(Mechanical) - Ignou

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ESE 2024 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-4 : Theory of Machines [All Topics]

Fluid Mechanics & Turbo Machinery-1 [Part Syllabus]

Heat Transfer-2 + Refrigeration and Air-conditioning-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	42
Q.2	57
Q.3	—
Q.4	46
Section-B	
Q.5	7
Q.6	—
Q.7	—
Q.8	30
Total Marks Obtained	182

Signature of Evaluator: Naveen V.

Cross Checked by

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.

Remarks:

- Representation is good.
- Accuracy is good.
- Many parts of compulsory question {Q5} not attempted
- Very less questions attempted in Section-B
- Practice more such questions and increase your speed.

Section : A

Q.1 (a) (i) How machine is different from mechanism. State Grashof's law and discuss the condition for which at least one link to make a full revolution.

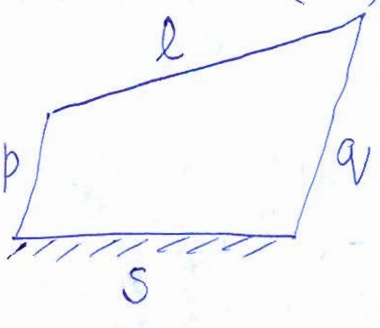
(ii) Discuss double slider crank chain mechanism and its inversions.

[6 + 6 marks]

Ans:– (i) A mechanism is a type of kinematic chain in which one link is fixed to obtain ~~to~~ from a constrained motion. Eg., single-slider crank mechanism.

And a machine is a device which utilises that mechanism to solve the daily world problem.
Eg., piston-cyl. arrangement in IC engine.

Grashof's Law :– It states that ~~for a const~~ in order to obtain constrained motion, the sum of length of longest and smallest link should be less than summation of length of other two links. $(s+l) \leq (p+q)$ → $\leq$



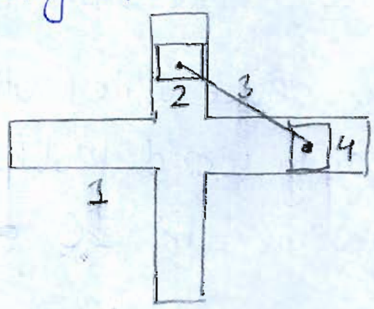
if shortest link is fixed, then we get double crank mechanism i.e, atleast one link makes full revolution.

(ii) In double slider crank mechanism, it consist of 2 sliders, one link connecting sliders and a plate.

– I-inversion : Elliptical Trammel :– When slotted plate is fixed. It is used to trace an ellipse ~~or~~ a circle.

II. ~~Oldham's Coupling~~ Scotch Yoke Mechanism :- either of the sliders is fixed to obtain reciprocation motion as output from rotating input.

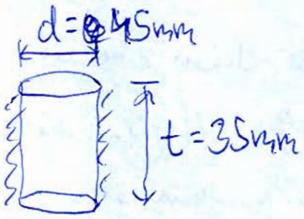
III :- ~~Scotch Yoke~~ Oldham's coupling :- The link connecting the sliders is fixed. It is used to connect two parallel shafts with lateral misallignment. It gives a constant velocity ratio.



Q.1 (b) A punching machine carries out 8 holes per minute. Each hole of 45 mm in 35 mm thick plate requires 9 Nm of energy/mm^2 of the sheared area. The punch has a stroke of 100 mm. Find the power of the motor required if the mean speed of the flywheel is 25 m/s. If total fluctuation of speed is not to exceed 3.5% of the mean speed, determine the mass of the flywheel.

[12 marks]

Ans- Total cycle time, $T_c = \frac{60}{8}$ sec. = 7.5 sec.



Area sheared = $\pi d t$

$= \pi \times 35 \times 45$

$= 4948.0084\ mm^2$

Total energy, $E = 9\ \frac{Nm}{mm^2} \times 4948.0084\ mm^2$

$= 44532.0758\ N\text{-}m$

Power of motor = $\frac{E}{T_c} = \frac{44532.0758}{7.5} = \boxed{5937.6101\ W}$ Ans-

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$(\Delta E)_{max} \rightarrow$ energy required through flywheel.

$= (P_{motor}) \times (T_c - T_a)$

For 2×stroke ⟶ 7.5 sec.

35 mm thick ⟶ $\frac{7.5}{2\times100} \times 35 = 1.3125$ sec. $= T_a$
↓
(Actual cutting time)

$(\Delta E)_{max} = 5937.6101 \times (7.5 - 1.3125)$
$= 36738.9624$ N-m $= I\omega^2 C_s$

$36738.9624 = mr^2\omega^2 C_s = mv^2 C_s$

$36738.9624 = m \times (25)^2 \times \frac{3.5}{100}$

$m = 1679.4954$ kg Ans.
↓
(mass of flywheel)

Q.1 (c) **(i)** Explain the differences between the flywheel and the governor.

(ii) Define the term interference. Discuss the methods that can be used to avoid interference.

[6 + 6 marks]

Ans-(i.) Flywheel :- It is a device which is used to reduce the cyclic fluctuations in speed by releasing energy when Energy required is less than available and absorbing energy when energy is surplus and more than required.

Better to show the difference in tabular form.

It reduces the cyclic fluctuation and do not eliminate it.

Governor :- It is a device which is used to maintain the machine at constant mean speed with varying load torque requirement. If load torque is more, then the sleeve moves downward, radius of rotation decreases, speed ↓, and hence fuel supply increases. If load torque is less, then the sleeve moves upward and rotates at high speed and hence, fuel supply decreases.

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(ii.) Interference :- When the involute tip of gear touches the non-involute portion of pinion (or vice-versa), then it removes some material from that part which causes rubbing and this is known as interference. Interference is caused due to the addendum of gears.

Methods to avoid interference :-

a) By undercutting - It the process of removing some material from non-involute portion of gear. It also decreases the

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strength of gear upto high extent. ~~B/a~~ Undercutting reduces interference but cannot eliminate it.

(b) By ~~a~~ increasing pressure angle :- Pressure angle and base circle radius are inversely proportional to each other due to which the non-involute part decreases. Pressure angle has limitation of about (20°, 25°) as it will also decrease the power transmission.

(c) By increasing no. of teeth :- Addendum decrease, Add. circle radius decreases, Pitch circle and pressure angle remains same, also contact ~~ratio~~ ratio increases due to which gear becomes strong.

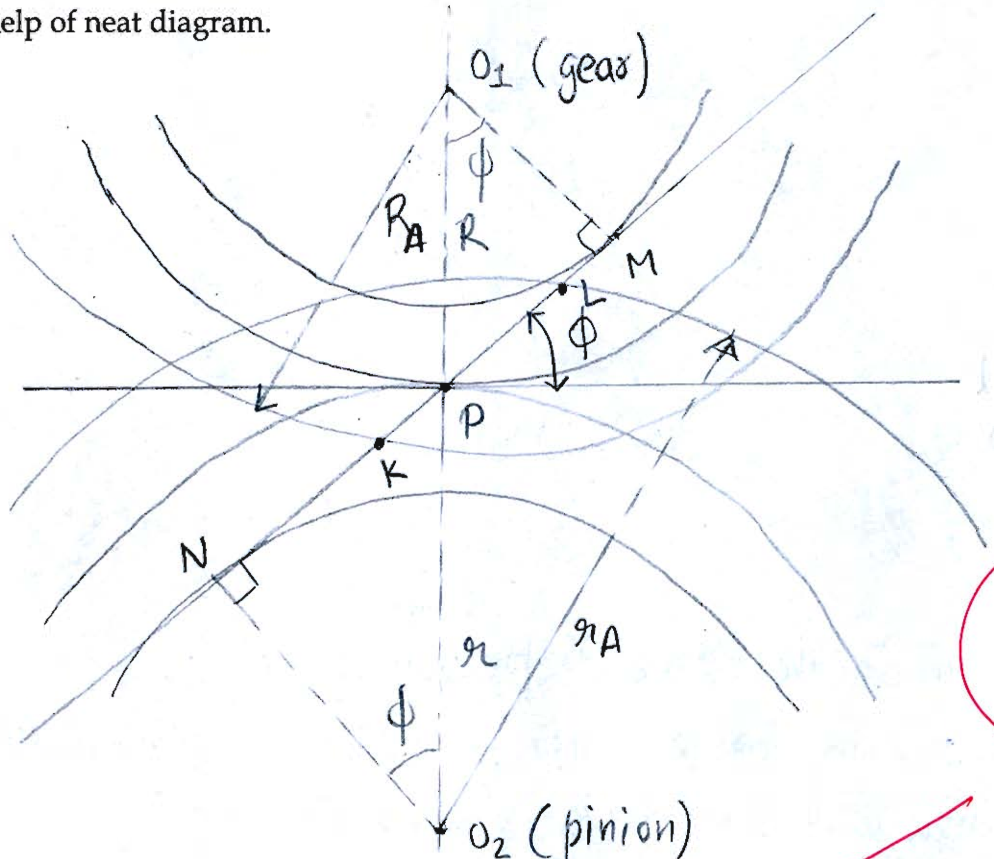
(d) By stubbing :- It decreases add. circle radius but also decreases contact ratio.

