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ESE 2023 : 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	
Q.2	
Q.3	
Q.4	
Section-B	
Q.5	
Q.6	
Q.7	
Q.8	
Total Marks Obtained	183

Signature of Evaluator .... 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.

Section : A

Q.1 (a) (i) The crank of a crank and slotted lever quick return mechanism is driven at 240 rpm clockwise. The vertical distance between the centres of rotation of the crank and slotted lever is 100 cm. What should be the length of the crank if the quick return ratio is 1 : 2? Also, determine the angular velocity of the slotted lever when the tool post attains maximum velocity during cutting stroke.

(ii) Compare involute tooth profile with cycloidal tooth profile for a gear.

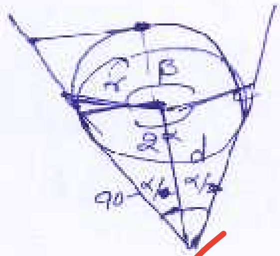
[6 + 6 marks]

Ans:- a i)

$N_{crank} = 240$ rpm.

$l = 100$ cm

$QRR = \frac{1}{2}$



$QRR = \frac{360 - 2\alpha}{2\alpha}$

$\frac{1}{2} = \frac{360 - 2\alpha}{2\alpha}$

$2\alpha = 720 - 4\alpha$

$6\alpha = 720°$

$\alpha = 120°$

$V_{max} = \omega_{slotted} \times$

$(V_{max})_f = r\omega \frac{l}{(l+r)} = \frac{100}{3} \times \frac{2\pi \times 240}{60} \times \frac{100}{(100 + \frac{100}{3})}$

$\Rightarrow \frac{8\pi}{3} \times \frac{3}{4} \Rightarrow 2\pi$ m/s.

$(V_R)_{max} = r\omega \frac{l}{(l-r)}$

$\frac{1}{2} = \frac{l-r}{l+r}$

$l + r = 2l - 2r$

$3r = l$

$r = \frac{100}{3}$ cm

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ii)

Cycloidal tooth profile	Involute tooth profile
a) pressure Angle (ϕ) is maximum at start & end point & minimum at pitch point.	a) ϕ is Const. throughout the gear profile
b) Double Curve is required bcz Epicycloid & hypocycloid profile for gear.	b) A Single Curve profile is required.
c) Degined should be difficult.	c) Design should be Simple.
d) Interference doesn't occurs.	d) Interference occures when the no. of teeth is minimum on gear profile.

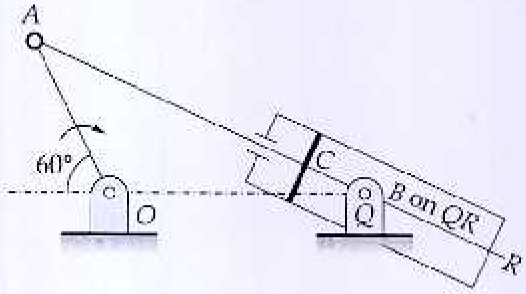
Q.1 (b) In the pump mechanism shown in figure, OA = 320 mm, AC = 680 mm and OQ = 650 mm. For the given configuration, determine the

(i) angular velocity of the cylinder.

(ii) sliding velocity of the plunger.

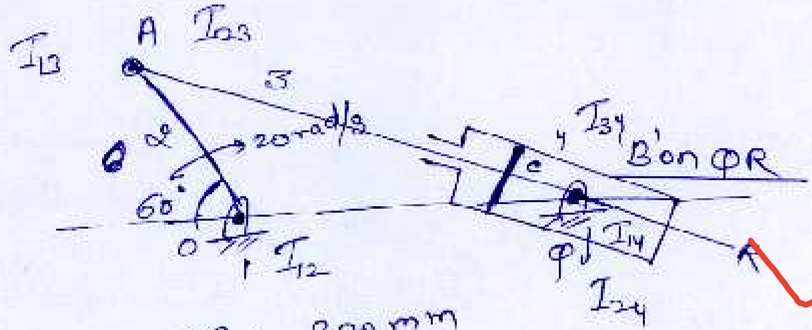
(iii) absolute velocity of the plunger.

The crank OA rotates at 20 rad/s clockwise.



[12 marks]

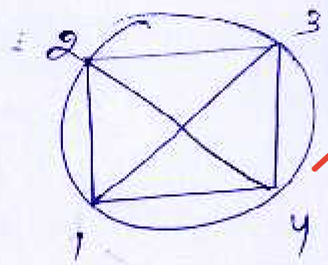
Ans:-



OA = 320 mm

AC = 680 mm

OQ = 650 mm.



$$\omega_2 (I_{12} I_{23}) = \omega_4 (I_{14} I_{24})$$

2/12

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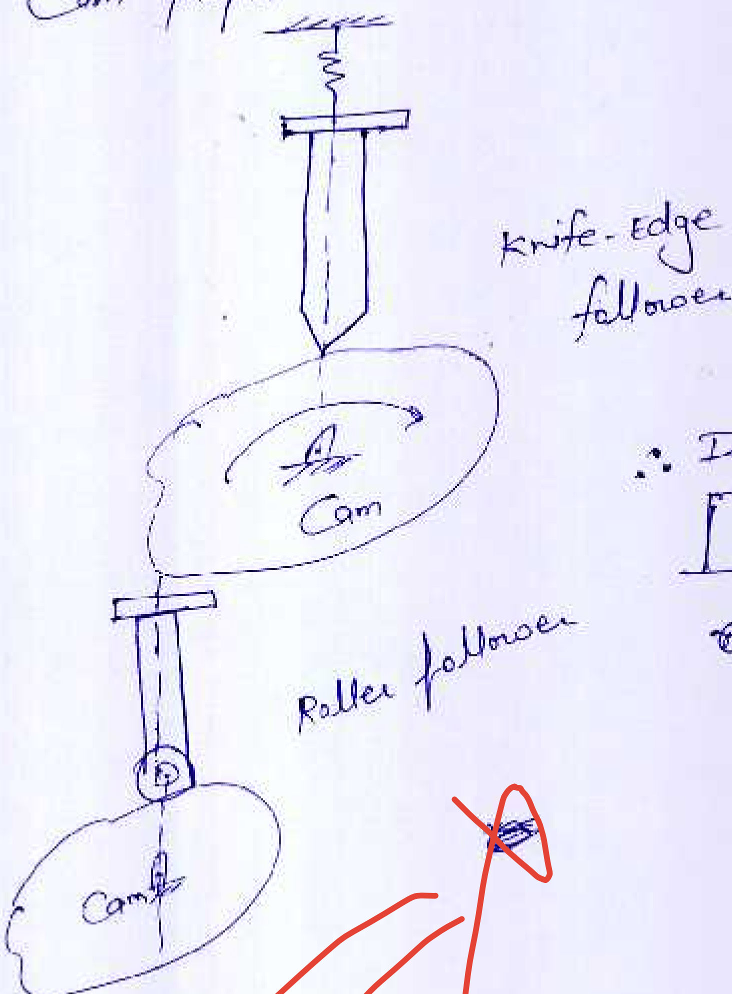
Q.1 (c) Define the terms used in radial cams with the help of a neat sketch.

[12 marks]

Ans:-

Radial Cams :- The axis of follower passing through the centre of Cam profile is called as radial Cam.



