MADE EASY

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

Delhi ☑ Bhopal ☐ Jaipur ☐

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Student's Signature

D. Bhaskar

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	53
Q.2	30
Q.3	—
Q.4	29
Section-B	
Q.5	24
Q.6	—
Q.7	38
Q.8	—
Total Marks Obtained	174

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.

Section A : Production Engineering & Material Science

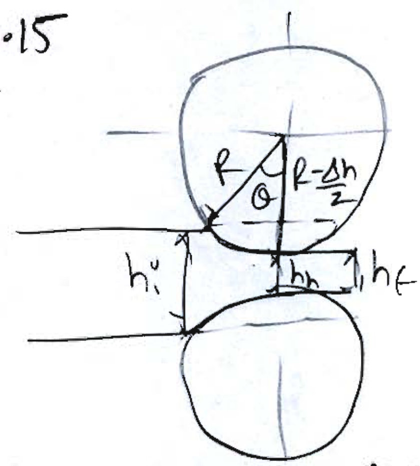
Q.1 (a) A rectangular strip of cross-section 200 mm × 8 mm is being rolled with 25% reduction in area using steel rolls having radius of 250 mm. The average shear yield stress during the process is 380 MPa. Calculate the final strip thickness, angle subtended at the roll centre and the location of neutral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

[12 marks]

Sol) $W = 200mm$ $\quad R = 250mm$ $\quad$ → Assumption: width is Constant

$h_i = 8mm$ $\quad S_{ys} = 380MPa$

$h_f = 6mm$ $\quad \mu = 0.15$



→ i) $h_f = 6mm$

ii) $\cos\theta = \dfrac{R - \frac{\Delta h}{2}}{R}$

$\cos\theta = \dfrac{250 - \left(\frac{2}{2}\right)}{250}$

$\theta = 5.126°$

→ $25\% = \dfrac{A_i - A_f}{A_i}$

→ $\dfrac{A_f}{A_i} = 0.75$

$\therefore A_f = 1200 mm^2$

iii) location of Neutral plane $\theta_n = \sqrt{\dfrac{h_f}{R}} \tan\left(\sqrt{\dfrac{h_f}{R}} \cdot \dfrac{H_n}{2}\right)$

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$\theta_n = \sqrt{\dfrac{6}{250}} \tan\left(\sqrt{\dfrac{6}{250}} \times \dfrac{2.4425}{2}\right)$ $\quad$ → $H_n = \dfrac{1}{2}\left[H_0 - \dfrac{1}{\mu}\ln\left(\dfrac{h_i}{h_f}\right)\right]$

$= \sqrt{\dfrac{6}{250}} \times 0.19148$ $\quad$ $H_n = 2.4425$

$\theta_n = 0.02965$ radian

→ $H_0 = 2\sqrt{\dfrac{R}{h_f}} \tan^{-1}\left(\sqrt{\dfrac{R}{h_f}} \times \theta_0\right)$

$\theta_n = 1.6996°$

$H_0 = 12.9909 \times 0.52370$

$H_0 = 6.8029$

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

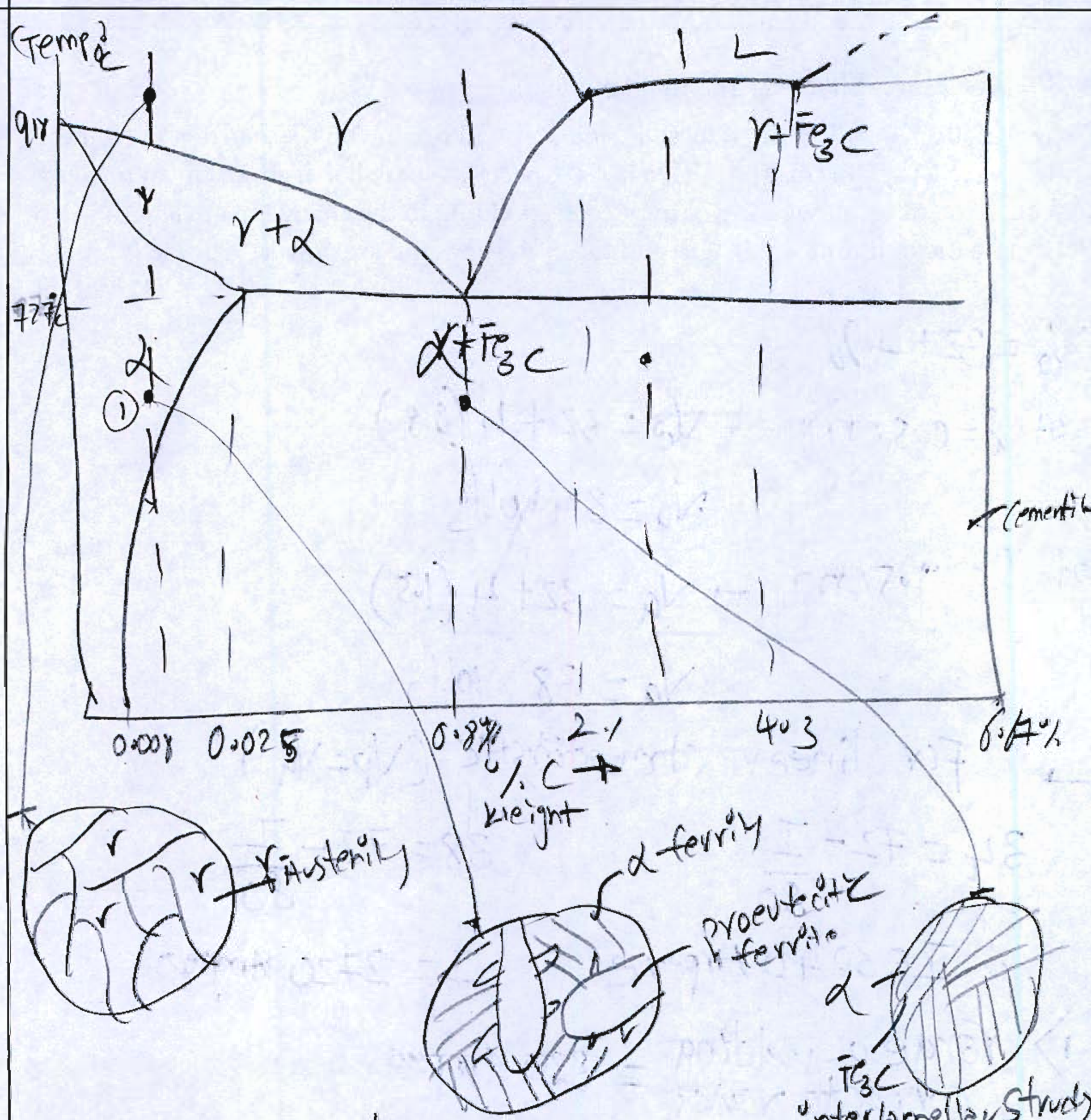
[12 marks]