.1 (d) The exhaust from a single cylinder four stroke diesel engine is connected to a silencer and the pressure therein to be measured with a simple U-tube manometer. Calculate the minimum length of a manometer tube so that the natural frequency of oscillation of the liquid column will be 3.25 times slower than the frequency of pressure fluctuations in the silencer for an engine speed of 540 rpm.

[12 marks]

Q.1 (e) Distinguish between the pressure angle of a radial cam and that of a spur gear with the help of neat diagram.

[12 marks]



Spur gear diagram

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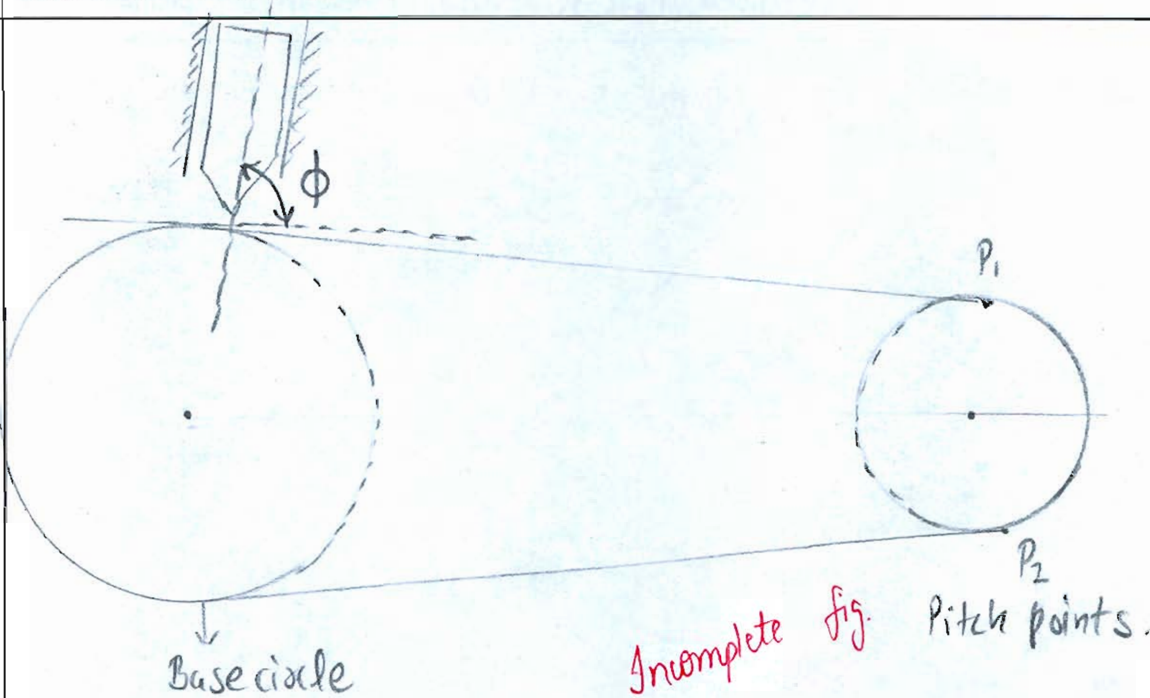
Pressure angle in Spur gear :- It is the angle between line of action of gears and common normal drawn to their base circle and passing through the fixed point. It's limit is (20°, 25°). High value leads to low power transmission and low value leads to interference in gears. So, 20° stubbed involute gears are ~~used~~ recommended.

Pressure angle in Cam :- It is the angle b/w line of motion of follower and the normal drawn to the cam profile. High pressure angle leads to jamming in the cam and follower.

$\phi \le 30° \rightarrow$ for reciprocation follower

$\phi \le 45° \rightarrow$ for oscillating follower.



At pitch points, the value of pressure angle is maximum and the circle which passes through pitch points and concentric with base circle is called pitch circle.

Q.2 (a) A machine has a total mass of 120 kg and unbalanced reciprocating parts of a mass 2 kg which moves through a vertical stroke of 90 mm with simple harmonic motion. The machine is mounted on four springs. The machine is having only one degree of freedom and can undergo vertical displacement only. Calculate the combined stiffness of the springs if the force transmitted to the foundation is $\frac{1}{25^{th}}$ of the applied force. Neglect damping and take the speed of rotation of the machine crank-shaft as 900 rpm. When the machine is actually supported on the springs. it is found that the damping reduces the amplitude of the successive free vibration to 70%. Determine:

(i) the force transmitted to the foundation at 900 rpm.

(ii) the force transmitted to the foundation at resonance, and

(iii) the amplitude of the forced vibrations at resonance.

[20 marks]

Ans- Given:- $M = 120\ kg$, $m_{reci} = 2\ kg$, $r = 0.045$

$\frac{F_T}{F_o} = \frac{1}{25}$, $N = 900\ rpm$, $\omega = \frac{2\pi \times N}{60} = 94.2477$ rad/s.

when:- $\xi = 0$ (no damping) -

$$\frac{1}{25} = \frac{\sqrt{1 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}} = \pm\frac{1}{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)}$$

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$$1-\left(\frac{\omega}{\omega_n}\right)^2 = -25 \Rightarrow 26 = \left(\frac{\omega}{\omega_n}\right)^2$$

$$\omega_n = \frac{94.2477}{\sqrt{26}} = 18.4835 = \sqrt{\frac{s}{M}}$$

$$(18.4835)^2 \times 120 = s$$

$\Rightarrow$ stiffness, $s = 40996.8182\ N/m$ Ans

when damping is observed:-

given:- $\frac{x_0}{x_1} = \frac{1}{0.7}$

So, logarithmic decrement →

$$\ln\left(\frac{1}{0.7}\right) = \frac{2\pi\xi}{\sqrt{1-\xi^2}} \Rightarrow \xi = 0.0566$$

(a) $F_o = m_{reci}\, r\, \omega^2 = 2 \times 0.045 \times (94.2477)^2$

$= 799.4366\ N$

$$\frac{\omega}{\omega_n} = \frac{94.2477}{18.4835} = 5.099$$

$$\frac{F_T}{F_o} = \frac{\sqrt{1+\left(\frac{2\times0.0566\times 94.2477}{18.4835}\right)^2}}{\sqrt{\left(1-(5.099)^2\right)^2+\left(2\times0.0566\times5.099\right)^2}}$$

$$\frac{F_T}{799.4366} = 0.004617 \Longrightarrow \boxed{(F_T)_{at\,N=900rpm} = 3.6909\,N}$$ Ans.