∴ Displacement by follower

$x = e - e\cos\omega t$

$e \Rightarrow$ offeset of follower

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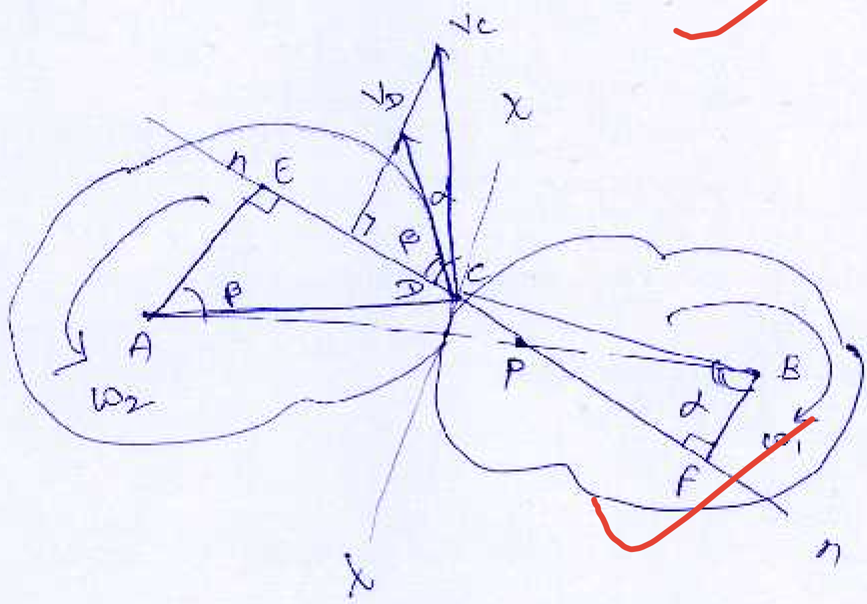
Q.1 (d) Explain the fundamental law of gearing with a neat sketch.

[12 marks]

Ans:- The fundamental Law of gearing :-



$V_C = \omega_1 \times BD$ ——— (1)

$V_D = \omega_2 \times AC$ ——— (2)

Velocity Component along n-n axis.

$V = V_C \cos\alpha - V_D \cos\beta$

$V = V_C \times \frac{BF}{BD} - V_D \times \frac{AE}{AC}$

$0 = V = \omega_1 \times BD \times \frac{BF}{BD} - \omega_2 \times AC \times \frac{AE}{AC}$

$$\boxed{\frac{\omega_1}{\omega_2} = \frac{AE}{BF} = \frac{AP}{BP} = \frac{EP}{FP}}$$

$\Delta BFD \cong \Delta AEC$

$$\boxed{\frac{AP}{BP} = \frac{EP}{FP}}$$

Velocity Component along t-t axis

$$V_{sliding} = (\omega_1 + \omega_2) \times PC$$

The ratio of angular Velocity is Constant throughout Somewhat the little Variation in pressure angle in gear tooth profile.

12/12

Q.1 (e) In a Hartnell governor, the extreme radii of rotation of the balls are 30 mm and 70 mm, and the corresponding speeds are 320 rpm and 350 rpm. The mass of each ball is 5 kg. The length of the ball arm and the sleeve arm are 80 mm and 40 mm respectively. Determine the initial compression and the constant of the central spring.

[12 marks]

Ans:-

$r_1 = 30\,mm$; $N_1 = 320$ rpm

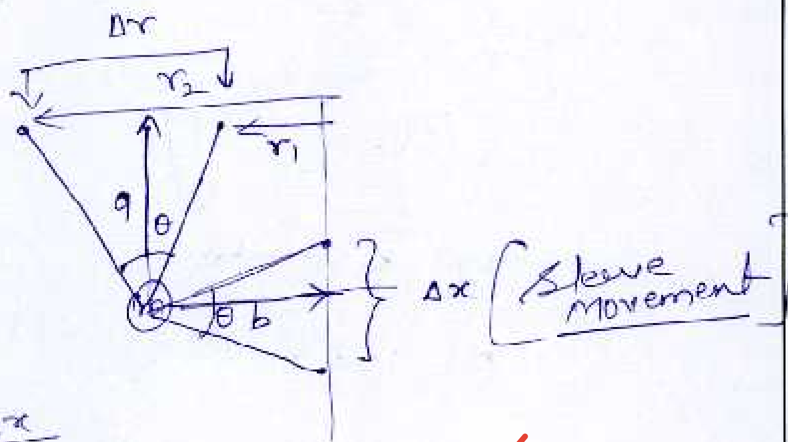
$r_2 = 70\,mm$; $N_2 = 350$ rpm

$m = 5\,kg$

$a = 80\,mm$

$b = 40\,mm$

$x_i = \frac{F_{s1}}{K}$



$F_{s1} = 2\left(\frac{b}{a}\right) F_1$

$F_{s1} = 2 \times \frac{1}{2} \times 168.44$

$F_{s1} = 168.44\ N$

$\frac{\Delta r}{a} = \frac{\Delta x}{b}$

$x_i = \frac{168.44}{60.3472}$

$x_i = 2.79\ mm$

$K = 2\left(\frac{a}{b}\right)^2 \left(\frac{F_2 - F_1}{r_2 - r_1}\right)$

$F_2 = m r_2 \omega_2^2 = 5 \times 0.07 \times \left(\frac{2\pi \times 350}{60}\right)^2$

$F_2 = 470.176\ N$

$F_1 = m r_1 \omega_1^2 = 5 \times 0.03 \times \left(\frac{2\pi \times 320}{60}\right)^2$

$F_1 = 168.44\ N$

$K = 2\left(\frac{80}{40}\right)^2 \left[\frac{470.176 - 168.44}{70 - 30}\right]$

$K = 60.3472\ N/mm$

12/12

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Q.2 (a) The piston diameter of an internal combustion engine is 120 mm and the stroke is 250 mm. The connecting rod is 4.5 times the crank length and has a mass of 50 kg. The mass of reciprocating parts is 20 kg. The centre of mass of the connecting rod is 160 mm from the crank pin centre and the radius of gyration about an axis through the centre of mass is 130 mm. The engine runs at 320 rpm. Determine the magnitude and the direction of the inertia force and the corresponding torque on the crankshaft when the angle turned by the crank is 120° from the inner dead centre.

[20 marks]

Ans:- Given data $D_p = 120\,mm$

$L = 2r = 250\,mm$

$n = \frac{l}{r} = 4.5$ $m_{Rc/rod} = 50\,kg.$

$m_{Reci} = 20\,kg.$

$N = 320\,rpm.$

$\theta = 120° = \frac{2\pi}{3}\,rad.$

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

$a = \frac{0.250}{2} \times \left(\frac{2\pi \times 320}{60}\right)^2 \left[\cos 120° + \frac{\cos 240°}{4.5}\right]$

~~140.3677~~

$a = -85.78026\ m/s^2$

$F_I = m \times a = -4289.013\ (N)$

$\Delta T_o = F \times r \times \left[\sin\theta + \frac{\sin 2\theta}{2\sqrt{n^2 - \sin^2\theta}}\right]$