1) Ferrite :- α-ferrite is interstitional solid solution of carbon in α-iron, having carbon solubility of 0.025%, in BCC structure having Average number of atom '2'.

2) Austenite :- γ-Austenite is interstitional solid solution of carbon in γ-iron.

→ having carbon solubility of 2%.

→ FCC structure and Average number of atom - 4



iv) → **Pearlite**: below eutectoid temperature, when γ-Austenite is cooled, It gets converted into pearlite

$$\gamma \rightarrow \alpha\text{-ferrite} + Fe_3C$$

v) **Cementite**: It is interstitial compound of iron and carbon.
→ having carbon solubility is 6.67%.

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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]

$V_a = 32 + 4l_a$

at $l = 0.5$ cm → $V_a = 32 + 4(0.5)$

$V_a = 34$ volts

at $l = 1.5$ cm → $V_a = 32 + 4(1.5)$

$V_a = 38$ volts

→ For linear characteristic ($V_p = V_a$)

$34 = 72 - \frac{I}{80}$ $\quad\quad$ $38 = 72 - \frac{I}{80}$

∴ $I = 3040$ Ampere $\quad\quad$ ∴ $I = 2720$ Amperes

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1) range of welding current varies = 320 Amperes

from optimum arc length

→ $\frac{dP}{dl_a} = 0 \Rightarrow (32 + 4l_a)\ [(32 + 4l_a) \times 80]$

$P = (32 + 4l_a)(5760 - (2560 + 320 l_a))$

$P = (32 + 4l_a)(3200 + 320 l_a)$ — (1)

$\frac{dP}{dl_a} = 102400 + 10240 l_a + 12800 l_a + 1280 l_a^2$

→ $2560 l_a = 2560$ ∴ $l_a = 1$ cm

→ Power $= 36 \times 2880$

$= 103.680$ KW

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]

$$V_{rise} = 3.5 \times \frac{6.5}{100}(V_{castin})$$

$$= 3.5 \times \frac{6.5}{100}(25 \times 15 \times 5)$$

$$V_{riser} = 426.5625 \text{ cm}^3$$

at optimum side : d = h

$$\therefore \frac{\pi}{4}d^3 = 426.5625$$

$$d = 8.1588 \text{ cm} \qquad \therefore d = h = 8.1588 \text{ cm}$$

Checking dimension under cooling characteristic

$$\left(\frac{A_s}{V}\right)_{castin} \geq \left(\frac{A_s}{V}\right)_{riser} \quad \text{[for valid riser design]}$$

$$\left(\frac{A_s}{V}\right)_{cast} = \frac{2[(25 \times 15) + (15 \times 5) + (5 \times 25)]}{25 \times 15 \times 5} = 0.61333$$

$$\left(\frac{A_s}{V}\right)_{rise} = \frac{2\left(\frac{\pi}{4}d^2\right) + \pi d h}{\frac{\pi}{4}d^3} = \frac{313.684}{\frac{\pi}{4}d^3} = 0.7354$$

$$\therefore \left(\frac{A_s}{V}\right)_{castin} < \left(\frac{A_s}{V}\right)_{riser}$$

$\therefore$ New dimension →

$$\frac{\frac{3}{2}\pi d^2}{\frac{\pi}{4}d^3} = 0.61333$$

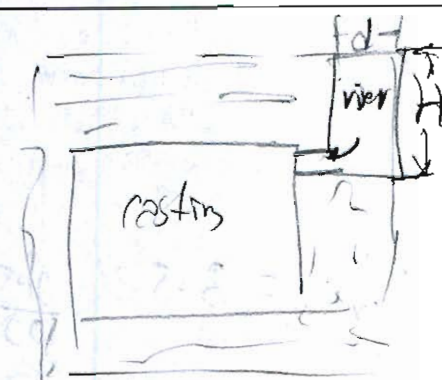
$$\frac{6}{d} = 0.6133$$

$$\therefore D = 9.78314 \text{ cm}$$

$$H = 9.78314 \text{ cm}$$

→ $A_s = 2\frac{\pi}{4}d^2 + \pi d h$ —(1)

