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ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-3: Fluid Mechanics and Turbo Machinery, Heat Transfer-1 + TOM-1, Thermodynamics-2 + Refrigeration and Air-conditioning-2

Name :

Roll No : M E 1 9 M B D L C 6 6 0

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Student's Signature

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. 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.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

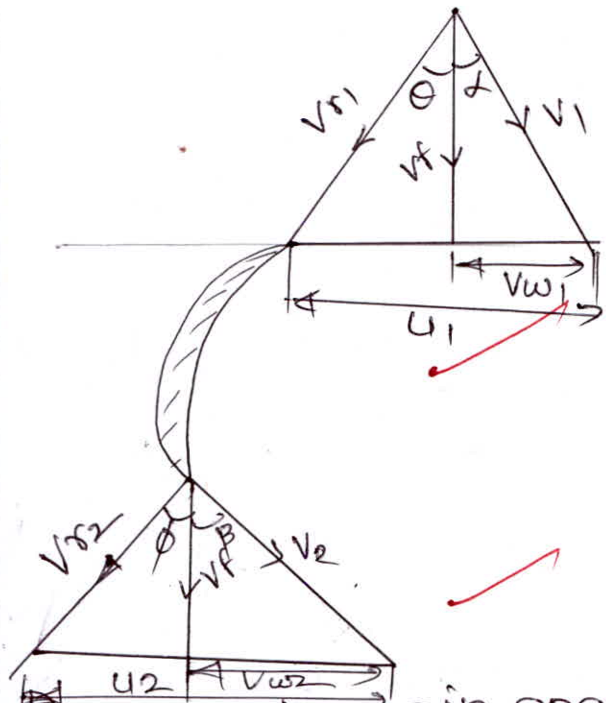
Question No.	Marks Obtained
Section-A	
Q.1	23
Q.2	—
Q.3	37
Q.4	—
Section-B	
Q.5	45-2=43
Q.6	—
Q.7	56
Q.8	40+2=42
Total Marks Obtained	201

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

Section A : Fluid Mechanics and Turbo Machinery

Q.1 (a) Define degree of Reaction. Derive the expression of degree of reaction for an axial flow compressor in terms of inlet and outlet blade angles, blade and flow velocity.

[12 marks]



$$DOR = \frac{\text{change in energy in a moving blade}}{\text{change in total energy}}$$

$$\text{workdone} = \frac{V_2^2 - V_1^2}{2} + \cancel{\frac{U_2^2 - U_1^2}{2}}^{\to 0} + \frac{V_{r1}^2 - V_{r2}^2}{2}$$

$$U_2 = U_1$$

$$V_{w1}U_1 + V_{w2}U_2 = \frac{V_2^2 - V_1^2}{2} + \frac{V_{r1}^2 - V_{r2}^2}{2} \quad \text{—— (1)}$$

$$DOR = \frac{\frac{V_{r1}^2 - V_{r2}^2}{2}}{V_{w1}U_1 + V_{w2}U_2}$$

$$= \frac{(V_{w1}U_1 + V_{w2}U_2) - \left(\frac{V_2^2 - V_1^2}{2}\right)}{(V_{w1}U_1 + V_{w2}U_2)}$$

$$= 1 - \left[\frac{V_2^2 - V_1^2}{2(V_{w1}U_1 + V_{w2}U_2)}\right]$$

$$= 1 - \left[\frac{V_2^2 - V_1^2}{2\left[\frac{V_2^2 - V_1^2}{2} + \frac{V_{r2}^2 - V_{r1}^2}{2}\right]}\right]$$

$$= 1 - \left[\frac{V_2^2 - V_1^2}{2(V_2^2 - V_1^2) + (V_{r_2}^2 - V_{r_1}^2)}\right]$$

$$\cancel{\sin\alpha} = \frac{V_{f_1}}{V_1}$$

$$\cos\alpha = \frac{V_{f_1}}{V_1} \qquad \cos\beta = \frac{V_{f_2}}{V_2}$$

$$= 1 - \cancel{\left[\frac{\frac{V_{f_1}^2}{\cos^2\alpha} - \frac{V_{f_2}^2}{\cos^2\beta}}{\left[\frac{V_{f_1}^2}{\cos^2\alpha} - \frac{V_{f_2}^2}{\cos^2\beta} + \frac{V_{f_2}^2}{\cos^2\phi} - \frac{V_{f_1}^2}{\cos^2\theta}\right]}\right]}$$

Don't skip the steps

$$= 1 - \frac{V_2^2 - V_1^2}{2(V_{w_1}u_1 + V_{w_2}u_2)}$$

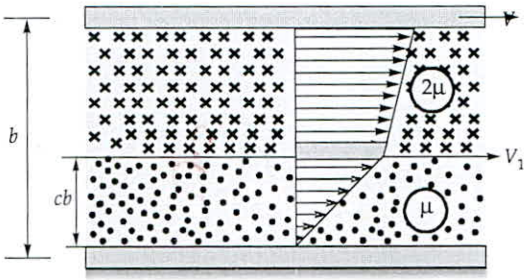
explain steps?

$$= 1 - \frac{V_f}{2u}(\tan\theta + \tan\phi)$$

06

.1 (b) Two flat plates are oriented in parallel configuration above a fixed lower plate as shown in figure. The top plate, located a distance, b above the fixed plate, is pulled along with speed V. The other thin plate is located a distance (cb) where $0 < c < 1$, above the fixed plate. This plate moves with speed V_1 which is determined by the viscous shear forces imposed on it by the fluids on its top and bottom. The fluid on the top is twice as viscous as that on the bottom, then obtain the ratio $\left(\frac{V_1}{V}\right)$ corresponding to value of c as given in table.

c	0	0.2	0.5	0.7	1.0
V_1/V	?	?	?	?	?



$(b-cb)$.

[12 marks]

→ shear force on a middle plate due to both side fluid is equal.

$$F_L = F_U$$

Assuming linear velocity profile

$$\left(\mu_1 \times A \cdot \frac{du}{dy}\right)_L = \left(\mu_2 \times \cancel{A} \frac{du}{dy}\right)_U$$

$$\cancel{\mu} \times \cancel{A} \times \left(\frac{V_1 - 0}{cb}\right) = 2\cancel{\mu} \times \cancel{A} \times \frac{V - V_1}{(b - cb)}$$

$$\frac{V_1}{c\cancel{b}} = \frac{V - V_1}{\cancel{b} - c\cancel{b}}$$

check Calculation?

$$\frac{V_1}{c} = \frac{V - V_1}{1 - c}$$

$$\frac{V_1}{c} = \frac{V}{1 - c} - \frac{V_1}{1 - c}$$

$$V_1\left[\frac{1}{c} + \frac{1}{1 - c}\right] = \frac{V}{1 - c}$$

$$\frac{V_1}{V}\left[\frac{(1 - \cancel{c}) + \cancel{c}}{c(\cancel{1 - c})}\right] = \frac{1}{\cancel{1 - c}}$$

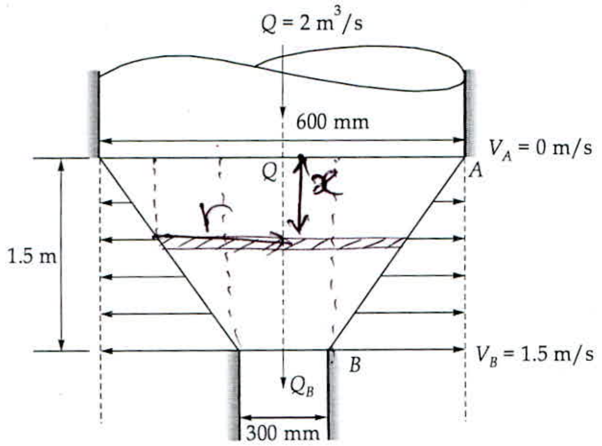
$$\boxed{\cancel{\frac{V_1}{V} = C}}$$

table

C	0	0.2	0.5	0.7	1.0
$\frac{V_1}{V}$	0	0.2	0.5	0.7	1.0

03

Q.1 (c) Water flow downward in a pipe of 600 mm diameter at the rate of 2 m^3/s. It then enters a conical duct with porous wall such that there is a radial outflow with flow velocity varying linearly from zero at A to 1.5 m/s at B. What is the rate of flow at B coming out from the conical duct.



