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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 ☑	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	19
Q.2	—
Q.3	—
Q.4	25
Section-B	
Q.5	26
Q.6	—
Q.7	42
Q.8	29
Total Marks Obtained	141

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

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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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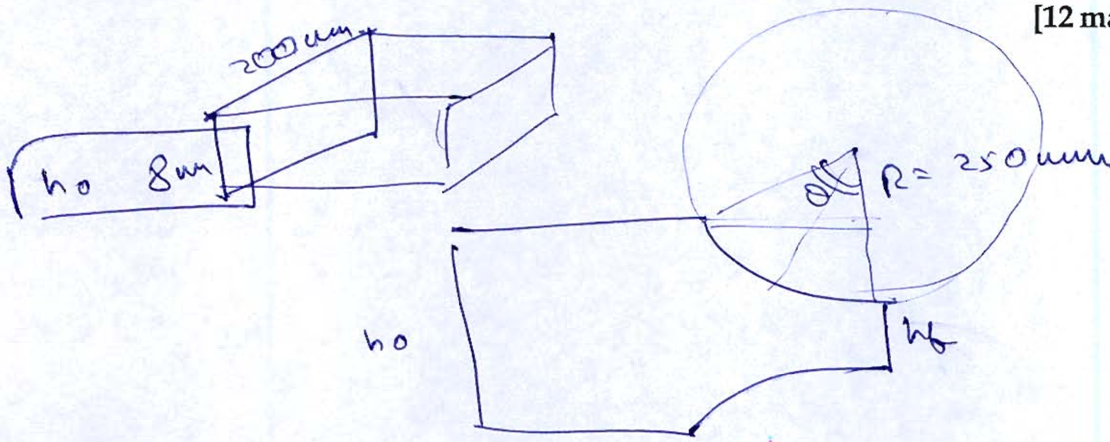
Section A : Production Engineering & Material Science

Q.1 (a) A rectangular strip of cross-section 200 mm × 8 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]



$A_0 = 200 \times 8 = 1600\ mm^2$ $\tau = 380\ MPa.$

$A_f = 1600 \times 0.75$

$= 1200\ mm^2$

3

$1200 = 200 \times h_f.$

$h_f = 8\ mm$ → final strip thickness

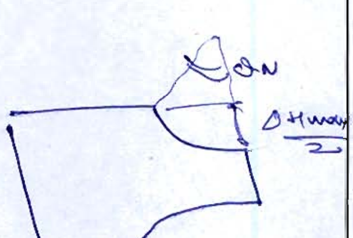
$\tan\theta = \frac{l_p}{R - \frac{\Delta H}{2}} = \frac{\sqrt{R\Delta H}}{R} = \sqrt{\frac{\Delta H}{R}}$

$= \sqrt{\frac{2}{250}}$

$\theta = 5.111°$ → angle subtended at centre

$\Delta H_{max} = \mu^2 R = 0.15^2 \times 250$

$= 5.625\ mm$



$\tan\theta_n = \sqrt{\frac{\Delta H_{max}}{R}}$

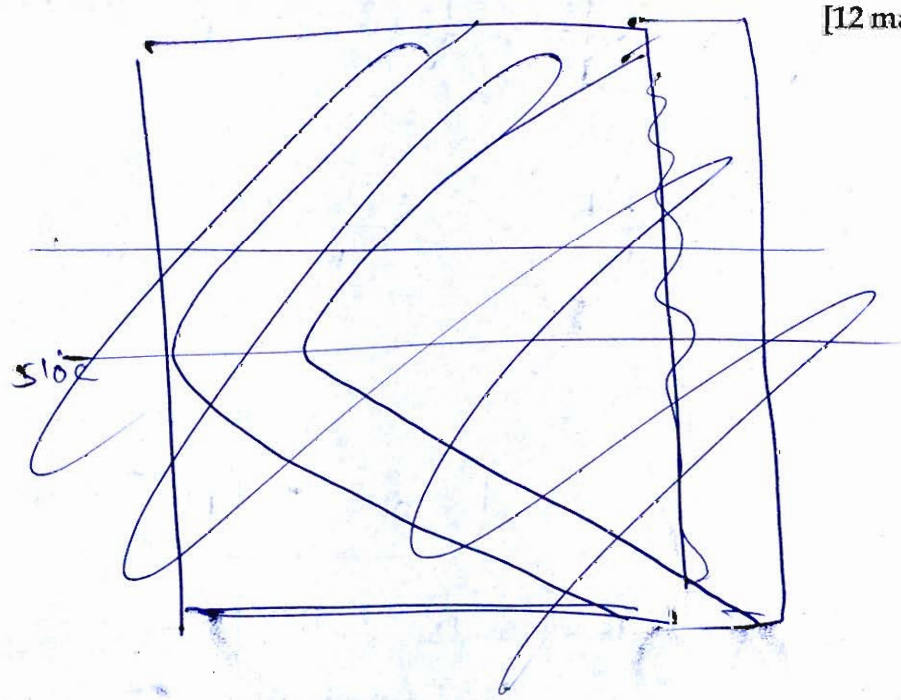
$\theta_N = 8.5307°$ → ~~Neutral~~ Neutral plane angle.