→ $V = \frac{\pi}{4}d^2 h$ —(A) ∴ $h = \frac{4V}{\pi d^2}$ —



from eq (1)

$A_s = \frac{\pi}{2}d^2 + \pi d\left(\frac{4V}{\pi d^2}\right)$

By differentiating area w.r.t d

d = dia of riser
h → height of riser

$\frac{dA_s}{dd} = 0$ → $\frac{\pi}{2}d + \left(-\frac{\pi 4V}{d^2}\right)$

∴ $V = \frac{\pi}{4}d^3$ —(2)

compare eq (A) and (2)

∴ $\boxed{d = h}$ — optimum dimensions of side rise

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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?

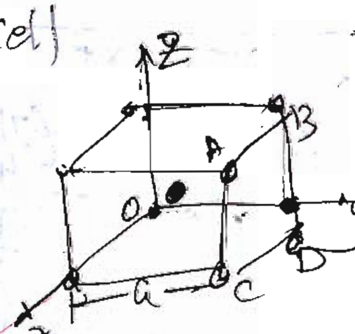
[12 marks]

→ Atomic packing faction = $\frac{N_{avg} \times V_{atom}}{V_{unit\ cell}}$

for B.C.C → $N_{avg} = 2$

$4r = a\sqrt{3}$

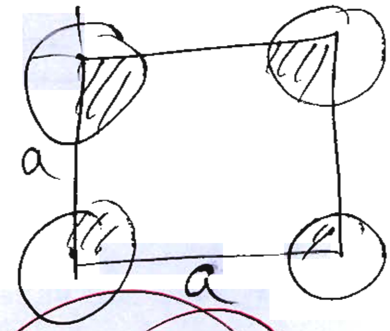
∴ $a = \frac{4r}{\sqrt{3}}$



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

$APF = 0.68$

→ For a plane ABC



$$\text{planer density} = \frac{\frac{1}{4}\times 4}{a^2}$$

$$= \frac{1}{a^2}$$

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

$$a = \frac{4\times 0.1280\times 10^{-9}}{\sqrt{3}}$$

$$a = 2.95603\times 10^{-10}\ m$$

$$\text{planer density} = 1.144\times 10^{13}\ \text{atoms}/m^2$$

$$= 1.144\times 10^{13}\ \text{atoms}/mm^2 \quad 1 mm^2$$

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Cu has FCC Structure

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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.

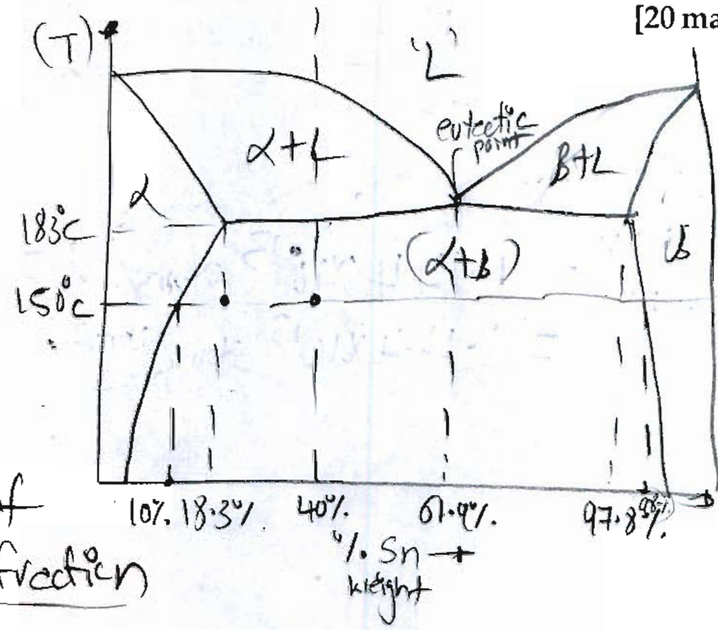
Also draw Pb-Sn phase diagram.

[20 marks]

Sol Given data

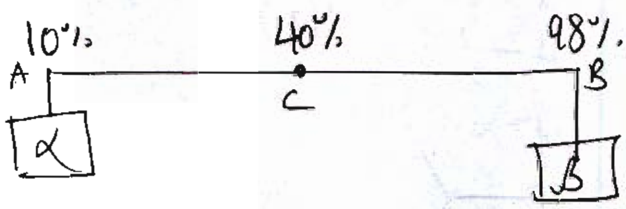
$\rho_{Pb} = 11.23 g/cm^3$

$\rho_{Sn} = 7.24 g/cm^3$



→ relative amount of 'α' and 'β' in mass fraction

By lever rule



$$\alpha = \frac{0.98 - 0.4}{0.98 - 0.1} = 0.659 \rightarrow 65.90\%$$

$$\beta = \frac{0.4 - 0.1}{0.98 - 0.1} = 0.340 \rightarrow 34.09\%$$

2)