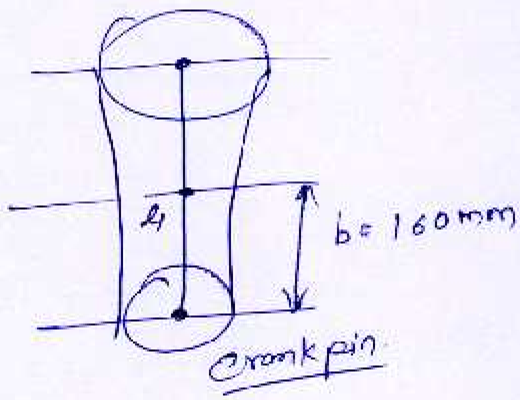
4/20

$l \sin\beta = r \sin\theta$

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

$\boxed{\beta = 11.095^\circ}$

$K_y = 130\text{ mm}$



$b + \frac{K_y^2}{b} = L$

$L = 160 + \frac{(130)^2}{160}$

$L = 265.625\text{ mm}$

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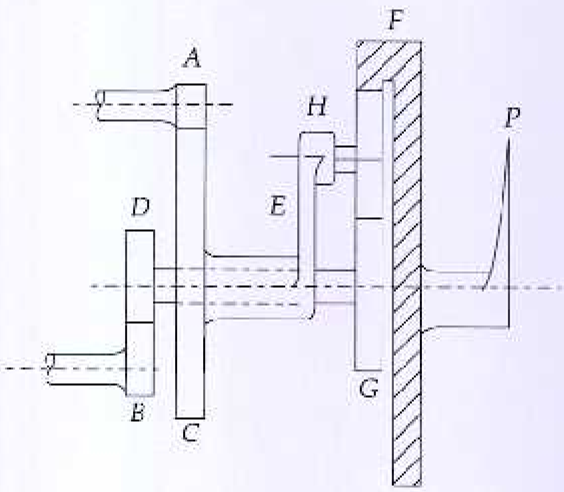
Q.2 (b) A port indicator for a twin-screw ship is shown in figure below. It is found that the pointer '*P*' remains stationary if the propeller runs at the same speed and drive the gears C and D in the same direction through equal gears A and B. If the number of teeth on G and F are 32 and 60 respectively. Find the ratio of the number of teeth on gear 'C' to that on gear 'D'. Also, calculate the speed of the pointer, if B runs at 10% faster than A and if the speed of gear 'C' is 120 rpm.



[20 marks]

Given data

$N_F = 0$

$T_G = 32$

$T_F = 60$

$\frac{T_C}{T_D} = ??$

$N_B = 1.1 N_A$

$N_C = 120$ rpm.

Shaft A	Shaft B	Gear C	Gear D	Gear G	Gear H	Gear F
0	x	$-x\frac{T_B}{T_C}$	$-x\frac{T_B}{T_D}$	$-x\frac{T_B}{T_C}$	$+x\frac{T_B}{T_C}\times\frac{T_G}{T_H}$	$+x\frac{T_B}{T_C}\times\frac{T_G}{T_H}\times\frac{T_H}{T_F}$
y	$y+x$	$y-x\frac{T_B}{T_C}$	$y-x\frac{T_B}{T_D}$	$y-x\frac{T_B}{T_C}$	$y+\frac{T_B}{T_C}\times\frac{T_G}{T_H}$	$y+\frac{T_B}{T_C}\times\frac{T_G}{T_F}$

values

$T_F = T_G + 2T_H$

$60 = 32 + 2T_H$

$T_H = 14$

$N_F = 0$

$y + \frac{T_B}{T_C}\times\frac{32}{60} = 0$

$y - x\frac{T_B}{T_C} = 120$

$y + x = 1.1y$

$x = 0.1y$

$y = 10x$

Do not write in this margin

$$10x + \frac{T_B}{T_C} \times \frac{32}{60} = 0 \quad \text{--- (11)}$$

$$10x - x\frac{T_B}{T_C} = 120$$

~~$10x + 10 \times \frac{32}{60} = 0$~~

$$K = \frac{T_B}{T_C}$$

~~$\frac{T_B}{T_C} = 10$~~

$$x = \frac{120}{(10-K)}$$

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$$x\left[10 - \frac{T_B}{T_C}\right] = 120$$

$$\frac{10 \times 120}{(10-K)} + K \times \frac{32}{60} = 0$$

Q.2 (c) A shaft, rotating at a uniform speed, carries two discs A and B of masses 5 kg and 4 kg, respectively. The C.G. of each disc is 2.5 mm from the axis of rotation, and the angle between the radii containing the centres of gravity is 90°. The shaft has bearings at C and D, between A and B, such that AC = 300 mm, AD = 900 mm and AB = 1200 mm. It is desired to make the dynamic forces on the bearings equal and opposite and to have a minimum value for a given speed by means of a mass in the plane E at a radius of 25 mm. Determine

(i) the magnitude of the mass to be attached at E and its angular position with respect to that at A.

(ii) the distance of the plane E from the plane through A_1 and

(iii) the dynamic force on the bearing with the attached mass in the plane E for a speed of 250 rpm.

[20 marks]

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Q.3 (a) (i) Write a short note on the following terms used in governors:

(a) Sensitiveness of a governor

(b) Hunting

(c) Isochronism

(ii) The following data relate to two meshing gears:

Number of teeth on the gear wheel = 80

Pressure angle = 20°

Gear ratio = 2

Speed of gear wheel = 120 rpm

Module = 5 mm

The addendum on each wheel is such that the path of approach and the path of recess on each side are 60% of the maximum possible length each. Determine the addendum for the pinion and the gear. Also calculate the length of the arc of contact.

[8 + 12 marks]

i) Sensitiveness :- It's the ratio of the Avg. speed to the Range of speed.

$$\text{Sensitiveness} = \frac{N_1 + N_2}{2(N_1 - N_2)}$$

Hunting :- When the flut^n of speed is too large then governor should be Unstable ~~Consit~~ Condition when hunting will be occurs.

Isochronism :- when the fluctuation of speed is Constant

$\left\{ \begin{matrix} r = r_1 \\ r = r_2 \end{matrix} \right\} \rightarrow N = \text{Constant}$

In this Case Sensitiveness is approximately Infinity.

The Range of governor is zero.

ii) Given data

$T_4 = 80$

$\phi = 20^\circ \quad l_4 = \frac{T_4}{T_p} = 2 \quad D_4 = 5 \times 80 = 400\,mm$

$N_4 = 120\,rpm \quad R_4 = 200\,mm.$

$m = 5\,mm$

$T_p = 40 \quad D_p = mT_p = 5 \times 40 = 200\,mm$

$R_p = 100\,mm$

path of approach $= \sqrt{R_a^2 - R^2\cos^2\phi} - R\sin\phi$

Max^{m} path of approach $= r\sin\phi$

$$r\sin\phi = \sqrt{R_a^2 - R^2\cos^2\phi} - R\sin\phi$$

$$(r+R)\sin\phi = \sqrt{R_a^2 - R^2\cos^2\phi}$$

$$(300)\sin 20^\circ = \sqrt{R_a^2 - (200)^2\cos^2 20^\circ)}$$

$$R_a^2 = 10528.0 + 35320.88$$

$$R_a = 214.123$$

Addendum of wheel $= R_a - R = 14.1235$ mm.

Simillarly.

path of Recess.

$$R\sin\phi = \sqrt{r_a^2 - r^2\cos^2\phi} - r\sin\phi$$

$$r_a = 139.133$$

Adden. of pinion $\Rightarrow$ 39.133 mm path of Contact $= (r+R)\sin\phi$

Arc of Contact $= \dfrac{(r+R)\sin\phi}{\cos\phi}$

$= (r+R)\cdot\tan\phi$

$= 109.19$ mm

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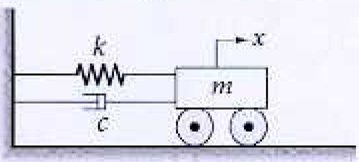
Q.3 (b) A mass 'm' of the system shown in figure, is displaced from its static equilibrium position to the right at a distance of 0.01 m. An impulsive force acts towards the left on the mass at the instant of its release to give it an initial velocity V_0 in that direction. The stiffness and damping coefficient values are 15700 N/m and 1570 N-sec/m respectively. If the mass of the block is 10 kg, then

(a) Derive the expression for the displacement from the equilibrium position in terms of time t and initial velocity V_0.

(b) What value of 'V_0' would be required to make mass pass the position of the static equilibrium 0.01 sec after it is applied?