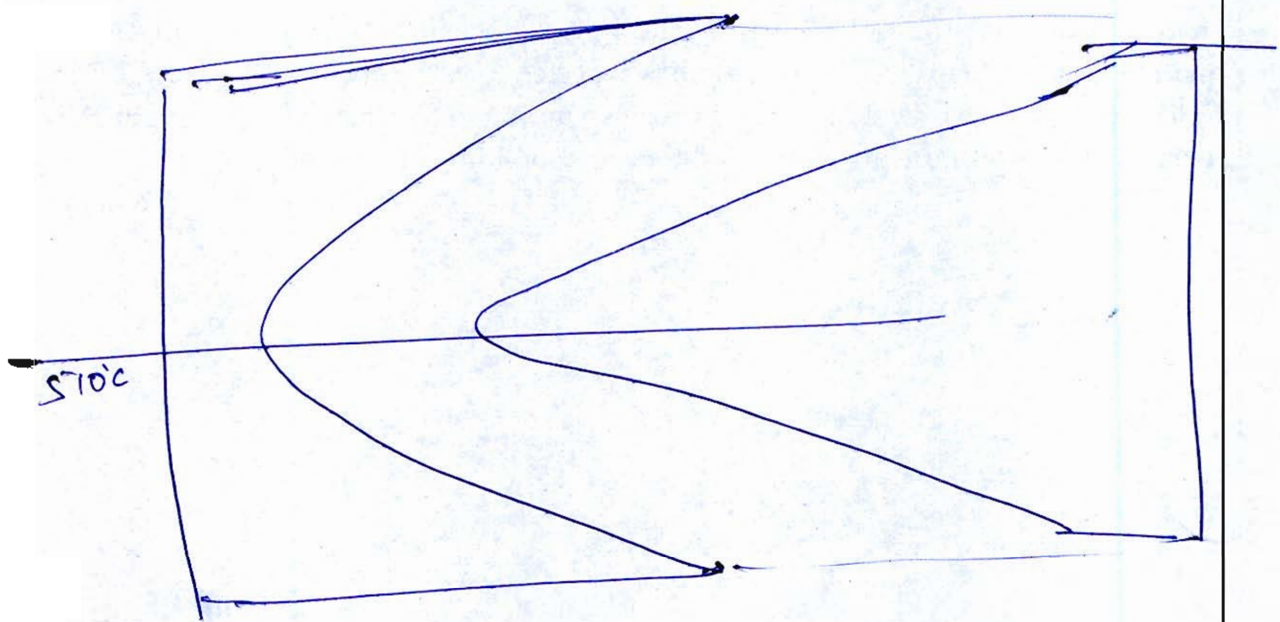
Q.1 (b) Using neat and property labelled diagrams, explain the microstructures of the different phases of steel, highlighting the presence of the following constituents:

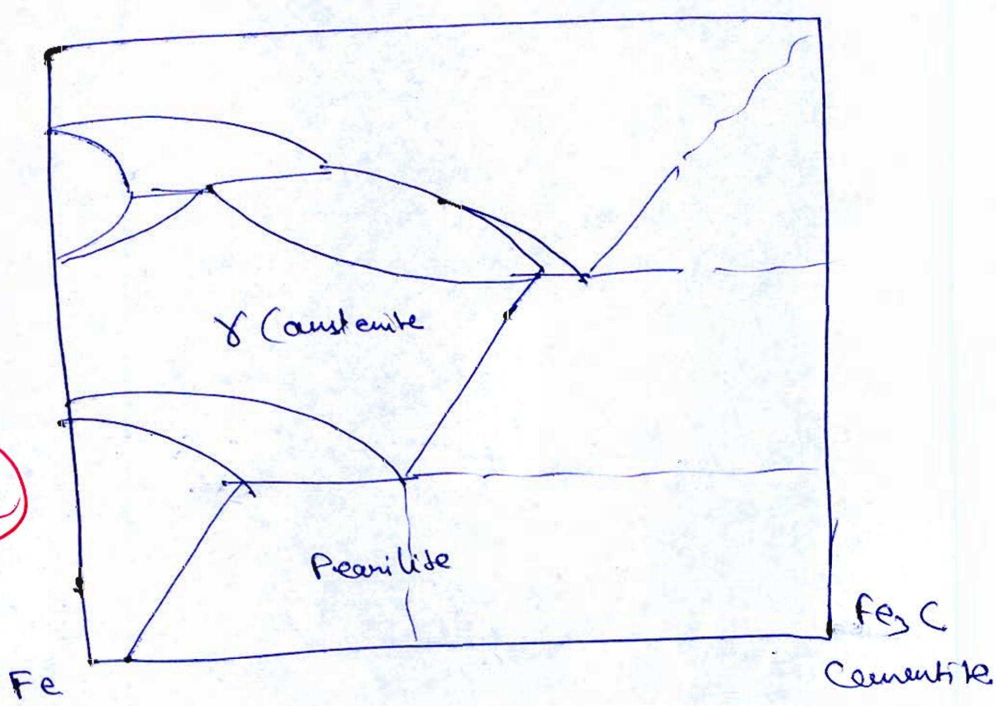
(i) Ferrite (ii) Austenite

(iii) Cementite (iv) Pearlite

[12 marks]







2

Austenite (γ)

Cementite (Fe_3C)

Pearlite →

7

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]

$V_a = 32 + 4l_a$

0 (3)

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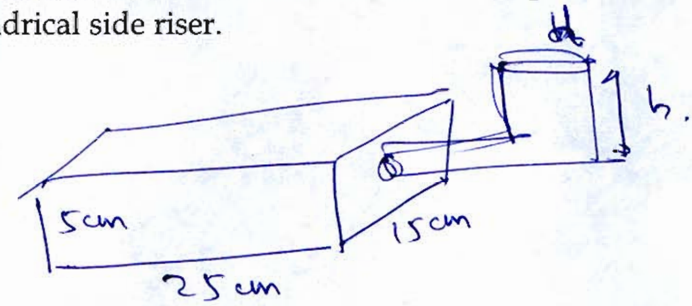
Q.1 (d) Determine the dimensions of an optimum cylindrical riser attached to the side of a aluminium slab casting with dimensions 25 cm × 15 cm × 5 cm. The volume shrinkage of aluminium during solidification is 6.5%. Also, derive the expression for the dimensions of an optimum cylindrical side riser.

[12 marks]



For optimum riser

$d = h$

8

Vol. of riser = 3 × shrinkage volume of casting.

$= 3 \times \frac{6.5}{100} \times (5 \times 25 \times 15)$

$\frac{\pi}{4} d^2 (d) = 365.625 \text{ cm}^3$

$d = 7.75 \text{ cm} = h$

$t_{riser} \geq t_{casting}$

$\left(\frac{V}{A}\right)^2_{riser} \geq \left(\frac{V}{A}\right)^2_{casting}$

$\left(\frac{d}{6}\right) \geq \left(\frac{5 \times 25 \times 15}{5 \times 25 + 5 \times 15 + 25 \times 15}\right) \times \frac{1}{2}$

$d \geq \frac{19.56}{2}$ cm.