$$\rightarrow \frac{1}{\rho_\alpha} = \frac{0.1}{7.24} + \frac{0.9}{11.23}$$

$$\rho_\alpha = 10.6434 \text{ g/cm}^3$$

$$\rightarrow \frac{1}{\rho_\beta} = \frac{0.98}{7.24} + \frac{0.02}{11.23}$$

$$\rho_\beta = 7.29181\ g/cm^3$$

→ volume fraction of 'α'

$$\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\beta} = \frac{\frac{W_\alpha}{\rho_\alpha}}{V_\alpha} \rightarrow \frac{0.6590}{10.643} + \frac{0.3409}{7.2918} = \frac{\frac{0.6590}{10.643}}{V_\alpha}$$

$$\therefore V_\alpha = \frac{0.6590/10.643}{0.108669} = 0.5697 \rightarrow 56.97\%$$

→ volume fraction of 'β'

$$\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\alpha} = \frac{\frac{W_\beta}{\rho_\beta}}{V_\beta} \rightarrow \frac{0.6590}{10.643} + \frac{0.3409}{7.2918} = \frac{\frac{0.3409}{7.298}}{V_\beta}$$

$$V_\beta = 43.45\%$$

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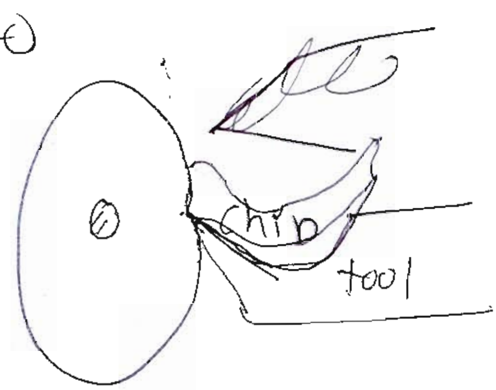
Q.2 (b) (i) Describe the mechanism of chip formation, and state the conditions for the formation of various types of chips.

(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]

* When work tool is forced against work-piece, due to straps of cutting the chip will flow along the rake face.



1) Continuous Chips

a) at high cutting speed
→ at high rake angle
→ at fine feed
→ during machining ductile material
→ tool life is more

2) discontinuous chips
→ at low cutting speed
→ at low rake angle
→ at fine feed
→ during maching brittle materic
→ tool life is less

3) Continous chips with built-up edge
→ at low cutting speed and maching ductile matteric
→ at low rake angle
→ at Coarse feed
→ at Metallic-adhesion
→ slip-stick motion
→ due to stiction
→ tool life first increase and then decreasing

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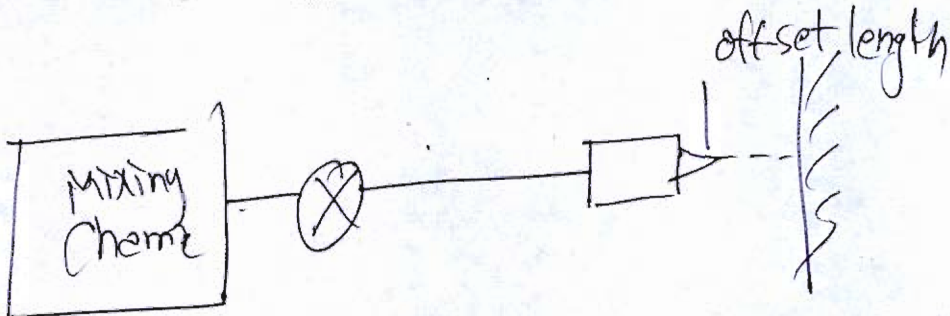
Q.2 (c) Explain the principle of abrasive water-jet machining using suitable schematic diagram. Write the advantages and applications of AWJM.

[20 marks]



A water with Abrasive is mixed with water in chamber and pumped with high velocity into the machining space where machining to be done.

4

Application: 1) fine drilling of hole
2) Machining in unaccessible area
3)

advantage: 1) It is easy process and required less maintenance
2) It require less skill to operate

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]

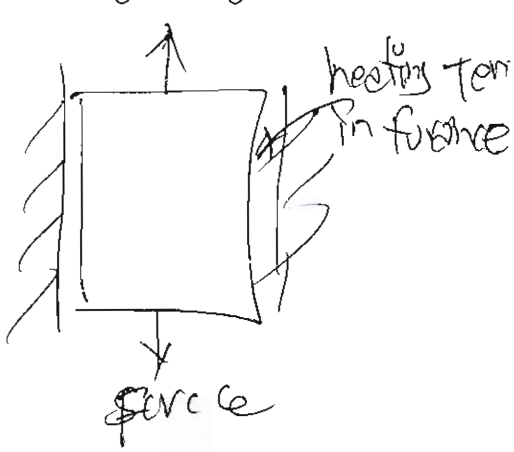
Q.3 (c) With the help of a neat and property labelled RC circuit diagram of electric discharge machining (EDM), derive the relationship between supply voltage (V_0), charging voltage (V), resistance (R), capacitance (C) and the cycle time for the capacitor charging process. Further, obtain the expression 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.