$r_1 = 300$ mm

$r_2 = 150$ mm

[12 marks]

→ ~~cho~~ velocity of water leaving the porous is given as,

$$V = V_A + \frac{(V_B - V_A)}{L} \times x$$

$$= 0 + \frac{1.5}{L}x = \frac{1.5}{L}x$$

$$V = \frac{1.5}{L}x$$

$$dQ = V_r \times 2\pi r\,dr$$

$$dQ = \frac{1.5}{L}x \times 2\pi r\,dr.$$

$$r = 300 - \frac{300-150}{1500}x$$

$$r = 300 - 0.1x.$$

$$r = 0.3 - 0.1x \rightarrow m.$$

$$dr = -0.1\,dx$$

$$dQ = \frac{1.5}{L}x \times 2\pi(0.3 - 0.1x)(-0.1)dx$$

$$= \frac{-0.15 \times 2\pi}{1.5} \times (0.3x - 0.1x^2)dx$$

$$= \frac{-0.15 \times 2\pi}{1.5}\int_0^{1.5}(0.3x - 0.1x^2)dx$$

$$= \frac{-0.15 \times 2\pi}{1.5} \times \left[\frac{0.3x^2}{2} - 0.1\frac{x^3}{3}\right]_0^{1.5}$$

$$= 0.14137\ m^3/sec.$$

Calculation mistake

Hence

$Q_B = 2 - 0.14137$

$= 1.8586\, m^3/sec$

06

Q.1 (d) (i) Explain why there is a need of compounding of impulse steam turbine. Also mention types of compounding done.

(ii) What are the differences between impulse and reaction turbine? Explain in a tabular form.

[6 + 6 marks]

→ since, steam turbine is utilifeed for a power Generation purpose which is coupled to Generator.

→ The frequency of power produced depends upon the $f = \frac{PN}{60}$ where P = N· of pair of poles.

$f \propto N$

Hence frequency is directly proportional to speed. Hence we have to kept speed of turbine constant.

→ If we use a single turbine, then there is a large enthalpy drop in a single stage and the speed of Rotation can exceed above to 12000 to 24000 RPM, such a high speed is very dangerous to Rotating component

→ Hence, we used compounding so that enthalpy droop can be takes place in a No. of stages. and speed of Rotation is kept in a practile limit

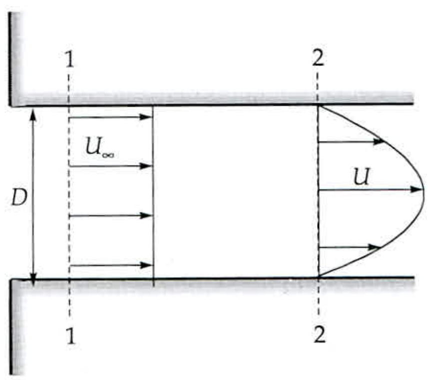
(iv) Types of compounding → (i) velocity compounding (ii) pressure compounding (iii) velocity - pressure comp.

Impulse turbine	Reaction turbine
(i) kinetic energy is utilized.	(i) both pressure and kinetic energy utilized.
(ii) symmetrical blades are employed ($V_{r2} = V_{r1}$)	(ii) Aerofoil type blades are used which acts as nozzle.
(iii) Degree of Reaction is zero	(iii) Degree of Reaction is is 0.5 for parson.
(iv) simple in construction and less costly.	(iv) complicated in construction and costly.

18

Q.1 (e) In a steady entrance flow in a pipe of diameter D as shown in figure. The flow develops from uniform flow at section (1) to a parabolic profile at section (2). If the momentum correction factor at section (2) is $\frac{4}{3}$, then show that the wall drag force F is given by

$$F = \frac{\pi D^2}{4}\left(P_1 - P_2 - \frac{1}{3}\rho U_\infty^2\right)$$



Where P_1 and P_2 are pressure at respective sections.

[12 marks]

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Q.2 (a) A model having scale ratio of $\frac{1}{10}$ is constructed to determine the best design of Kaplan turbine. The prototype Kaplan turbine develop 7355 kW under a net head of 10 m at a speed of 100 rpm. If the head available at the laboratory is 6 m and the model efficiency is 88% whereas the efficiency of prototype turbine is 4% better that of the model turbine. Find:

(i) running speed of the model.

(ii) the flow rate required in the laboratory.

(iii) the specific speed in each case.

[20 marks]

Q.2 (b) A centrifugal compressor develops a pressure ratio of 4 : 1. The inlet eye of the compressor impeller is 0.3 m in diameter. The axial velocity at inlet is 120 m/s and the mass flow rate is 10 kg/s. The velocity in the delivery duct is 110 m/s. The tip speed of the impeller is 450 m/s and runs at 16000 rpm with a total head isentropic efficiency of 80%. The inlet stagnation temperature and pressure are 300 K and 101 kPa.

(Take $c_p = 1.005$ kJ/kgK, $\gamma = 1.4$)

(i) the static temperature and pressure at inlet and outlet of the compressor

(ii) the static pressure ratio

(iii) the power required to drive the compressor

(iv) Mach number (based on relative velocity) at inlet

[20 marks]

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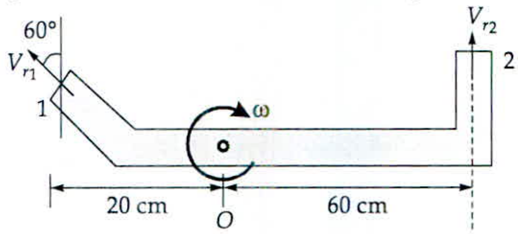
Q.2 (c) A sprinkler with unequal arms and jets of area 0.7 cm^2 is shown in figure. A flow of 1.4 l/s enters the assembly normal to the rotating arm.

(i) Assuming the frictional resistance to be zero calculate its speed of rotation,

(ii) What torque is required to hold it from rotating?



[20 marks]

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Q.3 (a) An impulse steam turbine has a number of pressure stages, each having a row of nozzles and a single ring of blades. The nozzle angle in the first stage is 20° and the blade exit angle is 30° with reference to the plane of rotation. The mean blade speed is 125 m/s and the velocity of steam leaving the nozzles is 350 m/s.

(i) Taking the blade friction factor as 0.9 and nozzle efficiency of 0.85, determine the work done in the stage per kg of steam and the stage efficiency.

(ii) If the steam supply to the first stage is at 20 bar, 250°C and the condenser pressure is 0.07 bar, estimate the number of stages required, assuming that the stage efficiency and the work done are the same for all stages and the reheat factor is 1.05.

at 20 bar, 250°C,

$h = 2902.5$ kJ/kg, $s = 6.5453$ kJ/kgK

at 0.07 bar,

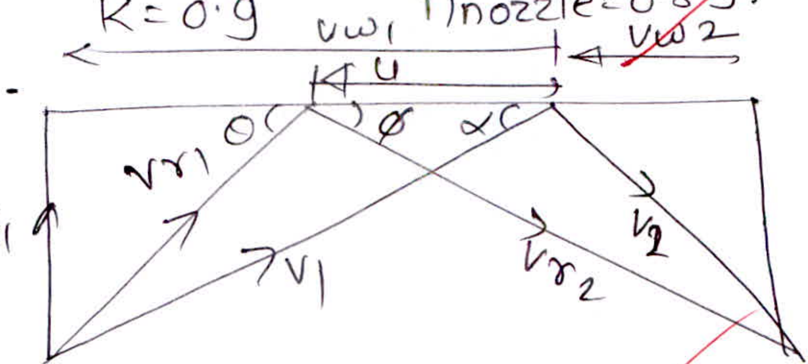
h_f (kJ/kg)	h_{fg} (kJ/kg)	s_f (kJ/kgK)	s_{fg} (kJ/kgK)
163.16	2409.54	0.5582	7.7198

[20 marks]

$\alpha = 20^\circ \quad \phi = 30^\circ \quad U_1 = U_2 = 125$ m/s.

$V_1 = 350$ m/s.

$K = 0.9 \quad \eta_{nozzle} = 0.85$.