$d \geq 9.782 \text{ cm}$

Ans

∴ optimum dimension of riser is $= d = h = 9.782$ cm

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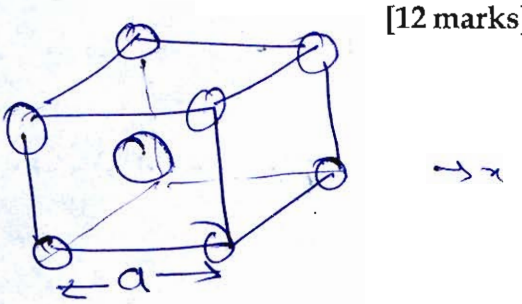
Q.1 (e) Prove that the packing fraction for a B.C.C structure is 0.68. Also, determine the number of atoms per mm^2 on the (010) planes of copper (Cu), given that the atomic radius is 0.1280 nm?

[12 marks]

~~APF~~=



$\sqrt{3}a = 4r$

$a = \frac{4r}{\sqrt{3}}$

r = radius of atom

a = length of cube side.

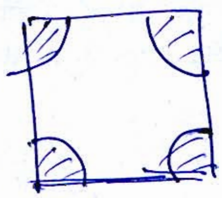
$Z = 2$

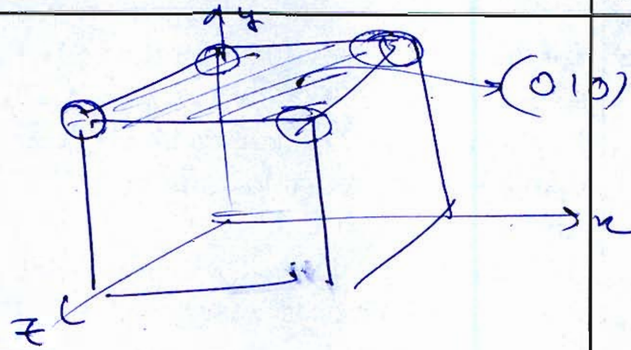
$APF = \frac{(Z) \times \frac{4}{3}\pi r^3}{a^3}$

$= 2 \times \frac{4}{3} \times \pi \times \left(\frac{r}{a}\right)^3$

$= \frac{8}{3} \times \pi \times \left(\frac{\sqrt{3}}{4}\right)^3 = 0.68$

6





$$\frac{\text{No. of atoms}}{\text{area}} = \frac{1}{a^2}$$

$$= \frac{1}{\left[\frac{8}{\sqrt{3}} \times (0.1280 \times 10^{-6})\right]^2}$$

$$= 2.8610229 \times 10^{12} \ \frac{\text{atoms}}{\text{mm}^2}$$

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^3 and 7.24 g/cm^3 respectively. Calculate the relative amount of α and β phase present in terms of

(i) mass fraction and

(ii) 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 μm. The turning tool has a nose radius of 0.5 mm. The tool life equation for this work tool combination is $Vf^{0.18}\,T^{0.24} = 24$, where V is in m/min, f in 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]

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

[20 marks]

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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. Specific 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.

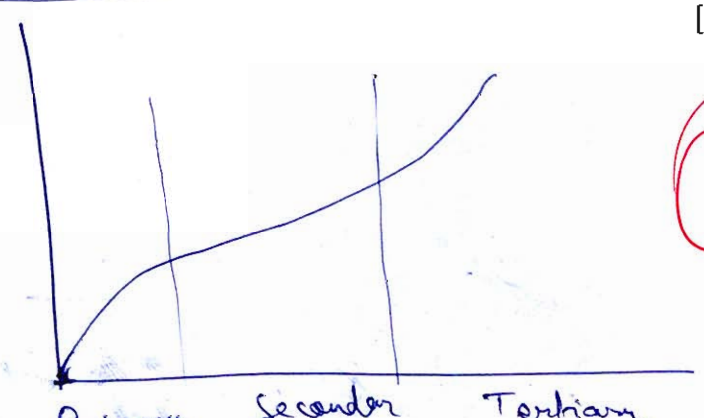
[20 marks]

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]

(a)



1

Cathodic protection is based on the principle of electromagnetic series.

A new cathode material is introduced from the EMF series which has higher value. Therefore the parent (m). metal is saved because chemical reaction takes place in the new cathode material.

eg Galvanisation is one of the method in which Zinc metal is plated around the metal to saved from corrosion.

3

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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^3
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

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

[8 + 12 = 20 marks]

(i) → CNC Machine has computer numerical control.

→ Programmable codes can be used for automatic programming.

→ Feedback mechanism is also present

→ Tool holding (Turret) is also present

→ less skill labour can also be used.

(3)

7

(iii)

$$\frac{1}{e_{eq}} = \frac{1}{e_1} + \frac{1}{e_2} + \frac{1}{e_3} + \frac{1}{e_4} + \frac{1}{e_5}$$

$e_1 = \frac{58.71}{2}$ $e_3 = \frac{55.85}{2}$ $e_5 = \frac{47.9}{3}$

$e_2 = \frac{51.99}{2}$ $e_4 = \frac{26.97}{3}$

2

$$e_{eq} = 4.459$$

$$M_{eq} = \frac{\Sigma \omega}{\Sigma n} = \frac{76 + 19.5 + 2.5 + 1 + 1}{\frac{76}{58.71} + \frac{19.5}{51.99} + \frac{2.5}{55.85} + \frac{1}{26.97} + \frac{1}{47.9}}$$

$$M_{eq} = 56.4242$$

~~ρ_{eq} =~~

$m = Z I t$

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

$$\frac{m}{t} = \frac{eI}{F}$$

$$MRR = \frac{V}{t} = \left(\frac{eI}{F\rho}\right) = \frac{(4.459) \times (950)}{96500 \times \rho_{eq}}$$

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

$$V_T = V_1 + V_2 + V_3 + V_4 + V_5$$

$$\frac{100}{\rho_{eq}} = \frac{76}{8.90} + \frac{51.99}{7.19} + \frac{55.85}{7.86} + \frac{26.97}{2.67} + \frac{47.9}{4.51}$$

$$\rho_{eq} = 2.2936 \ g/cm^3$$

$$MRR = \frac{V}{t} = 0.019138 \ \frac{cm^3}{s}$$

$$MRR = 1.14833 \ cm^3/min$$

Ans

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Q.4 (c) An orthogonal turning operation is carried out on a steel cylindrical workpiece using 10° 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:

(i) Workdone by friction

(ii) Workdone by shear

(iii) Total workdone

(iv) Shear stress

(v) Shear strain

[20 marks]

$\alpha_0 = 10°$ $t = 2.5$ mm

$f = 0.10$ mm/rev.

