$

$\phi = 90°$ so feed $= t_1 = 0.25$ mm

$t_2 = 0.32$

chip thickness ratio $r_0 = \frac{t_1}{t_2} = 0.78125$

Shear angle ($\theta$)

$$\tan\theta = \frac{r_0 \cos\alpha}{1 - r_0 \sin\alpha} \Rightarrow \frac{0.78125 \cos 10°}{1 - 0.78125 \sin 10°}$$

$$\boxed{\theta = 41.67°}$$

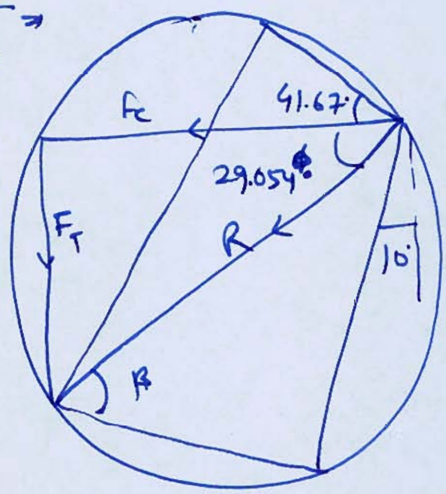
$F_c = 180g = 1765.8\text{N}$

$F_T = 100g = 981\text{ N}$

$R = \sqrt{F_c^2 + F_T^2}$

$R = 2020\text{N}$

Marchant circle ⇒




friction angle $\beta = 10 + 29.054 = 39.054°$

$\mu = \tan\beta = 0.81134$ $\boxed{\mu = 0.81134}$ Ans

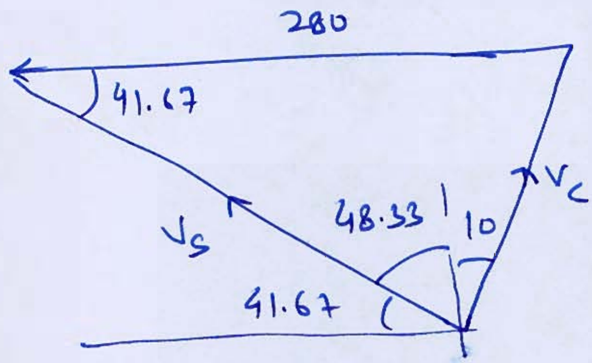
friction force $= R\sin\beta = 1272.706$ N

Normal on shear plane $= R\sin(29.054 + 41.67)$
$= 1906.75$N

Shear force $= R\cos(29.054 + 41.67) = 666.84$ N

Velocity of chip flow

$V = 280 \text{ m/min}$




$$\frac{V_c}{\sin(41.67)} = \frac{280}{\sin(48.33+10)} = \frac{V_s}{\sin(80)}$$

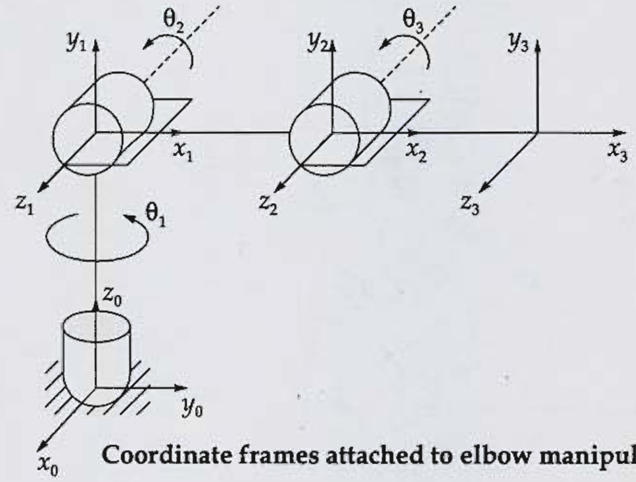
chip velocity $V_c = 218.72$ m/min

shear velocity $V_s = 324$ m/min

20

Do not write in this margin

**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]**

Ans

(1) D-H table

| | d | $\theta$ | a | $\alpha$ |
|---|---|---|---|---|
| $^0T_1$ | $d_1$ | $\theta_1 + 90°$ | 0 | 90° |
| $^1T_2$ | 0 | $\theta_2$ | $a_2$ | 0 |
| $^2T_3$ | 0 | $\theta_3$ | $a_3$ | 0 |