~~total~~ enthalpy drop

$= h_1 - h_2$

$= 2902.5 - h_2$

$h_2 = h_{f2} + x_2 h_{fg2}$

$S_2 = s_{f1} + x_1 s_{fg1}$

$6.5453 = 0.5582 + x \times 7.7198$

$x = 0.788$ 0.7755 check calculation

$h_2 = 163.16 + 0.788 (2409.54)$

$= 2061.88$ kJ/kg

Workdone per stage

$= (V_{w1} + V_{w2})u$

$= (V_1 \cos\alpha + V_{r2}\cos\phi - u)u$

$= (V_1 \cos\alpha + K V_{r1}\cos\phi - u)u$

$V_{r1}\cos\theta + u = V_{w1}$

$V_{r1}\cos\theta + u = V_1\cos\alpha$

assuming symmetrical blading $\theta = \phi$

$V_{r1}\cos\phi = 350 \times \cos 20 - 125$

$V_{r1}\cos\phi = 203.892$

$W = (350\cos 20 + 0.9 \times 203.892 - 125) \times 125$

$= \underline{48424.4}$ kJ/kg

(ii) stage efficiency

$\eta_{stage} = \eta_{blade} \times \eta_{nozzle}$

$= \frac{\text{workdone}}{\frac{V_1^2}{2}} \times 0.85$

$= \frac{48424.4}{\frac{350^2}{2}} \times 0.85$

$= \underline{67.2\%}$

Reheat factor $= \frac{\text{cumultative enthalpy droperstage}}{\text{enthalpy drop perstage}}$

~~total~~ enthalpy drop $= 1.05 \times (h_1 - h_2)$

$= 1.05 \times (2902.5 - 2061.88)$

$= 882.651$ ~~KJ~~/kg

$\underline{\text{No. of stages}} = \frac{\text{total enthalpy drop}}{\text{enthalpy drop per stage}}$

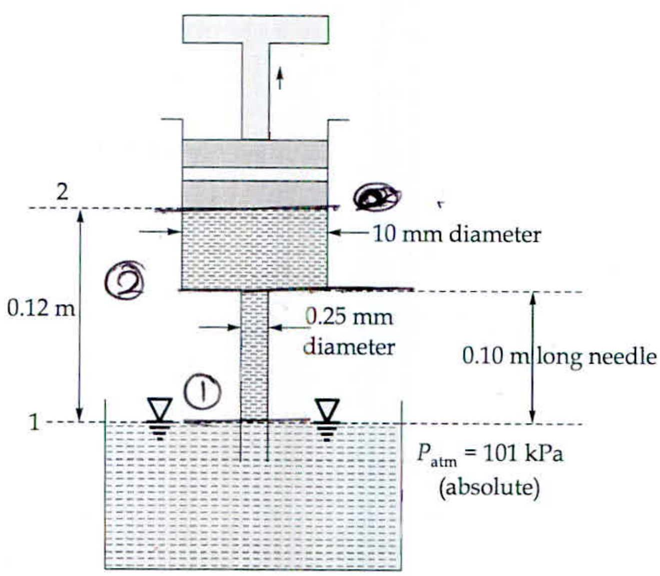
$= \frac{882.651 \text{ KJ/kg}}{48.42}$

$= 18.229$

≈ 19 stages

14

Q.3 (b) A liquid with specific gravity of 0.96, dynamic viscosity 9.2×10^{-4} Ns/m^2 and vapor pressure (P_v) = 1.2×10^4 N/m^2 (absolute) is drawn into the syringe as indicated in figure. What is the maximum flow rate if cavitation is not to occur in the syringe? Assume that the flow corresponding to the small diameter is laminar and support your answer with the necessary calculations.



[20 marks]

→ Applying Bernoullis @ point ① and ②.

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

→ As the flow is laminar ∞ → 0.

$$(h_L)=\frac{32\mu \bar{V_1} L_n}{\rho g D^2}+\frac{32\mu \bar{V_2} L_L}{\rho g d_2^2}$$

$P_1 = P_{atm} = 101\times10^3\ N/m^2$

$V_1 = Q/A_1 \qquad V_2 = Q/A_2$

$A_1 = \pi/4 \times (0.25\times10^{-3})^2 \quad A_2 = \pi/4 \times (0.01)^2$

$$\left(\frac{P_1}{\rho g}+z_1\right)-\left(\frac{P_2}{\rho g}+z_2\right)=\frac{V_2^2-V_1^2}{2g}+(h_L)$$

$$\left(\frac{101\times10^3}{960\times9.81}\right)-\left(\frac{1.2\times10^4}{960\times9.81}+0\right)=\frac{V_2^2-V_1^2}{2g}+h_L$$

$$9.33=\frac{V_2^2-V_1^2}{2g}+h_L$$

$$9.33=\frac{(Q/A_2)^2-(Q/A_1)^2}{2\times9.81}+\frac{32\times9.2\times10^{-4}\times\frac{Q}{A_1}\times0.1}{960\times9.81\times(0.25\times10^{-3})^2}$$

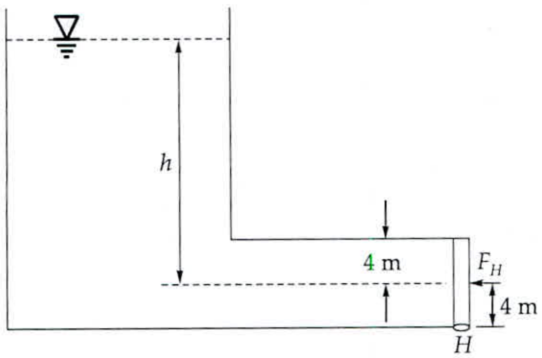
$$9.33=-2.115\times10^{13}Q^2+108.89\times10^6 Q$$

$$Q=4.72\times10^{-6}\ m^3/sec$$

In this question, both types of losses need to considered

04

Q.3 (c) A 3 m wide, 8 m high rectangular gate is located at the end of a rectangular passage that is connected to a large open tank filled with water as shown in figure. The gate is hinged at its bottom and held closed by a horizontal force, F_H located at the centre of the gate. The maximum value for F_H is 3500 kN.



(i) Determine the maximum water depth above the centre of the gate that can exist without the gate opening.

(ii) Will the answer be same, if the gate is hinged at the top? Explain your answer.

[20 marks]

→ Area of gate $= 3 \times 8 = 24 m^2$

→ $\bar{x} = h$.

$F = \rho g A \bar{x} = \rho g A h$

$= 9810 \times 24 \times h = 235440\, h$

centre of pressure.

$\bar{h} = \bar{x} + \frac{I_{GG}}{A\bar{x}} = h + \frac{\frac{3 \times 8^3}{12}}{3 \times 8 \times h}$

$\bar{h} = h + \frac{16}{3h}$

so distance between $\bar{x}$ and $\bar{h}$ is $\left[\frac{16}{3h}\right]$

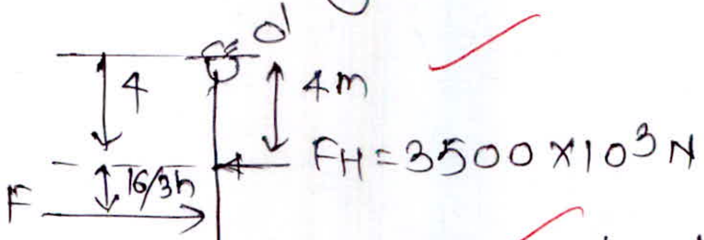
taking moment about the Hinge point

$F \times \left(4 - \frac{16}{3h}\right) = F_H \times 4$

$235440h\left(4 - \frac{16}{3h}\right) = 3500 \times 10^3 \times 4$

$\boxed{h = 16.2\, m}$

(ii) when the gate is hinged at top.



again taking moment about o'

$F\left(4 + \frac{16}{3h}\right) = 3500 \times 10^3 \times 4$

$235440 \times \left(4 + \frac{16}{3h}\right) \times h = 3500 \times 10^3 \times 4$

$h = 13.53 m$

so If the gate is hinged @ bottom the $h_1 = 16.2m$ and when hinged @ the top $h_2 = 13.53m$. this due to the moment due to the force F_H @ the top of the hinge is less than the $F \times \left(4 + \frac{16}{3h}\right)$.

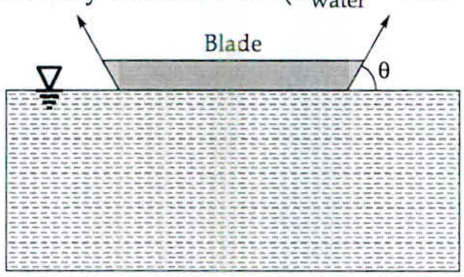
19

Q.4 (a) As surface tension forces can be strong enough to allow a double edge steel razor blade to 'float' on water. But a single edge blade will sink. Assume that the surface tension forces act at an angle θ relative to the water surface as shown in figure.