[20 marks]

Ans:- Given data

$m = 10$ kg $x_0 = 0.01$ m

$K = 15700$ N/m

$C = 1570$ N-s/m

$$m\ddot{x} + c\dot{x} + Kx = 0$$

$$m s^2 L(s) - V_0 + c s L(s) + K L(s) = 0 \quad \left\{ \begin{array}{l} t = 0 \\ x = 0 \\ V = V_0 \end{array} \right\}$$

$$L(s)\{ms^2 + cs + K\} = V_0$$

$$L(s) = \frac{V_0}{ms^2 + cs + K}$$

?!

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Q.3 (c) A machine of mass 500 kg is acted upon by an external force of 2650 N at a frequency of 2000 rpm. To reduce the effect of vibration, isolator of rubber having a static deflection of 1.5 mm under the machine load and an estimated damping factor of 0.25 are used. Determine

(i) the force transmitted to the foundation

(ii) the amplitude of vibration of machine

(iii) the phase lag **[20 marks]**

Ans:-

$m = 500$ kg $\quad F_0 = 2650$ N

$$\omega = \frac{2000 \times 2\pi}{60} = 209.4395 \text{ rad/s.}$$

$\delta = 1.5$ mm

$$\omega_n = \sqrt{\frac{9.81 \times 1000}{1.5}} = 80.8702 \text{ rad/s.}$$

$$p = \frac{\omega}{\omega_n} = 2.589 \qquad K = 3269978.45 \text{ N/m}$$

$\xi = 0.25$

$$\epsilon = \frac{F_T}{F_0} = \frac{\sqrt{1+\left(2\xi\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2+\left(2\xi\frac{\omega}{\omega_n}\right)^2}}$$

$$\epsilon = \frac{\sqrt{1+(1.2945)^2}}{5.8479}$$

$$\epsilon = \frac{F_T}{F_0} = 0.2797 \qquad F_T = 741.254 \text{ N}$$

$$X = \frac{F_0/K}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}}$$

$$X = \frac{F_0/K}{5.8479}$$

$$\boxed{X = 0.1385 \text{ mm}}$$

phase lag ??

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Q.4 (a) The total mass of a four-wheeled trolley car is 1600 kg. The car runs on rails of 1.5 m gauge and rounds a curve of 20 m radius at 36 km/h. The track is banked at 15°. The external diameter of the wheels is 650 mm and each pair with axle has a mass of 210 kg with a radius of gyration of 250 mm. The height of centre of mass of the car above the wheel base is 850 mm. Determine the pressure on each rail allowing for centrifugal force and gyroscopic couple.

[20 marks]

Q.4 (b) In a Proell governor, the mass of each ball is 10 kg and the mass of the sleeve is 130 kg. Each arm is 200 mm long. The length of extension of lower arms to which the balls are attached is 80 mm. The distance of pivots of arms from axis of rotation is 30 mm and the radius of rotation of ball is 170 mm when the arms are inclined at 30° to the axis of rotation. Determine the

(i) equilibrium speed.

(ii) coefficient of insensitiveness if the friction of the mechanism is equivalent to 50 N.

(iii) range of speed when the governor is inoperative. **[20 marks]**

Q.4 (c) **(i)** Write the differences between the functions of flywheel and Governor.

(ii) The crankshaft torque of a petrol engine varies as follows:

- During the first 30° crank angle, the torque increases from zero to 800 N-m linearly.
- During the next 30° crank angle, it remains constant.
- During the next 120° crank angle, it decreases linearly to zero.

The average speed is 250 rpm and the cycle is repeated every half revolution. Assuming that the engine drives a machine that requires a constant torque. Calculate the maximum fluctuation of energy of flywheel. Also, determine the mass of the flywheel, if the radius of gyration of the flywheel is 200 mm and the variation of speed is limited to 1% of the mean speed.

[5 + 15 marks]

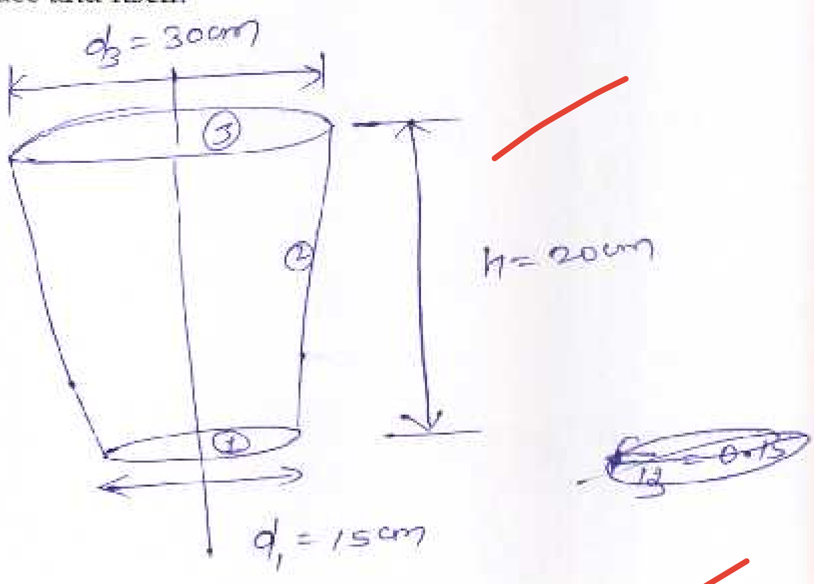
Section : B

Q.5 (a) A truncated cone of height 20 cm has bottom and top diameters of 15 cm and 30 cm respectively. The bottom surface is stated to intercept 15 percent of radiation leaving the top surface. Calculate the shape factor between the

(i) top surface and conical side surface, and

(ii) the side surface and itself.

[12 marks]



$F_{31} = 0.15$

$F_{11}^{\nearrow 0} + F_{12} + F_{13} = 1$

$F_{12} + 0.15 = 1$

$F_{13} = 0.85$

$F_{31} + F_{32} + F_{33}^{\nearrow 0} = 1$

$F_{32} = 0.85$

$F_{21} + F_{22} + F_{23} = 1$

$F_{23} = \frac{F_{32} A_3}{A_2}$

$F_{23} = \frac{0.85 \times \pi/4 \times (30)^2}{\pi [15 - 7.5] \, l \to (25)}$

$F_{23}' =$

3

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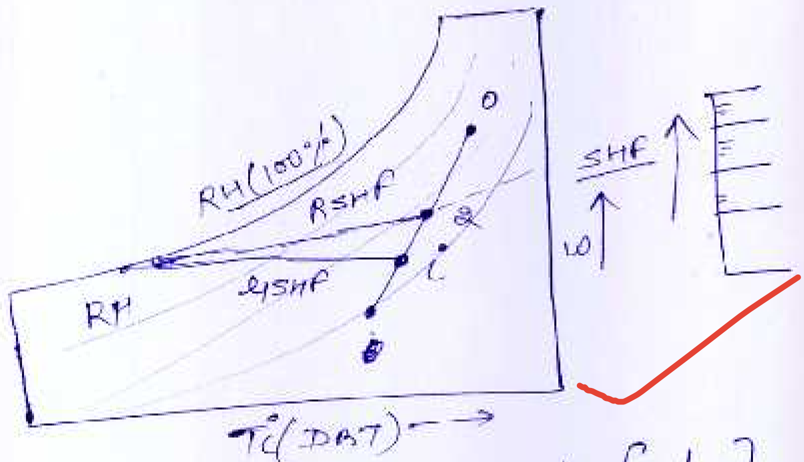
Q.5 (b) (i) Define RSHF and GSHF by showing it on Psychrometric chart.