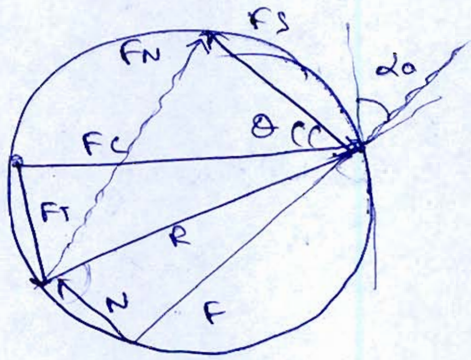
$V = 150$ m/min

$r = 0.35$ $F_C = 650$ N

$F_T = 1250$ N

$\tan\theta = \frac{r \cos\alpha_0}{1 - r\sin\alpha_0} = 0.36698$

$\theta = 20.1524°$



Total work done $= F_C \cdot V$

$= \frac{(650)(150)}{60}$ → Ans (iii)

$= 1625$ W

F = friction force $= F_C \cdot \cos(90 - \alpha_0) + F_T \cdot \cos\alpha_0$

$= F_C \sin\alpha_0 + F_T \cos\alpha_0$

$= 1343.881$ N

F_S = shear force $= F_C \cos\theta - F_T \sin\theta$

$= 179.558$ N

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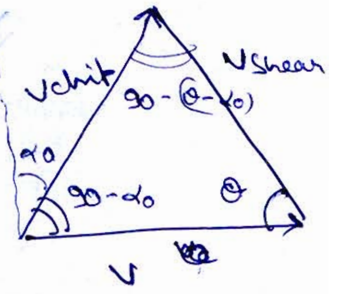
$$\frac{V}{\sin(90-(\theta-\alpha_0))} = \frac{V_{chip}}{\sin\theta} = \frac{V_{shear}}{\sin(90-\alpha_0)}$$



$$V_{chip} = \frac{\sin\theta}{\cos(\theta-\alpha_0)} \times \left(\frac{V}{60}\right)$$

$$= 0.8749 \text{ m/s}$$

$$V_{shear} = \frac{\cos\alpha_0}{\cos(\theta-\alpha_0)} \times \frac{V}{60} = 2.5011 \text{ m/s.}$$

Ans (i)

Workdone by friction $= (F \cdot V_{chip}) = 1175.76$ W

Workdone by shear $= (F_s \cdot V_{shear}) = 449.0925$ W

Ans (ii)

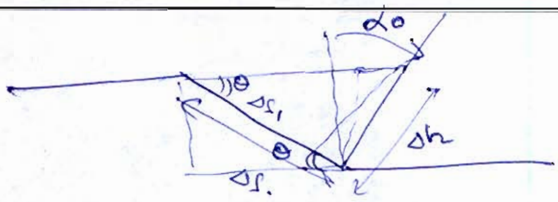
$$\tau_{shear} = \frac{F_s}{A_s} = \frac{F_s \cdot \sin\theta}{A_0}$$

$$= \frac{F_s \cdot \sin\theta}{b t_1}$$

$b t_1 = A_0$.

$$= \frac{F_s \cdot \sin\theta}{A_0}$$

$\tau_{shear} = 618.8825$ MPa Ans (iv)



$$\gamma = \frac{\Delta s}{\Delta h}$$

$$= \frac{\Delta s_1}{\Delta h} + \frac{\Delta s_2}{\Delta h}$$

$$= \cot\theta + \cot(90 - \theta + \alpha_0)$$

$$= \cot\theta + \tan(\theta - \alpha_0)$$

$$\boxed{\gamma = 2.9039}$$

16

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

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

(i) Power developed

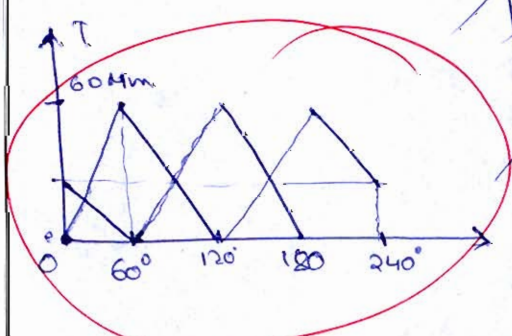
(ii) Coefficient of fluctuation of speed if the mass of the flywheel is 12 kg and radius of gyration is 78 mm.

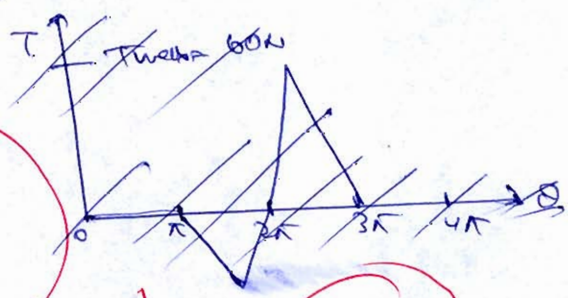
(iii) Coefficient of fluctuation of energy

(iv) Maximum angular acceleration of flywheel.

[12 marks]

~~Assuming 4 stroke engine -~~

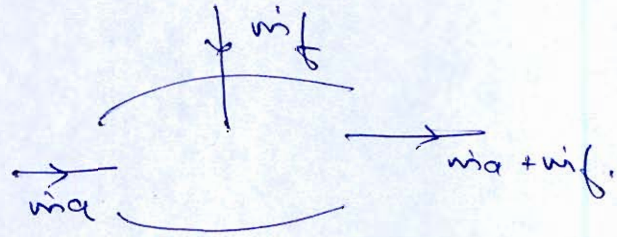




Q.5 (b) Define the following terms as used in an aircraft propulsion system.

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

[12 marks]



(4) Specific thrust

$$F_{thrust} = (\dot m_a + \dot m_f) V_2 - \dot m_a V_1$$

$$\frac{F_{thrust}}{\dot m_a} = \left(1 + \frac{\dot m_f}{\dot m_a}\right) V_2 - V_1$$

$$\text{Specific Thrust} = (V_2 - V_1) \qquad \frac{\dot m_f}{\dot m_a} <<< 1$$

→ force per unit mass of air.
→ This force is applied on aircraft.