(i) The mass of the double edge blade is 0.64×10^{-3} kg and the total length of its sides is 206 mm. Determine the value of θ required to maintain equilibrium between the blade weight and resultant surface tension force.

(ii) The mass of the single edge blade is 2.61×10^{-3} kg and the total length of its side is 154 mm. Explain why this blade sink.

(iii) If suppose one bug having weight of 10^{-4} N stays on the upper (air side) surface of steel razor, then what changes you expect in value of (θ) for case (a) and support your answer with the necessary calculations ($\sigma_{water} = 7.34 \times 10^{-2}$ N/m)?



[5+5+10 = 20 marks]

Q.4 (b) A steam turbine plant works between the limit of 150 bar, 600°C and 0.1 bar. The mean blade velocity is 220 m/s. The average nozzle efficiency is 0.91. The nozzle (fixed blade) angle is 20°. All stages operate at the condition of maximum efficiency. The total isentropic enthalpy drop is 1400 kJ/kg. Determine the number of stages required for the following cases.

(i) All simple impulse stages.

(ii) All 50% impulse-reaction stages.

(iii) A two-row Curtis stage followed by simple impulse stages.

(iv) A two row Curtis stage followed by 50% impulse reaction stages.

[20 marks]

Do not write in this margin

Q.4 (c) (i) Explain the purpose of installing draft tube at the exit of reaction turbine.

(ii) The draft tube of a Kaplan turbine has inlet diameter 2.8 m and inlet is set at 3 m above the tail race. When the turbine develops 1500 kW power under a net head of 6 m, it is found that the vacuum gauge fitted at inlet to draft tube indicates a negative head of 4 m. If the turbine overall efficiency is 88%, determine the draft tube efficiency. If the turbine output is reduced to half with the same head, speed and draft tube efficiency, what would be the reading of the vacuum gauge? (Neglect minor losses).

[5 +15 = 20 marks]

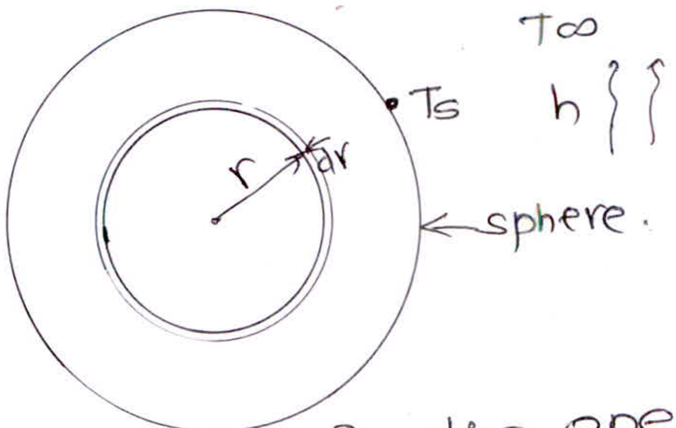
Section B : Heat Transfer - 1 + TOM - 1, Thermodynamics - 2 + RAC - 2

Q.5 (a) For a sphere of radius R having a surface temperature of T_s in which heat is generated at a uniform rate of q_G W/m^3, derive the following expression

$$T = T_\infty + \frac{q_G R}{3h} + \frac{q_G R^2}{6k}\left(1 - \frac{r^2}{R^2}\right)$$

where, T_∞ = Ambient temperature.

[12 marks]



for a sphere, the onedimensional Radial Heat conduction with uniformly Heat generation is given by

$$\frac{1}{r^2}\cdot\frac{d}{dr}\left(r^2\frac{dT}{dr}\right) + \frac{q_g}{k} = 0. \quad (1)$$

show initial steps

Assuptions

(I) constant thermal conductivity K
(II) uniform heat generation q_g
(III) steady state condition ie. No Heat stored in a system.

$$\frac{d}{dr}\left(r^2\frac{dT}{dr}\right) = -\frac{q_g}{k}r^2$$

Integrating w.r.to r.

$$r^2\frac{dT}{dr} = \frac{-q_g}{3K}r^3 + C_1$$

Boundary condition $r=0 \quad \frac{dT}{dr} = 0$

$$0 = 0 + C_1 \qquad C_1 = 0$$

$$r^2\frac{dT}{dr} = \frac{-q_g}{3K}r^3$$

$$\frac{dT}{dr} = \frac{-q_g}{3K}r$$

Again Integrating w.r.t r.

$$T = \frac{-\dot{q}_g}{6K} r^2 + C_2$$

B.C. @ $r = R$ $T = T_s$

$$T_s = \frac{-\dot{q}_g}{6K} R^2 + C_2 \Rightarrow C_2 = \dot{q}_g/6K \, R^2 + T_s$$

$$T = \frac{\dot{q}_g}{6K}(R^2 - r^2) + T_s \quad \text{--- (2)}$$

@ the surface of sphere,

Total Heat generated in a body = Heat dessipated due to convection

$$\dot{q}_g \times \frac{4}{3}\cancel{\pi} R^3 = h \times \cancel{4\pi} R^2 (T_s - T_\infty)$$

$$T_s = T_\infty + \frac{\dot{q}_g R}{3h} \quad \text{--- (3)}$$

putting eq^n (3) in eq^n (2) given

$$T = \frac{\dot{q}_g}{6K}(R^2 - r^2) + T_\infty + \frac{\dot{q}_g R}{3h}$$

Rearranging the term

$$\boxed{T = T_\infty + \frac{\dot{q}_G R}{3h} + \frac{\dot{q}_g R^2}{6K}\left(\cancel{R}^2 - \frac{r^2}{R^2}\right)}$$

10

Q.5 (b) The barometer for atmospheric air reads 750 mm of Hg, the dry bulb temperature is 33°C, wet bulb temperature is 23°C. Determine:

(i) the relative humidity.
(ii) the humidity ratio.
(iii) the dew point temperature.
(iv) density of atmospheric air.

Use the following relation,

Partial pressure of vapour, $P_v = (P_s)_{WB} - \frac{(P_t - (P_s)_{WB})(t_{DB} - t_{WB})}{1527.4 - 1.3 t_{WB}}$

$P_t \rightarrow$ Barometric pressure

$(P_S)_{WB} \rightarrow$ Saturation pressure corresponding to WBT

$t_{WB} \rightarrow$ Wet bulb temperature (in °C)

$t_{DB} \rightarrow$ Dry bulb temperature (in °C)

Use following table:

P_s (mm of Hg)	t_s (°C)
16.19	18.7
21.06	23
37.72	33

At 33°C density of Hg, $\rho_{Hg} = 13600\ kg/m^3$

Assume v_g (Specific volume of saturated vapour) at 37.72 mm of Hg is 28.05 m^3/kg.

[12 marks]

→ $P_t = 0.75 \times 13600 \times 9.81 = \underline{100.062\ kPa}$

partial pressure of vapour

$(P_s)_{WB=23^\circ C} = 21.06 \times 10^{-3} \times 13600 \times 9.81$
$= 2809.74\ Pa.$

$P_v = 2809.74 - \left[\frac{(100.062 \times 10^3 - 2809.74)(33-23)}{1527.4 - 1.3 \times 23}\right]$

$\boxed{P_v = 2160.31\ Pa}$

① Relative humidity.

