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Leading Institute for ESE, GATE & PSUs

# ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

## Mechanical Engineering

Test-5 : Section A : Production Engineering & Material Science [All Topics]

Section B : Theory of Machines-1 [Part Syllabus]

Fluid Mechanics & Turbo Machinery-2 [Part Syllabus]

Name : .....

Roll No : .....

| Test Centres  | Student's Signature |
|---|---------------------|
| Delhi <input checked="" type="checkbox"/> Bhopal <input type="checkbox"/> Jaipur <input type="checkbox"/><br>Pune <input type="checkbox"/> Hyderabad <input type="checkbox"/> |                     |

- ### Instructions for Candidates
- Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
  - There are Eight questions divided in TWO sections.
  - Candidate has to attempt FIVE questions in all in English only.
  - 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.
  - Use only black/blue pen.
  - 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.
  - Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
  - 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                         | 39             |
| Q.2                         | -              |
| Q.3                         | -              |
| Q.4                         | 28             |
| Section-B                   |                |
| Q.5                         | 28             |
| Q.6                         | -              |
| Q.7                         | 36             |
| Q.8                         | 16             |
| <b>Total Marks Obtained</b> | <b>147</b>     |

Signature of Evaluator *[Signature]* Cross Checked by .....

*Keep up the consistent effort*

## 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.

## Section A : Production Engineering &amp; Material Science

- Q.1 (a) A rectangular strip of cross-section  $200 \text{ mm} \times 8 \text{ mm}$  is being rolled with 25% reduction in area using steel rolls having radius of 250 mm. The average shear yield stress during the process is 380 MPa. Calculate the final strip thickness, angle subtended at the roll centre and the location of neutral plane. Assume coefficient of friction between workpiece and roller surface as 0.15.

[12 marks]

$$A_0 = 200 \times 8 \text{ mm}^2 \quad A_f = 0.75 \times A_0$$

$$h_0 = 8 \text{ mm}$$

$$h_f = 0.75 \times 8 = 6 \text{ mm}$$

$$\Delta h = 2 \text{ mm}$$

(i) find strip thickness: -  $h_f = 6 \text{ mm}$

$$(ii) \quad \Delta h = D(1 - \cos \theta)$$

$$2 = 500(1 - \cos \theta)$$

$$\theta = 5.1264^\circ$$

$$(iii) \quad H_n = 2 \sqrt{\frac{R}{h_f}} \times \tan^{-1} \left[ \sqrt{\frac{R}{h_f}} \times \theta \right]$$

$$H_n = 6.7614$$

$$H_0 = \frac{1}{2} \left[ H_n - \frac{1}{2\mu} \ln \left( \frac{1}{2\mu} \right) \right]$$

$$H_0 = 1.374$$

$$\theta_n = \sqrt{\frac{h_f}{R}} \times \tan \left( \sqrt{\frac{R}{h_f}} \times \frac{H_0}{2} \right)$$

$$\theta_n = 0.01655 \text{ radian}$$

$$\theta_n = 0.9482^\circ$$

$$\theta_n = 0.0817 \text{ rad}$$

$$\theta_n = 4.698^\circ$$

$$h_n = h_f + D(1 - \cos \theta)$$

~~$$h_n = 6.034 \text{ mm}$$~~

$$h_n = 6.84 \text{ mm}$$

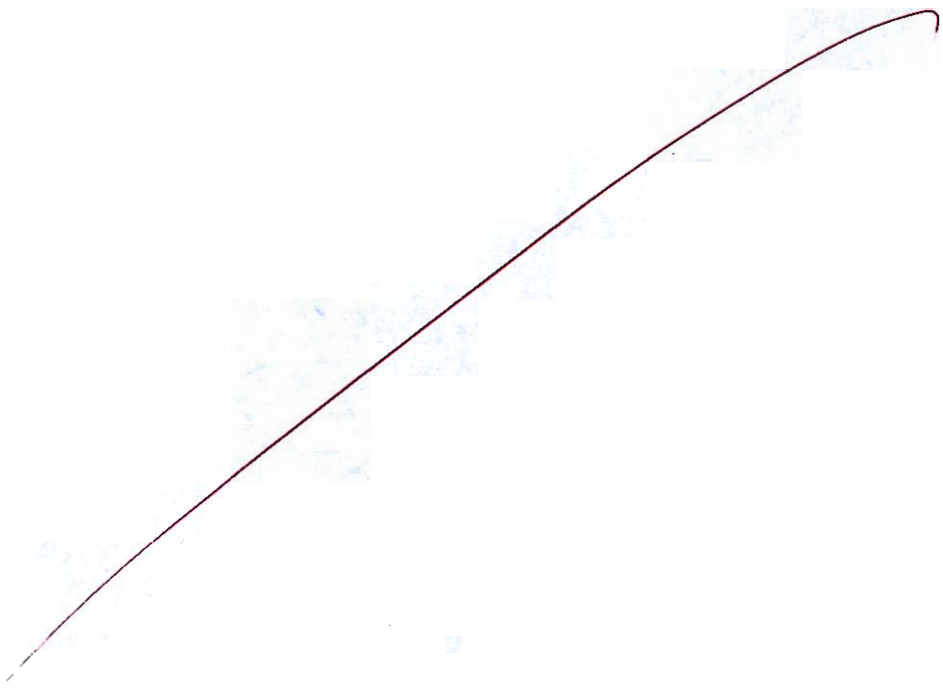


Q.1 (b) Using neat and properly labelled diagrams, explain the microstructures of the different phases of steel, highlighting the presence of the following constituents:

- (i) Ferrite                      (ii) Austenite  
(iii) Cementite                (iv) Pearlite

[12 marks]





- Q.1 (c) The power source characteristic in a arc welding process is  $V_p = 72 - \frac{I}{80}$ , and the arc characteristic is  $V_a = 32 + 4L_a$ , where  $V_c$  and  $V_a$  is voltage in volts,  $I$  is current in Ampere and  $L_a$  is arc length in cm. The arc length is expected to vary between 0.5 cm and 1.5 cm. Calculate the range of welding current corresponding to the change in arc length. Also determine the optimum arc length and the corresponding arc power.

[12 marks]

$$\text{for } l_a = 0.5 \text{ cm}$$

$$V_a = 32 + 4 \times 0.5 \\ = 34 \text{ V}$$

$$V_a = V_p$$

~~$$\frac{I}{80} = 72 - 34$$~~

$$\frac{I}{80} = 72 - V_p$$

$$I_a = 3040 \text{ A}$$

$$l_a = 1.5 \text{ cm}$$

$$V_a = 32 + 4 \times 1.5 \\ = 38 \text{ V}$$

$$V_a = V_p$$

$$\frac{I}{80} = 72 - 38$$

$$I_a = 2720 \text{ A}$$

$$\therefore \text{Range of welding current} = 3040 - 2720 \\ = 320 \text{ A}$$

for optimum arc length:-

$$P = V_a \times I_a$$

$$= (32 + 4l_a) \times 80 \times [70 - (38 + 4l_a)]$$

$$= 80 \times [70 \times (34 + 4l_a) - (32 + 4l_a)^2]$$

$$\frac{dP}{dl_a} = 0$$

$$70 \times 4 = 2 \times 4 \times (32 + 4l_a)$$

$$4l_a = 35 - 32$$

$$l_a = 0.75 \text{ cm}$$

$$P_{\text{power}} = 35 \times 2960 = 103.6 \text{ kW}$$

12

- Q.1 (d) Determine the dimensions of an optimum cylindrical riser attached to the side of a aluminium slab casting with dimensions  $25 \text{ cm} \times 15 \text{ cm} \times 5 \text{ cm}$ . The volume shrinkage of aluminium during solidification is 6.5%. Also, derive the expression for the dimensions of an optimum cylindrical side riser.

[12 marks]

$$\text{Shrinkage in Cast} = 0.065 \times 25 \times 15 \times 5$$

$$= 121.875 \text{ cm}^3$$

Side riser:-

$$SA = 2 \times \frac{\pi D^2}{4} + \pi D h$$

$$V = \frac{\pi D^2 h}{4} \Rightarrow h = \frac{4V}{\pi D^2}$$

$$SA = 2 \times \frac{\pi D^2}{4} + \pi D \times \frac{4V}{\pi D^2}$$

$$SA = \frac{\pi D^2}{2} + \frac{4V}{D}$$

$$\frac{d(SA)}{d(D)} = 0 \rightarrow \pi D = \frac{4V}{D^2}$$

$$\pi D^3 = 4 \times \frac{\pi D^2 h}{4}$$

$$\therefore \boxed{D = h}$$

for optimum cylindrical riser:-

$$V_r = 3 \times \text{shrinkage of Cast} = 3 \times 121.875$$

$$3 \times 121.875 = \frac{\pi D^3}{4} \Rightarrow \boxed{D = 7.75 \text{ cm}}$$

$$\text{rise} = \left( \frac{V}{SA} \right)_{\text{riser}} = \frac{D}{6} = 1.291$$

$$\left(\frac{V}{SA}\right)_{\text{cast}} = \frac{1875}{2 \times (25 \times 15 + 15 \times 5 + 5 \times 25)} = 1.6304$$

$$\therefore \left(\frac{V}{SA}\right)_{\text{cast}} > \left(\frac{V}{SA}\right)_{\text{riser}} \therefore \text{riser not optimised.}$$

$\therefore$  for optimised riser:-

$$\left(\frac{V}{SA}\right)_{\text{riser}} \geq \left(\frac{V}{SA}\right)_{\text{cast}}$$

$$\frac{D}{6} = 1.6304$$

$$D = 9.7826$$

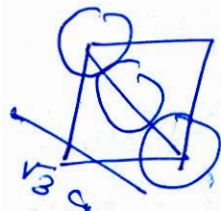
(12)

- Q.1 (e) Prove that the packing fraction for a B.C.C structure is 0.68. Also, determine the number of atoms per  $\text{mm}^2$  on the (010) planes of copper (Cu), given that the atomic radius is 0.1280 nm?

[12 marks]

For BCC:- Total atoms =  $8 \times \frac{1}{8} + 1 = 2$

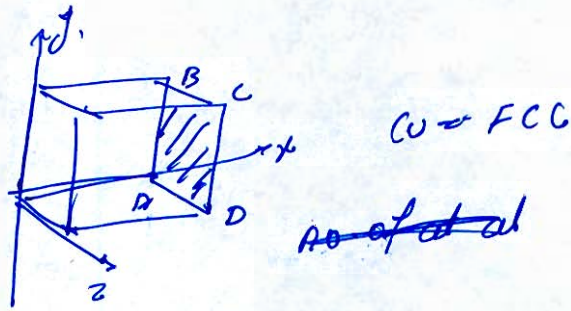
$$APF = \frac{n \times V_{\text{atom}}}{V_{\text{lattice}}} = \frac{2 \times \frac{\pi}{6} \times D^3}{a^3}$$