36.909 N

(ii):– at resonance :–

$$F_o = mr\omega_n^2 = 2\times0.045\times(18.4835)^2$$

$$= 30.7475\,N$$

$$\frac{F_T}{F_o} = \frac{\sqrt{1+(2\zeta)^2}}{\sqrt{0+(2\zeta)^2}} = \frac{\sqrt{1+(2\zeta)^2}}{2\zeta}$$

$$\frac{F_T}{30.7475} = \frac{\sqrt{1+(2\times0.0566)^2}}{2\times0.0566}$$

$$\Rightarrow \boxed{(F_T)_{resonance} = 273.3557\,N}$$ Ans

(iii):– Amplitude at resonance :–

$$A = \frac{(F_o/s)}{(2\zeta)} = \frac{30.7475}{2\times0.0566\times40996.8182}$$

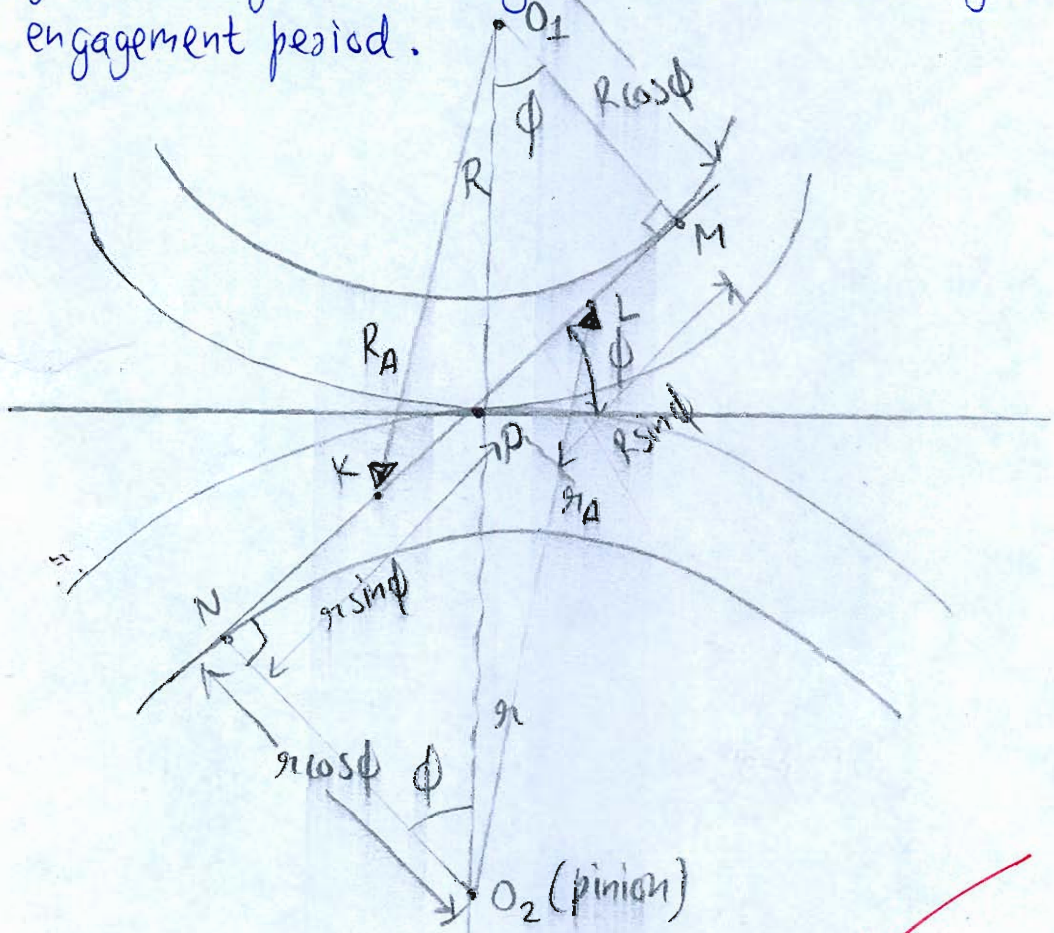
$$= 6.6254\times10^{-3}\,m = \boxed{6.6254\,mm}$$ Ans.

Q.2 (b) **(i)** Define arc of contact and deduce the expression to find its magnitude.

(ii) Each of two gears in a mesh has 54 teeth and a module of 8 mm. The teeth are of 20° involute profile. The arc of contact is 2.3 times the circular pitch. Determine the addendum.

[10 + 10 marks]

Ans- (i) Arc of contact :- It is the length on pinion or gear during which they are in contact during one engagement period.



Path of contact = KP + PL

KP ↓ start of engagement

PL ↳ end of engagement

In ΔO_1KM, $(O_1K)^2 = (O_1M)^2 + (KM)^2$

$$R_A^2 = R^2\cos^2\phi + (R\sin\phi + KP)^2$$

$$(R\sin\phi + KP)^2 = R_A^2 - R^2\cos^2\phi$$

$$\Rightarrow KP = \sqrt{R_A^2 - R^2\cos^2\phi} - R\sin\phi$$

similarly in ΔO_2LN,

$$(O_2L)^2 = (O_2N)^2 + (LN)^2$$

$$r_A^2 = r^2\cos^2\phi + (r\sin\phi + PL)^2$$

$$\sqrt{r_A^2 - r^2\cos^2\phi} = r\sin\phi + PL$$

$$\Rightarrow PL = \sqrt{r_A^2 - r^2\cos^2\phi} - r\sin\phi$$

Path of contact = KP + PL

$$\text{Arc of contact} = \frac{\text{Path of contact}}{\cos\phi}$$

$$\frac{\left(\sqrt{R_A^2 - R^2\cos^2\phi} - R\sin\phi\right) + \left(\sqrt{r_A^2 - r^2\cos^2\phi} - r\sin\phi\right)}{\cos\phi}$$

10

(ii) Given :- $T = t = 54$, $G = 1$, $\phi = 20°$, $m = 8\,mm$

Arc of ~~path~~ contact = 2.3 x (circular pitch)

$= 2.3 \times (\pi \times m) = 2.3 \times \pi \times 8$

$= 57.8053\ mm$

Path of contact = $(57.8053) \times \cos\phi = 54.3192\ mm$

$$54.3192 = \left(\sqrt{R_A^2 - R^2\cos^2\phi} - R\sin\phi\right) + \left(\sqrt{r_A^2 - r^2\cos^2\phi} - r\sin\phi\right)$$

as no. of teeth are same, so $\boxed{r = R} = \frac{mt}{2} = 216\,mm$

$$54.3192 = 2 \times \left(\sqrt{r_A^2 - r^2\cos^2\phi} - r\sin\phi\right)$$

$$54.3192 = 2 \times \left(\sqrt{r_A^2 - 216^2\cos^2 20°} - 216 \times \sin 20°\right)$$

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$\Rightarrow r_A = R_A = 226.7301$ mm

So, addendum $= (R_A - R) = (226.7301 - 216)$

$= \boxed{10.7301 \text{ mm}}$ Ans-

Q.2 (c) The driven shaft has a moment of inertia 3 g-m^2 and is inclined at 25° to the axes of the driving shaft. If the driving shaft rotates at 2700 rpm with a steady torque of 280 Nm, determine the maximum fluctuation of output torque. Also, determine the maximum and minimum torque at driving shaft.