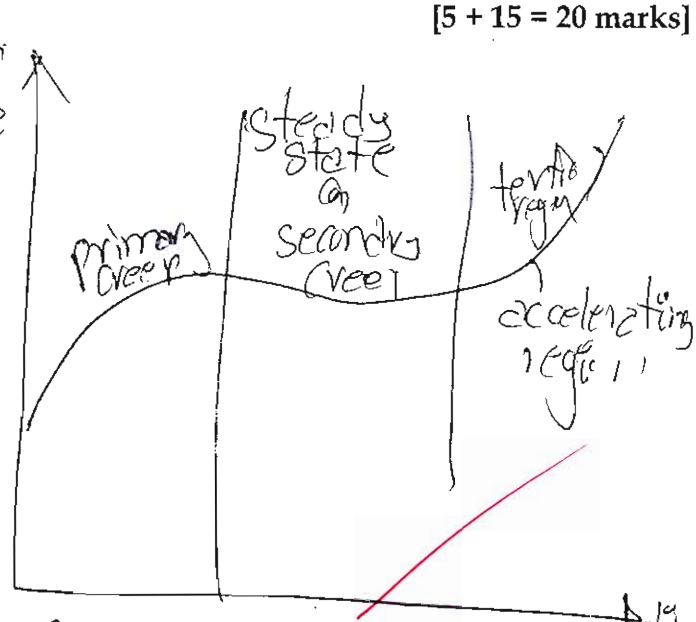
[20 marks]

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]





→ during primary creep → stress due to force is more dominant and heating

∴ there is slow creep

→ at secondry creep :- the stress is due force and furnace is heat →
It is compromise is creep
→ It is steady state region also.
at teritiory region → It is accelerating region, creep increase due extreme heating → there is no involvement due force applied.

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ii) the meterial 'Anode' to be coated with cathode coating with the help of coating mechaning such as electrode disposition, spraying, immersion (or) dipping.

→ the cathode coating on Anode make the disconnect b/w Metals, in presence of electrolyte ; therefore corrusion is prevented.

3

Ex: Ni-coating on steel
cadiumium coating on bismuth

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 is Computer numerical controlled Machines, where human efforts are not required.

2) data is provided interms of Geometric Codes and Machines Codes in CNC.

3) Material Movements will be done through Automatic guided Vehicle in CNC layout

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4) It doesn't required skill person where as in convention machining skilled operated is required.

5) Feed back sensors are using in CNC, to correct the errors and improves the accuracy.

ii)
$$\frac{1}{e} = \left(\frac{2(0.76)}{58.71} + \frac{0.195\times 2}{51.99} + \frac{0.025\times 3}{47.9} + \frac{0.01\times 3}{26.97} + \frac{0.01\times 2}{55.85} \right)$$

$\therefore e = 27.4516$ gm

$\rightarrow \rho = (0.76\times 8.9) + (0.195\times 7.19) + (0.01\times 7.86) + (0.01\times 2.67) + (0.025\times 4.51)$

$\rho = 8.3841$ gm/cm3

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$\therefore$ material removal rate $\Rightarrow MRR = \frac{eI}{\rho F}$

$$MRR = \frac{27.4516\times 950}{8.3841\times 96500}\times 60$$

$MRR = 1.934$ gm/min

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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]

Given data :- $\alpha_0 = 10^\circ$ $V = 150\ m/min$

$d = 2.5\ mm$ $r = 0.35$

$f = 0.1\ mm/rev$ $F_C = 650\ N$

$F_t = 1250\ N$

i) $V_{chip} = V \times r$

$= 150 \times 0.35$

$= 52.5\ m/min$

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

$\tan\theta = \frac{0.35 \times \cos 10}{1 - 0.35 \sin 10}$

$\theta = 20.152^\circ$

→ $F = \frac{F_C \cos(90 - \tau_0)}{\cos(\tau_0 - \alpha_0)}$

→ Merchant 1st angle relationship

$2\theta + \tau - \alpha_0 = \frac{\pi}{2}$

$\therefore \tau = 56.695^\circ$

$F = \frac{650 \cos(90 - 56.695)}{\cos(56.695 - 10)}$

$F = 792.036\ N$

i) Workdone by friction

$W.D = F \times V_{chip}$ → $792.036 \times \frac{52.5}{60}$

$= 693.032\ J/sec$

→

$$F_S = \frac{F_C \cos(\theta + \tau - \alpha_0)}{\cos(\tau - \alpha_0)}$$

$$F_S = \frac{650 \cos(20.152 + 56.695 - 10)}{\cos(56.695 - 10)}$$

$$F_S = 372.6182 \text{ N}$$

→ $V_S = \frac{V \times \cos\alpha_0}{\cos(\theta - \alpha_0)}$

$= \frac{150 \times \cos 10}{\cos(20.152 - 10)}$

$V_S = 150.0707$ m/min

→ ii) Workdone by shear ⇒ $F_S \times V_S$

$= 372.6182 \times \frac{150.0707}{60}$

$= 931.984$ J/sec

iii) Total work done $= F_C \times V$

$= 650 \times \frac{150}{60}$

$= 1625$ J/sec

6+4

iv) Shear stress $= \frac{F_S}{\left(\frac{d \times f}{\sin\theta}\right)} = \frac{372.6182}{\left(\frac{2.5 \times 0.1}{\sin 20.152}\right)}$