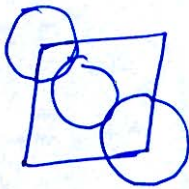
$$\sqrt{3}a = 4R = 2D$$

$$a = \frac{2D}{\sqrt{3}}$$

$$= \frac{2 \times \frac{\pi}{6} \times D^3}{\left(\frac{2}{\sqrt{3}}\right)^3 \times D^3} = 0.68$$



$$\text{No. of atom at plane ABCD} = \frac{1}{2} + 1 = \frac{3}{2} = n$$



No. of atoms per  $\text{mm}^2$

$$= \frac{2}{2} \times \frac{4\pi}{3} \times$$

$$\text{No. of atom per } \text{mm}^2 = \frac{\frac{3}{2}}{a^2}$$

$$= (1.1444 \times 10^{13} \frac{\text{atoms}}{\text{mm}^2})$$

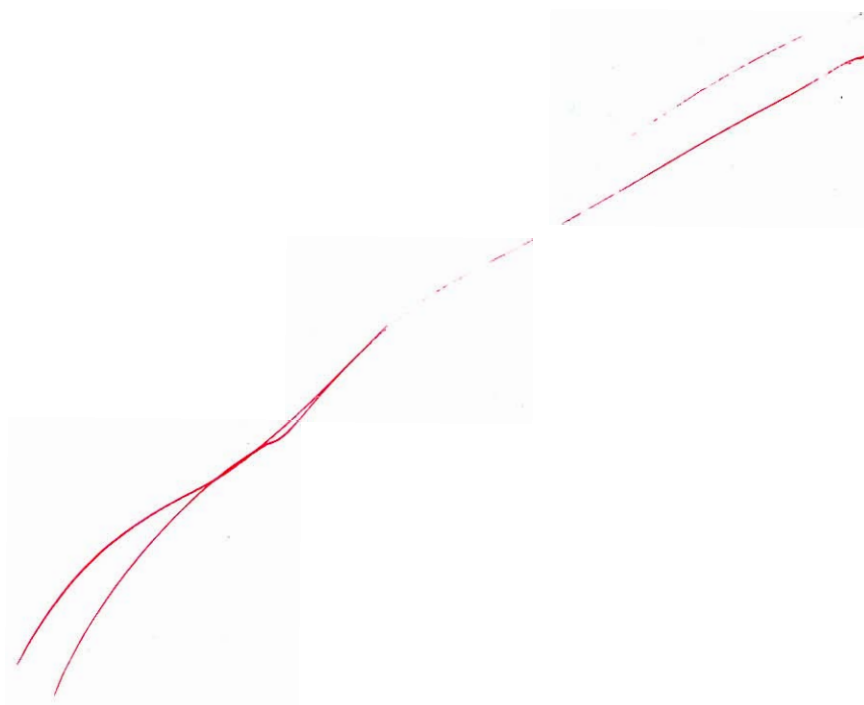
$$\sqrt{2}a = 4r$$

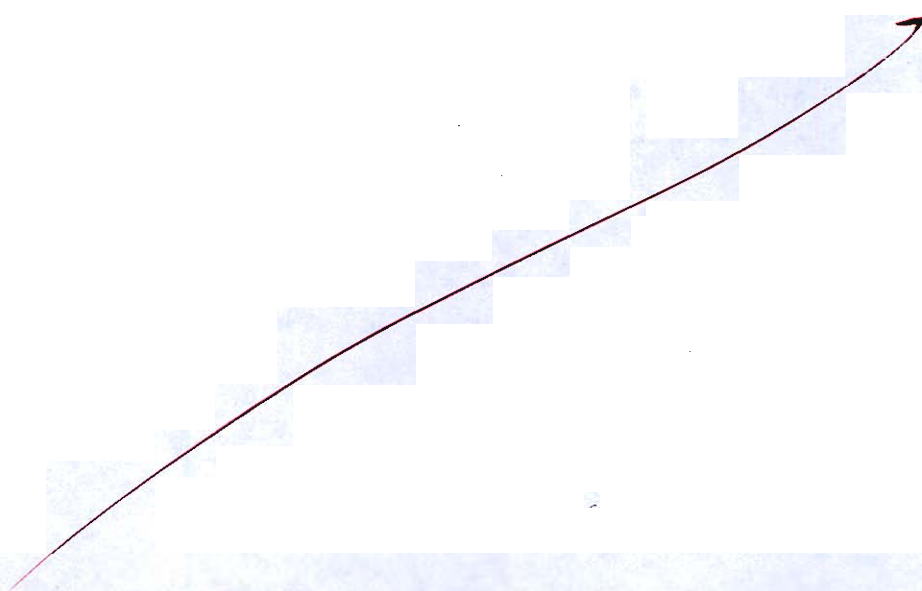
$$a = \frac{4 \times 0.128 \times 10^{-6} \text{ mm}}{\sqrt{2}}$$

8

- Q.2 (a) For the lead-tin alloy 40 wt% Sn and 60 wt% Pb at 150°C. Assume that 10 wt% Sn is fully soluble in Pb at 150°C and 2 wt% Pb is fully soluble in Sn at 150°C. At 150°C densities of Pb and Sn are 11.23 g/cm<sup>3</sup> and 7.24 g/cm<sup>3</sup> respectively. Calculate the relative amount of  $\alpha$  and  $\beta$  phase present in terms of
- mass fraction and
  - volume fraction.
- Also draw Pb-Sn phase diagram.

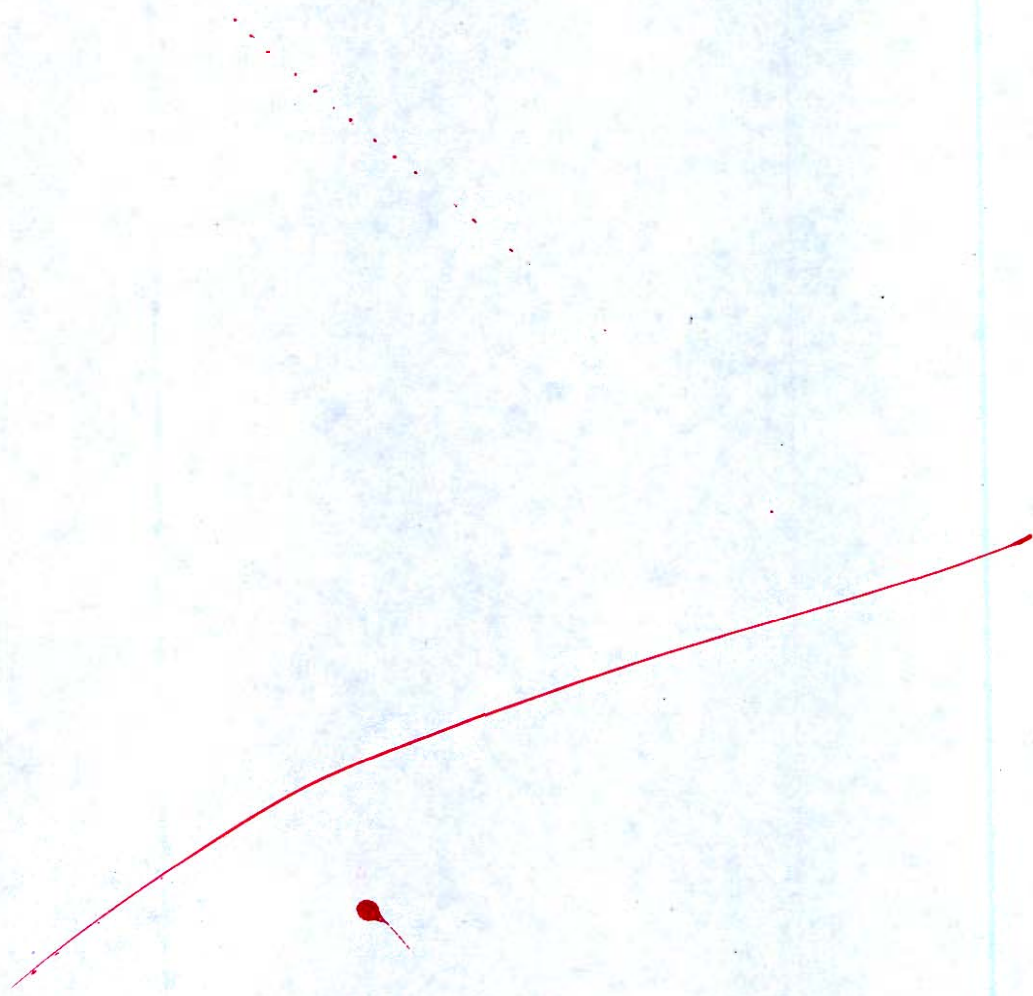
[20 marks]

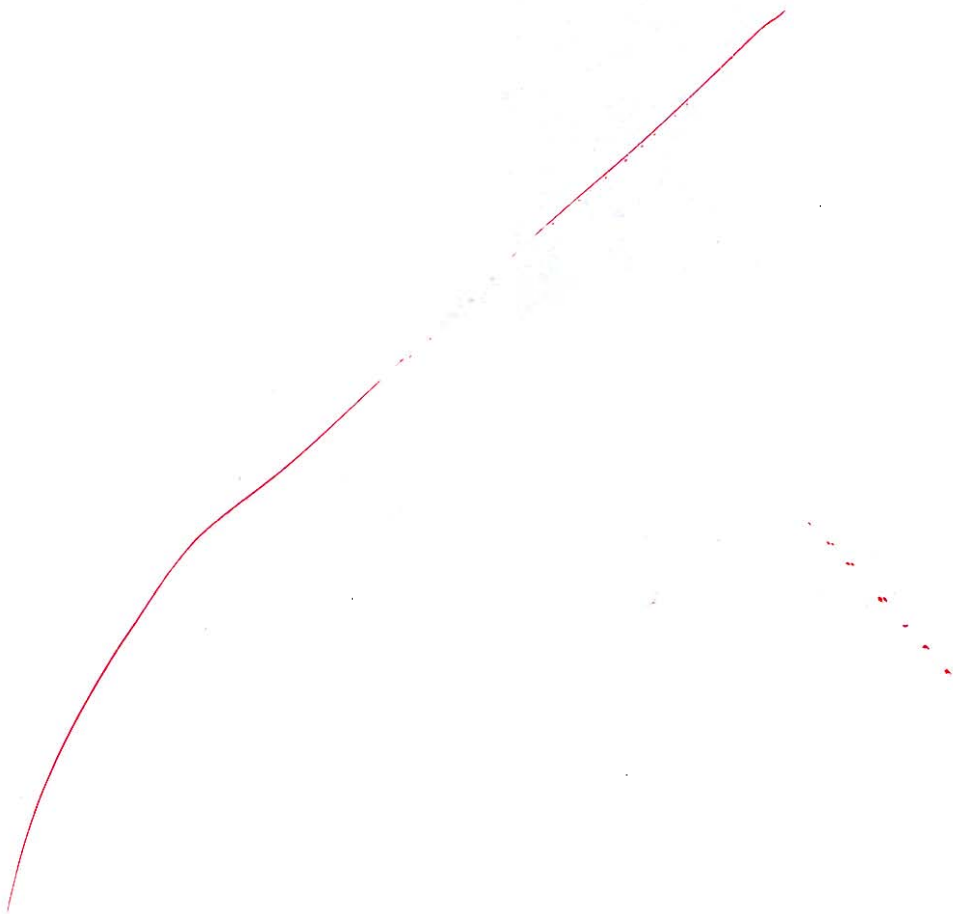




- Q.2 (b) (i) Describe the mechanism of chip formation, and state the conditions for the formation of various types of chips.
- (ii) In a turning operation of a cylindrical pieces, the maximum unevenness allowed is  $16 \mu\text{m}$ . The turning tool has a nose radius of  $0.5 \text{ mm}$ . The tool life equation for this work tool combination is  $Vf^{0.18} T^{0.24} = 24$ , where  $V$  is in  $\text{m/min}$ ,  $f$  in  $\text{mm/rev}$ , and  $T$  in minutes. On average, it takes about  $2.7$  minutes to change the tool. Estimate the most productive cutting speed.