$= \frac{P_v}{P_{vs\,DBT}} = \frac{2160.31}{P_{vs\,DBT}}$

$(P_{vs})_{DBT} = 37.72 \times 10^{-3} \times 13600 \times 9.81 = 5032.45\ P.$

$\phi = \frac{2160.31}{5032.45} = 42.93\%$

(ii) humidity Ratio

$$\omega = \frac{\text{Actual amount of water vapour}}{\text{total mass of dry air}}$$

$$\omega = \frac{m_v}{m_a} = 0.622 \frac{P_v}{P_t - P_v} = 0.622 \times \frac{2160.31}{(100.062 \times 10^3 - 2160.31)}$$

$$= 0.01372 \frac{\text{kg of w.v}}{\text{kg of dry air}}$$

(iii) dew point Temp.

$$P_v = 2160.31 \text{ Pa} = h_{Hg} \times 13600 \times 9.81$$

$$h_{Hg} = 16.19 \text{ mm of Hg}$$

from table corresponding dew point temp

$$\boxed{t_{dp} = 18.7^\circ C}$$

(iv) density of atmospheric air

Assuming mixture of ~~wat~~ is an Ideal gas

$$P_a = \rho_a R_a T \quad \text{--- (3)}$$

$$P_v = \rho_v \cdot R_v \cdot T \quad \text{--- (4)}$$

$$\frac{P_a}{P_v} = \frac{\rho_a \cdot R_a}{\rho_v \cdot R_v}$$

$$\rho_a = \frac{P_a}{P_v} \times \frac{\rho_v \times R_v}{R_a}$$

$$\rho_a = \frac{(100.062 \times 10^3 - 2160.31)}{2160.31} \times \frac{1}{28.05} \times \frac{18}{29}$$

$$\rho_a = 1.0049 \text{ kg/m}^3$$

1.13 kg/m3

09

$$\rho_{air} = \rho_{d.a} + \rho_{w.v.}$$

Q.5 (c) What is the mobility of mechanism? Explain the Kutzback equation for planar mechanism and in what way is the Gruebler's criterion different from it.

[12 marks]

→ mobility of Mechanism :-

It is the No. of Independent parameter's Required to define the position of Mechanism or

It is the No. of Inputs Required to obtains a completely constrained motion.

→ kutzback eq^n for a planar mechanism

$F = 3(n-1) - 2j - h$

where F = Degree of freedom.
n = no. of links in a mechanism
j = no. of joints.
h = No. of higher pairs.

Grubler's criterion

It is a special case of kutzback Relation, $F = 1$, $h = 0$

$1 = 3(n-1) - 2j - 0$

$1 = 3n - 3 - 2j$

$\cancel{3n + 6 - 2j = 0}$

$\cancel{3(n-2) - 2j = 0}$

$3n - 4 - 2j = 0$

$3n - 4 = 2j$

$3n = 2j + 4$

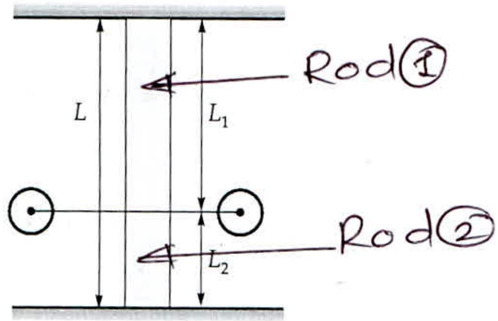
$n = \frac{1}{3}(2j + 4)$

$n = \frac{2}{3}(j + 2)$

06

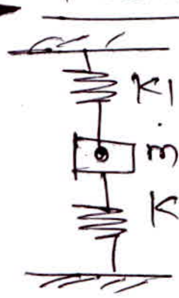
comment about the major difference

.5(d) A flywheel is mounted on a vertical shaft as shown in figure. The ends of the shaft being fixed. The shaft is having 20 cm diameter, the length L_1 is 0.9 m and the length L_2 is 0.6 m. The flywheel weighs 500 kg and its radius of gyration is 50 cm, then find the natural frequencies of the longitudinal, the transverse and torsional vibrations of the system. E = 200 GPa, G = 80 GPa.



[12 marks]

Natural frequencies of longitudinal



k_1 = Axial stiffness of shaft.

$= \frac{A_1 E_1}{L_1} = \frac{\pi/4 \times 0.2^2 \times 2\times10^{11}}{0.9}$

$K_1 = 6.98\times10^{9}$ N/m

$K_2 = \frac{A_2 E_2}{L_2} = \frac{\pi/4 \times 0.2^2 \times 2\times10^{11}}{0.6}$

$= 10.47\times10^{9}$ N/m

both the shafts are in parallel.

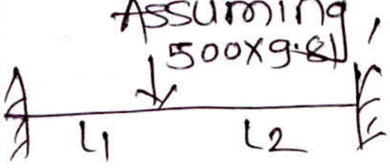
$K_{eq} = K_1 + K_2$

$= 6.98\times10^{9} + 10.47\times10^{9} = 1.745\times10^{10}$ N/m

$\omega_n = \sqrt{\frac{K_{eq}}{m}} = \sqrt{\frac{1.745\times10^{10}}{500}} = 5907.95$ Rad/sec

(II) Natural frequency of ~~tor~~ transverse vibration

Assuming, shaft is fixed @ both ends.



$\delta = \frac{Wa^3b^3}{3EIl^3} = \frac{500\times9.81\times0.9^3\times0.6^3}{3\times2\times10^{11}\times\pi/64\times0.2^4 \times 1.5^3}$

~~$\delta = 1.639\times10^{-5}$ m~~

$\delta = 4.856\times10^{-6}$ m

$\omega_n = \sqrt{g/\delta} = \sqrt{\frac{9.81}{4.856\times10^{-6}}}$

$\omega_n = 1421.28$ Rad/sec

(III) Natural frequency due to torsional vibrations.

$$K_{teq} = K_{t1} + K_{t2}$$

$$= \left(\frac{G_1 J_1}{L}\right) + \left(\frac{G_2 J_2}{L_2}\right)$$

$$= \frac{80\times10^9 \times \pi/32 \times 0.2^4}{0.9} + \frac{80\times10^9\times \pi/32 \times 0.2^4}{0.6}$$

$$K_{teq} = 34906585.04 \text{ N.m}$$

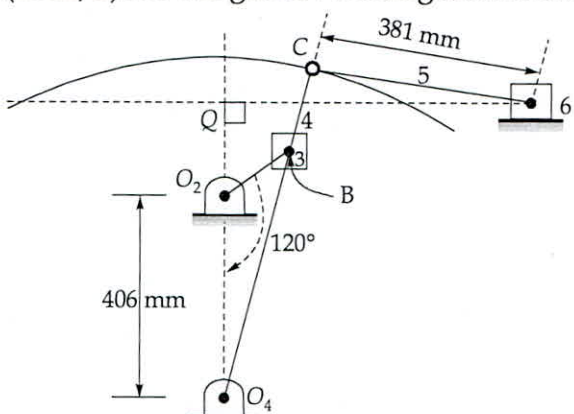
$$\omega_n = \sqrt{\frac{K_{teq}}{I}} = \sqrt{\frac{34906585.04}{500\times0.5^2}}$$

$$= 528.44 \text{ Rad/sec.}$$

Good

12

.5 (e) In order to design a crank-shaper mechanism as shown below, that will give a time ratio of 1.75:1 with a working stroke of 660 mm. Assumed that, point C as it moves along the arc of radius O_4C. The fixed dimensions are given in the figure and compute the required value of O_2B and O_4C. If the crank rotate at a constant speed of 40 rpm. Find the average speed of slider (in m/s) for the given working stroke and for the returning stroke.

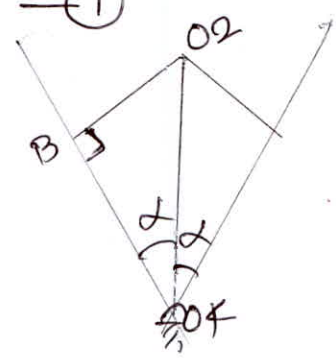


[12 marks]

→ we know that

$$\text{stroke} = \frac{2 \times \text{Radius of crank} \times O4C}{O2O4}$$

$$660 = \frac{2 \times O2B \times O4C}{406} \quad —①$$



we know that,

$$QRR = \frac{180 + 2\alpha}{180 - 2\alpha}$$

$$1.75 = \frac{180 + 2 \times \alpha}{180 - 2\alpha}$$

$$\alpha = 24.54°$$

$$\sin\alpha = \frac{O2B}{O2O4} = \frac{O2B}{406} = \sin(24.54)$$

$$\boxed{O2B = 168.62\ mm}$$

putting in eqⁿ ①

$$660 = \frac{2 \times 168.62 \times O4C}{406}$$

$$\boxed{O4C = 794.567\ mm}$$

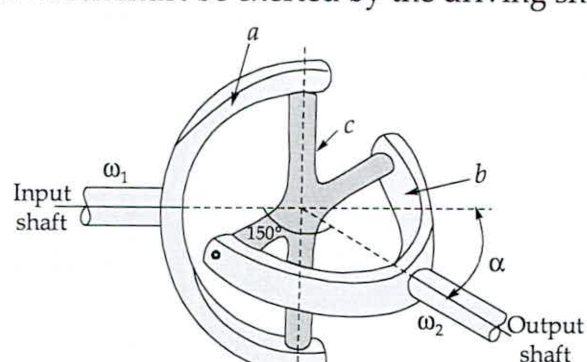
06

Slider velocity = ?