(ii) The air-handling unit of an air-conditioning plant supplies a total of 4800 cmm of dry air which comprises by weight 25 percent fresh air at 40°C DBT and 27°C WBT, and 75% recirculated air at 25°C DBT and 50 percent RH. The air leaves the cooling coil at 13°C saturated state. Calculate the total cooling load and room heat gain. [Use Psychrometric chart]

[4 + 8 marks]

i)



RSHF [Room Sensible Heat factor]

$$RSHF = \frac{RSH}{RSH + RLH}$$

GSHF [Grand Sensible Heat factor]

$$GSHF = RSHF + x \times OSHF$$

$x \rightarrow$ By pass factor

OSHF [outside sensible Heat]

$\hookrightarrow$ 0.0204 (cmm) ΔT

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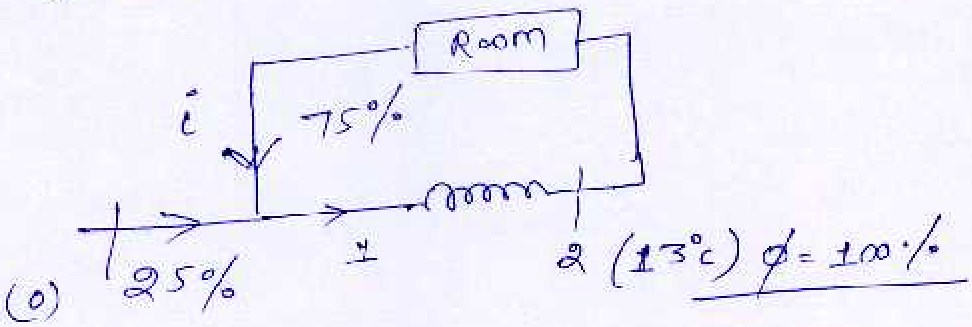
ii) $\dot{V}_a$ cmm = 4800 m^3/min



$T_1 = 0.75\ T_i + 0.25\ T_o$

$T_1 = 0.75 \times 25 + 0.25 \times 40$

$T_1 = 28.75$ $\qquad v_1 = 0.87\ m^3/kg$

Total Cooling load $= h_1 - h_2$

$= 61 - 37$

$= 24\ kJ/kg$ of air

$\Rightarrow 24 \times \frac{4800}{60 \times 0.87}$

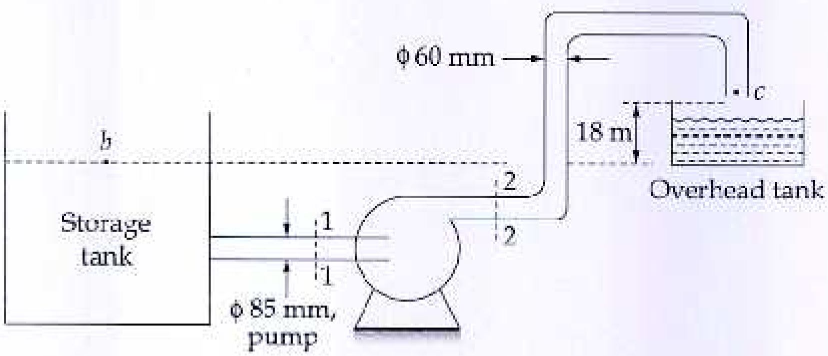
$\Rightarrow$ 2206.89 kW

Room Heat gain $\Rightarrow 0.0204\,(cm)\,\Delta T$

$\Rightarrow 0.0204 \times 4800 \times (25 - 13)$

$\Rightarrow$ 1175.04 kW

Q.5 (c) A pump of the equipment is shown in figure, draws a solution (density 1750 kg/m^3) from a store tank through a 85 mm steel pipe in which the flow velocity is 2.0 m/s. The pump discharges through a 60 mm steel pipe to an overhead tank, the end of discharge pipe is 18 m above the level of the solution in the feed tank and the friction losses in the entire piping system are 6 m. What pressure must the pump develop and what should be it's power? Pump efficiency is given 70%.



[12 marks]

$A_1 V_1 = A_2 V_2$

$\frac{\pi}{4}(85)^2 \times 2 = \frac{\pi}{4}(60)^2 \times V_2$

$V_2 = 4.0138 \text{ m/s}$

$V_c = V_2$

$$\phi = \pi/4 \times (0.085)^2 \times 2$$

$$\phi = 0.01134 \ m^3/s.$$

Apply Bernou. eqn 'point b' to 'point c'

$$h_{pump} + 0 + \frac{P_b}{\rho g} + \frac{V_b^2}{2g} = \frac{P_c}{\rho g} + \frac{V_c^2}{2g} + 18 + 6$$

$P_c = P_b =$ atm.

$V_b = 0$ [∵ large Reservior]

$$h_{pump} = \frac{V_2^2}{2g} + 18 + 6$$

$$= \frac{(4.0138)^2}{2 \times 9.81} + 24$$

$$h_{pump} = 24.8211 \ m$$

6/12

$$\text{Power} = \frac{\rho g \phi h_p}{\eta_p}$$

$$= \frac{10^3 \times 9.81 \times \phi \times 24.8211}{0.70}$$

power => 3947.75 W

$$\text{Pressure}(p) = \rho g h_p = 10^3 \times 9.81 \times 24.8211$$

$$P_{pump} \Rightarrow 243.494 \ kPa$$

Q.5 (d) The outer surface of a vertical tube which is of length 2.5 m and outer diameter 100 mm is exposed to saturated steam at atmospheric pressure. If the tube surface is maintained at 80°C by the flow of cooling water through it, determine the rate of heat transfer to the coolant and the rate at which steam is condensed at the tube surface.

If the tube is held in horizontal position, calculate the percentage change in condensation rate. Use the following data:

For saturated steam, $t_{sat} = 100°C$

Latent heat, $h_{fg} = 2285$ kJ/kg

At mean film temperature, the properties of saturated water are:

Density, $\rho = 965.3$ kg/m^3

Thermal conductivity, $k = 0.68$ W/mK

Dynamic viscosity, $\mu = 3.14 \times 10^{-4}$ kg/ms

Use the following relation for average heat transfer coefficient,

$$\bar{h}_v = 0.943\left[\frac{k^3\rho^2 g h_{fg}}{\mu l(t_{sat} - t_s)}\right]^{0.25}, \text{Vertical position}$$

$$\bar{h}_h = 0.725\left[\frac{k^3\rho^2 g h_{fg}}{\mu D(t_{sat} - t_s)}\right]^{0.25}, \text{Horizontal position}$$

[12 marks]

~~Case I~~ (Vertical tube)

Given data

$l = 2.5\ m$ $T_s = 80°C$

$D_o = 100\ mm$ $T_{sat} = 100°C$

$$\bar{h}_v = 0.943 \left[\frac{(0.68)^3 (965.3)^2 \times 9.81 \times 2285 \times 1000}{3.14 \times 10^{-4} \times 2.5 \times 20} \right]^{0.25}$$

$$\bar{h}_v = 4264.0699 \ W/m^2K$$

If tube is Horizontal

$$\bar{h}_h = 0.725 \left[\frac{(0.68)^3 \times (965.3)^2 \times 9.81 \times 2285 \times 1000}{3.14 \times 10^{-4} \times 0.1 \times 20} \right]^{0.25}$$

$$\bar{h}_h = 7331.6164 \ W/m^2K$$

$$Q_v = \bar{h}_v (\pi D_o L)(T_s - T_\infty)$$

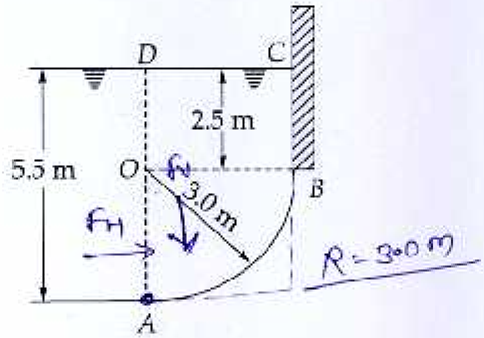
$$\boxed{Q \propto h}$$

% change in Condensation rate $= \dfrac{Q_v - Q_h}{Q_v} \times 100$

$= 71.91\ \%$

12/12

Q.5 (e) The curved surface AB, which is the quadrant of a circular cylinder as shown in figure, given that the radius of the surface is 3.0 m, the cylinder is 4 m long and water is 2.5 m above B. Determine the magnitude, direction and location (horizontal distance from point A) of total pressure force exerted by water on it.