[20 marks]

Ans- given:- $I_{driven} = I_2 = 0.003 \text{ kgm}^2$, $\alpha = 25°$

$\omega_{driver} = \omega_1 = \frac{2\pi \times 2700}{60} = 282.7433$ rad/s

$T_{mean} = 280$ N-m

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$\cos 2\theta = \frac{2\sin^2\alpha}{2-\sin^2\alpha} = \frac{2\sin^2 25°}{2-\sin^2 25} = 0.1961$

$2\theta = 78.6898, 281.3101$

$\theta = 39.3449, 140.655$

$\downarrow \theta_1 \quad \downarrow \theta_2$

Let $\omega_{driven} = \omega_2 = \frac{\omega_1 \cos\alpha}{(1-\cos^2\theta \cdot \sin^2\alpha)}$

$(\omega_2)_{\theta_1} = 286.8941 \text{ rad/s}$, $(\omega_2)_{\theta_2} = 286.8941 \text{ rad/s}^2$

$$(\alpha_2)_{\theta} = \frac{-\omega_1^2 \cos\alpha \sin 2\theta \cdot \sin^2\alpha}{(1 - \cos^2\theta \sin^2\alpha)^2} \rightarrow \alpha_{driven}$$

$(\alpha_2)_{\theta_1} = -15905.4877 \text{ rad/s}^2$, $(\alpha_2)_{\theta_2} = 15905.4877 \text{ rad/s}^2$

$$(T_2 - T_{mean}) = I_2\alpha_2$$

at $\theta = \theta_1$:- $(T_2 - T_{mean})_{\theta_1} = (I_2\alpha_2)_{\theta_1}$

$$((T_2)_{\theta_1} - 280) = 0.003 \times (-15905.4877)$$

$$\boxed{(T_2)_{\theta_1} = 232.2835 \text{ N-m}} \rightarrow (T_2)_{min}.$$

$$[(T_2)_{\theta_2} - 280] = 0.003 \times 15905.4877$$

$$\boxed{(T_2)_{\theta_2} = 327.7164 \text{ N-m}} \rightarrow (T_2)_{max}.$$

Fluctuation in output shaft $= (T_2)_{\theta_2} - (T_2)_{\theta_1}$

$$= \boxed{95.4329 \text{ N-m}} \text{ Ans -}$$

Now, driver shaft :-

$$T_1\omega_1 = T_2\omega_2 \Rightarrow T_1 = T_2 \frac{\omega_2}{\omega_1}$$

$$(T_1)_{\theta_1} = 232.2835 \times \frac{286.8941}{282.7433} = \boxed{235.6935 \text{ N-m}}$$

$\downarrow$ ($T_{minimum}$)

$$(T_1)_{\theta_2} = 327.7164 \times \frac{286.8941}{282.7433} = \boxed{332.5274 \text{ N-m}}$$

$\downarrow$ T_{max}

Q.3 (a) A door having mass moment of inertia of 19.25 kg-m^2 is fitted with an automobile door closer. The door opens against a spring with a modulus of 2 kg-cm/radian. If the door is opened 90° and released, how long will it take the door to be within 2° of closing? Assume the return spring of the door to be critically damped.

[20 marks]

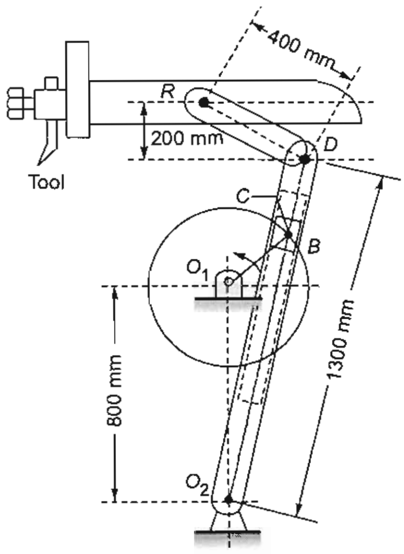
Q.3 (b) A quick return mechanism of the crank and slotted lever type shaping machine is shown in figure below. The links dimensions are as follows:

$O_1O_2 = 800$ mm; $O_1B = 300$ mm; $O_2D = 1300$ mm; $DR = 400$ mm

The crank O_1B makes an angle of 45° with the vertical and rotates at 40 rpm in anticlockwise direction. Determine:

(i) the velocity of ram, and

(ii) the angular velocity of link O_2D



(a) Configuration diagram

[20 marks]

Q.3 (c) The length of each connecting rod of a 60° V-engine is 240 mm and the stroke is 120 mm. The mass of the reciprocating part is 1.2 kg per cylinder and the crank speed is 3000 rpm. Determine the values of primary and secondary forces.

[20 marks]

Q.4 (a) Each wheel of a four-wheeled rear engine automobile has a moment of inertia of 2.5 kgm^2 and an effective diameter of 640 mm. The gear ratio of engine to back wheel is 3 to 1. The rotating parts of the engine have a moment of inertia of 1.25 kg-m^2. The engine axis is parallel to the rear axle and the crankshaft rotates in the same sense as the road wheels. The mass of the vehicle is 2500 kg and the centre of the mass is 560 mm above the road level. The track width of the vehicle is 1.6 m. Determine the limited speed of the vehicle around a curve with 80 m radius so that all the four wheels maintain contact with the road surface.

[20 marks]

Ans- given :- $I_{wheel} = 2.5\ kgm^2$, $r_w = 0.64 m$, $G = 3$

$I_e = 1.25\ kg\text{-}m^2$, $M = 2500 kg$, $h = 0.56m$, $x = 1.6 m$

$R = 80 m$. Let speed of car be 'v'.

$$\omega_w = \frac{V}{r} = \frac{V}{0.64} = 1.5625V, \quad \omega_E = \frac{V \times G}{r} = \frac{V\times 3}{0.64} = 4.6875V$$

$$\omega_p = \frac{V}{R} = \frac{V}{80} = 0.0125V$$

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weight ~~centrifugal~~ effect :-

$$\text{For each wheel} = \frac{mg}{4} = \frac{2500\times 9.81}{4} = 6131.25\ kg$$

centrifugal effect :-

$$Q = \frac{mV^2}{R}\times h = \frac{2500\times V^2}{80}\times 0.56 = 17.5V^2$$

$$\frac{Q}{2x} = 5.4687V^2$$

Engine effect :-

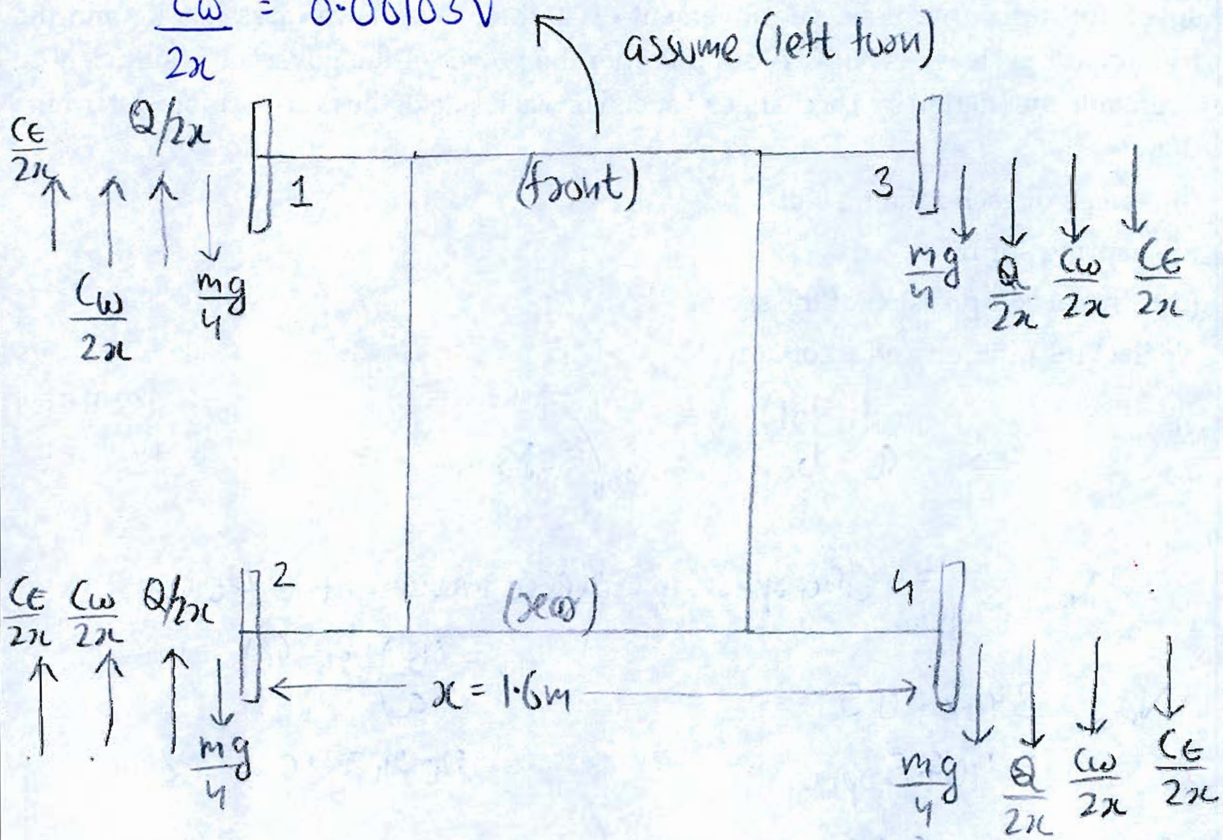
$$C_E = I_E\omega_E\omega_p = 1.25\times 4.6875V\times 0.0125V = 0.07324V^2$$