(2) Transformation matrices,

$$^0T_1 = \begin{bmatrix} c(90+\theta_1) & -s(90+\theta_1) & 0 & 0 \\ s(90+\theta_1) & c(90+\theta_1) & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & c90 & -s90 & 0 \\ 0 & s90 & c90 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^0T_1 = \begin{bmatrix} -S\theta_1 & -S\theta_1 & 0 & 0 \\ C\theta_1 & -S\theta_1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^0T_1 = \begin{bmatrix} -S\theta_1 & 0 & -S\theta_1 & 0 \\ C\theta_1 & 0 & S\theta_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^1T_2 = \begin{bmatrix} C\theta_2 & -S\theta_2 & 0 & 0 \\ S\theta_2 & C\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3)

$$^1T_2 = \begin{bmatrix} C\theta_2 & -S\theta_2 & 0 & a_2 C\theta_2 \\ S\theta_2 & C\theta_2 & 0 & a_2 S\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$ ✓

$$^2T_3 = \begin{bmatrix} C\theta_3 & -S\theta_3 & 0 & a_3 C\theta_3 \\ S\theta_3 & C\theta_3 & 0 & a_3 S\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3) Overall transformation matrix

$$^0T_3 = {}^0T_1 \times {}^1T_2 \times {}^2T_3$$

$$= \begin{bmatrix} -S\theta_1 & 0 & S\theta_1 & 0 \\ C\theta_1 & 0 & S\theta_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C\theta_2 & -S\theta_2 & 0 & a_2 C\theta_2 \\ S\theta_2 & C\theta_2 & 0 & a_2 S\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C\theta_3 & -S\theta_3 & 0 & a_3 C\theta_3 \\ S\theta_3 & C\theta_3 & 0 & a_3 S\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \sout{-S\theta_1 C\theta_2 \quad S\theta_1 S\theta_2 \quad S\theta_1 - a_2} \; S\theta_1 C\theta_2 \\ C\theta_1 C\theta_2 \quad \sout{C\theta_1 S\theta_2} \\ \\ \end{bmatrix}$$

?

10

Do no write i this ma

**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) | | | $t_{mean} = \frac{t_o + 4t_m + t_p}{6}$ |
|---|---|---|---|---|
| | Optimistic | Most likely | Pessimistic | |
| 1 - 2 | 1 | 1 | 7 | 2 |
| 1 - 3 | 1 | 4 | 7 | 4 |
| 1 - 4 | 2 | 2 | 8 | 3 |
| 2 - 5 | 1 | 1 | 1 | 1 |
| 3 - 5 | 2 | 5 | 14 | 6 |
| 4 - 6 | 2 | 5 | 8 | 5 |
| 5 - 6 | 3 | 6 | 15 | 7 |

(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?

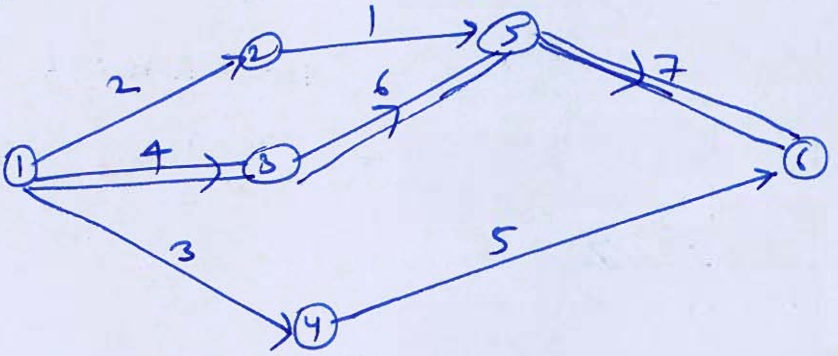
(iii) Calculate the variance and standard deviation of the project length. What is probability that the project will be completed:

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]**

(1)