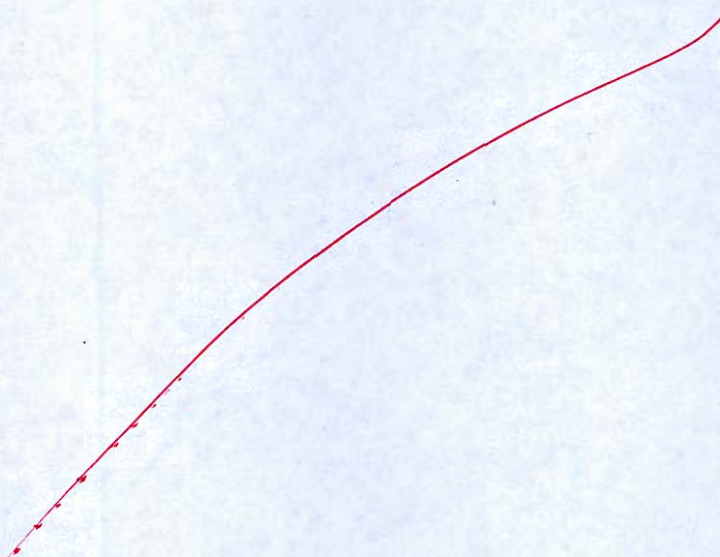
[10 + 10 = 20 marks]

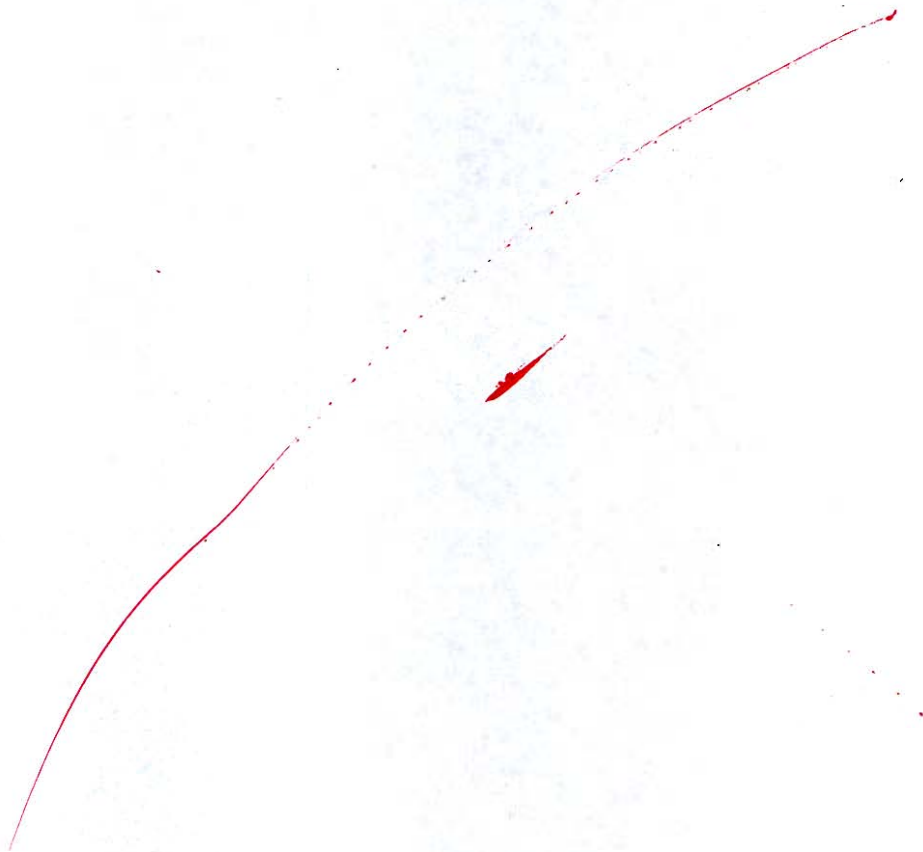




Q.2 (c) Explain the principle of abrasive water-jet machining using suitable schematic diagram.  
Write the advantages and applications of AWJM.

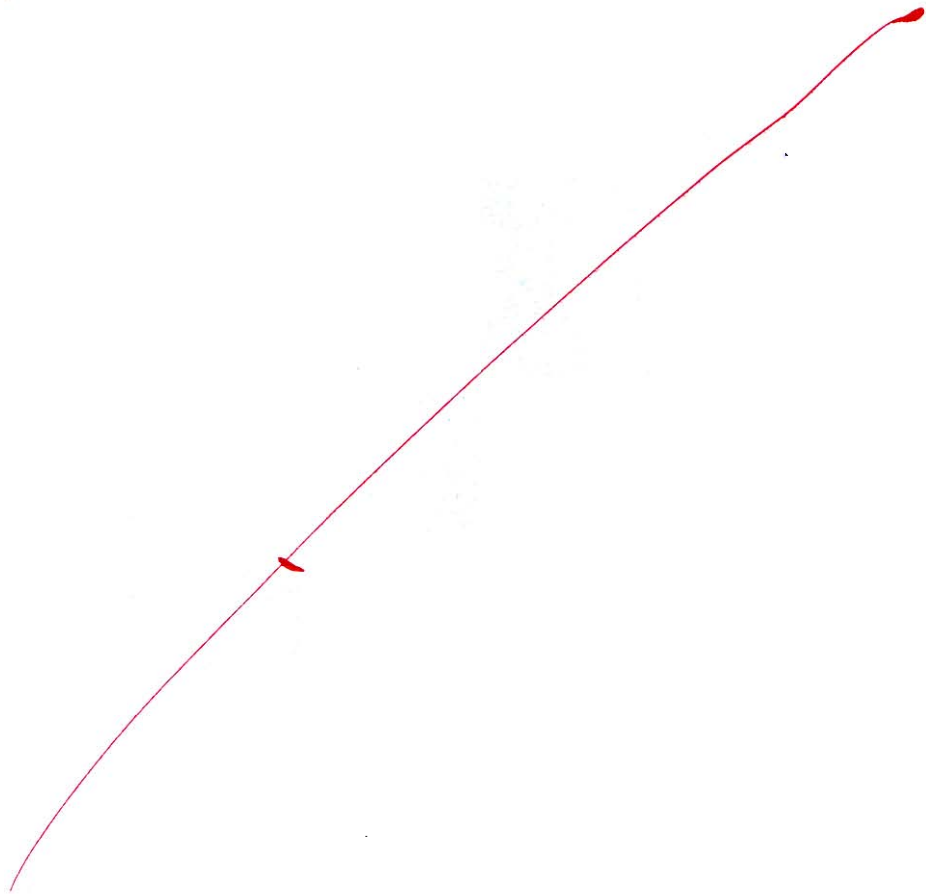
[20 marks]





- Q.3 (a) (i) With the help of a neat and property labelled schematic diagram, explain the construction and working of a hot chamber die casting machine. Also describe the step-by-step operating procedure of the process.
- (ii) A gear ring of 60 mm bore is fitted on a hub resulting in a  $\frac{H7}{m6}$  fit. Calculate the fundamental deviation and hence obtain the limits of size for the hub and the gear bore. Specify the type of fit. The diameter steps are 50 mm and 80 mm. The fundamental deviation for m shaft is  $+(IT7 - IT6)$

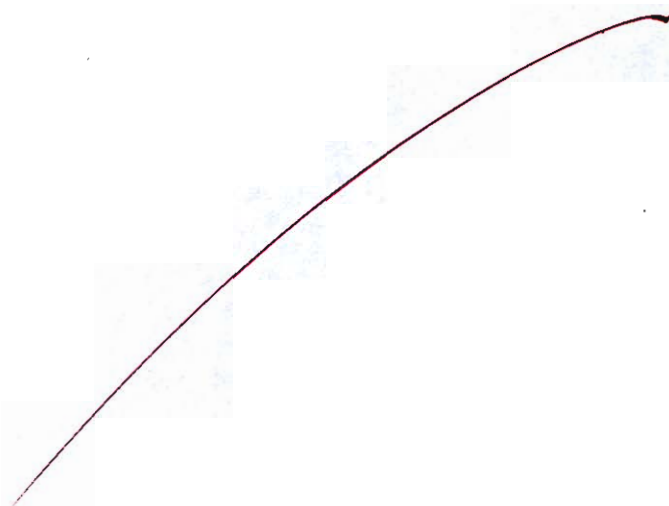
[10 +10 = 20 marks]



Q.3 (b) What are linear defects in crystal? Describe different types of linear defects.

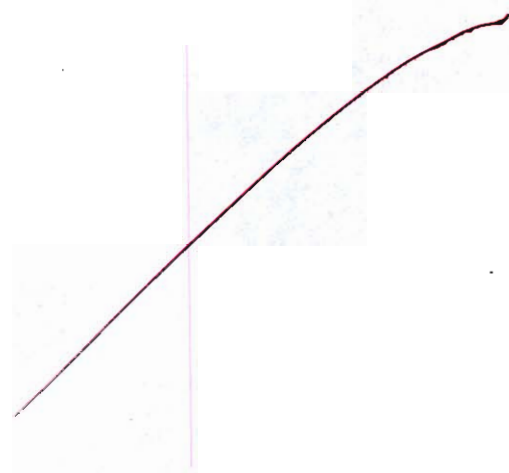
[20 marks]

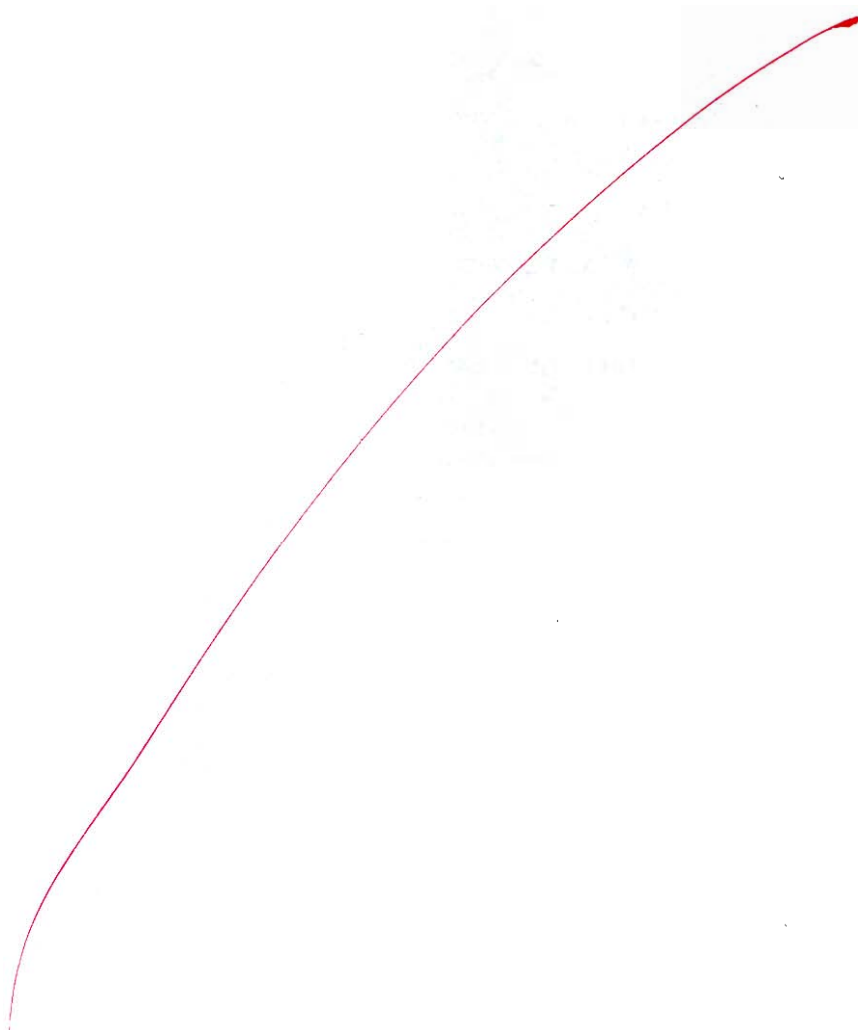


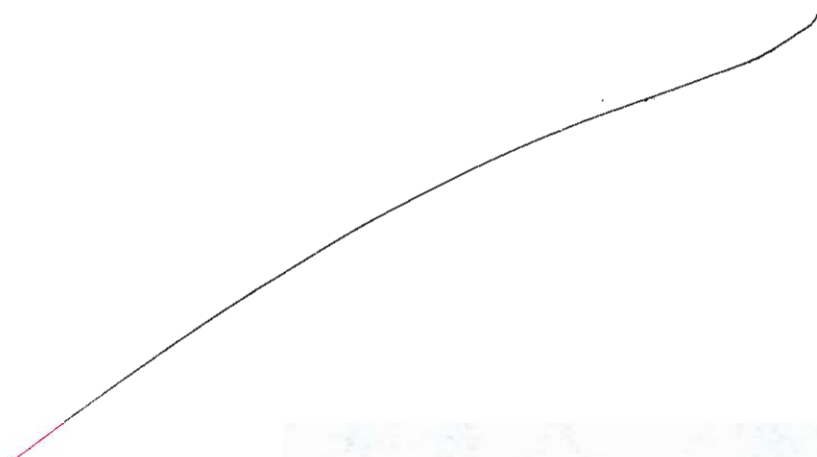


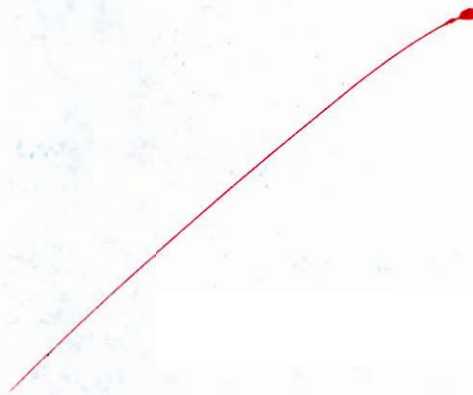
- Q.3 (c) With the help of a neat and property labelled RC circuit diagram of electric discharge machining (EDM), derive the relationship between supply voltage ( $V_0$ ), charging voltage ( $V$ ), resistance ( $R$ ), capacitance ( $C$ ) and the cycle time for the capacitor charging process. Further, obtain the expression for the discharge voltage across the gap and illustrate the variation of gap voltage with time. Also determine the condition for optimum discharge voltage and express the optimum discharge voltage as a percentage of the supply voltage. Assume suitable conditions wherever necessary.