$$\frac{C_E}{2x} = 0.02288V^2$$

wheel effect :-

$$C_\omega = 4 \times I_\omega \omega_\omega \omega_p = 4 \times 2.5 \times 1.5625 V \times 0.0125 V$$
$$= 0.1953 V^2$$

$$\frac{C_\omega}{2x} = 0.06103 V^2$$



Hence, rxn. on wheel 1 and 2 are same, and on 3 and 4 are same.

Rxn. on 1 and 2 :- $\left(\frac{C_E}{2x} + \frac{C_\omega}{2x} + \frac{Q}{2x} - \frac{mg}{4}\right) = 5.5526 V^2 - 6131.25$

Rxn. on 3 and 4 :- $\left(\frac{C_E}{2x} + \frac{C_\omega}{2x} + \frac{Q}{2x} + \frac{mg}{4}\right) = 5.5526 V^2 + 6131.25$

Wheel 1 and 2 can lift.

So, $5.5526 V^2 - 6131.25 = 0$

$$\boxed{V = 33.2296 \text{ m/s}}$$ Ans

(limiting speed to maintain the contact with road.)

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Q.4 (b) The arms of Hartnell governor are of equal length. When the sleeve is in the mid-position, the masses rotate in a circle with diameter of 160 mm (the arms are vertical in the mid-position). Neglecting friction, the equilibrium speed for this position is 390 rpm. Maximum speed variation, taking friction into account, is to be 5% of the mid-position speed for a maximum sleeve movement of 40 mm. The sleeve mass is 6 kg and the friction at the sleeve is 36 N. Assuming that the power of the governor is sufficient to overcome the friction by 1% change of speed on each side of the mid-position, determine the

(i) mass of each rotating ball

(ii) spring stiffness

(iii) Initial compression of the spring

Neglect the obliquity effect of arms

[20 marks]

Ans given:- $a = b$, $r_{mean} = 80\text{ mm} = \frac{r_1 + r_2}{2}$ --- (1)

$N_{mid\text{-}position} = 390$ rpm, sleeve movement = 40 mm

$40 = \left(\frac{b}{a}\right)(r_2 - r_1)$

$r_2 - r_1 = 40$ --- (2)

$N_{max} = 390 \times 1.05$
$= 409.5$ rpm

$N_{min} = 390 \times 0.95 = 370.5$ rpm

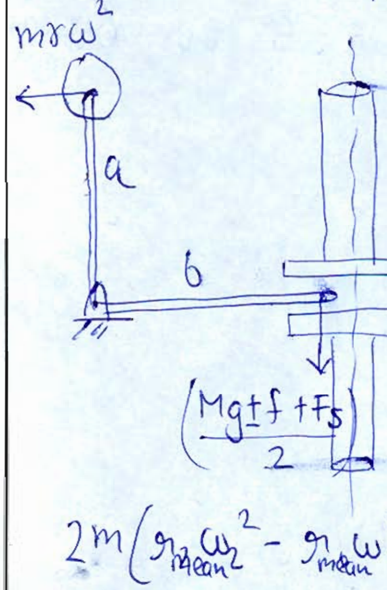
From (1) and (2) :-
$r_1 = 60$ mm, $r_2 = 100$ mm

$M_{sleeve} = M = 6$ kg, $f = 36$ N

(i):-
at mid position :-

$N_{mid}(+f) = 1.01 \times 390 = 393.9$ rpm $= N_2$

$N_{mid}(-f) = 0.99 \times 390 = 386.1$ rpm $= N_1$



$m r_1 \omega_1^2 \times a = \left(\frac{Mg - f + F_{s1}}{2}\right) \times b$ --- (3)

$m r_2 \omega_2^2 a = \left(\frac{Mg + f + F_{s2}}{2}\right) b$ --- (4)

Subtract (4) - (3) :-

$2m\left(r_{mean}\omega_2^2 - r_{mean}\omega_1^2\right) = \left(F_{s2} - F_{s1}\right) + (2 \times f)$

same radius

$\omega_1 = 2\pi \times \frac{386.1}{60} = 40.4322\, rad/s$, $\omega_2 = 41.2491\, rad/s$

$2m\left[0.08^2 \times 41.2491^2 - 0.08^2 \times 40.4322^2\right] = (2\times 36)$

$0.85408\, m = 72 \Rightarrow \boxed{m = 84.3012\, kg}$ Ans

(ii):-

Nmax :- (at upper position) :-

$m \times r_2 \times \omega_{max}^2 \times a = \left(\frac{Mg + f + F_{S_2}}{2}\right) \times b$

$84.3012 \times 0.1 \times \left(\frac{\pi \times 409.5}{30}\right)^2 = \left(\frac{(6\times 9.81) + 36 + F_{S_2}}{2}\right)$

$F_{S_2} = 30909.9304\, N$

Refer solution

Nmin :- (at lower position) :-

$m r_1 \omega_{min}^2 \times a = \left(\frac{Mg - f + F_{S_1}}{2}\right) \times b$

$84.3012 \times 0.06 \times \left(\frac{\pi \times 370.5}{30}\right)^2 = \left(\frac{(6\times 9.81) - 36 + F_{S_1}}{2}\right)$

$F_{S_1} = 15205.3432\, N$

$(F_{S_2} - F_{S_1}) = s(x_2 - x_1) \Rightarrow \boxed{s = 392614.6799\, N/m}$

$= 392.614\, N/mm$ Ans

(iii):-

$F_{S_1} = s x_1 \Rightarrow x_1 = \frac{F_{S_1}}{s}$

$x_1 = \frac{15205.3432}{392614.6799} = 0.03872\, m$

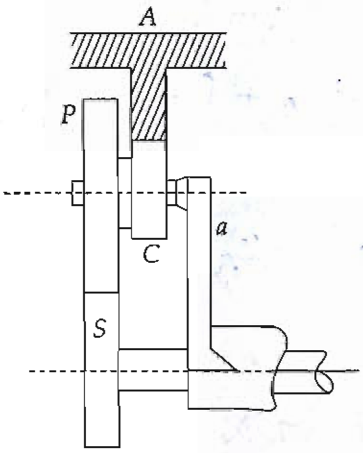
$= \boxed{38.7284\, mm}$ Ans

Q.4 (c) **(i)** Make a comparison of cycloidal and involute tooth forms.

(ii) The number of teeth in the gear train shown in figure below are as follows:

$T_S = 18, T_P = 24, T_C = 12, T_A = 72$

P and *C* form a compound gear carried by the arm '*a*' and the annular gear *A* is held stationary. Determine the speed of the output at '*a*'. Also, find the holding torque required on *A* if 6 kW is delivered to *S* at 840 rpm with an efficiency of 95%. In case the annulus *A* rotates at 100 rpm in the same direction as *S*, what will be the new speed of '*a*'?