$\frac{t_o + 4t_m + t_p}{6}$ $\left(\frac{t_p - t_o}{6}\right)^2$

(2) ~~Expected duration~~

| Activity | $t_o$ | $t_m$ | $t_p$ | $t_e$ | $\mu^2$ |
|---|---|---|---|---|---|
| 1-2 | 1 | 1 | 7 | 2 | 1 |
| 1-3 | 1 | 4 | 7 | 4 | 1 |
| 1-4 | 2 | 2 | 8 | 3 | 1 |
| 2-5 | 1 | 1 | 1 | 1 | 0 |
| 3-5 | 2 | 5 | 14 | 6 | 4 |
| 4-6 | 2 | 5 | 8 | 5 | 1 |
| 5-6 | 3 | 6 | 15 | 7 | 4 |

Expected duration — variance

Critical path ⇒ (1) − (3) − (5) − (6)

Expected project length = 4 + 6 + 7
= 17

15

(3) total variance on critical path

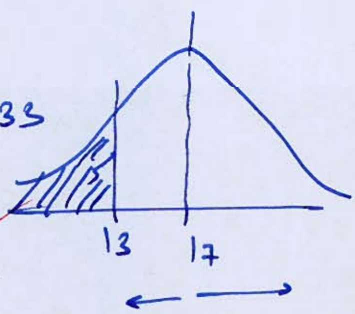
= 1 + 4 + 4 = 9

standard deviation = $\sqrt{9}$ = 3

(1) at least 4 week earlier

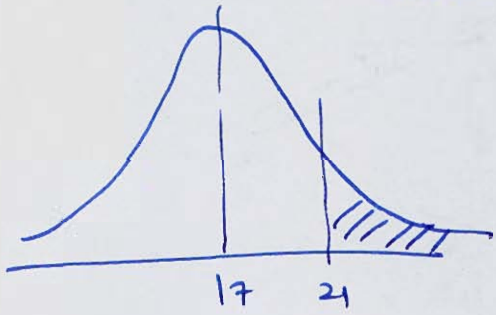
$z = \frac{-4}{3} = -1.333$

probability = 9.028 %



Do not write in this margin

(2) no more than 4 weeks later than expected




= 100 − 9.028

= 90.972

Do not write in this margin

(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]**

~~machining time per piece = $\frac{L}{fN}$ = $\frac{200}{0.15 \times N}$~~

① Optimum cutting speed for minimum cost

$C_m = \frac{360}{60} = 6$ ₹/min

Tool life $T = \left(\frac{C_e}{C_m} + TCT\right)\left(\frac{1}{n} - 1\right)$

$T = \left(\frac{60}{6} + 1\right)\left(\frac{1}{0.2} - 1\right)$

$T = 11 \times 4 = 44$ min

$VT^{0.2} = 600$

$V(44)^{0.2} = 600$ $\quad V = 281.48$ m/min

② Tool life = 44 min

③ Total production cost

per piece m/c time $= \frac{L}{fN} = \frac{200}{0.15 \times 895.97}$

$\pi DN = 281.48$ $\quad = 1.488$ min

$N = 895.97$ rpm

Total = Setup. time + tool change time + loading time + time

total No of tool = $\frac{1.4880 \times 1200}{44}$ = 40.58

total Cost = $\underbrace{40.58 \times 60}_{\text{tool Cost}}$ + $\underbrace{1200(1.488+3) \times 6}_{\text{M/c cost}}$

+ 2 × 60 × 6 → setup cost

+ $\underbrace{40.58 \times 1 \times 6}$ cost to reset the edge

= 35711.88 ₹ / batch

(4) total production for batch

= 1200 (1.488 + 3) + 2 × 60
M/c time + loading time → setup time

+ 40.58 × 1 → tool set time

= 5546.18 min

= 92.44 hr

20

Do not write in this margin

(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]**

Do not write in this margin

Do not write in this margin

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

**[20 marks]**

Do not write in this margin

Do not write in this margin

(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]**

Do not write in this margin

(c) Explain the following NDT techniques:

(i) Vibration Monitoring

(ii) Wear debris analysis

(iii) Thermography

(iv) Visual inspection

**[20 marks]**

OOOO

**Space for Rough Work**

**Space for Rough Work**