[20 marks]





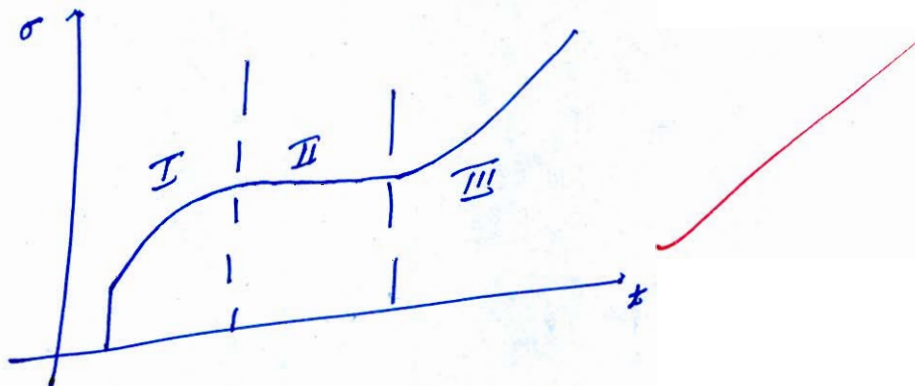




- Q.4 (a) (i) Draw a typical creep curve and elaborate the primary, secondary and tertiary regions of creep.
- (ii) Explain the principle of cathodic protection and describe with neat sketches the sacrificial anode and impressed current methods used for corrosion control of engineering structures.

[5 + 15 = 20 marks]

Creep is a natural deformation phenomenon where a material continuously deforms simultaneously under influence of time and temperature.



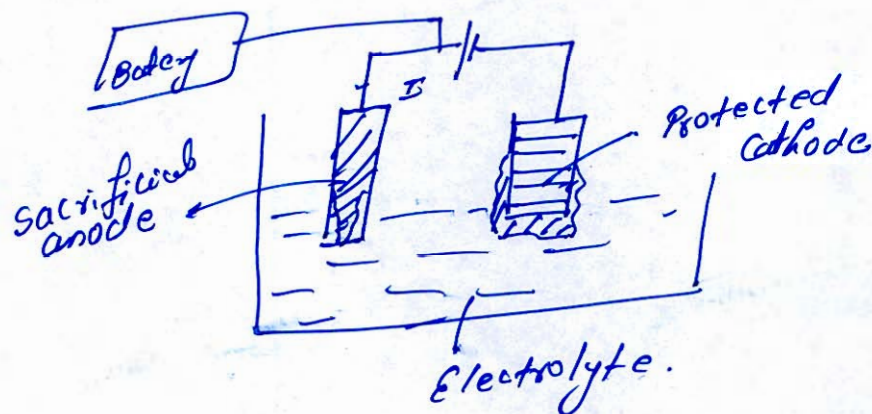
In primary creep, the deformation is dominated by time and gravity than temperature influence.

In secondary creep, both time and temperature create an equilibrium condition due to which this state is stable.

In tertiary creep, temperature dominates and result in higher strain rate deformation leading to failure. (4)

(ii) Cathodic protection:- It is a corrosion prevention method where the anodic material gets deposited on cathode material and create an active and passive layer which prevent cathode (parent material) from corrosion.

Principle:- Electro-chemical based on Faraday's law.



Current method use for corrosion control are:-

1. Galvanising during wet corrosion
2. Enlarging the cathode dimension through cathodic protection.
3. Creation of additional active and passive layer of film in dry corrosion
4. Usage of lubricants and cutting fluids to provide thermal equilibrium
5. Reducing internal stress through tempering or heat treatment.
6. Application of oxide films on dry corrosion with stable (P-V) ratio.

7

?

Q.4 (b) (i) Describe four features of CNC machines that differentiate them from conventional machine tools.

(ii) The composition (% by weight) of the Nimonic 80A alloy is given here:

| Ni  | Cr    | Ti   | Al | Fe |
|-----|-------|------|----|----|
| 76% | 19.5% | 2.5% | 1% | 1% |

Consider the following data :

| Metal | Gram atomic weight | Valency | Density gm/cm <sup>3</sup> |
|-------|--------------------|---------|----------------------------|
| Ni    | 58.71              | 2       | 8.90                       |
| Cr    | 51.99              | 2       | 7.19                       |
| Fe    | 55.85              | 2       | 7.86                       |
| Al    | 26.97              | 3       | 2.67                       |
| Ti    | 47.9               | 3       | 4.51                       |

An electrochemical machining is used for machining of alloy. Determine the material removal rate (in cm<sup>3</sup>/min), when a current of 950A is applied.

[8 + 12 = 20 marks]

(i) CNC machine:- is an automated machine which can perform special and flexible type of machining under flexible manufacturing system and special manufacturing system

CNC machines

1. Autonomous in working
2. precision through feedback mechanism
3. Flexible manufacturing system
4. complex contour and profiles

Conventional machine tools

1. Manual or semi-autonomous
2. Lack feedback mechanism
3. specialised manufacturing system.
4. simpler contour and profiles.

$$(ii). \quad MRR = \frac{E_{eq} \times I}{P_{eq} \times F}$$

$$\frac{1}{E_{eq}} = \sum_{i=1}^n \frac{x_i V_i}{A_i}$$

$$\frac{1}{P_{eq}} = \sum_{i=1}^n \frac{1}{P_i}$$

$$\frac{1}{E_{eq}} = 0.76 \times \left( \frac{2}{58.71} \right) + 0.19 \times \left( \frac{2}{51.93} \right) + \cancel{0.025} \times \left( \frac{2}{55.85} \right) \\ + 0.01 \times \left( \frac{3}{26.97} \right) + 0.025 \times \left( \frac{3}{47.9} \right)$$

$$\boxed{E_{eq} = 27.597}$$

$$\frac{1}{P_{eq}} = \frac{0.76}{8.9} + \frac{0.195}{7.19} + \frac{0.01}{7.86} + \frac{0.01}{2.67} + \frac{0.025}{4.51}$$

$$\boxed{P_{eq} = 8.12512 \frac{gm}{cm^3}}$$

$$MRR = \frac{27.597 \times 950 \times 60}{8.12512 \times 96500} = \boxed{2.006 \frac{cm^3}{min}}$$

10

- Q.4 (c) An orthogonal turning operation is carried out on a steel cylindrical workpiece using  $10^\circ$  rake tool with a depth of cut of 2.5 mm, and feed rate of 0.10 mm/rev. The cutting speed is 150 m/min. The chip thickness ratio is 0.35. The horizontal cutting force is 650 N and vertical force is 1250 N.

Using Merchant's theory, calculate:

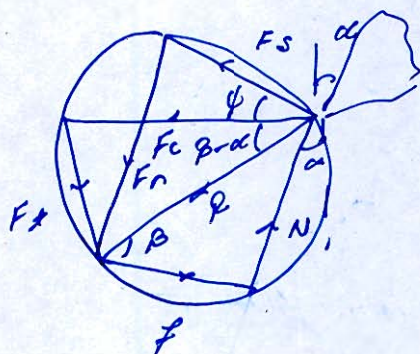
- Workdone by friction
- Workdone by shear
- Total workdone
- Shear stress
- Shear strain

[20 marks]

Given:  $\alpha = 10^\circ$      $d = 2.5 \text{ mm}$      $f = \frac{0.1 \text{ mm}}{\text{rev}}$

$V = 150 \text{ m/min}$      $\gamma = 0.35$

$F_c = 1250 \text{ N}$      $F_t = 650 \text{ N}$



$$\tan(\beta - \alpha) = \frac{F_t}{F_c}$$

$$\tan(\beta - 10) = \frac{650}{1250}$$

$$\beta = 37.4744^\circ$$

By  $\tan \phi = \frac{\gamma \cos \alpha}{1 - \gamma \sin \alpha} = \frac{0.35 \cos 10^\circ}{1 - 0.35 \sin 10^\circ}$

$$\phi = 20.1524^\circ$$

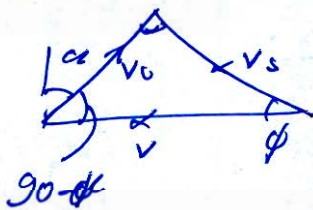
$$R = \sqrt{F_c^2 + F_t^2} = 1408.90 \text{ N}$$

$$F_s = R \times \cos(\phi + \beta - \alpha) = 1408.9 \times \cos(47.6268) = 949.537 \text{ N}$$

$$f = R \times \cos \beta = 1408.9 \times \cos(37.4744) = 1118.1386 \text{ N}$$

3

velocity diagram:-



$$\frac{V}{\sin(79.846^\circ)} = \frac{V_s}{\sin(90-10)} = \frac{V_c}{\sin(20.154)}$$

$$\frac{150}{\sin 79.846^\circ} = \frac{V_s}{\sin 80^\circ} = \frac{V_c}{\sin(20.154)}$$

$$V_s = 150.0716 \text{ m/min}$$

$$V_c = 52.504 \text{ m/min.}$$

Work done by shear force

$$= W_{\text{shear}} = F_s \times V_s$$

$$= 949.537 \times \frac{150.0716}{60}$$

$$= 2374.9756 \text{ W}$$

Work done by friction force

$$W_{\text{friction}} = f \times V_c$$

$$= 1118.1386 \times \frac{52.504}{60}$$

$$= 978.4458 \text{ W}$$

Total work done =  $F_c \times V$

$$= \frac{1250 \times 150}{60} = 3125 \text{ W}$$

$$(i) \text{ shear stress} = \frac{949.537}{bt} \times \sin \phi = \frac{949.537 \times \sin 20.154}{2.5 \times 0.1}$$

$$= 1308.6314 \text{ MPa}$$

$$(v) \text{ shear strain} = \frac{V_s}{t_s} = \frac{150.0716}{60 \times 2.663}$$

$$= 0.93923 \text{ s}^{-1}$$

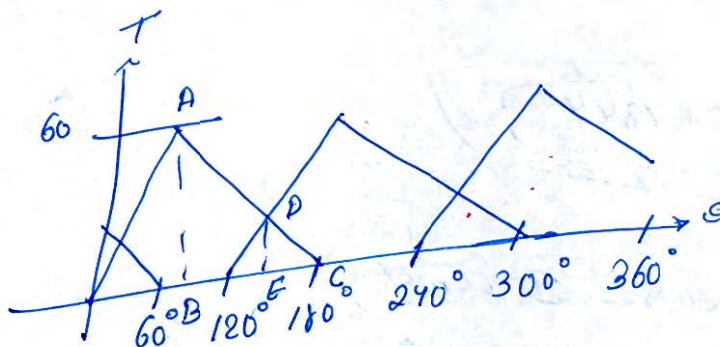


### Section B : Theory of Machines-1 + Fluid Mechanics & Turbo Machinery-2

Q.5 (a) A three cylinder engine has its crank at  $120^\circ$ . The turning moment diagram for each cycle is a triangle for power stroke with a maximum torque 60 Nm at  $60^\circ$  after the dead centre of corresponding crank. There is no torque on the return stroke. The engine runs at 450 rpm. Determine the

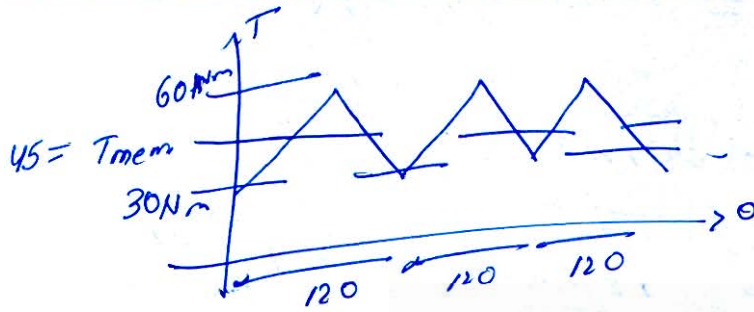
- Power developed
- Coefficient of fluctuation of speed if the mass of the flywheel is 12 kg and radius of gyration is 78 mm.
- Coefficient of fluctuation of energy
- Maximum angular acceleration of flywheel.