$\tau = 513.4855$ N/mm²

v) Shear strain $= \cot\theta + \tan(\theta - \alpha_0)$

$= \cot 20.152 + \tan(20.152 - 10)$

$= 2.90402$

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

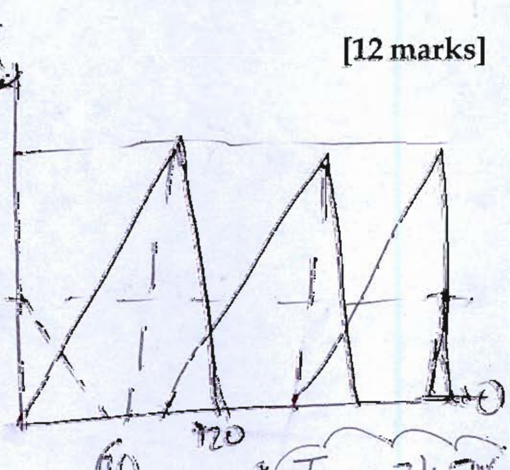
(ii) Coefficient of fluctuation of speed if the mass of the flywheel is 12 kg and radius of gyration is 78 mm.

(iii) Coefficient of fluctuation of energy

(iv) Maximum angular acceleration of flywheel.

[12 marks]

$\omega = 47.123$ rad/sec



$$\frac{T_{mean}}{60 \times \frac{\pi}{180}} = \frac{T_{max}}{120 \times \frac{\pi}{180}}$$

$T_{mean} = 30$ N-m $\rightarrow \frac{(W.D)}{} = \int_0^{2\pi}$ area under curve

$30 = T_{mean}$

$\therefore T_{mean} = 45$ N-m

∴ i) power developed $= T_{mean} \times \omega$

$= \frac{45 \times 2\pi \times 450}{60}$

$= 2120.58$ watts

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$(\Delta E)_{max} = \frac{1}{2} \times 15 \times 30 \times \frac{\pi}{180}$

$(\Delta E)_{max} = 3.926534\ J$

$\therefore (\Delta E)_{max} = I\omega^2 C_S$

$3.926 = 0.0930 \times (47.123)^2 \times C_{S}$

$C_S = 0.0242 \rightarrow 2.421\%$

$\left[\frac{60^\circ}{120^\circ} = \frac{30}{x} \right.$

$\therefore x = \frac{60^\circ \times \pi}{180}$

$T_{mean} = 45\ N\text{-}m$

$\frac{60}{120} = \frac{15}{x}$

$x \rightarrow 30^\circ$

iii) $C_E = \frac{(\Delta E)_{max}}{W.D}$

$= \frac{3.9265}{45 \times 2\pi}$

$= 0.01388 \rightarrow 1.388\%$

iv) $(60-45) = I\,\alpha_{max}$

$15 = 0.0930 \times \alpha_{max}$

$\alpha_{max} = 161.290\ rad/sec^2$

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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

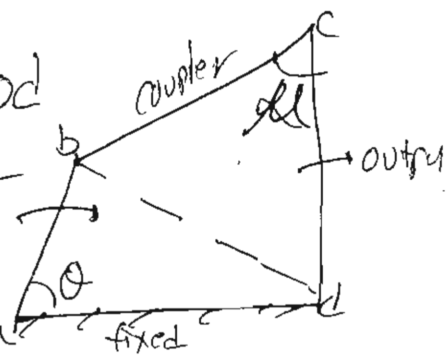
[12 marks]

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° or 180°.

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

[6 + 6 = 12 marks]

→ transmission angle is angle b/w output link and coupler rod in 4-bar mechanism. It is denoted 'μ'



→ By applying cos rule (Δabd)

$(bd)^2 = (ab)^2 + (ad)^2 - 2(ab)(ad)\cos\theta$ — (1)

→ By applying cos rule (Δbcd)

$(bd^2) = (bc)^2 + (cd)^2 - 2(bc)(cd)\cos\mu$ — (2)

from (1) and (2) [equating]

$(ab)^2 + ad^2 - 2(ab)(ad)\cos\theta = (bc)^2 + (cd)^2 - 2(bc)(cd)\cos\mu$

By differential equation w.r.t θ

$+2(ab)(ad)\sin\theta \cdot d\theta = 2(bc)(cd)\sin\mu \, d\mu$

$$\frac{d\mu}{d\theta} = \frac{(ab)(ad)\sin\theta}{(bc)(cd)\sin\mu}$$

6

$\therefore \frac{d\mu}{d\theta} = 0 \rightarrow \sin\theta = 0$

$\theta = 0°, 180°$

ii) effort:- the mean force exerted on sleeve (governor) to move its equilibrium position for a fractional change in speed of governor

power of governor:- the work-done on sleeve to move its equilibrium position for a fractional change in speed of governor

4

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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 :- By fixing different links in kinematic chain would gives different Mechanism.