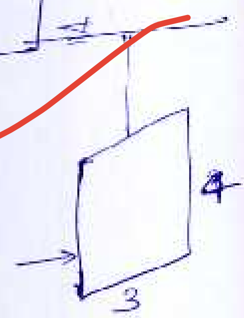
[12 marks]

Ans:- Given data $l = 4\,m$

$\bar{x} = 2.5 + 1.5 = 4\,m$

$F_H = \rho g \times A\bar{x} = 10^3 \times 9.81 \times (3 \times 4) \times 4$

$F_H = 470.88\,(kN)$



$h_p = \bar{x} + \frac{I_G}{A\bar{x}}$

$= 4 + \frac{4 \times 3^3/12}{4 \times 3 \times 4}$

$h_p = 4.1875\,m$

Force of vertical dirn (F_V)

$F_V = \rho g (V) = 10^3 \times 9.81 \times [3 \times 5.5 \times 4 - 7.785]$

$F_V = 571.678\,(kN)$

$$F_V \times x \text{ (from A)} = F_{V_1} \times 1.5 + F_{V_2} \times \left(\frac{4R}{3\pi}\right)$$

$$58.275 \times x = 30 \times 1.5 + 7.725 \times \left(\frac{4 \times 3}{3\pi}\right)$$

$$x = 0.94098$$

$$\tan\theta = \frac{F_V}{F_H} = \frac{571.678}{470.88}$$

$$\boxed{\theta = 50.522^\circ}$$

distance

$\frac{11}{12}$

Q.6 (a) Two large parallel plates with emissivity as 0.7 for hot plate and 0.5 for cold plate are maintained at 1200 K and 800 K respectively. Calculate the net radiant heat exchange per unit area of two infinite parallel plates. What should be the emissivity of a polished aluminium shield placed between them if heat flow is to be reduced to 30 percent of its original value? Also calculate the equilibrium temperature of the shield.

[20 marks]

Q.6 (b) (i) For a conditioned space given:

Room sensible heat gain = 40 kW

Room latent heat gain = 10 kW

Inside design condition : 25°C DBT, 50% RH

Bypass factor of the cooling coil = 0.15

The return air from the space is mixed with the outside air at 43°C DBT and 27.5°C WBT before entering the cooling coil in the ratio of 3 : 1 by weight determine:

(a) Condition of air leaving cooling coil.

(b) Dehumidified air quantity.

(c) Ventilation air mass and volume flow rates.

(d) Total refrigeration load on air-conditioning plant.

Take, apparatus dew point temperature = 12.8°C

[Use Psychrometric chart]

(ii) With help of neat sketch, briefly explain working of evaporative condensor.

[15 + 5 marks]

Q.6 (c) A centrifugal pump running at 800 rpm has an impeller of 0.6 m outer diameter discharges 10000 LPM against a head of 35 m. The water enters the impeller radially without whirl or shock. The inner diameter is 0.2 m. The vanes are set back at an angle of 32° to the tangent at the periphery of the outlet. The area of flow is constant from inlet to outlet of the impeller and is 0.06 m^2. Calculate the

(i) Vane angle at inlet

(ii) Manometric efficiency of the pump.

(iii) Minimum speed at which the pump commences to work.

[20 marks]

Q.7 (a) A 7 m diameter penstock supplied water to a Francis turbine, running at a speed of 140 rpm producing 64700 kW.

Following other particulars is given below:

Flow rate = 120 m^3/s, Hydraulic efficiency = 94%, mean diameter of turbine at entry = 4.5 m, mean blade width at entry = 1.2 m, entry diameter of draft tube = 4.6 m, velocity in tail race = 2.5 m/s. The static pressure head in the penstock measured just before entry to the runner is 60.4 m. The point of measurement is 4 m above the level of tail race. The loss in draft tube is equal to 35% of velocity head at entry to it. The exit plane of the runner is 2.5 m above the tail race and flow at outlet of runner is without swirl. Determine

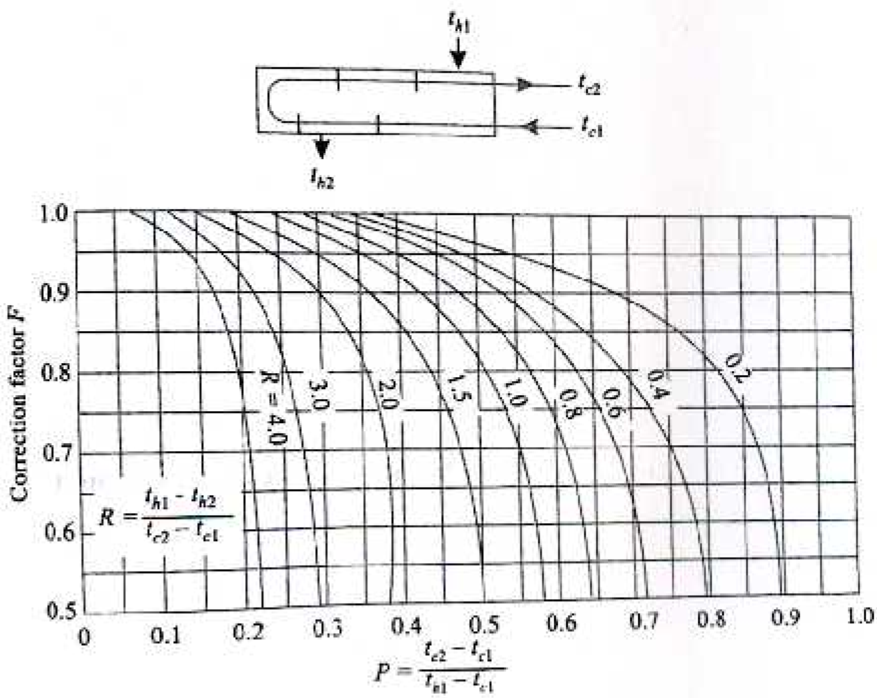
(i) The overall efficiency

(ii) The direction of flow relative to the runner at inlet.

(iii) The pressure head at entry to draft tube.

[20 marks]

Q.7 (b) A single-shell pass, four-tube counter flow heat exchanger is used as an economiser on a steam generator. Flue gases enter the exchanger at 250°C and leave at 150°C with a flow rate of 2 kg/s. The feed water enters at 125°C at the rate of 1.4 kg/s. Determine number of transfer units and the effectiveness of the heat exchanger. Also, if a change in the operating conditions occurs, the feed water must be by-passed so the water enters at 60°C with a flow rate of 0.5 kg/s. Calculate the exit temperature of water when the exchanger operates under the changed conditions and assume that the effectiveness of exchanger remains unchanged. Take specific heat of flue gases as 1.05 kJ/kgK and for water as 4.18 kJ/kgK.