[12 marks]



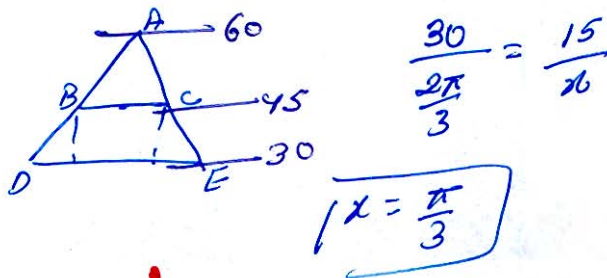
$$\frac{60}{BC} \cdot \frac{AB}{CE} = \frac{DE}{CE} \Rightarrow \frac{60}{120} = \frac{x}{60}$$

$$x = 30$$



$$\text{work done} = 3 \times \frac{1}{2} \times 15 \times \left(\frac{2\pi}{3}\right) + 30 \times 2\pi = \boxed{90\pi \text{ Nm}}$$

$$T_{\text{mean}} = \frac{\text{work done}}{2\pi} = 45 \text{ Nm}$$



$$\therefore \Delta E = \text{area of } \triangle ABC$$

$$\Delta E = \frac{1}{2} \times 15 \times \left(\frac{\pi}{3}\right) = \boxed{7.8539 \text{ Nm}}$$

$$\Delta E = I \omega^2 \times C_s$$

$$7.8539 = 12 \times (0.078)^2 \times \left(\frac{2\pi \times 450}{60}\right)^2 \times C_s$$

$$\boxed{C_s = 0.04844}$$

$$(T - T_{\text{mean}})_{\text{max}} = I \alpha_{\text{max}}$$

$$15 = 12 \times (0.078)^2 \times \alpha_{\text{max}}$$

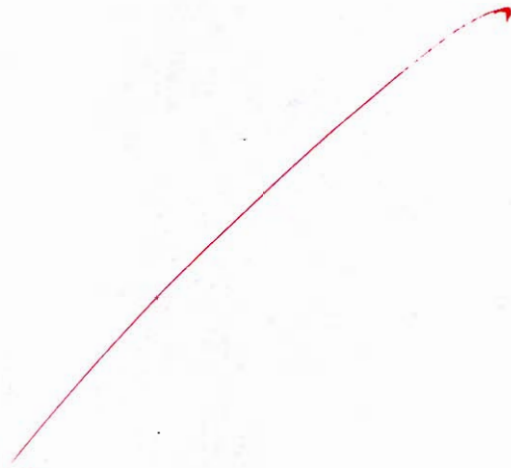
$$\boxed{\alpha_{\text{max}} = 205.456 \text{ rad/s}^2}$$

6

Q.5 (b) Define the following terms as used in an aircraft propulsion system.

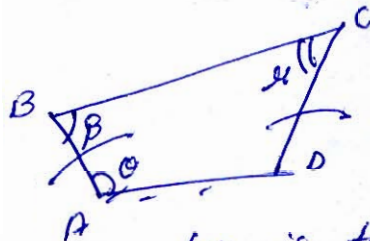
1. Propulsive efficiency
2. Propeller efficiency
3. Overall efficiency of a propulsive system
4. Specific thrust

[12 marks]

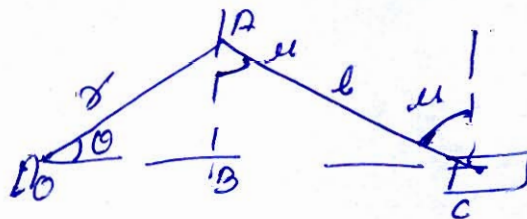


- Q.5 (c) (i) What is the transmission angle? Prove that in a four bar mechanism, the transmission angle attains its maximum or minimum value when the crank is in its extreme positions, i.e. when the crank angle is  $0^\circ$  or  $180^\circ$ .
- (ii) Define the terms effort and power of a governor.

[6 + 6 = 12 marks]



Transmission angle :- is the angle between coupler link and ~~output~~ output link.



$$AB = r \sin \theta = l \cos \mu$$

2

$$x \cos \theta \, d\theta = l(-\sin u) \, du$$

$$\frac{du}{d\theta} = \frac{x}{l} \left( -\frac{\cos \theta}{\sin u} \right) = 0$$

$$\therefore \cos \theta = 0$$

$$\theta = 0^\circ \text{ \& \ } 180^\circ$$

(ii) Effort of governor is the required force to lift the sleeve from two extreme radii of flying balls.

Power of governor is the power required to perform the effort from moving sleeve from both to highest point.

3

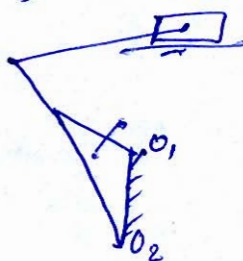
Q.5 (d) What do you mean by the inversions of a kinematic chain? List down all the inversions of a single slider-crank chain. Explain briefly any two. [12 marks]

Inversion of a kinematic chain is a process in which different links of a kinematic chain are constrained to achieve different set of output.

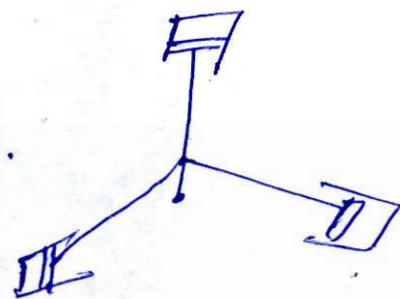
Inversions of single slider crank chain:-

1. Connecting rod is fixed:-

a).

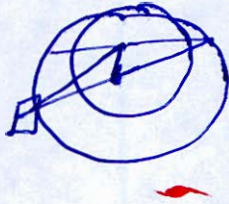


b).

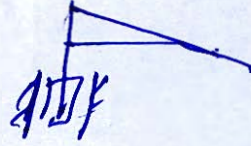


rotary cylinder engine

2. Crank fixed :-



3. piston fixed



4. cylinder fixed

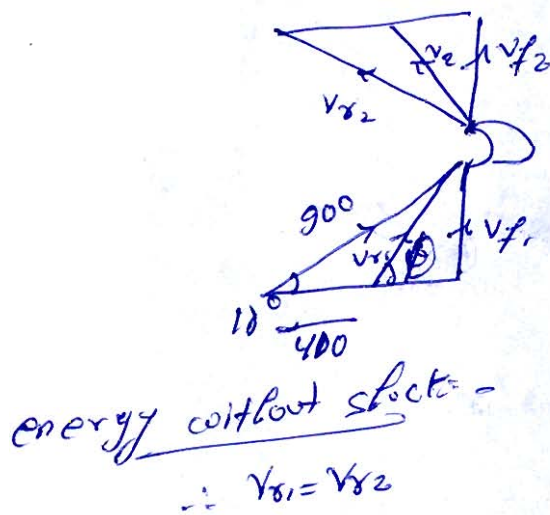


oscillating cylinder



- Q.5 (e) The velocity of steam entering a simple impulse turbine is  $900 \text{ m/s}$  and nozzle angle is  $18^\circ$ . The mean peripheral speed of blades is  $410 \text{ m/s}$  and blades are symmetrical. If the steam is to enter the blades without shock, what will be the blade angles? Neglecting the friction effects on the blades, calculate the tangential force on the blades and diagram power for a mass flow of  $0.75 \text{ kg/s}$ . Estimate also the axial thrust and diagram efficiency.

[12 marks]



$$\begin{aligned}
 V_1 &= 900 \text{ m/s} \\
 \alpha &= 18^\circ \\
 U &= 410 \text{ m/s} \\
 \text{symmetrical blade} \\
 \therefore \theta &= \phi
 \end{aligned}$$

$$\theta = \tan^{-1} \left[ \frac{V_1 \sin \alpha}{V_1 \cos \alpha - U} \right] = \tan^{-1} \left[ \frac{900 \times \sin 18^\circ}{900 \cos 18^\circ - 410} \right]$$

$$\theta = \phi = 31.945^\circ$$

$$v_{r1} \times \sin \theta = v_1 \sin \alpha$$

$$v_{r1} \times \sin 31.945^\circ = 900 \times \sin 18^\circ$$

$$| v_{r1} = v_{r2} = 525.566 \text{ m s}^{-1}$$

$$v_{w1} = v_1 \cos \alpha = 900 \times \cos 18^\circ$$

$$= 855.95 \text{ m s}^{-1}$$

$$v_{w2} = v_{r2} \cos \phi - u = 35.972 \text{ m s}^{-1}$$

$$F_{\text{tangential}} = m \times (v_{w1} + v_{w2})$$

$$= 0.75 \times (855.95 + 35.972)$$

$$= 1668.94 \text{ N}$$

$$\text{Power diagram} = F_{\text{tangential}} \times u$$

$$= 668.94 \times 410$$

$$= 274.2661 \text{ kW}$$

$$F_c = m \times [v_1 \sin \alpha - v_{r1} \sin \phi]$$

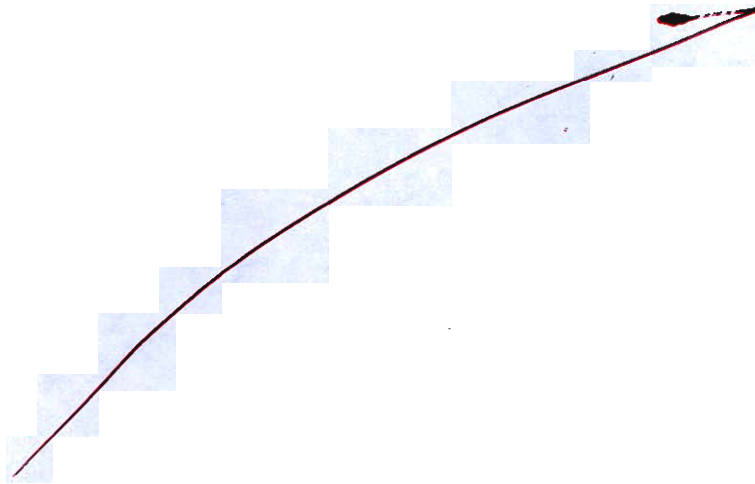
$$= 10.02679 \text{ N}$$

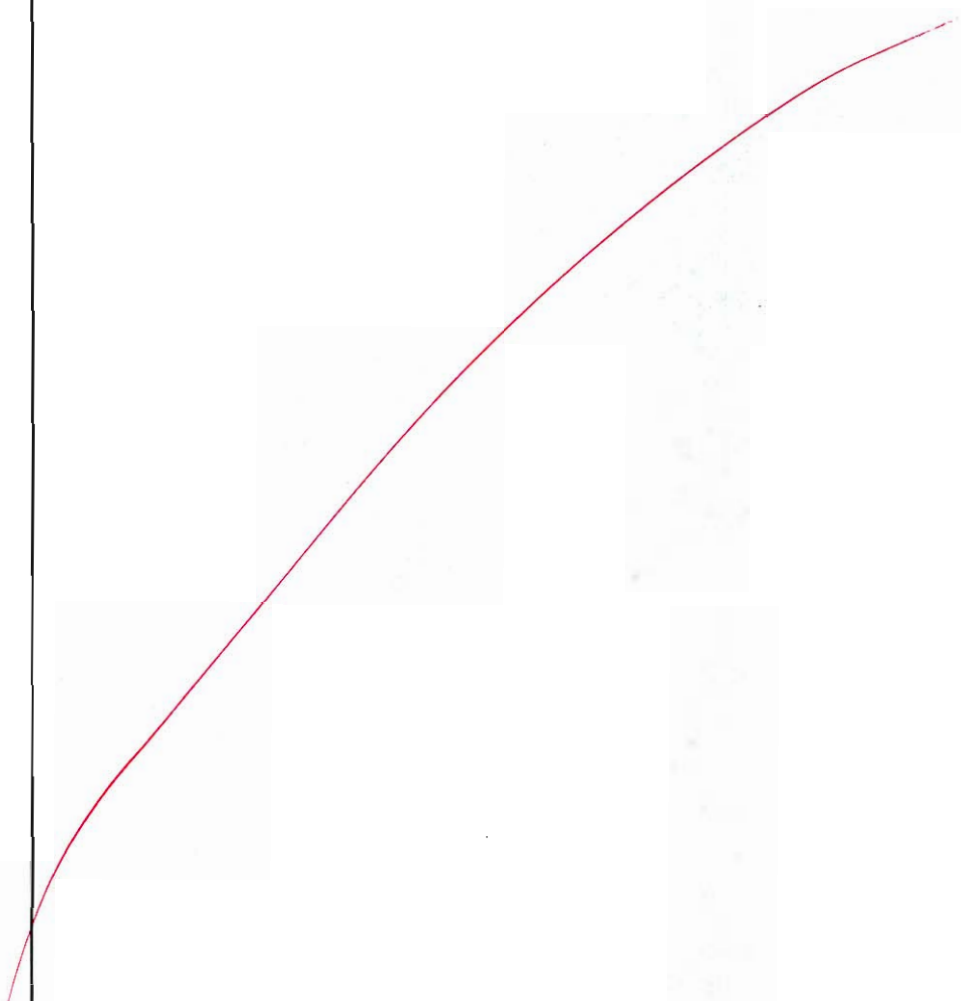
$$\eta = \frac{2 \times (855.95 + 35.972) \times 410}{(900)^2}$$