(1) Propulsive efficiency (η_{pr}

5

$$\eta_{pr} = \frac{\frac{1}{2}(\dot m_a + \dot m_f) V_2^2 - \frac{1}{2}\dot m_a V_1^2}{\frac{1}{2}\dot m_a V_1^2}$$

$$= \frac{\left(1 + \frac{\dot m_f}{\dot m_a}\right) V_2^2 - V_1^2}{V_1^2}$$

Propulsive efficiency is defined as propulsive power divided by the power input through air.

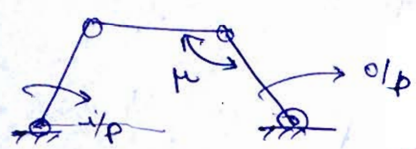
Q.5 (c) (i) What is the transmission angle? Prove that in a four bar mechanism, the transmission angle attains its maximum or minimum value when the crank is in its extreme positions, i.e. when the crank angle is 0° or 180°.

(ii) Define the terms effort and power of a governor.

[6 + 6 = 12 marks]

(i) Transmission angle is ~~a~~ the angle between coupler rod and output ~~rod~~ link.

It is represented in the figure by μ.



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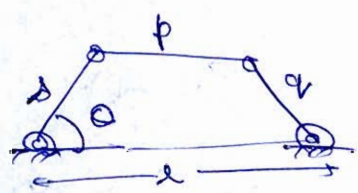
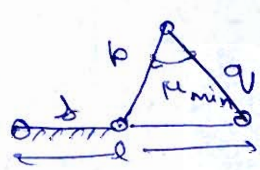
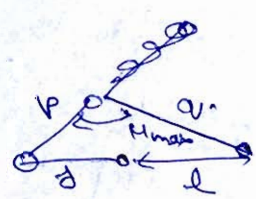


at. θ = 0°



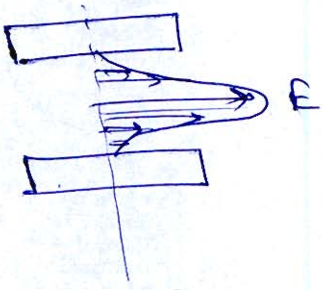
at θ = 180°



(ii) Effort of Governor $\left(\frac{E}{2}\right)$.

→ It is the amount force needed to move the sleeve from its equilibrium position.

→ It's maximum value is E in newton



→ Numerically it is given by its

$$\text{avg. value} = \frac{E}{2}$$

Power of Governor (P) –

→ It is the amount of workdone in moving the sleeve from its equilibrium position.

S

→ Numerically it is given by –

$$P = \frac{E}{2} \times (\text{sleeve movement})$$

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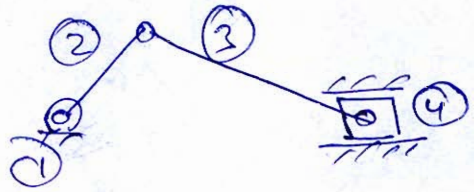
Q.5 (d) What do you mean by the inversions of a kinematic chain? List down all the inversions of a single slider-crank chain. Explain briefly any two.

[12 marks]

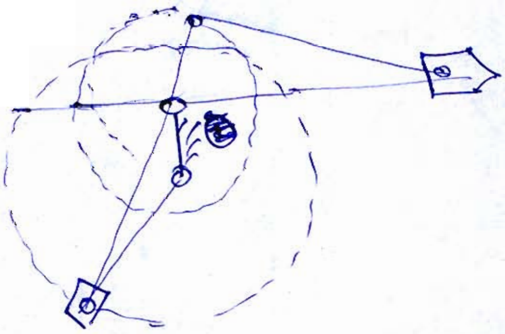
→ Inversion of a kinematic chain is method of obtaining different mechanism keeping the No. of links same. ~~but alternately~~ ~~fixing the different each link~~

→ diff. inversion is obtained by fixing the each link one by one & obtaining new mechanism.

→ No. of inversion is always less than or equal to No. of links in the mechanism.

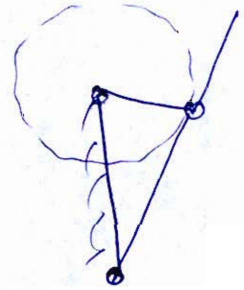


Slider crank



Whitworth quick return Mechanism

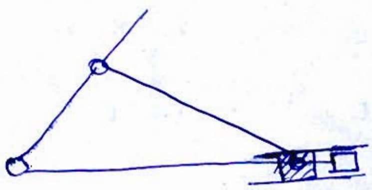
here crank is fixed, i.e the smallest link is fixed. i.e link (1).



Slotted lever

→ here connecting rod i.e link (3) is fixed.

→ used in Shaping & Planning Machines.



Hand Pump mechanism

→ here slider of the ~~mech~~ slider crank mechanism is fixed. i.e link (4).

→ used in Hand Pump for lifting water.

7

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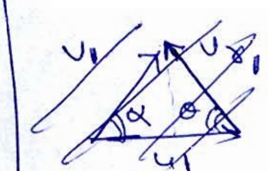
Q.5 (e) The velocity of steam entering a simple impulse turbine is 900 m/s and nozzle angle is 18°. The mean peripheral speed of blades is 410 m/s and blades are symmetrical. If the steam is to enter the blades without shock, what will be the blade angles? Neglecting the friction effects on the blades,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

[12 marks]