→ inversions of single slider-crank chain

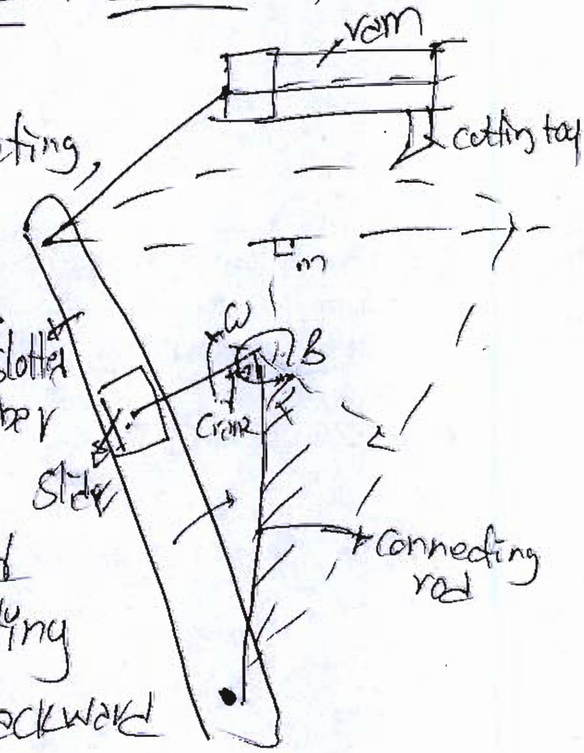
1) when cylinder is fixed
a) reciprocating engine
b) reciprocating pump

2) when crank is fixed
1) Withworth quick-return motion Mechanism
2) rotary internal combustion engine / Genome engine

3) When connecting rod is fixed
a) Crank and slotted lever quick-return motion mechanism
b) oscillating cylinder engine

4) When slider is fixed
a) pump

1) single slider crank mechanism

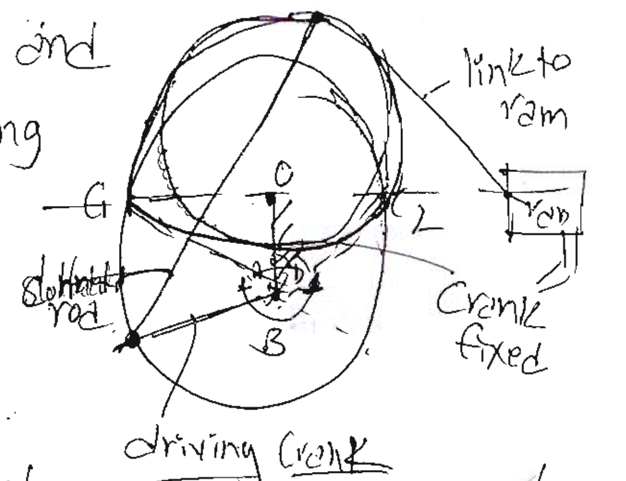


When crank is rotating, the slider in the slotted bar is sliding and rotating the slotted bar.
the link connecting to ram from end of slotted bar leads to move cutting tool in forward and Backward motion.

→ This Mechanism give less time for return stoke then forward stroke ie It has quick return ratio $= \frac{\beta}{\alpha}$

Whitworth quick-return Motion Mechanism

When crank is fixed, and driving crank is rotating with angular velocity, leads to movemen of ram to forward stroke and Backward stroke.



→ It gives quick return during return stroke then cutting stroke

$QRR = \frac{\beta}{\alpha}$

10

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]

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]

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]

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

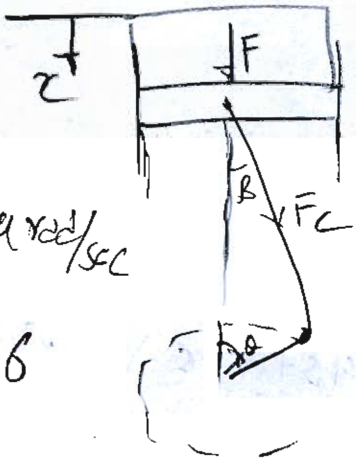
(i) Net force on the piston.

(ii) Net load on the gudgeon pin

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

[20 marks]

Given data



$N = 2000\ rpm$

$\omega = \frac{2 \times \pi \times 2000}{60} = 209.484\ rad/sec$

$r = 0.045\ m$ $\quad \therefore n = \frac{l}{r} = 6$

$l = 0.270$

$D = 0.08\ m$ $\quad \theta = 30°$

$m_{reci} = 2.5\ kg$ $\quad P_{gas} = 1250 \times 10^3\ N/m^3$

$\therefore \beta = \sin^{-1}\left(\frac{\sin\theta}{n}\right)$

$\beta = 4.780^\circ$

<u>piston effort</u> $P = F_{gas} + Mg - F_I$

$F_{gas} = \frac{\pi}{4}(0.08)^2 \times 1250 \times 10^3 = 6283.185\ N$

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

$= 2.5 \times 0.045\,(209.439)^2 \left[\cos 30 + \frac{\cos 60}{6}\right]$

$F_I = 4684.8747\ N$

i) <u>Net force on the piston</u> $F = 6283.185 + 24.525 - 4684.8747$

$\therefore F = 1622.8353\ N$

ii) Net load on gudgeon pin $= F_c = \frac{F}{\cos\beta}$

$\therefore F_c = 1628.499\ N$

iii) $0 = F_{gas} + mg - F_I$

$F_I = F_{gas} + mg$

$m_r \omega^2 \left(\cos\theta + \frac{\cos 2\theta}{n}\right) = 6283.185 + 24.525$

$\omega = 243.021$ rad/s

$\frac{2\pi N}{60} = 243.021$

N = 2320.6824 rpm

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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;