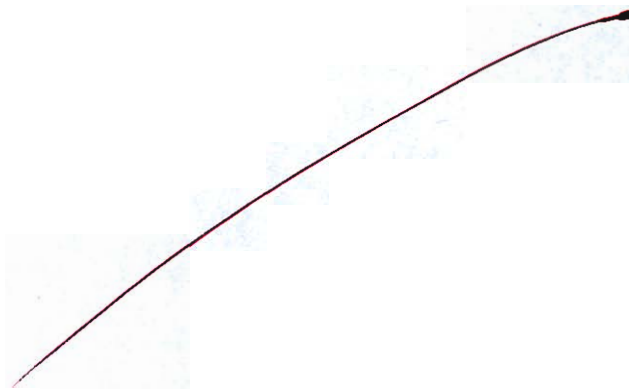
$$| \eta = 90.293\% |$$

- Q.6 (a) For a single degree of freedom system subjected to harmonic excitation with viscous damping, derive the expression for the steady state amplitude of vibration. Also draw the vector (phasor) diagram showing the forces acting on the system.

[20 marks]







- Q.6 (b) A 20-stage 50% reaction turbine develops a diagram power of 15 MW. The inlet conditions of steam is at 16 bar, 360°C, while condenser pressure is 0.14 bar. The stage efficiency is 80% for each stage and reheat factor is 1.03. At one stage the steam is at 1 bar, dry saturated. The exit angle of the blades is 19° and the blade velocity ratio 0.72. The blade height may be taken as  $\frac{1}{12}$  of the mean blade diameter.

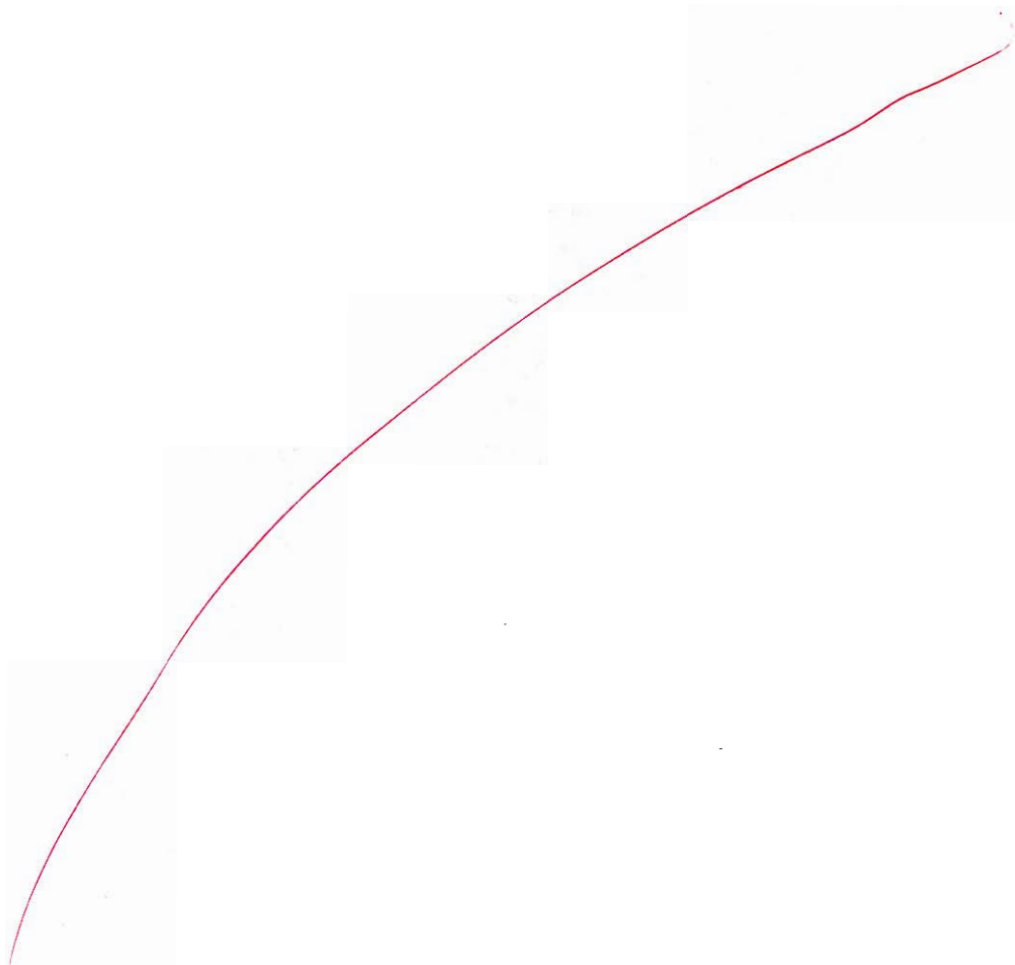
Calculate:

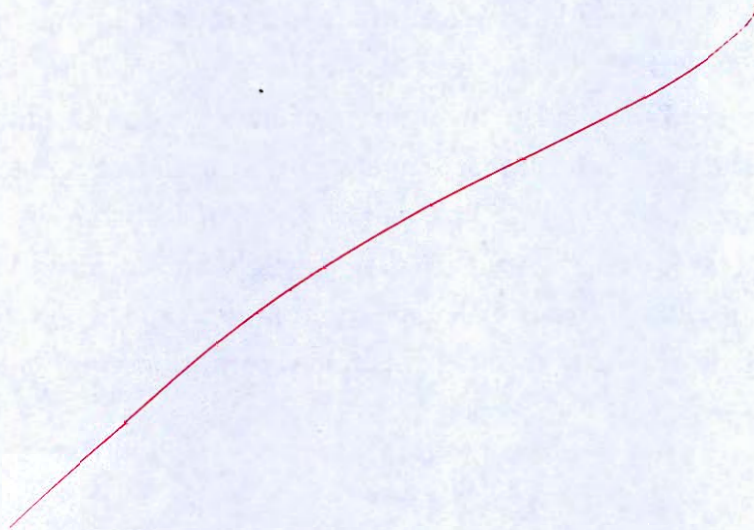
- (i) The flow rate of steam required, assuming that all stage develop equal work.
- (ii) The mean blade diameter.
- (iii) The speed of the rotor.

[Take,  $v_g = 1.6939 \text{ m}^3/\text{kg}$  at 1 bar and At  $p = 1.6 \text{ MPa}$ ,  $T = 360^\circ\text{C}$ ,  $h = 3167.8 \text{ kJ/kg}$  and  $s = 7.1061 \text{ kJ/kgK}$ ]

| p<br>MPa | $T_{sat}$<br>°C | Enthalpy (kJ/kg) |        |          | Entropy, kJ/(kgK) |        |          |
|----------|-----------------|------------------|--------|----------|-------------------|--------|----------|
|          |                 | $h_f$            | $h_g$  | $h_{fg}$ | $s_f$             | $s_g$  | $s_{fg}$ |
| 0.014    | 52.547          | 219.99           | 2595.8 | 2375.8   | 0.73644           | 8.0311 | 7.2945   |

[20 marks]

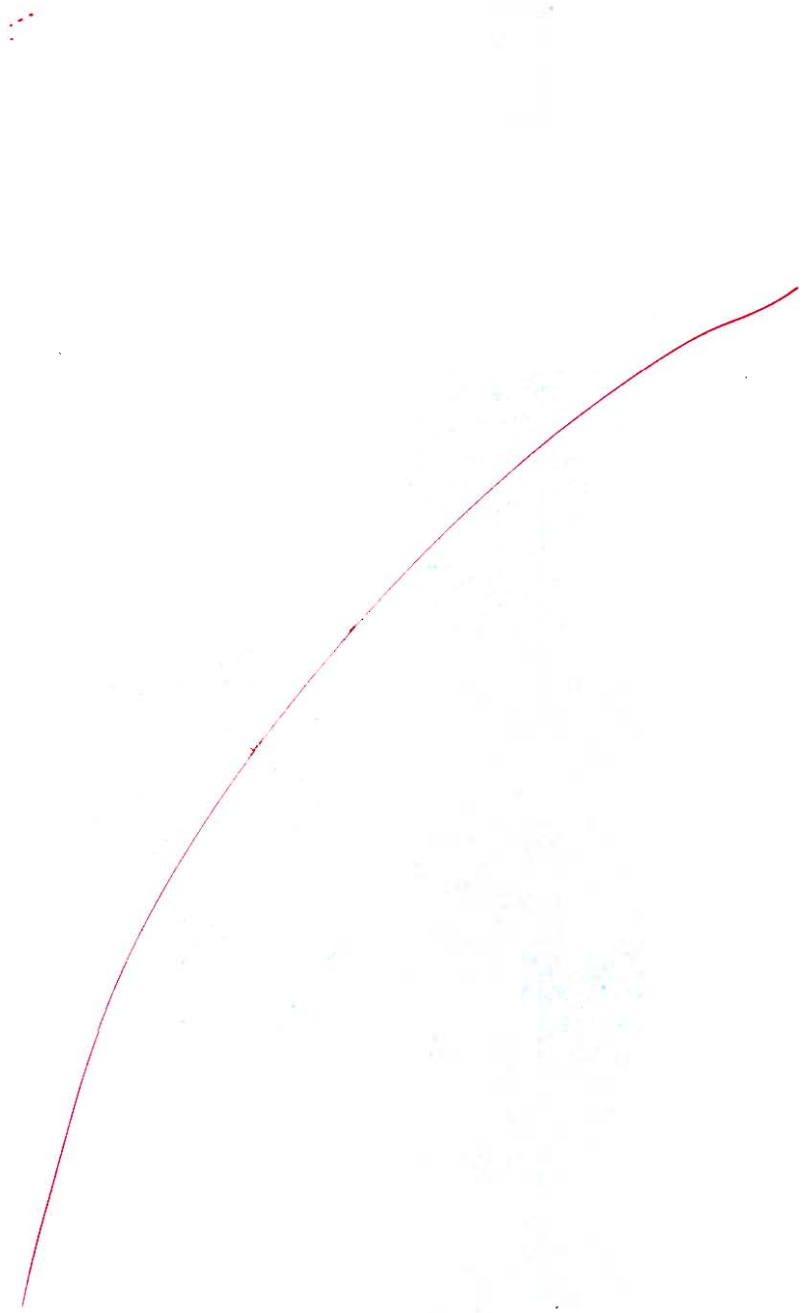


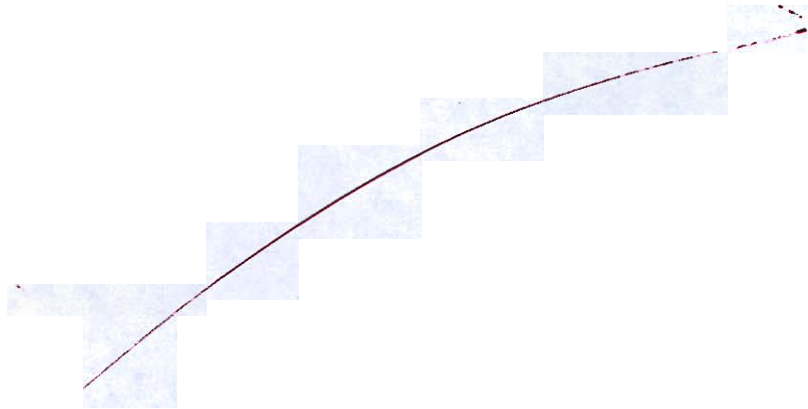


- Q.6 (c) An axial flow compressor has an overall pressure ratio of 4.0 and mass flow of 3 kg/s. If the polytropic efficiency is 84 percent and the stagnation temperature rise per stage must not exceed 23 K, calculate the number of stage required and the pressure ratio of first and last stages. Assume equal temperature rise is all stages. If the absolute velocity approaching the last rotor is 160 m/s at an angle of  $18^\circ$  from the axial direction, the work done factor is 0.85, the velocity diagram is symmetrical, and the mean diameter of the last stage rotor is 16 cm. Calculate the rotational speed and the length of the last stage rotor blade at inlet to the stage. Ambient conditions are 1 bar and 293 K.