.6 (a) A furnace is insulated with a firebrick lining of 200 mm thickness. The temperature of hot gases in the furnace is 1800 K and the temperature of the surroundings of the furnace is 300 K. The thermal conductivity of the firebricks is given by $k = k_0(1 + \beta T)$ where k_o is equal to 0.85 W/m-K and β is equal to 7×10^{-4} per K. The heat transfer coefficient on the hot and cold sides of wall is 40 W/m^{2}K and 10 W/m^{2}K respectively. Determine the temperature at inner and outer surfaces of the wall. Also find out the heat lost per unit area of the wall.

[20 marks]

(b) 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]

Q.6 (c) Water flows through a 1.5 cm × 3.5 cm rectangular cross-section smooth tube at a velocity of 1.2 m/s. The inlet temperature of water is 40°C and tube wall is maintained at 85°C. Determine the length of tube required to raise the temperature of water to 70°C. Also find out the pumping power required if pump efficiency is 60%.

Properties of water at the mean bulk temperature of 55°C are:

$\rho = 985.5\ \text{kg/m}^3$, $c_p = 4.18\text{kJ/kgK}$, $\nu = 0.517 \times 10^{-6}\ \text{m}^2/\text{s}$, $k = 0.654\ \text{W/mK}$ and $\text{Pr} = 3.26$.

[20 marks]

7 (a) A punching machine punches 25 holes of 30 mm diameter and 20 mm thickness per minute. The actual punching operation is done in $\left(\frac{1}{15}\right)^{th}$ of a revolution of crank-shaft. The ultimate shear strength of the steel plate is 300 MPa. The coefficient of fluctuation of speed is 0.12. The flywheel with a maximum diameter of 1.5 m rotate at 10 times the speed of the crank shaft.

Determine the following:

(i) Power of motor assuming the mechanical efficiency to be 92%.

(ii) Cross-section of the flywheel rim if width is twice the thickness of the flywheel. Flywheel is of cast iron with a working tensile stress 6 N/mm^2 and density of 7000 kg/m^3.

Assume the hub and the spokes of the flywheel delivers 10% of the rotational inertia of the wheel.

[20 marks]

→ cycle time $= \frac{60}{25} = 2.4$ sec

actual punching operation $= \frac{1}{15} \times 360 = 24°$

$\tau_{sut} = 300$ MPa $\quad C_s = 0.12$

→ energy Required per ~~operation~~ penetration operation

Avg.

$= \frac{1}{2} \times F_{max} \times t \quad \frac{1}{2} \times 300 \times \pi \times 30 \times 20 \times t$

$= 282.74 \times t$ N·m

$= 5654.86$ N·m

power of motor $= \dfrac{\text{Energy Required per operation}}{t_{cycle} \times \eta}$

$= \dfrac{5654.86}{2.4 \times 0.92}$

$= 2561.08$ W

(ii) $\sigma = \rho v^2$ ← condition.

$6 \times 10^6 = 7000 \times v^2$

$V_{max} = 29.277$ m/sec $= \frac{\pi D N}{60}$

$\omega_{crank} = \frac{\theta}{t} = \frac{2\pi}{2.4} = 2.62$ Rad/sec

$N_{max} = 25$ RPM $\quad N$ ~~max flywheel~~ avg. $= 250$ RPM

$$29.277 = \frac{\pi \times D N}{60}$$

$$N_{max} = 372.766 \, RPM.$$

$$C_s = \frac{N_{max} - N_{min}}{N}$$

$$N_{min} = 342.766 \, RPM$$

$$\Delta E = \frac{1}{2} I \left(\omega^2_{max} - \omega^2_{min} \right)$$

$$= I\omega^2 C_s = I \times \left\{ \frac{2\pi \times 250}{60} \right)^2 \times 0.12$$

$$= 82.246 \times I = 5654.86 \left\{ 1 - \frac{\frac{1}{15} \times 360}{360} \right)$$

$$I_{total} = 64.17 \, kg \cdot m^2.$$

$$I_{Rim} = 57.75 \, kg \cdot m^2$$

$$mR^2 = 57.75$$

$$\rho \times \pi D \times B \times t \times R^2 = 57.75$$

$$7000 \times \pi \times 1.5 \times 2t^2 \cdot \left(1.5/2 \right)^2 = 57.75$$

$$t = 0.0394 \, m$$

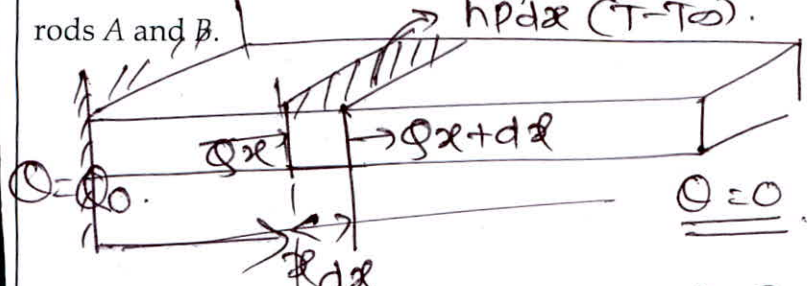
$$B = 0.0789 \, m.$$

19

[redacted] b) Derive an expression for temperature distribution in case of infinite fin.

Two long slender rods A and B, made of different materials having same diameter of 12 mm and length 1 m, are attached to a surface maintained at a temperature of 100°C. The surfaces of the rods are exposed to ambient still air at 20°C. By traversing along the length of the rods with a temperature sensor, it is found that the surface temperatures of rods A and B are equal at positions 15 cm and 7.5 cm respectively away from the base surface. If material of A is carbon steel with thermal conductivity 60 W/mK, what is the thermal conductivity of rod B? List the assumptions made. Assume that the average convection coefficient of air is 5 W/m²K. Find the ratio of the rate of heat transfer for rods A and B.

[20 marks]



$$Q_x = Q_{x+dx} + h P \cdot dx\,(T-T_\infty).$$

$$\cancel{Q_x} = \left[\cancel{Q_x} + \frac{\partial}{\partial x}(Q_x)\,dx\right] + h P\,dx\,(T-T_\infty).$$

$$\frac{\partial}{\partial x}(Q_x)\,dx - hP\,dx\,(T-T_\infty) = 0$$

$$\theta^2 - m^2\theta = 0 \qquad \theta = T - T_\infty.$$

where $m = \sqrt{hP/kA_c}$

$$\theta = C_1 e^{mx} + C_2 e^{-mx}$$

@ $x = 0$ $\quad \theta = \theta_0$

$\theta_0 = C_1 + C_2$.

@ $x = \infty$ $\quad \theta = 0$

$0 = C_1$ $\quad C_1 = 0 \quad C_2 = \theta_0$

$$\theta = \theta_0 e^{-mx}$$

$$T - T_\infty = (T_0 - T_\infty) e^{-mx}$$

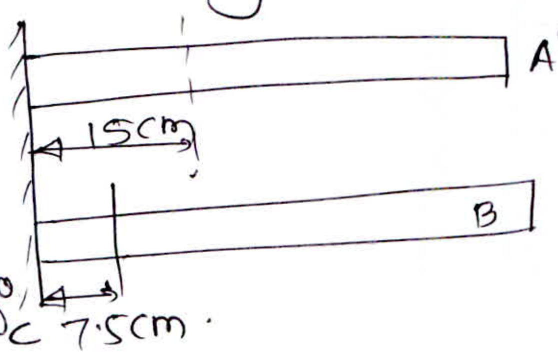
$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-mx}$$

Assuptions :-

(I) constant thermal conductivity

(II) Heat transfer takes place only in a x-direction

(III) Negligible contact Resistance.



$T_\infty = 20^\circ C$

$d_A = d_B = 0.012 m$

$L = 1 m$.