[20 marks]

Q.7 (c) **(i)** Calculate the volume of air to be handled and quantity of make up water in kg/min required by cooling tower which is used to cool 1200 kg of water per minute from temperature of 35°C to 30°C.

Atmospheric conditions are 35°C DBT and 25°C WBT and air leaves the tower at 30°C DBT and 80% RH.

(ii) 100 m^3 of air per minute at 5°C DBT and 2.5°C WBT is passed through a heating coil which gives 42.7 kW energy to the air. Saturated steam at 110°C and with a rate of 50 kg/hr is mixed with the air leaving the heating coil. Determine DBT and WBT of the air after mixing the stream.

Take, h_s enthalpy of saturated steam at 110°C as 2691 kJ/kg.

[Use Psychrometric chart]

[10 + 10 marks]

Q.8 (a) A Kaplan turbine working under a head of 30 m with a rotational speed of 170 rpm develops 25 MW of power. The outer diameter of the blade is 500 cm and hub diameter is 250 cm. The overall efficiency of the turbine is 94 percent and the hydraulic efficiency is 96 percent. Determine the

(i) Discharge

(ii) Following angles at the tip of blades.

(a) inlet guide vane angle

(b) the inlet blade angle

(c) outlet blade angle

[Assume radial exit] $\beta = 90^\circ$; $V_{w_2} = 0$

[20 marks]

Ans:-

Given data

Kaplan turbine $H = 30m$

$N = 170 rpm$

$P = 25 MW = 25 \times 10^3 kW$

$D_o = 0.5 m$

$D_h = 0.25 m$

$\eta_o = 0.94$

$\eta_{hyd} = 0.96$

$$\eta_o = 0.94 = \frac{25000}{\rho g Q H}$$

$$25000 = 0.94 \times 9.81 \times Q \times 30$$

$$Q = 90.3695 \ m^3/s$$

$$Q = \frac{\pi}{4}\left[D_o^2 - D_h^2\right] \times V_{f_1}$$

$$90.3695 = \frac{\pi}{4}\left[0.5^2 - 0.25^2\right] \times V_{f_1}$$

$$V_{f_1} = 613.664 \text{ m/s}$$

6 13664

$$\cancel{Q_1 = \frac{\pi \times 0.25 \times 170}{60} = 33.379} \text{ m/s}$$

$$\cancel{u_2 = \frac{\pi \times 0.5 \times 170}{60} = 66.7588}$$

$$\eta_h = \frac{R.P}{\rho g Q H}$$

12/20

$$R.P = \dot{m}\left[V_{w_1} u\right]$$

x

Do not write in this margin

Q.8 (b) A Pelton turbine working under a net head of 200 m at a speed of 520 rpm, producing power of 1500 kW.

Following are some relevant data of the turbine:

Bucket angle = 170°

Coefficient of velocity = 0.96

Friction and windage losses = 7 percent of velocity head of the jet

Bucket friction coefficient = 0.92

Pitch diameter of runner = 1.4 m

Draw the outlet velocity triangle and prepare an energy balance of the jet and determine

(i) Hydraulic efficiency

(ii) Mechanical efficiency

(iii) Overall efficiency of the turbine

[20 marks]

Ans:- Given data

pelton wheel turbine

$H_{net} = 200\ m$

$N = 520\ rpm$

$P = 1500\ kW$

$\delta = 170°$ $\phi = 10°$

$C_v = 0.96$

$K = 0.92$

$D_p = 1.4\ m$

$P_w = \rho g Q H$

$P_w = 10^3 \times 9.81 \times Q \times 200 \times 0.93 \Rightarrow 168913.15\ kW$

$u = \frac{\pi \times 1.4 \times 520}{60} = 38.1179\ m/s.$

~~$Q = A \times V_1$~~

$V_1 = 0.96\sqrt{2 \times g \times 200}$

$V_1 = 60.1361\ m/s.$

$Q = A \times V$

$= \pi/4 \times (1.4)^2 \times 60.1361$

$= 92.5724 \ m^3/s.$ ✓

10/20

$\dot{m}_1 = \dot{m}\left(1 - \frac{7}{100}\right) = 0.93\dot{m}$

$\boxed{\dot{m}_1 = 0.93 \times \rho Q}$

$W.D = \rho Q (V_1 - u) u (1 + K\cos\phi) \times 0.93$

$= 0.93(60.14 - 38.12) \times 38.12 \times (1 + 0.92\cos 10^\circ)$

$=$ ~~1487.925 kW~~

$= 137737.22 \ kW$ ⇒ ✗

$\eta_o = \frac{1500}{168913.15}$ ✗

$\eta_o = 0.88\ \%$ ✗

$(K.E)_{inlet} = 0.93 \rho Q \frac{V_1^2}{2}$

$= 0.93 \times 10^3 \times 92.57 \times \frac{(60.1361)^2}{2}$

$\Rightarrow 155665.98 \ kW$ ⇒ ✗

$\eta_{mech} = 81.54\ \%$ ✗

$\eta_{hydraulic} =$

Q.8 (c) In a two-dimensional incompressible flow field. The velocity components are expressed as

$$u = \frac{y^3}{3} + 4x - x^2 y$$

$$v = xy^2 - 4y - \frac{x^3}{3}$$

(a) Is the flow physically possible? If so obtain an expression for the stream function.

(b) Determine acceleration at point at a point P ($x = 2$ m, $y = 3$ m).

(c) What is discharge between the streamlines passing through (2, 3) and (3, 4)?

(d) Is the flow irrotational? If so determine the corresponding velocity potential.

(e) Show that each of the stream and potential functions satisfy Laplace equation.

[20 marks]

Ans:-

$u = \frac{y^3}{3} + 4x - x^2 y$; $v = xy^2 - 4y - x^3/3$

$\frac{du}{dx} = 4 - 2xy$

$\frac{dv}{dy} = 2xy - 4$

$$\frac{du}{dx} + \frac{dv}{dy} = 0$$

Flow is ~~incom~~ incompressible

a) ϕ $u = -\frac{d\psi}{dy}$

$v = +\frac{d\psi}{dx}$

$$-\frac{d\psi}{dy} = \frac{y^3}{3} + 4x - x^2 y$$

$$\psi = -\frac{y^4}{12} - 4xy + \frac{x^2y^2}{2} + f^n(x)$$

$$\frac{d\psi}{dx} = xy^2 - 4y - x^3/3$$

$$\psi = \frac{x^2y^2}{2} - 4xy - \frac{x^4}{12} + f^n(y)$$

$$\boxed{\psi = \frac{x^2y^2}{2} - 4xy - \frac{x^4}{12} - \frac{y^4}{12}}$$

b) at point $(x,y) \Rightarrow (2,3)$

$$a_x = u\frac{du}{dx} + v\frac{du}{dy}$$

$$a_x = \left(\frac{y^3}{3} + 4x - x^2y\right)(4 - 2xy) + \left(xy^2 - 4y - \frac{x^3}{3}\right)(y^2 - x^2)$$

$$a_x = (9 + 8 - 12)(4 - 12) + (18 - 12 - 8/3)(9 - 4)$$

$$= -40 + 16.67$$

$$\Rightarrow -23.33 \text{ m/s}^2$$

$$a_y = u\frac{dv}{dx} + v\frac{dv}{dy} \qquad (2,3)$$

$$= \left(\frac{y^3}{3} + 4x - x^2y\right)\left(y^2 - x^2\right) + \left(xy^2 - 4y - \frac{x^3}{3}\right)\left(2xy - 4\right)$$