[20 marks]







- Q.7 (a) The crank and connecting rod of a vertical petrol engine, running at 2000 rpm are 45 mm and 270 mm long respectively. The diameter of the piston is 80 mm and the mass of the reciprocating parts is 2.5 kg. During the expansion stroke when the crank has turned  $30^\circ$  from the top dead centre, the gas pressure is  $1250 \text{ kN/m}^2$ . Determine the
- Net force on the piston.
  - Net load on the gudgeon pin
  - Speed at which gudgeon pin load is reversed in direction.

[20 marks]

$N = 2000 \text{ rpm}$   
 $r = 45 \text{ mm}$   
 $l = 270 \text{ mm}$   
 $D_p = 80 \text{ mm}$   
 $m_{\text{reci}} = 2.5 \text{ kg}$

$\theta = 30^\circ$   
 $P_{\text{gas}} = 1250 \text{ kN/m}^2$

$n = \frac{l}{r} = \frac{270}{45} = 6$

$\sin \beta = \frac{\sin \theta}{n} = \frac{\sin 30^\circ}{6}$

$\beta = 4.781^\circ$

$\omega = \frac{2\pi \times 2000}{60}$   
 $= 209.44 \text{ rad/s}^{-1}$

$$F_{\text{piston}} = P_{\text{gas}} \times A_p$$

$$= 1250 \times 10^3 \times \frac{\pi}{4} \times (0.08)^2$$

$$\boxed{F_{\text{piston}} = 6283.185 \text{ N}} \text{ downward}$$

13

$$F_{\text{rod on pin}} = F_{\text{piston}} - ma + mg$$

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

$$= (209.4395)^2 \times 0.045 \times \left[ \cos 20^\circ + \frac{\cos 60^\circ}{6} \right]$$

$$a = 1873.959 \text{ m}^2 \cdot \text{s}^{-1}$$

$$F_{\text{rod on pin}} = 6283.185 + 2.5 \times (-1873.95 + 9.81)$$

$$\boxed{F_{\text{rod on pin}} = 1622.8127 \text{ N}} \text{ downward}$$

(iii) speed at which reverse the direction of force:-

$$F_{\text{piston}} \leq m(a - g)$$

$$6283.185 = 2.5 \times \left[ \omega^2 \times 0.045 \times \left[ \cos 30^\circ + \frac{\cos 60^\circ}{6} \right] \right]$$

$$- 9.81$$

$$\omega = 243.021 \text{ rad} \cdot \text{s}^{-1}$$

$$\frac{2\pi \times N}{60} = 243.0213$$

$$N = 2320.68 \text{ rpm}$$

Q.7 (b) Lubricating oil of specific gravity 0.82 and dynamic viscosity  $12.066 \times 10^{-2} \text{ N.s/m}^2$  is pumped at a rate of  $0.02 \text{ m}^3/\text{s}$  through a 0.15 m diameter 300 m long pipe.

Calculate the pressure drop, average shear stress at the wall of the pipe and the power required to maintain the flow:

- (i) if the pipe is horizontal;
- (ii) if the pipe is inclined at 15 degrees with the horizontal and the flow is
  1. in the upward direction,
  2. in the downward direction.

Also determine the slope of the pipe and the direction of flow so that the pressure gradient along the pipe is zero.

[20 marks]

(i)



$$Re = \frac{\rho v D}{\mu} = \frac{\rho \times \left(\frac{4Q}{\pi D}\right)}{\mu}$$

$$Q = \frac{\pi}{4} D^2 v$$

$$\frac{4Q}{\pi D} = v$$

$$= \frac{820 \times 4 \times 0.02}{\pi \times 0.15 \times 12.066 \times 10^{-2}} = 1153.717$$

$\therefore$  Laminar flow.

$$\Delta P = \frac{32 \mu V l}{\rho g d^2}$$

$$0.02 = \frac{\pi}{4} \times 0.15^2 \times v$$

$$v = 1.131768 \text{ ms}^{-1}$$

$$\Delta P = 32 \times 12.066 \times 10^{-2} \times 1.131768 \times 300$$

$$(0.15)^2$$

$$\Delta P = 58.265 \text{ KPa}$$

$$\tau_{\text{wall}} = \frac{8 \mu V}{d} = \frac{8 \times 12.066 \times 10^{-2} \times 1.1317}{0.15} = 7.282 \text{ N/m}^2$$

$$\text{Power} = \rho Q g h_f$$

$$h_f = 7.235 \text{ m}$$

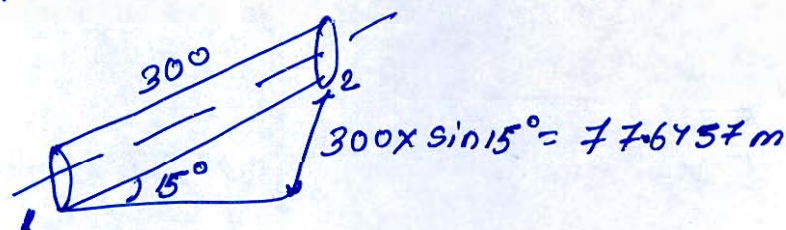
$$f = \frac{16 \gamma}{\rho c} = \frac{16 \gamma}{1153.717} = 0.0554$$

$$\text{Power} = 10^3 \times 0.02 \times 9.81 \times 0.0554 \times 300 \times (0.02)^2$$

$$12.1 \times (0.15)^5$$

$$\text{Power} = 1421.409 \text{ W}$$

(ii). a).



$$\frac{P_1}{\omega} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\omega} + \frac{v_2^2}{2g} + z_2 + h_f$$

$$\frac{P_1 - P_2}{\rho g} = 77.6457 + 7.235$$

$$\Delta P = 88.8681 \text{ KPa}$$

$$\Delta P = 832.679 \text{ KPa}$$

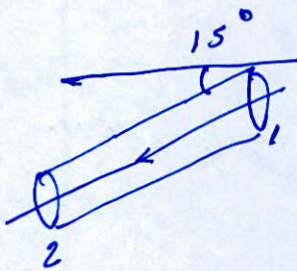
$$\text{Power} = \rho g \times (h \sin 15^\circ + h \ell)$$

$$= 9810 \times 0.02 \times (84.88)$$

$$\text{Power} = 16.653 \text{ KW}$$

$$T_{\text{wall}} = 7.282 \frac{\text{N}}{\text{m}^2}$$

b).



$$\frac{P_1}{\omega} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\omega} + \frac{V_2^2}{2g} + z_2 + h_l$$

$$\left( \frac{P_1 - P_2}{\omega} \right) = h_l - z_1 = 7.235 - 77.675$$

$$\left( \frac{P_1 - P_2}{\omega} \right) = -690.728 \text{ KPa}$$

$$\therefore \Delta P = 690.728 \text{ KPa}$$

$$T_{\text{wall}} = 7.282 \frac{\text{N}}{\text{m}^2}$$

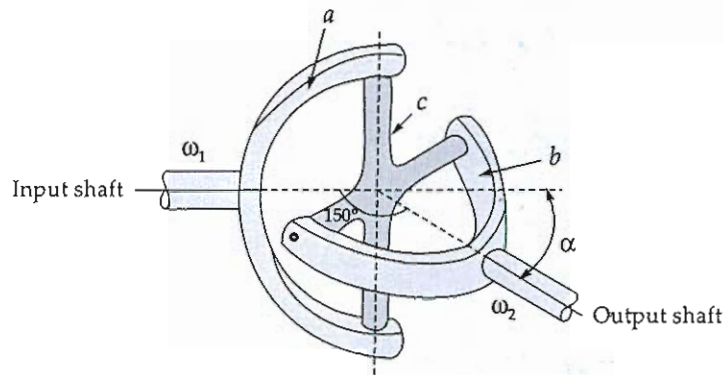
$$\text{Power} = 13.814 \text{ KW}$$

for  $\Delta P = 0$  :-

$$300 \times \sin \theta = 7.235 = h_l$$

$$\theta = 1.3819^\circ \text{ from horizontal}$$

- Q.7 (c) A Hooke's joint is to connect two shafts whose axes intersect at  $150^\circ$ . The driving shaft rotates uniformly at 120 rpm. Deduce a general expression for the angular velocity of the driven shaft. The driven shaft operates against a steady torque of 135 Nm and carries a flywheel whose weight is 45 kg and radius of gyration 0.15 m. What is the maximum value of the torque which must be exerted by the driving shaft?



$$\alpha = 30^\circ \quad \omega_1 = 120 \text{ rpm} \quad T_{\text{mean}} = 135 \text{ Nm}$$

$$m = 45 \text{ kg} \quad k = 0.15 \text{ m}$$

[20 marks]

(i) general equation of Hooke's Joint:-

$$\tan \theta = \tan \phi \times \cos \alpha$$

Here:-  $\theta$ :- angle of rotation of driven  
 $\phi$ :- angle of rotation of driver

Differentiating both sides:-

$$\sec^2 \theta \tan \theta \frac{d\theta}{dt} = \sec^2 \phi \tan \phi \frac{d\phi}{dt} \times \cos \alpha$$

$$\sec^2 \theta \omega_2 = \sec^2 \phi \omega_1 \times \cos \alpha$$

$$(1 - \tan^2 \theta) \omega_2 = (1 - \tan^2 \phi) \omega_1 \times \cos \alpha$$

$$\omega_2 = \frac{\omega_1 \times (1 - \tan^2 \phi) \cos \alpha}{(1 - \tan^2 \theta)}$$

$$\omega_2 = \frac{\omega_1 \cos \alpha}{(1 - \cos^2 \theta \times \sin^2 \alpha)}$$

$$\omega_1 = \frac{2\pi \times 120}{60} = 12.5663 \text{ rad s}^{-1}$$

$$\omega_2 = 12.5663 \times \cos 30^\circ$$

$$\alpha_2 = \frac{-\omega_1 \cos \alpha \times \sin^2 \alpha \times (-2 \cos \theta \sin \theta / (-1))}{(1 - \cos^2 \theta \times \sin^2 \alpha)^2}$$

$$\alpha_2 = \frac{-\omega_1 \cos \alpha \times \sin^2 \alpha \times \sin 2\theta}{(1 - \cos^2 \theta \times \sin^2 \alpha)^2}$$

For maximum torque:-

$\cos 2\theta$  need to be maximum

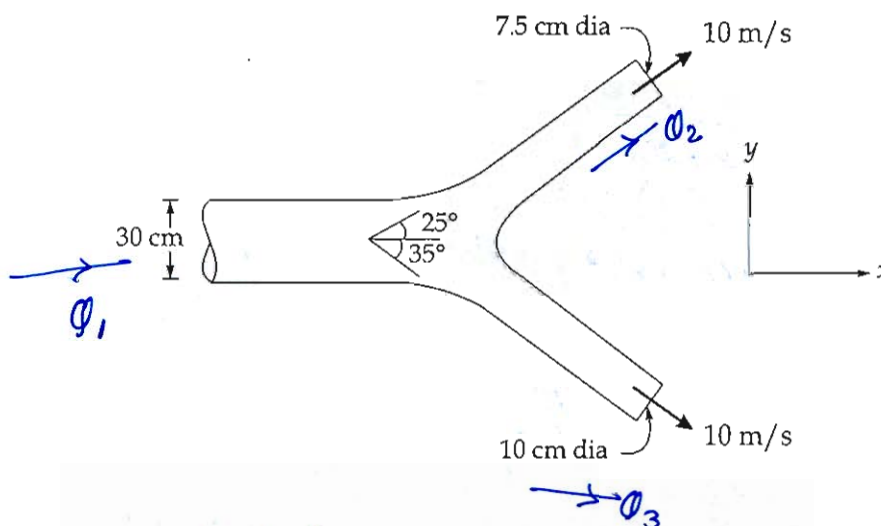
~~$\cos \theta$~~

$$\cos(2\theta) = \frac{2 \sin^2 \alpha}{2 + \sin^2 \alpha} =$$

$$2\theta = 56.9442^\circ, 236.9442^\circ, 416.944^\circ$$

$$\theta = 28.472, 118.4721^\circ$$

- Q.8 (a) A 30 cm diameter pipe is bifurcated into two nozzles at a Y-junction as shown in figure. The nozzles discharge to atmosphere and have a velocity of 10 m/s each. The junction is in the horizontal plane and the friction can be neglected. Determine the magnitude and direction of the resultant force on Y-junction.