[6 + 14 marks]

15

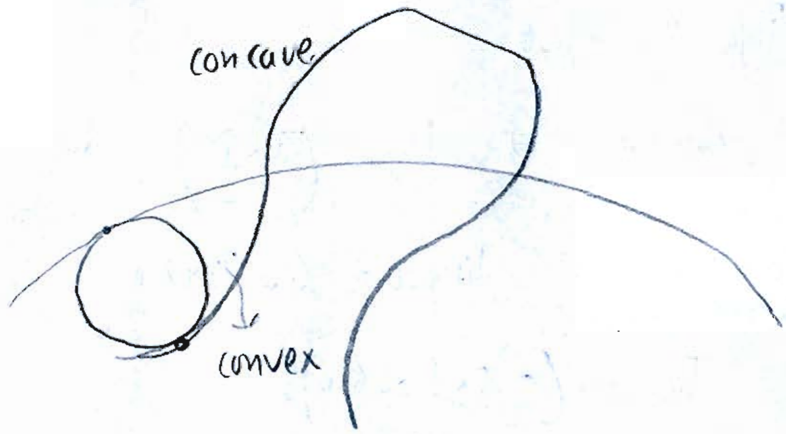
Ans- (i):- Involute Tooth :-

- It is formed by the locus of the point on the line rotating on a fixed circle.
- It has only ~~concave~~ concave profile.
- Only tooth which can be used even under vibrations.

Cycloidal Tooth :-

- It is formed by the locus of the point on the circle which rolls without slipping on a fixed line.
- These are having convex- concave profile.
- These tooth have undercutting.
- Pressure angle is maximum at start of engagement,

and zero at centre and max. at point of disengagement.



(ii):-

	Arm	S (18)	P/C (24/12)	A (72)
1)	0	$+x$	$-x\times\frac{18}{24}$	$-x\times\frac{18}{24}\times\frac{12}{72}$
2)	Let y	$y+x$	$y-\frac{3x}{4}$	$y-\frac{x}{8}$

$N_S = y+x = 840$

$N_A = 0 = y-\frac{x}{8} \Rightarrow y=\frac{x}{8}$

$\frac{x}{8}+x = 840 \Rightarrow x = 746.666\ rpm$

$y = 93.333\ rpm$

$N_{output} = N_{P/C} = y-\frac{3x}{4} = \boxed{-466.666\ rpm}$ Ans

-ve sign shows that N_{output} rotates opposite to direction of N_{input} i.e., gear S.

$$\eta = \frac{T_{output} \times \omega_{output}}{T_{input} \times \omega_{input}} = 0.95$$

$T_{input} \times \omega_{input} = \text{Power} \Rightarrow T_{input} \times \left(\frac{\pi \times 840}{30}\right) = 6000$

$T_{input} = 68.2092 \text{ N-m}$

$$0.95 = \frac{T_{output} \times \left(-\frac{\pi \times 466.666}{30}\right)}{6000}$$

$T_{output} = -116.638 \text{ N-m}$

$\Sigma \text{Torque} = 0 \Rightarrow T_{inp.} + T_{out.} + T_{holding} = 0$

$68.2092 + (-116.638) + T_{holding} = 0$

$\boxed{T_{holding} = 48.4288 \text{ N-m}}$ Ans

When A rotates at 100 rpm :-

$y - \frac{x}{8} = 100$ and $x + y = 840$

$y = 100 + \frac{x}{8}$ $\quad x + 100 + \frac{x}{8} = 840$

$y = 182.222 \text{ rpm}$ $\quad x = 657.777 \text{ rpm}$

$\therefore N_a = N_{output} = \left(y - \frac{3x}{4}\right) = \boxed{-311.1107 \text{ rpm}}$ Ans

-ve sign shows that N_a rotates in opposite dirn to that of gear S and A.

Section : B

Q.5 (a) A vertical rectangular gate, 5 m high and 3 m wide, has water on one side to a depth of 3 m and a liquid of specific gravity 0.85 to a depth of 2 m on the other side. Calculate:

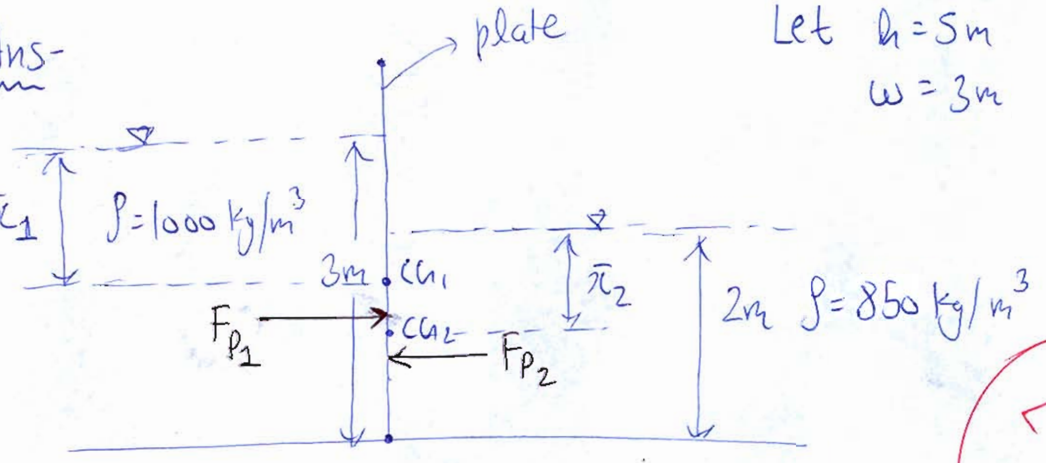
(i) total pressure exerted on each side of the gate and

(ii) resultant hydraulic pressure both in magnitude and point of application with respect to the bottom.

[12 marks]

Ans-

Let $h = 5m$, $w = 3m$



7

(a.) $F_{P_1} = \rho g \bar{x} A = 1000 \times 9.81 \times 1.5 \times (3 \times 3)$

$= 132.435\ kN$ (on water side)

$F_{P_1} = \rho g \bar{x} A = 950 \times 9.81 \times 1 \times (2 \times 3)$ → 850

$= 55.917\ kN$ (on liquid side)

(b) Resultant pressure force $= F_{P_1} - F_{P_2}$

$= 76.518\ kN$

Point of application of $F_{P_1} = \bar{y}_1 = \frac{2}{3} h_1 = \frac{2}{3} \times 3 = 2m$

$= 1m$ (from bottom)

Point of application of $F_{P_2} = \bar{y}_2 = \frac{2}{3} h_2 = \frac{2}{3} \times 2 = \frac{4}{3} m$

$= 0.6667\ m$ (from bottom)

Refer solution

Q.5 (b) In a centrifugal pump, the outside diameter D_2 is twice the inner diameter D_1. For this condition, show that the minimum diameter of an impeller which will enable it to pump water to a head H_e metres at a speed of N rpm at a manometric efficiency of 0.75 is

$$D_2 = 84.6\frac{\sqrt{H_e}}{N}$$

where H_e is theoretical head generated by a centrifugal impeller.

[12 marks]

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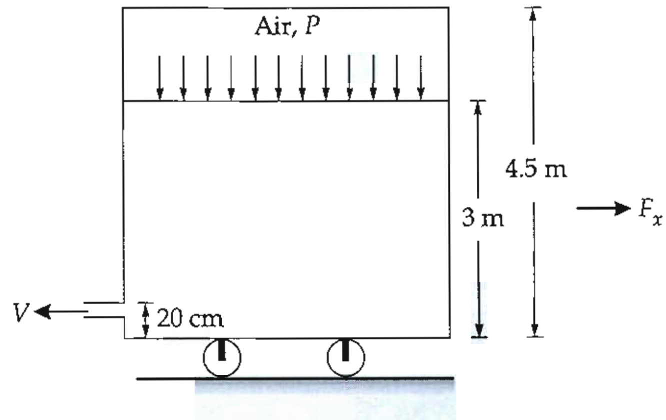
Q.5 (c) Define Lambert's cosine law of radiation and prove that intensity of radiation is always constant at any angle of emission for a diffused surface.