$T_0 = 100^\circ C$

for Rod A

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-m_A x_A} \quad \text{——} (1)$$

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-m_B x_B}. \quad \text{——} (2)$$

eq^n (1) and (2) are equal

$$e^{-m_A x_A} = e^{-m_B x_B}$$

$$e^{m_A x_A} = e^{m_B x_B}$$

$$m_A x_A = m_B x_B$$

$$\frac{m_B}{m_A} = \frac{x_A}{x_B}$$

$$\frac{\left(\frac{\cancel{hP}}{KA}\right)_B}{\left(\frac{\cancel{hP}}{KA}\right)_A} = \frac{x_B^2}{x_A^2} = \left(\frac{x_A}{x_B}\right)^2$$

$$\frac{K_A}{K_B} = \left(\frac{x_A}{x_B}\right)^2$$

$$\frac{60}{K_B} = \left(\frac{15}{7.5}\right)^2$$

$$\boxed{K_B = 15\ W/m^\circ K}$$

There is no degree sign on Kelvin

Ratio of Heat transfer Rate

$$\frac{Q_A}{Q_B} = \frac{\sqrt{(hPKA)_A}\ \cancel{(T_0 - T_\infty)}}{\sqrt{(hPKA)_B}\ \cancel{(T_0 - T_\infty)}}$$

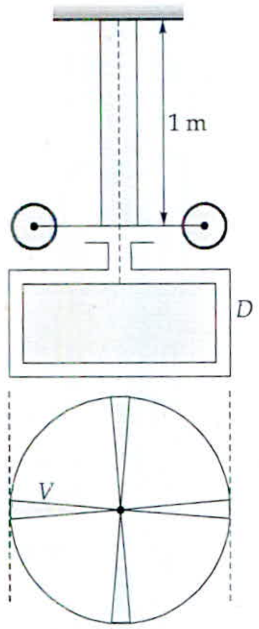
$$= \sqrt{\frac{K_A}{K_B}} = \sqrt{\frac{60}{15}} = 2$$

$$\boxed{\frac{Q_A}{Q_B} = 2}$$

We don't use degree symbol for Kelvin temp. scale

18

Q.7(c) A flywheel of moment of inertia 25 kg.m^2 is fixed to one end of a vertical shaft diameter 2.54 cm and the length 1 m. The other end of the shaft is fixed. The torsional oscillations of the flywheel are damped by means of a vane as shown in figure, which moves in a dashpot D filled with oil. The amplitude of oscillations is found by experiment to diminish to $\left(\frac{1}{20}\right)^{th}$ of its initial value in three complete oscillations. Assuming the damping torque to be directly proportional to the angular velocity, find its magnitude at a speed of 1 rad/s. The modulus of rigidity of the shaft material is 85 GPa and compare later with the frequency of the free vibrations.



[20 marks]

→ logarithmic decrement

$$\delta = \frac{2\pi\xi}{\sqrt{1-\xi^2}} = \frac{1}{n}\cdot \ln\left(\frac{x_0}{x_3}\right)$$

$$= \frac{1}{3}\cdot \ln(20)$$

$$\underline{\xi = 0.1569}$$

→ $\xi = \dfrac{c}{c_c}$

$c_t = \xi \times c_{c_t}$ ← coefficient of damping

$C_t = \xi \times 2 \times I\,\underline{\omega_n}$ $\qquad \omega_n = \sqrt{\dfrac{K_{teq}}{I}}$

$I = 25$ kg$\cdot$m^2

$$K_t = \frac{GJ}{\ell} = \frac{85\times10^9 \times \pi/32\,(0.0254)^4}{1}$$

$= 3473.39$ N$\cdot$m

$\omega_n = 11.79$ Rad/sec

$C_t = 0.1569 \times 2 \times 25 \times 11.79$

$C_t = 92.49 \ \frac{N \cdot m\,sec}{Rad}$

damping torque @ 1 Rad/sec

$T_d = 92.49 \ N \cdot m$

* frequency of damping

$\omega_d = \omega_n \sqrt{1-\xi^2}$

$\omega_d = 11.79 \sqrt{1-0.1569^2}$

$= 11.64$ Rad/sec.

so in case of damped vibration the frequency of vibration Reduces,

$f_d = 1.85$ Hz

$f_n = 1.876$ Hz

19

Good

most of the calculations are ok. Keep it up

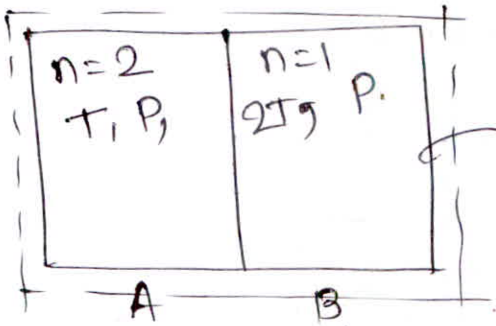
Good Luck

Q.8 (a) Two moles of an ideal gas at temperature T and pressure P are contained in a compartment. In an adjacent compartment one mole of an ideal gas is at temperature 2T and pressure P. The gases mix adiabatically but do not react chemically when a partition separating the compartments is withdrawn. Show that the entropy increase due to the mixing process is given by:

$$\bar{R}\left(\ln\frac{27}{4}+\frac{\gamma}{\gamma-1}\ln\frac{32}{27}\right) \text{ where, } \bar{R} \text{ - Universal gas constant}$$

provided that the gases are different and that the ratio of specific heat γ is the same for both gases and remains constant.

[20 marks]



$\delta Q = 0$

Applying first law of thermodynamic

$$\cancel{\delta Q}^{0} = du + \cancel{\delta W}^{0}$$

$$du = 0$$

$$(du)_A + (du)_B = 0$$

$$n_A \times \cancel{\bar{C}_V}(T_f - T_A) + n_B \cancel{\bar{C}_{V_B}}(T_f - T_B) = 0$$

$$2 \times (T_f - T) + 1(T_f - 2T) = 0$$

$$2T_f - 2T + T_f - 2T = 0$$

$$3T_f = 4T$$

$$\boxed{T_f = \frac{4T}{3}}$$

$$(\Delta S)_A = C_v \cdot \ln\left(\frac{T_2}{T_1}\right) - R \cdot \ln\left(\frac{V_2}{V_1}\right)$$

$$= n_A\left[\bar{C}_{VA} \ln\left(\frac{\frac{4T}{3}}{T}\right) - \bar{R}\ln\left(\frac{V_f}{V_1}\right)\right.$$

$$V_{1A} = \frac{nRT}{P} \qquad V_{1B} = \frac{n\bar{R}(2T)}{P}$$

$$V_{1A} = \frac{2\times \bar{R}T}{P} \qquad V_{1B} = \frac{2\bar{R}T}{P}$$

$$V_f = V_{1A} + V_{1B} = \frac{4\bar{R}T}{P}$$

$$(\Delta S)_A = 2\left[\bar{C}_{VA} \ln\left(4/3\right) - \bar{R}\ln(2)\right]$$

similarly change in entropy of B.

$$(\Delta S)_B = n_B\left(\bar{C}_{VB} \cdot \ln\left(\frac{4/3\,T}{2T}\right) - \bar{R}\ln(2)\right]$$

$$= 1\left(\bar{C}_{VB} \ln\left(\frac{4}{6}\right) - \bar{R}\ln(2)\right].$$

$$(\Delta S) = \Delta S_A + \Delta S_B$$

$$= \bar{C}_V \ln\left(\frac{16}{18}\right) - \bar{R}\ln(4)$$

$\frac{16}{9}\times\frac{2}{3}$ $\qquad$ $(2^2\times 2)$

$$= \frac{\bar{R}}{r-1}\ln\left(\frac{16}{18}\right) - (\bar{R})\ln(4)$$

$$= \bar{R}\left[\frac{1}{r-1}\ln\left(\frac{16}{18}\right) - \ln(4)\right]$$

$$= \bar{R}\left(\frac{1}{r-1}\ln\left(\frac{8}{9}\right) - \ln(4)\right)$$

$$= \bar{R}\left[\frac{1}{r-1}\ln\left(\frac{24}{27}\right) - \ln(4)\right]$$

$$= \bar{R}\left[\frac{r}{r-1}\ln\left(\frac{32}{27}\right) - \frac{r}{r-1}\ln\left(\frac{32}{27}\right) + \frac{1}{r-1}\ln\left(\frac{24}{27}\right) - \ln(4)\right]$$

$$= \bar{R}\left[\frac{r}{r-1}\ln\left(\frac{32}{27}\right) - \frac{\ln\left(\frac{32}{27}\right)^{1.4} + \ln\left(\frac{24}{27}\right)}{r-1} - \ln(4)\right]$$

$$= \bar{R}\left[\frac{r}{r-1}\ln\left(\frac{32}{27}\right) - \frac{\ln\left(\left(\frac{32}{27}\right)^{1.4}\times\frac{24}{27}\right)}{0.4} - \ln(4)\right]$$

$$= \bar{R}\left[\frac{r}{r-1}\ln\left(\frac{32}{27}\right) + \ln\left(4\times\left(\frac{32}{27}\right)^{1.4}\times\frac{24}{27}\right]^{0.4}\right]$$

$$= \bar{R}\left[\frac{r}{r-1}\ln\left(\frac{32}{27}\right) + \ln\left(27/4\right)\right]$$

$$(\Delta s) = \bar{R}\left[\ln\left(\frac{27}{4}\right) + \frac{r}{r-1}\ln\left(\frac{32}{27}\right)\right]$$