[20 marks]

$$Q = AV$$

$$Q_2 = \frac{\pi}{4} \times (0.075)^2 \times 10 = 0.04417 \text{ m}^3 \text{ s}^{-1}$$

$$Q_3 = \frac{\pi}{4} \times (0.1)^2 \times 10 = 0.0785 \text{ m}^3 \text{ s}^{-1}$$

$$Q_1 = Q_2 + Q_3 = 0.1227 \text{ m}^3 \text{ s}^{-1}$$

$$Q_1 = \frac{\pi}{4} \times (0.3)^2 \times V_1$$

$$V_1 = 1.73598 \text{ m s}^{-1}$$

$$P_2 = P_3 = P_{atm} = 101.3 \text{ kPa}$$

1-2

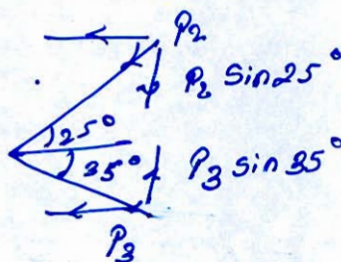
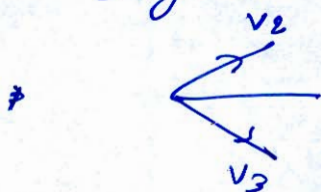
$$\frac{P_1}{\rho} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho} + \frac{V_2^2}{2g} + z_2$$

$$z_1 = z_2 = 0$$

$$\frac{P_1}{\rho \times g} + \frac{(1.73598)^2}{2 \times 9.81} = \frac{101.3}{\rho \times g} + \frac{10^2}{2 \times 9.81}$$

7  $P_1 = 149.81 \text{ kPa}$

$$\sum F_y = 0$$

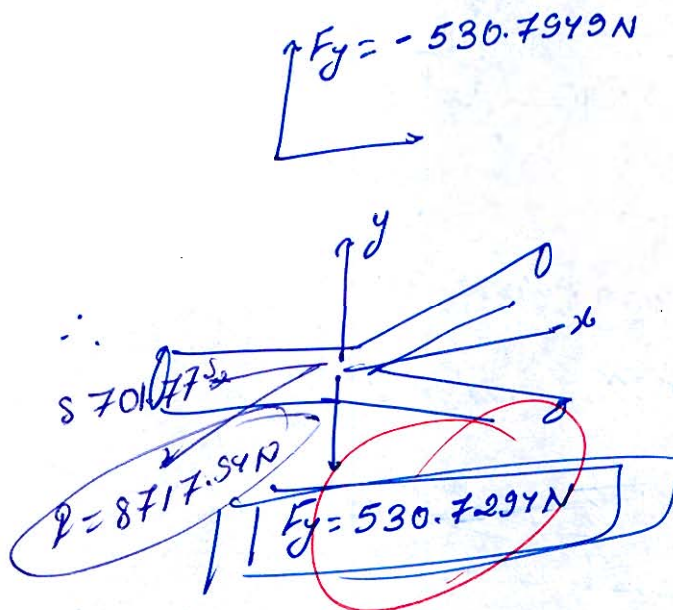


$$(P_3 A_3 \sin 35^\circ - P_2 A_2 \sin 25^\circ) + F_y = \rho [Q_2 \times V_2 \sin 25^\circ - Q_3 \times V_3 \times \sin 35^\circ]$$

$$101.3 \times \frac{\pi}{4} \times (0.1)^2 \times (\sin 35^\circ - \sin 25^\circ) + F_y$$

$$= [0.04417 \sin 25^\circ - 0.0785 \times \sin 35^\circ] \times 10$$

$$F_y =$$

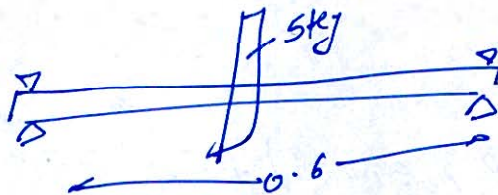


$$\begin{aligned} \sum F_x = 0 & \rightarrow P_1 A_1 - (P_2 A_2 \cos 25^\circ + P_3 A_3 \cos 35^\circ) + F_x \\ & = P \times [\omega_2 \times r_2 \cos 25^\circ + \omega_3 \times r_3 \cos 35^\circ - \omega_1 \times r_1] \\ 9532.121 + F_x & = \rightarrow F_x = 8701.775 \end{aligned}$$

Q.8 (b) A disc of mass 5 kg is mounted midway between bearing which may be assumed to be simple supports. The bearing span is 60 cm. The steel shaft is 20 mm diameter and is horizontal. The centre of gravity of the disc is displaced 2 mm from the geometric centre. The equivalent viscous damping at the centre of the disc-shaft may be assumed as 60 N-sec/m. If the shaft rotates at 360 rpm. Take  $E = 2 \times 10^{11} \text{ N/m}^2$ .

- (i) Determine the maximum stress in shaft.  
(ii) The power required to drive the shaft at the speed 360 rpm.

[20 marks]



$$\begin{aligned} d &= 0.02 \text{ m} & \Delta &= 0.002 \text{ m} & c &= 60 \frac{\text{Ns}}{\text{m}} \\ N &= 360 \text{ rpm} & E &= 2 \times 10^{11} \text{ N/m}^2 \end{aligned}$$

$$\Delta_s = \frac{mg l^3}{48EI} \quad \left. \vphantom{\Delta_s} \right\} \text{as simple support}$$

$$\omega = \frac{2\pi \times 360}{60} = 37.6991 \text{ rad/s}$$

$$\Delta s = \frac{5 \times 9.81 \times 0.6^3}{48 \times 2 \times 10^{11} \times \frac{\pi}{64} \times (0.02)^4}$$

$$\Delta s = 1.405178 \times 10^{-4} \text{ m}$$

$$\omega_n = \sqrt{\frac{g}{\Delta s}} = \sqrt{\frac{9.81}{1.405178 \times 10^{-4}}}$$

$$\omega_n = 264.221 \text{ rad s}^{-1}$$

$$s = \omega_n^2 \times m = 349065.8504 \text{ N/m}$$

for amplitude:-

$$A = \frac{e}{\left(\frac{\omega}{\omega_n}\right)^2 - 1} = \frac{2}{\left(\frac{264.221}{37.699}\right)^2 - 1}$$

$$2 \zeta \omega_n = \frac{c}{m}$$

$$2 \times \zeta \times 264.221 = \frac{60}{5}$$

$$\zeta = 0.0227$$

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

$$F_0 = m e \omega^2 = 5 \times 0.002 \times (37.699)^2 = 14.21214 \text{ N}$$

$$A = \frac{4.0715 \times 10^{-5}}{\sqrt{\left(1 - \left(\frac{37.699}{264.221}\right)^2\right)^2 + \left(2 \times 0.0227 \times \frac{37.699}{264.221}\right)^2}}$$

$$A = 4.156023 \times 10^{-5} \text{ m}^2$$

$$F_{dy} = \sqrt{(SA)^2 + (CWA)^2} = \sqrt{(349065)^2 + (60 \times 37.699)^2} \times A$$

$$F_{dy} = 2250.372 \text{ N}$$

$$F_{total} = F_{dy} + mg = 2299.422 \text{ N}$$

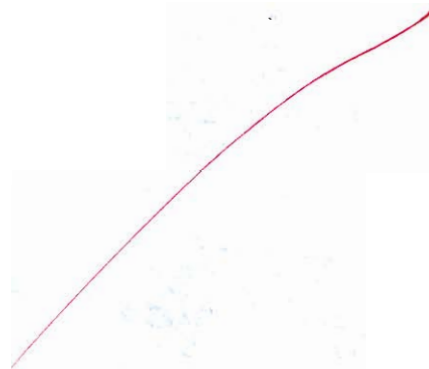
$$\sigma_b = \frac{8 F_{total} \times l}{\pi d^3} = \frac{8 \times 2299.422 \times 0.6}{\pi \times (0.02)^3} = 1439.157 \text{ MPa}$$

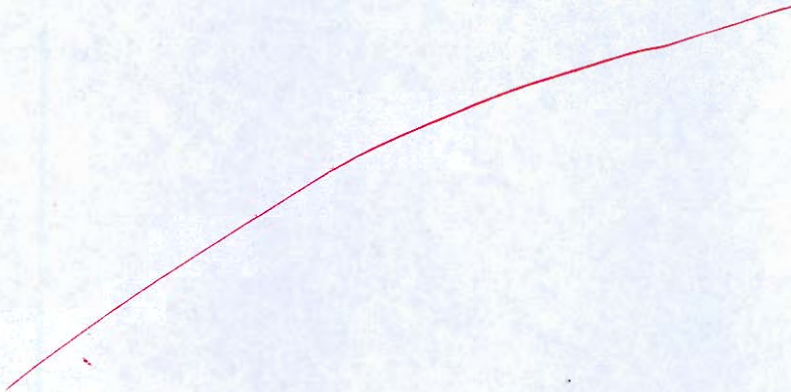
$$\text{Power} = F_{ox} \left( \frac{\pi \times 360}{60} \right)^2 = 14.212 \times (37.699)^2$$

$$= 20.198 \text{ kW}$$

- Q.8 (c) Describe the operating principle of a turboprop engine with the help of a neat sketch. Also, discuss its suitability by stating its advantages and disadvantages.

[20 marks]







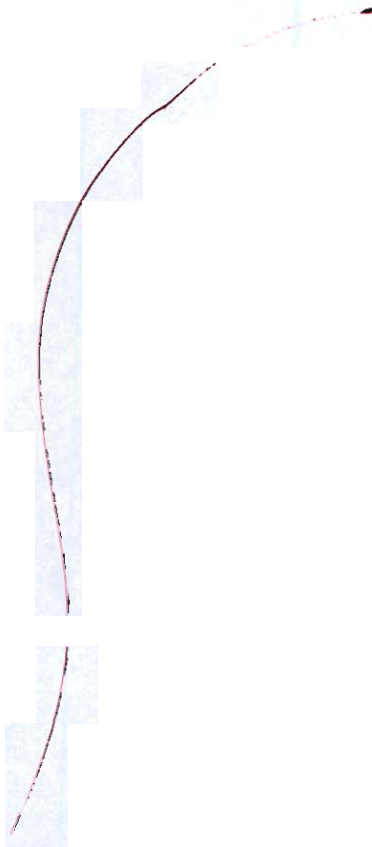
OOOO

Space for Rough Work

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1

2



3

4

5

## Space for Rough Work

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