$V_1 = 900$ m/s. $\quad u = 410$ m/s $= u_1 = u_2$

$\alpha = 18°$ $\quad \theta = \phi$

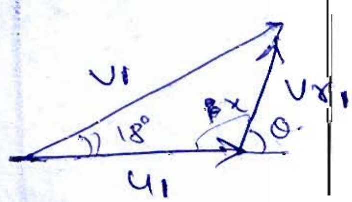
~~$\theta = 0$~~



~~$\tan\theta = \frac{V_{f1}}{u_1} = \frac{900 \sin 18°}{410}$~~

~~$\theta = 65.$~~

$V_{w1} = V_1 \cos\alpha = 855.95 \quad > (u = 410)$



$V_{r1}^2 = V_1^2 + u_1^2 - 2 V_1 u_1 \cos 18$

$V_{r1} = 525.566 \text{ m/s}$

$\frac{\sin(\theta)}{V_1} = \frac{\sin(18)}{V_{r1}}$

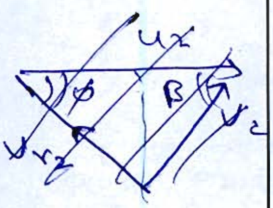
$\theta = 31.9495°$

$\phi = 31.9495°$ → Blade angles

$F_T = \dot{m}(V_{w1} - V_{w2})$

$= \dot{m}(V_{w1} - V_{w2})$

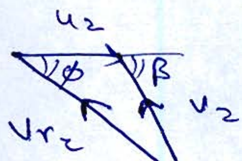
$= (0.5)(855.95 - V_{w2})$ — (1)



$V_{r2} = V_{r1} = 525.566 \text{ m/s}$

$u_2 = 410 \text{ m/s}$

$= V_{r2} \cos\phi = 445.95 \text{ m/s} > ((410 \text{ m/s}) = u_2)$



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$V_{w2} = V_{r2}\cos\phi - u_2$

$= 35.9505 \text{ m/s}$

By (1) —

$F_T = (0.5)(855.95 + V_{w2})$

$= 445.950 \text{ N}$

$\text{Power} = \frac{F_T(u)}{1000} = 182.839 \text{ kW}$

$F_a = \dot{m}\,(V_{F1} - V_{F2})$

$= (0.5)\,(900 \sin 18^\circ - 525.566 \sin 31.9495)$

$F_a = -0.0245\ N$

$\frac{kg}{s} \times \frac{m}{s}$

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

[20 marks]

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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 m^3/kg at 1 bar and At p = 1.6 MPa, T = 360°C, h = 3167.8 kJ/kg and s = 7.1061 kJ/kgK]

p MPa	T_{sat} °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]

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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° 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° from the top dead centre, the gas pressure is 1250 kN/m^2. Determine the

(i) Net force on the piston.

(ii) Net load on the gudgeon pin

(iii) Speed at which gudgeon pin load is reversed in direction.

[20 marks]

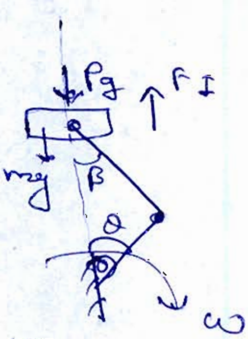
$N = 2000\, rpm$ $\quad$ $r = 45\, mm$

$\omega = 209.439\, rad/s$ $\quad$ $l = 270\, mm$

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

$d_p = 80\, mm.$ $\quad$ $m_{rec} = 2.5\, kg$

$\theta = 30^\circ$ $\quad$ $P_g = 1250\, kN/m^2$



(i) $F_{net} = mg + (P_g A_p) - F_I$

$= (2.5)g + 1250 \times 10^3 \times \frac{\pi}{4} \times (0.08)^2 - F_I.$

$F_{net} = 6307.7103 - F_I$ —— (1)

$\sin\beta = \frac{\sin\theta}{n} = \frac{0.5}{6}$

$\beta = 4.7802^\circ$

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

$= 1877.949 \ m/s^2$

$F_I = m_{rec}\, a = 4684.8747 \ N$ — (2)

By eq^n (1) & (2)

$F_{net} = 1622.835 \ N$

(ii) $F_c = \frac{F_{net}}{\cos\beta} = \frac{1622.835}{\cos 4.7802}$

Ans (ii) $F_c = 1628.0499 \ N$

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(iii) $F_{net} = 0$ and $\theta = (90 \times 2) = 180^\circ$

$mg + P_g(A_p) - F_I = 0.$

$(2.5)(9.81) + (1250) \times 10^3 \times \frac{\pi}{4} \times (0.08)^2 - 2.5\,\omega^2 r \left[\cos\theta + \frac{\cos 2\theta}{n}\right] = 0$

$6307.7103 - 2.5(\omega^2)\left(\frac{45}{1000}\right)\left[-1 + \frac{1}{6}\right] = 0$

$\omega = 259.388 \ rad/s.$

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

$N = 2476.97 \ rpm.$

Q.7 (b) Lubricating oil of specific gravity 0.82 and dynamic viscosity 12.066×10^{-2} N.s/m^2 is pumped at a rate of 0.02 m^3/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.

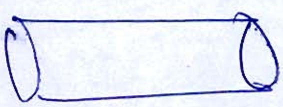
[20 marks]

$S.G = 0.82$ $\mu = 12.066 \times 10^{-2} \frac{N\text{-}s}{m^2}$

$Q = 0.02\, m^3/s$ $d = 0.15\, m$ $L = 300\, m.$

assume fully developed laminar flow.

(i) $\Delta P = \frac{32 \mu V l}{d^2}$



$Q = A \times V = \frac{\pi}{4} d^2 \times V$

$V = \frac{4Q}{\pi d^2} = 1.1317\, m/s$

Ans (i)

$\Delta P = \frac{32 \times (12.066 \times 10^{-2}) \times 300 \times 1.1317}{(0.15)^2} = 58261.726 \frac{N}{m^2}$

~~$\tau_w = -\frac{\partial P}{\partial x}\left(\frac{R}{2}\right)$.~~

~~$= \left(\frac{32 \mu V \cancel{L}}{d^2 \cancel{L}} \times \frac{R}{2}\right)$~~

~~$= \frac{32 \times (12.066 \times 10^{-2}) \times (1.1317)}{(0.15)^2} \times \frac{0.15}{2}$~~

~~$= 14.565 \ N/m^2$~~

$\tau_w = -\mu \left(\frac{du}{dr}\right)_{(r=R)}$.