Avoid these kind of practises

05

3 (b) A steam turbine receives 600 kg/h of steam at 25 bar and 350°C. At a certain stage of the turbine, steam at the rate of 150 kg/h is extracted at 3 bar and 200°C. The remaining steam leaves the turbine at 0.2 bar and 0.92 dry. During the expansion process, there is heat transfer from the turbine to the surrounding at the rate of 10 kW. Evaluate per kg of steam entering the turbine:

(i) the energy of steam entering and leaving the turbine,

(ii) the maximum work,

(iii) the irreversibility

The atmosphere is at 30°C.

Data given:

At 25 bar and 350°C, $h_1 = 3125.87$ kJ/kg; $s_1 = 6.8481$ kJ/kgK

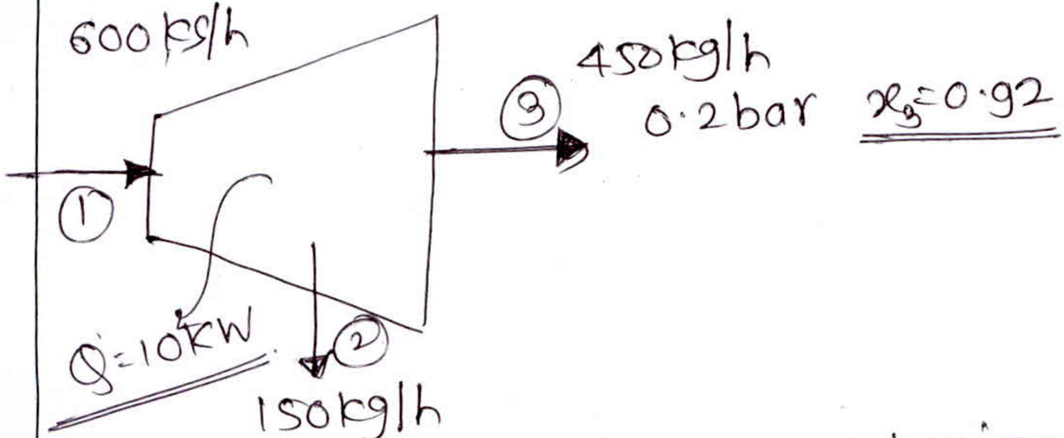
At 30°C, $h_0 = 125.79$ kJ/kg; $s_0 = s_{f30°C} = 0.4369$ kJ/kgK

At 3 bar and 200°C, $h_2 = 2865.5$ kJ/kg; $s_2 = 7.3115$ kJ/kgK

At 0.2 bar (0.92 dry), $h_f = 251.4$ kJ/kg; $h_{fg} = 2358.3$ kJ/kg

$s_f = 0.8320$ kJ/kgK; $s_g = 7.9085$ kJ/kgK

[20 marks]



(i) energy of steam entering the turbine

$= \dot{m} h_1$

$= \frac{600}{3600} \times 3125.87 = 520.978$ kW

energy of steam leaving the turbine

$= \frac{450}{3600} \times h_3 = \frac{450}{3600} \times \{251.4 + 0.92 \times (2358.3)\}$

$h_3 = 2421.03$ kJ/kg

$E_{out} = 302.63$ kW

(ii) maximum workdone

$= (h_1 - h_2) - T_0(s_1 - s_2) + (h_2 - h_3) - T_0(s_2 - s_3)$

$$= \left[(3125.87 - 2865.5) - 303 \times (6.8481 - 7.3115)\right] \times \frac{600}{3600}$$

$$+ \left[\frac{450}{3600}\right] \times \left[(2865.5 - 2421.03) - 303 \times (7.3115 - 7.34236)\right]$$

$$= \underline{\underline{123.52 \text{ kW}}}$$

(iii) Irreversibility

Applying steady flow energy

$$= \dot{m}(h_1 - h_2) + \dot{m}(h_2 - h_3) - \dot{Q}$$

$$W_{act} = \frac{600}{3600}(3125.87 - 2865.5) + \frac{450}{3600}(2865.5 - 2421.03) - 10$$

$$= \underline{88.95 \text{ kW}}$$

Irreversibility $= W_{max} - W_{act}$

$$= 123.52 - 88.95$$

$$= \underline{\underline{34.57 \text{ kW}}}$$

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(c) An air refrigerator working on Bell-Coleman cycle takes the air into the compressor at 1 bar and –7°C and it is compressed isentropically to 5.5 bar and it is further cooled to 18°C at the same pressure. Find the COP of the system if:

(i) the expansion is isentropic

(ii) the expansion follows the law $PV^{1.25}$ = constant.

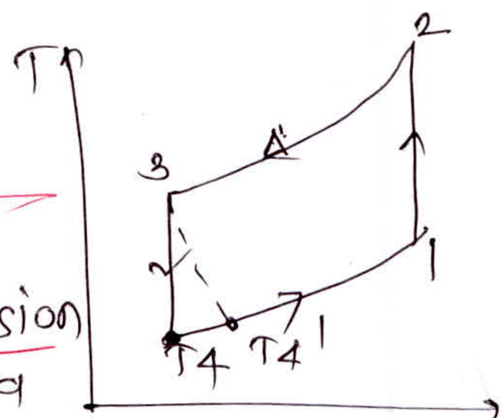
Take $\gamma = 1.4$ and $c_p = 1$ kJ/kgK for air.

[20 marks]

→ ① when the expansion is isentropic

$$(COP)_{cycle} = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1} = \frac{1}{5.5^{\frac{0.4}{1.4}} - 1}$$

$= 1.59$ //



$P_1 = 1$ bar $T_1 = 266$ K

$T_3 = 291$ K

1-2 → Isentropic compression

2-3 → Heat Rejection in a H·E

3-4 → Isentropic expansion in turbine

3-4' → Polytropic expansion in a expander.

Do not write in this ma

(ii) when the expansion follows

$$pv^{1.25} = C$$

$$n = 1.25.$$

$$\frac{T_4'}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{n-1}{n}}$$

$$= \left(\frac{1}{5.5}\right)^{\frac{0.25}{1.25}}$$

$$T_4' = 206.92\,K.$$

$$(COP) = \frac{\text{Refrigerating effect}}{\text{Net Work done.}}$$

$$RE = C_p(T_1 - T_4')$$

$$= 1 \times (266 - 206.92) = 59.07 \text{ kJ/kg}$$

$$W_{net} = W_C - W_T$$

$$= C_p(T_2 - T_1) - W_T$$

$$\frac{T_2}{T_1} = (r_p)^{\frac{\gamma-1}{\gamma}} = (5.5)^{\frac{0.4}{1.4}}$$

$$T_2 = 432.926\,K$$

$$C_p = \frac{\gamma R}{\gamma - 1}$$

$$1 = \frac{1.4}{0.4} R$$

$$R = 0.2857$$

$$W_T = \frac{n}{n-1}\left(P_3V_3 - P_4'V_4'\right)$$

$$= \frac{n}{n-1} \times R\,(T_3 - T_4')$$

$$= \frac{1.25}{0.25} \times 0.285 \times (291 - 206.92)$$

$$= 120.6548 \text{ KJ/kg}$$

$$W_{net} = 1 \times (432.926 - 266) - 120.6548$$

$$= 46.2712 \text{ KJ/kg.}$$

Do not write in this margin

$$COP = \frac{RE}{W_{net}}$$

$$= \frac{59.07}{46.2712}$$

$$= 1.2766$$

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Space for Rough Work

Space for Rough Work

Q.3, Q.5, Q.2, 7, 8