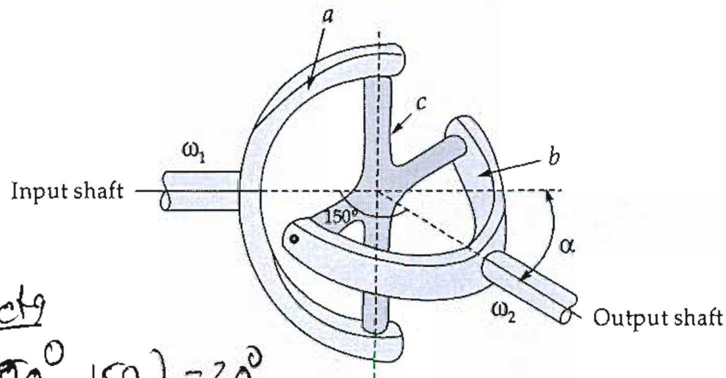
(ii) if the pipe is inclined at 15 degrees with the horizontal and the flow is

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]

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?



[20 marks]

Given data

$\alpha = (180^0 - 150) = 30^0$

$\omega_1 = \frac{2 \times \pi \times 120}{60} = 12.566$ rad/sec

$(T_{shaft_2}) = 135$ N-m

$m = 45$ kg $\quad I = mk^2 = 1.0125$ m^2

$K = 0.15$ m

→ from fundamental equation of Hooks joint

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

By differential above equation

$\sec^2\theta \cdot d\theta = \sec^2\phi \, d\phi \cos\alpha$

By diving with dt on both side

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

$(1+\tan^2\theta)\omega_1 = (1+\tan^2\phi)\cos\alpha\,\omega_2$

$1 + \frac{\sin^2\theta}{\cos^2\theta} \omega_1 = \left(1 + \frac{\tan^2\theta}{\cos^2\alpha}\right)\cos\alpha\,\omega_2$

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

Where ω_1 = Angular velocity driving shaft

ω_2 = Angular velocity of driven shaft

θ = Angle turned by driving shaft

ϕ = Angle turned by driven shaft

$\omega_1 = \frac{d\theta}{dt}, \; \omega_2 = \frac{d\phi}{dt}$

$$\omega_2 = \frac{\omega_1 \cos\alpha}{(1-\cos^2\theta \sin^2\alpha)}$$ — Angular velocity of driven shaft

Angular acceleration of driven shaft

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

for maximum α_2, $\frac{d\alpha_2}{d\theta} = 0$

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

$$\therefore \cos 2\theta = \frac{2(\sin 30)^2}{2-(\sin 30)^2}$$

$2\theta = 73.3984°, 253.3984$, | $2\theta = 286.6016$

$\theta = 36.6992°$, 126.694 | $\theta = 143.3°$

at $\theta = 36.6992$

$$(\alpha_2)_{max} = \frac{-(12.566)^2 \cos 30 \, (\sin 30)^2 \sin(2\times 36.699)}{(1-(\cos 36.699)^2(\sin 30)^2)^2}$$

$\therefore (\omega_2)_{max} = \frac{12.566 \times \cos 30}{0.83925}$

$(\omega_2)_{max} = 12.9663$

$$\alpha_2 = \frac{-32.7621}{0.70299}$$

$\alpha_2 = -46.649$ rad/sec² | Minimum angular acceleration

at $\theta = 143.3°$

$$(\alpha_2)_{max} = \frac{32.7621}{0.7044059} = 46.5107 \text{ rad/sec}^2$$

$(T_2 - T_{stn}) = I\alpha_{max} \rightarrow T_2 - 135 = 1.0125 \times 46.514$

$(T_2)_{max} = 181.987$ N-M

from 100% efficiency

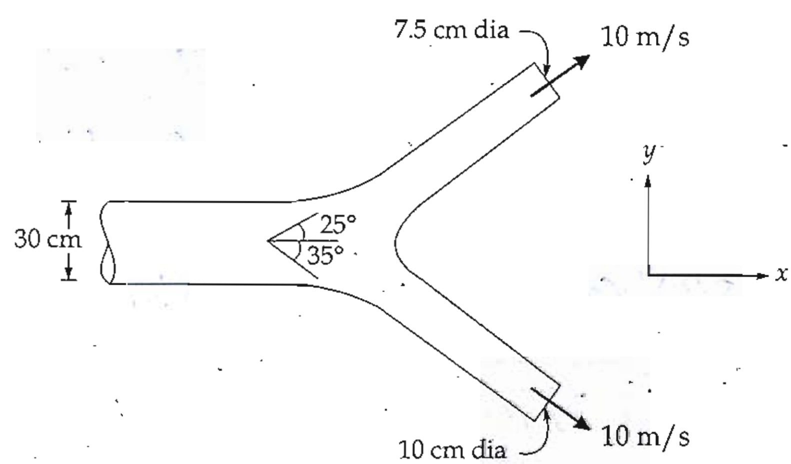
$(T_2)_{max}(\omega_2)_{max} = (T_1)_{max}\,\omega_1$

$181.981 \times 12.9613 = (T_1)_{max} \times 12.566$

$(T_1)_{max} = 187.784$ N-M

18

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]

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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]

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]

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Space for Rough Work

Space for Rough Work