$$\Rightarrow \quad 5 \times (9-4) + (6 - 8/3)(12-4)$$

$$a_y \Rightarrow 57.667 \text{ m/s}^2$$

$$a = \sqrt{(a_x)^2 + (a_y)^2} = \sqrt{(-23.33)^2 + (57.667)^2}$$

$$a = 56.06897 \text{ m/s}^2$$

c) $\psi = \dfrac{x^2y^2}{2} - 4xy - \dfrac{x^4}{12} - \dfrac{y^4}{12}$

$$|\psi_{(2,3)}| = \frac{36}{2} - 4\times6 - \frac{16}{12} - \frac{81}{12}$$

$$= 14.083$$

$$|\psi_{(3,4)}| = \frac{9\times16}{2} - 4\times12 - \frac{81}{12} - \frac{256}{12}$$

$$= 4.083$$

$$q = \psi_{(2,3)} - \psi_{(3,4)} \Rightarrow 10 \text{ m}^3/\text{s}$$

d)

$$\omega_z = \frac{1}{2}\left[\frac{dv}{dx} - \frac{du}{dy}\right]$$

$$\omega_z = \frac{1}{2}\left[y^2 - x^2 - y^2 + x^2\right]$$

$\omega_z = 0$ Flow Irrotational

$$u = -\frac{d\phi}{dx} = \frac{y^3}{3} + 4x - x^2 y$$

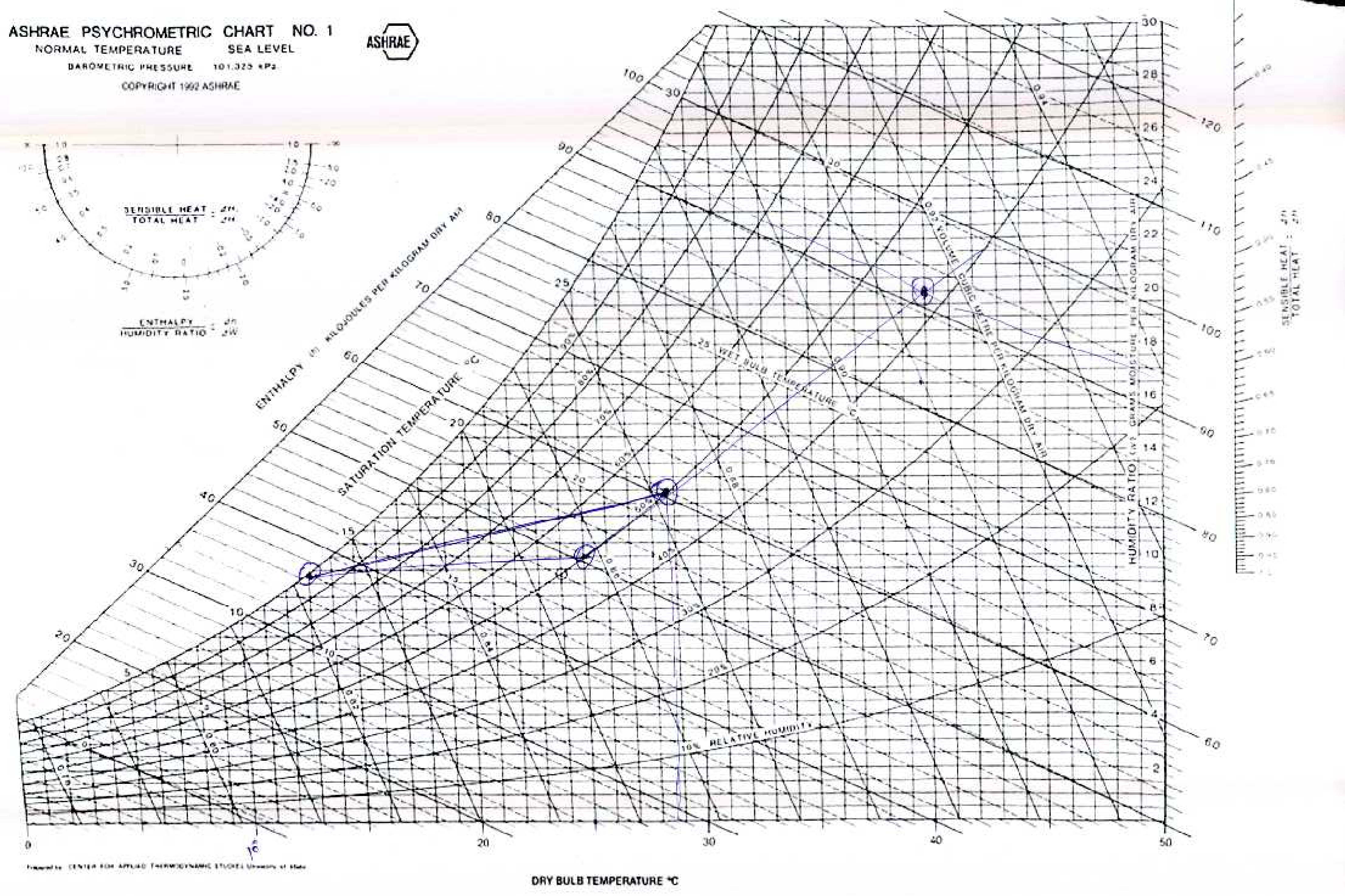
$$\phi = -\frac{xy^3}{3} - \frac{2x^2}{2} + y\frac{x^3}{3} + f'(y)$$

$$v = -\frac{d\phi}{dy} = xy^2 - 4y - \frac{x^3}{3}$$

$$\phi = -\frac{xy^3}{3} + 2y^2 + \frac{yx^3}{3} + f''(x)$$

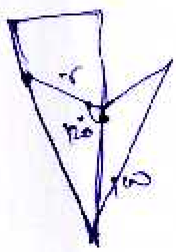
$$\boxed{\phi = -\frac{xy^3}{3} + \frac{yx^3}{3} + 2y^2 - 2x^2}$$

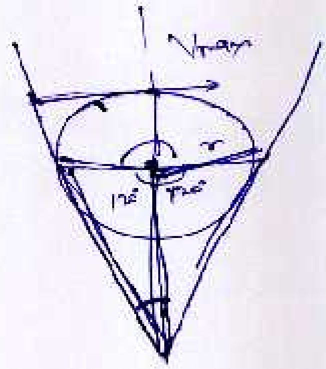
18/20



ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa
COPYRIGHT 1992 ASHRAE
ASHRAE
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
RELATIVE HUMIDITY
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
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





$\frac{1}{2} = \frac{360-\alpha}{\alpha}$

$\alpha = 720 - 2\alpha$

$3\alpha = 720$

240

$F_1 + F_{12} + F_{13} = 0$

$\frac{1200}{10-K} + \frac{32K}{60} = 0$

F_{21}

$\frac{2 l r}{d}$ $2x$

$9 - \frac{\pi}{4} \times 9$

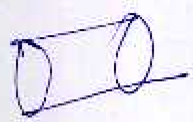
$9\left[1 - \frac{\pi}{4}\right]$

F_{22}

F_{23}

F_{32}

$-\frac{1}{2} = \frac{\left(\frac{100}{3}\right)^2 + (100)^2 - x^2}{2 \times \frac{100}{3} \times 100}$



-7.725

$x^2 = \left(\frac{100}{3}\right)^2 + \left(\frac{100}{9}\right)^2 + (100)^2$

$\frac{100}{3}\left[\frac{1}{3} + \frac{1}{9} + 1\right]$

$\frac{3+1+9}{9} \quad \frac{13}{9}$

F

$s^2 I(s) - s\,i(0) - i'(0)$

$s\,L(s) - s\,L(0)$

$\eta_h = \frac{WD}{KE}$

$\eta_m = \frac{P}{WD}$