[12 marks]

Q.5 (d) Describe briefly the working principle of the vortex tube refrigeration system. Also, write the general expression for C.O.P. of the vortex tube.

[12 marks]

Q.5 (e) A closed tank 2 m × 2.5 m in plan × 4.5 m high weighing 1250 N is filled with water to a depth of 3 m as shown below. A hole in one of the side walls has an effective area of 7.5 cm^2 and is located 20 cm above the tank bottom. If the coefficient of friction between the ground and the wheels is 0.015, determine the air pressure in the tank that is required to set it into motion.



[12 marks]

Q.6 (a) An inward flow reaction turbine with vertical shaft operates under a net head of 25 m and consumes 10 m^3/s of water while running at 250 rpm. The inlet angle of runner vane is 115° measured from the direction of runner rotation. Entry of water to the runner is without shock and with a velocity of flow 6.5 m/s, and to the draft tube is without whirl and with a velocity of 6 m/s. Discharge velocity from the exit of draft tube is 2.5 m/s. The height of the runner entry surface is 1.5 m and the entrance to the draft tube is 1.2 m above the tail race level. Assuming a hydraulic efficiency of 90% and mechanical efficiency as 95%. Make calculations for

(i) diameter of the runner at entry surface.

(ii) pressure head at entry to the runner and at entrance to the draft tube if friction loss in the runner is 0.9 m and that in the draft tube is 0.6 m of water.

(iii) specific speed of the turbine runner.

[20 marks]

Q.6 (b) **(i)** Write the assumptions made in Nusselt's analysis of laminar film condensation on a vertical plate.

(ii) An electric wire of 1.5 mm diameter and 250 mm long is laid horizontally and submerged in water at atmospheric pressure. The wire has an applied voltage of 20 V and carries a current of 45 ampere. Calculate

1. The heat flux, and
2. The excess temperature

The following correlation for water boiling on horizontal submerged surface holds good:

$$h = 1.58\left(\frac{Q}{A}\right)^{0.75} = 5.62(\Delta t_e)^3 \text{ W/m}^2{}^\circ\text{C}$$

where, Δt_e denotes the excess temperature.

[8 + 12 marks]

.6 (c) An air-conditioned space is maintained at 27°C DBT and 50% relative humidity. The ambient conditions are 40°C DBT and 27°C WBT. The space has a sensible heat gain of 25 kW. Air is supplied to the space at 7°C saturated. Calculate

(i) Mass of moist air supplied to the space in kg/h;

(ii) Latent heat gain of space in kW;

(iii) Cooling load of air washer in kW if 30% of the air supplied to the space is fresh, the remainder being recirculated.

[For moist air, take c_{pm} = 1.022 kJ/kgK; h_{fg} = 2500 kJ/kg]

[*Use Psychrometric chart attached*]

[20 marks]

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.7 (a) A counter-flow concentric tube heat exchanger is used to cool the lubricating oil for a large industrial gas turbine engine. The flow rate of cooling water through the inner tube is 0.2 kg/s, while the flow rate of oil through the outer annulus is 0.5 kg/s. The inlet and outer temperatures of oil are 90°C and 60°C, respectively. The water enters at 25°C to the exchanger. The inner tube diameter and outer annulus diameter are 25 mm and 50 mm respectively. Neglecting tube wall thermal resistance, fouling factors and heat loss to the surroundings, calculate the overall heat transfer coefficient and length of the tube. Assuming uniform temperature along the inner surface of annulus. Take the following properties at the bulk mean temperature:

Engine oil : c_p = 2120 J/kgK, μ = 0.0325 N-s/m^2; k = 0.14 W/mK

Water : c_p = 4180 J/kgK, μ = 725 × 10^{-6} N-s/m^2; k = 0.625 W/mK, Pr = 4.85

[20 marks]

7 (b) Air at 12°C DBT and 70% RH is to be heated and humidified to 36.5°C DBT and 21°C WBT. The air is preheated sensibly before passing to the air washer in which water is recirculated. The relative humidity of the air coming out of the air washer is 70%. This air is again reheated sensibly to obtain the final desired condition. Determine:

(i) Temperature to which the air should be preheated.

(ii) Total heating required.

(iii) Make up water required in the air washer.

(iv) Humidifying efficiency of the air washer.

[*Use Psychrometric Chart Attached*]

[20 marks]

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(c) A converging two-dimensional channel of length 1.5 m has a linear area variation. The depth of channel at inlet and outlet are 0.5 m and 0.2 m respectively. The flow rate of incompressible fluid is constant at 0.95 m^3/s per metre of channel width. Specify the acceleration as a function of distance x and determine its value at a point 0.3 m from the beginning of converging section. What would be the acceleration if the flow is unsteady and it increases at the rate of 0.18 m^2/s per unit width of channel.

[20 marks]

(a) A propeller turbine has been designed to develop 25000 kW under a head of 25 m, while running at 160 rpm. The relevant data is :

Hydraulic efficiency = 92%

Overall efficiency = 88%

Outer diameter = 5 m

Hub diameter = 2 m

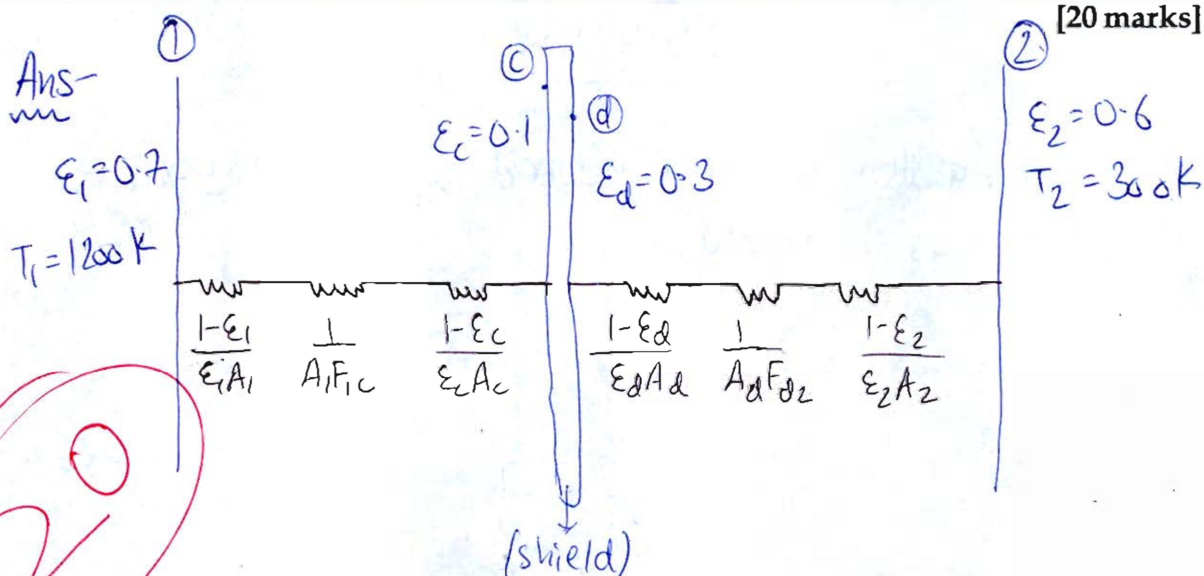
Determine the runner vane angles at the hub and at the outer periphery. Assume that the turbine discharges without whirl at exit.

[20 marks]

b) Consider two large parallel plates, one at 1200 K with emissivity 0.7 and other at 300 K having emissivity 0.6. A radiation shield is placed between them. The shield has emissivity as 0.1 on the side facing hot plate and 0.3 on the side facing cold plate. Calculate the percentage reduction in radiation heat transfer as a result of radiation shield.