$u = u_{max}\left(1 - \frac{r^2}{R^2}\right)$

$\frac{du}{dr} = u_{max}\left(-\frac{2r}{R^2}\right)$

$\frac{du}{dr} = -u_{max}\left(\frac{2}{R}\right)$

$= \mu (u_{max}) \left(\frac{2}{R}\right)$

$= \frac{2\mu(2V)}{R} = \frac{4\mu V}{R}$

$\boxed{\tau_w = 7.2827 \ N/m^2}$ → avg. wall shear stress (Ans i)

$F = (\tau_w \cdot A) = (7.2827) \times (\pi (0.15) \times 300) \ N$

$= 1029.569 \ N$

$Power = F \cdot V = (1029.569) \cdot (1.1317)$

$\boxed{Power = 1165.164 \ W}$ → Ans (ii)

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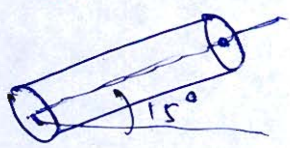
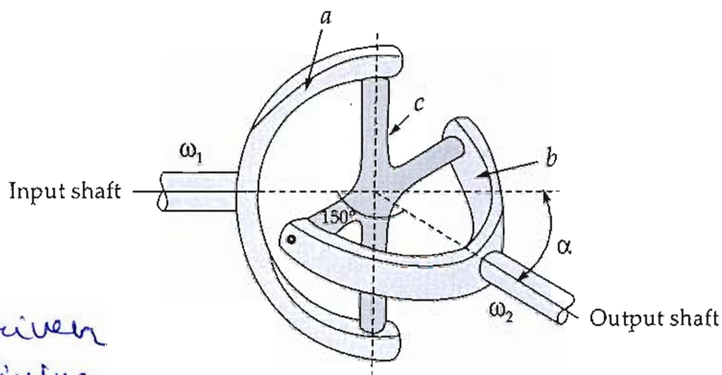
(ii)



Q.7 (c) A Hooke's joint is to connect two shafts whose axes intersect at 150°. 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?



② → driven
① → driving

[20 marks]

$N_1 = 120$ rpm. $\omega_1 = 12.5663$ rad/s.

$\alpha = 30°$ $\theta \rightarrow$ driver $\phi \rightarrow$ driven

$\tan\theta = \tan\phi \cdot \cos\alpha$. (Using this universal joint equatn.)

diff. wrt time t –

$$\sec^2\theta \frac{d\theta}{dt} = \sec^2\phi \frac{d\phi}{dt} \cdot (\cos\alpha).$$

$$\sec^2\theta\,(\omega_1) = \sec^2\phi\,(\omega_2)\,\cos\alpha.$$

$$\omega_2 = \frac{\sec^2\theta\;\omega_1}{\sec^2\phi\;\cos\alpha.}$$

$$= \frac{(1+\tan^2\theta)(\omega_1).}{(1+\tan^2\phi)\cos\alpha.}$$

$$= \frac{(1+\tan^2\theta)\;\omega_1}{\left(1+\frac{\tan^2\theta}{\cos^2\alpha}\right)\cos\alpha.}$$

$$= \frac{\left(1+\frac{\sin^2\theta}{\cos^2\theta}\right)\omega_1}{\left(1+\frac{\sin^2\theta}{\cos^2\alpha\cos^2\theta}\right)\cos\alpha.} = \frac{\frac{\omega_1}{\cos^2\theta.}}{\left(\frac{\cos^2\alpha.\cos^2\theta+\sin^2\theta.}{\cos^2\alpha\cos^2\theta}\right)}$$

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

diff. w.r.t time t –

$$\alpha_2 = \frac{(1-\cos^2\theta.\sin^2\alpha)(0) - (\omega_1^2 \cos\alpha)(0 + \sin^2\alpha.\sin 2\theta)}{(1-\cos^2\theta.\sin^2\alpha)^2}$$

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

$T_{mean} = 135$ N m.

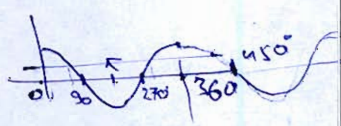
$J = (45)(0.15^2) = 1.0125$ kg-m^2

For α_2 to be maximum –

$$\cos 2\theta = \frac{2\sin^2\alpha}{2 - \sin^2\alpha}$$

$$\cos 2\theta = \frac{2\sin^2 30^\circ}{2 - \sin^2 30^\circ} = 0.2857$$

$2\theta = 73.3984^\circ, 286.6015^\circ$



$\theta = 36.6992^\circ, 143.3007^\circ$
θ_1 , θ_2

at θ_1

$\alpha_{max} = 0.2945\ \omega_1^2$ m/s^2

at θ_2

$\alpha_{min} = -0.2945\ \omega_1^2$ m/s^2

$T_{max} - T_{mean} = I\,\alpha_{max}$.

$T_{max} = I\alpha_{max} + T_{mean}$

$= 1.0125\,(0.2945)(12.5663)^2 + 135$

$T_{max} = 182.0868$ N-m → Ans.

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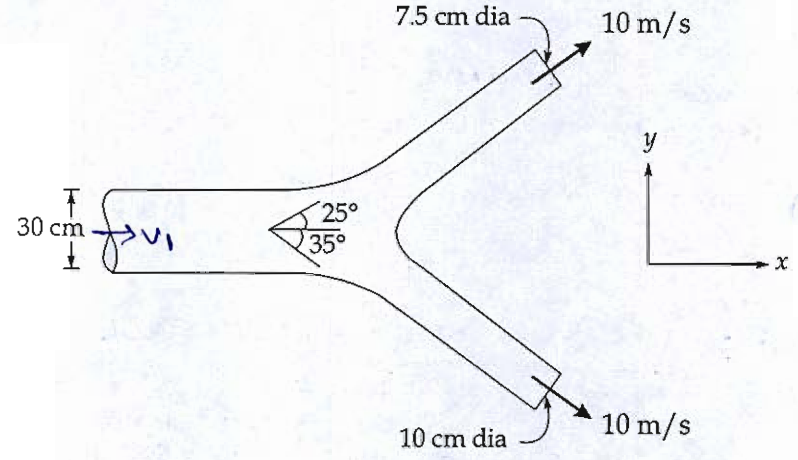
Q.8 (a) A 30 cm diameter pipe is bifurcated into two nozzles at a Y-junction as shown in figure. The nozzles discharge to atmosphere and have a velocity of 10 m/s each. The junction is in the horizontal plane and the friction can be neglected. Determine the magnitude and direction of the resultant force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



[20 marks]

By continuity eqn —

$(30)^2 v_1 = (7.5)^2(10) + (10)^2(10)$

$V_1 = 1.7361$ m/s

$\dot{m}_1 = \rho A_1 v_1$

$\dot{m}_1 = 122.717$ kg/s.

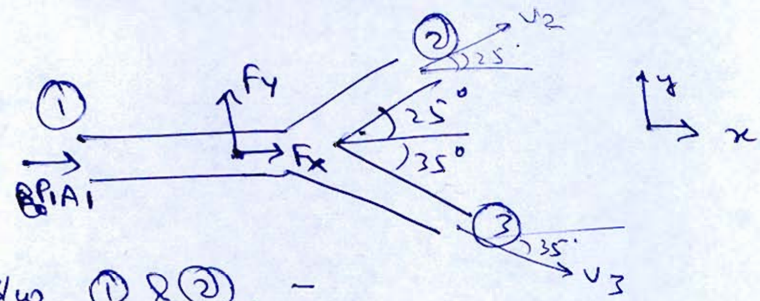
$\dot{m}_2 = 44.1786$ kg/s

$V_2 = 10$ m/s

$V_3 = 10$ m/s

$\dot{m}_3 = \rho A_3 V_3$

$\dot{m}_3 = 78.539$ kg/s



Bernoulli b/w ① & ② -

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g}^{0} + \frac{V_2^2}{2g} + z_2$$

$$P_1 = 48492.9784 \ N/m^2$$

Momentum conservatn along x directn -

→ +ve,

$$F_x + P_1 A_1 = \dot{m}_2 V_2 \cos 25° + \dot{m}_3 V_3 \cos 35° - \dot{m}_1 V_1$$

$$F_x = 830.698 - 48492.9784 \times \frac{\pi}{4} \times 0.3^2$$

$$F_x = -2597.06 \ N$$

In Y directn ↑ +ve

$$F_y + 0 = (\dot{m}_2 V_2 \sin 25° - \dot{m}_3 V_3 \sin 35°) - (0)$$

$$F_y = -263.774 \ N$$

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$$F_{resultant \ on \ Y \ Junctn} = \sqrt{F_x^2 + F_y^2} = 2610.4209 \ N$$

Ans.

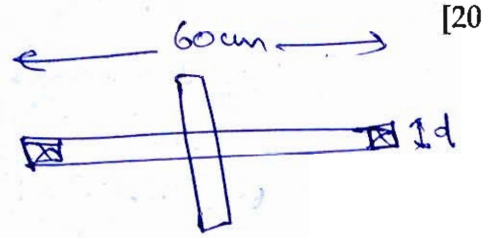
?

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 $E = 2 \times 10^{11}$ 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]



$m = 5$ kg.

$d = 20$ mm $= 20 \times 10^{-3}$ m

$e = 2$ mm $= 2 \times 10^{-3}$ m

$$\Delta_{static} = \frac{W l^3}{48 EI} = \frac{(5)(9)(0.6)^3}{(48)(2 \times 10^{11}) \times \frac{\pi \times (20 \times 10^{-3})^4}{64}}$$

$$= 1.40517 \times 10^{-4} \text{ m}$$

$$\omega_n = \sqrt{\frac{g}{\Delta_{static}}} = 264.22 \text{ rad/s}$$

$$s = m\omega_n^2 = 349061.042 \text{ N/m}$$

$$\omega = \frac{2\pi(360)}{60} = 37.699 \text{ rad/s}$$

$\gamma = \frac{\omega}{\omega_n} = 0.1426$

$F_0 = m\omega^2 e.$
$= 14.2121\ N$

$c = 60\ \frac{N \cdot s}{m}$

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

$\xi = \frac{c}{2m\omega_n} = 0.0227$

$\sigma_{max} = \left(\frac{F_{Total} \cdot L}{4}\right) \times \left(\frac{32}{\pi d^3}\right) = \frac{8 F_{Total} \times L}{\pi d^3}$ — (2)

$F_{dy} = \sqrt{(sA)^2 + (CA\omega)^2}$ — (1)

$A = \frac{F_0/s}{\sqrt{(1-\gamma^2)^2 + (2\xi\gamma)^2}} = 4.1559 \times 10^{-5}\ m$

$sA = 14.5068\ N$

$CA\omega = 0.09400 N$

By eqⁿ – (1)

~~F_{total}~~ $F(dy) = 14.5071\ N$; $F_{Total} = F_{dy} + mg$
$= 14.5071 + 5 \times 9.81$
$= 63.5571\ N$

By eqⁿ – (2)

$\sigma_{max} = 12138511.96\ N/m^2 = 12.1385\ MPa.$

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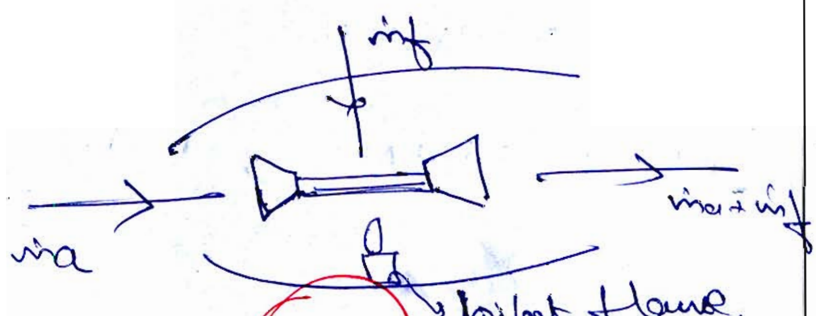
(ii) $P = T \cdot \omega$
$= \left\{(CA\omega) \cdot \frac{d}{2}\right\} \times \omega$
$= 0.03544\ W$

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]



Air

OOOO

Space for Rough Work

$y + r = R.$

$dy = -dr$

$\tau_w = \mu \left(\frac{du}{dy} \right).$

$u = u_{max} \left(1 - \frac{r^2}{R^2} \right)$

$\frac{du}{dr} = u_{max} \left(0 - \frac{2r}{R^2} \right).$

$= + \mu u_{max} \frac{(2r)}{R^2}$

$V = \frac{u_{max}}{2}$

$= + \mu \left(2V \right) \frac{2 \times R}{R^2}$

$= \frac{4 \mu V}{R}.$