[20 marks]

Ans-



$$Q_{without\,shield} = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1-\varepsilon_1}{\varepsilon_1 A_1}\right) + \frac{1}{A_1 F_{12}} + \left(\frac{1-\varepsilon_2}{\varepsilon_2 A_2}\right)}$$

$$\frac{Q_{\text{without shield}}}{A} = \frac{5.67\times10^{-8}\left(1200^4 - 300^4\right)}{\frac{1-0.7}{0.7} + \frac{1}{1} + \frac{1-0.6}{0.6}}$$

$$= 55895.2465 \text{ W/m}^2$$

$$\frac{Q_{\text{with shield}}}{A} = \frac{5.67\times10^{-8}\left(1200^4 - 300^4\right)}{\frac{1-0.7}{0.7} + 1 + \frac{1-0.1}{0.1} + \frac{1-0.3}{0.3} + 1 + \frac{1-0.6}{0.6}}$$

$$= 8116.8014 \text{ W/m}^2$$

$$\text{\%age reduction} = \frac{\left(\frac{Q}{A}\right)_{\text{without}} - \left(\frac{Q}{A}\right)_{\text{with shield}}}{\left(\frac{Q}{A}\right)_{\text{without}}} \times 100$$

$$= \boxed{85.4785\%}$$ Ans.

→ Heat transfer has been reduced by 85.4785% when there was no shield.

(c) A double acting single-cylinder reciprocating pump of 20 cm bore and 50 cm stroke runs at 40 rpm. The pump draws water from a sump 1 m below the pump through a suction pipe 10 cm in diameter and 2.5 m long. The water is delivered to a tank 35 m above the pump through a delivery pipe 10 cm in diameter and 40 m long. Determine the net force due to fluid pressure on the piston when crank has moved through 60° from the inner dead centre. Neglect size of piston rod and take friction coefficient $f = 0.0075$ for both suction and delivery pipes. Atmospheric head at the location is 10.3 m of water.

[20 marks]

Ans given :- $D = 0.2\,m$, $l = 0.5\,m$, $r = 0.25\,m$, $N = 400\,rpm$

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suction pipe → $d_s = 0.1\,m$, $l_s = 2.5\,m$, $h_s = 1\,m$

delivery pipe → $d_d = 0.1\,m$, $l_s = 40\,m$, $h_d = 35\,m$

$\frac{P_{atm}}{\rho g} = h_{atm} = 10.3\,m$, $f' = 0.0075$, $f = 4 \times f' = 0.03$

friction head :-

$$h_{fs} = \frac{f L_s V_s^2}{2g\,d_s} = \frac{f \times L_s}{2g\,d_s}\left(\frac{A}{A_s} r\omega \sin\theta\right)^2$$

$$h_{fs} = \frac{0.03 \times 2.5}{2 \times 9.81 \times 0.1} \times \left[\left(\frac{0.2}{0.1}\right)^2 \times 0.25 \times \left(\frac{\pi \times 40}{30}\right) \sin\theta\right]^2$$

$$= 0.6707 \sin^2\theta$$

$$h_{fd} = \frac{f L_d V_d^2}{2g\, d_d} = \frac{0.03 \times 40}{2 \times 9.81 \times 0.1}\left[\left(\frac{0.2}{0.1}\right)^2 \times 0.25 \times \left(\frac{\pi 40}{30}\right)\sin\theta\right]^2$$

$$= 10.7314 \sin^2\theta$$

at $\theta = 60^\circ$, $h_{fs} = 0.503\,m$

$h_{fd} = 8.0485\,m$

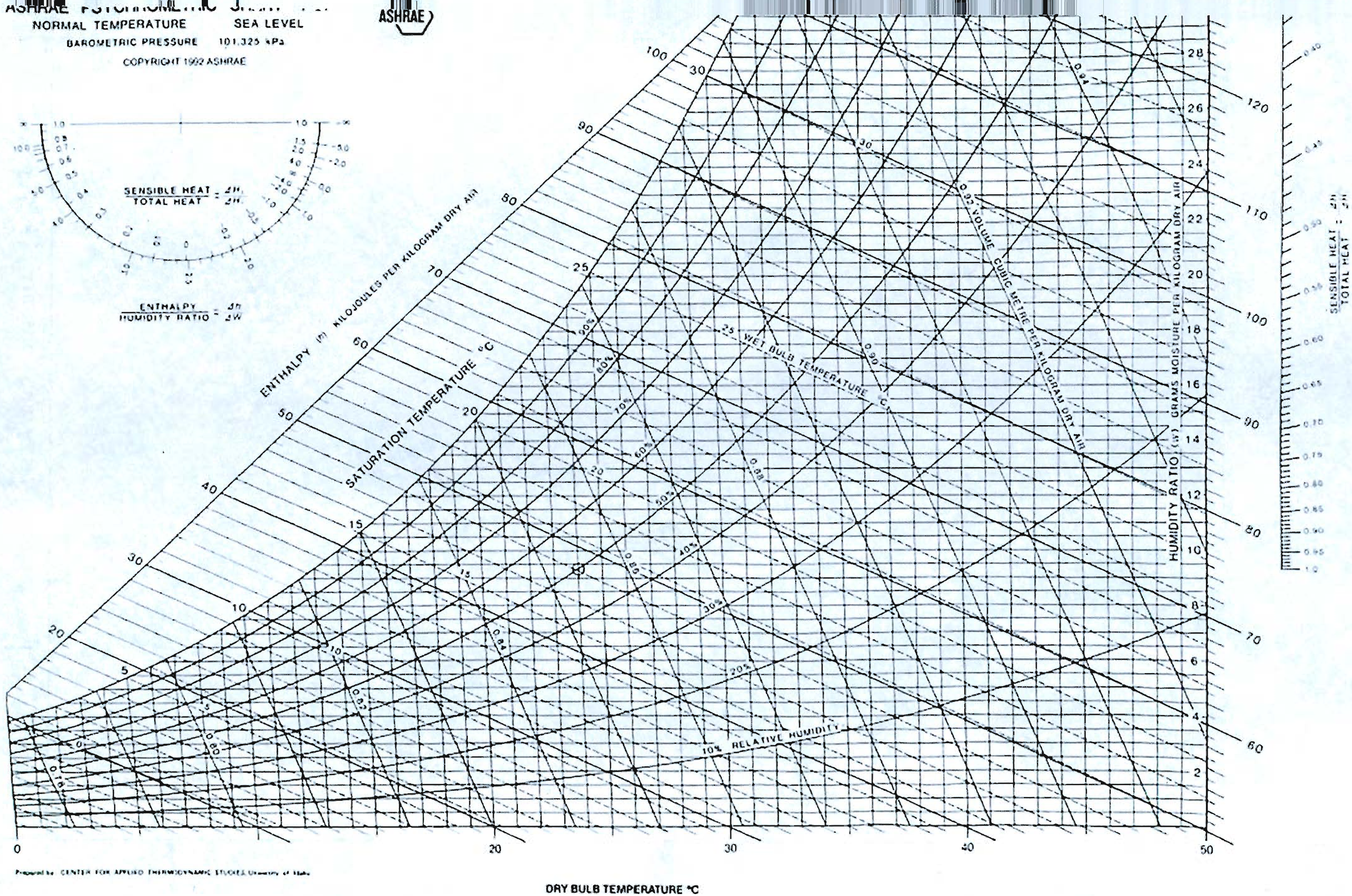
$$\text{work done} = \frac{2ALN}{60} \times \left(h_s + h_d + \frac{2}{3}h_{fs} + \frac{2}{3}h_{fd}\right)$$

$$= 2 \times \frac{\pi}{4}(0.2)^2 \times 0.5 \times \frac{40}{60}\left(1 + 3.5 + 0.503 + 8.0485\right)$$

$$= \boxed{0.9326 \text{ Watt.}}$$

Refer solution

OOOO


ASHRAE PSYCHROMETRIC CHART
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa
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SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔHt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO (W) GRAMS MOISTURE PER KILOGRAM DRY AIR
DRY BULB TEMPERATURE °C
Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho

Space for Rough Work

Space for Rough Work