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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 : ....

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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	49
Q.2	55
Q.3	—
Q.4	49
Section-B	
Q.5	33
Q.6	—
Q.7	25
Q.8	—
Total Marks Obtained	211

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]

Degree of reaction $(R) = \dfrac{\text{Enthalpy drop in moving blades}}{\text{Enthalpy drop in a stage}}$

$= \dfrac{(\Delta h)_{MB}}{(\Delta h)_S}$

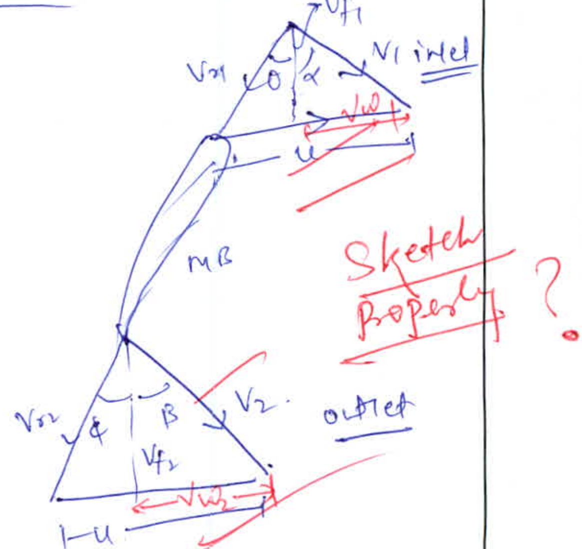
$(\Delta h)_S = (\Delta h)_{FB} + (\Delta h)_{MB}$; MB = moving blade, FB = fixed blade

$\therefore R = \dfrac{(\Delta h)_{MB}}{(\Delta h)_{MB} + (\Delta h)_{FB}}$

It can also be defined as $R = \dfrac{\text{contribution of press energy}}{\text{contribution of KE + contribution of pressure head.}}$

for an axial flow compressor

$\left\{ \begin{array}{l} V_{f1} = V_{f2} = V_f \\ \& \ u_1 = u_2 = u_m = u \end{array} \right\}$



Velocity diagram for AF compressor

@ inlet, $V_{f} \tan\theta + V_f \tan\alpha = u$

$V_{r1} = \dfrac{V_f}{\cos\theta}$, $V_1 = \dfrac{V_f}{\cos\alpha}$

@ outlet, $u = V_f(\tan\phi + \tan\beta)$

$\therefore V_{w1} = V_f \tan\alpha$

$\& \ V_{w2} = V_f \tan\beta$

Euler work $= (V_{w2} - V_{w1})u = V_f(\tan\beta - \tan\alpha)u \rightarrow (i)$

and contribution of pressure into work

$= \frac{V_{r1}^2 - V_{r2}^2}{2} + \frac{u_2^2 - u_1^2}{2} \rightarrow (ii)$

$(\because u_1 = u_2 = u) \Rightarrow$ (ii) becomes $\frac{V_{r1}^2 - V_{r2}^2}{2}$

$\because V_f \Rightarrow R = \frac{\frac{V_{r1}^2 - V_{r2}^2}{2}}{(V_{w2} - V_{w1})u}$

$\therefore R = \frac{V_f^2(\sec^2\theta - \sec^2\phi)}{2 V_f(\tan\beta - \tan\alpha)u}$

Also, $u = V_f(\tan\theta + \tan\alpha) = V_f(\tan\phi + \tan\beta)$ (from velocity diagram)

$\therefore \tan\beta - \tan\alpha = \tan\theta - \tan\phi$

Using the above, $\because \sec^2\theta - \sec^2\phi = \tan^2\theta - \tan^2\phi$

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

$$\boxed{R = \frac{V_f}{2u}(\tan\theta + \tan\phi)}$$

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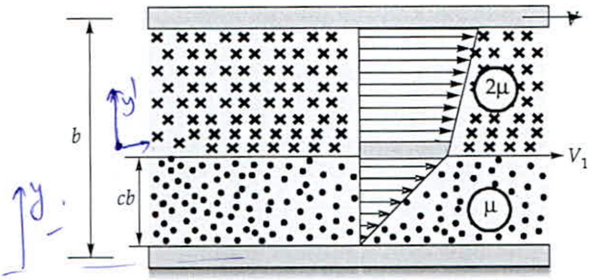
.1 (b) Two flat plates are oriented in parallel configuration above a fixed lower plate as shown in figure. The top plate, located a distance, b above the fixed plate, is pulled along with speed V. The other thin plate is located a distance (cb) where $0 < c < 1$, above the fixed plate. This plate moves 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	?	?	?	?	?



[12 marks]

Velocity distribution.

for $0 \le y < cb$, $V = \left(\frac{V_1}{cb}\right) \times y$.

and for $cb < y < b$, or $0 < y' < b - cb$

$V = V_1 + y' \left(\frac{V - V_1}{(b - cb)}\right)$

∵ the plate moves with V_1 = constant

∴ the shear forces on it must balance.

Force from bottom fluid = $\mu\left(\frac{V_1}{cb}\right) = \frac{\mu V_1}{cb}$ (towards left)

force on top surface = $(2\mu)\left[0 + \frac{\partial}{\partial y'}\left(V_1 + y'\left(\frac{V - V_1}{b - cb}\right)\right)\right]$

$= 2\mu\left[0 + \frac{V - V_1}{b - cb}\right]$

$= 2\mu\frac{(V - V_1)}{b(1 - c)}$ (towards right)

$\therefore \frac{A V_1}{C V} = \frac{2A(V-V_1)}{V(1-C)}$

or $\frac{V_1}{C} = \frac{2(V-V_1)}{1-C} \Rightarrow V_1 = \frac{2C}{1-C}(V-V_1)$

(i) for $C = 0$; $V_1 = 0 \Rightarrow \boxed{\frac{V_1}{V} = 0}$

(ii) for $C = 0.2$; $V_1 = 0.5(V-V_1) \Rightarrow 2V_1 = V - V_1$ or $V_1 = \frac{V}{3}$

$\therefore \boxed{\frac{V_1}{V} = \frac{1}{3}}$

(iii) for $C = 0.5$, $V_1 = \frac{2(0.5)}{1-0.5}(V-V_1) = 2(V-V_1)$

$\therefore 3V_1 = 2V$ or $\boxed{\frac{V_1}{V} = \frac{2}{3}}$

(iv) for $C = 0.7$,

$V_1 = \frac{2 \times 0.7}{1-0.7}(V-V_1) = \frac{1.4}{0.3}(V-V_1)$

$\therefore 3V_1 = 14V - 14V_1$

or $17V_1 = 14V$

$\therefore \boxed{\frac{V_1}{V} = \frac{14}{17}}$

Better to show in table

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(v) for $C = 1.0$

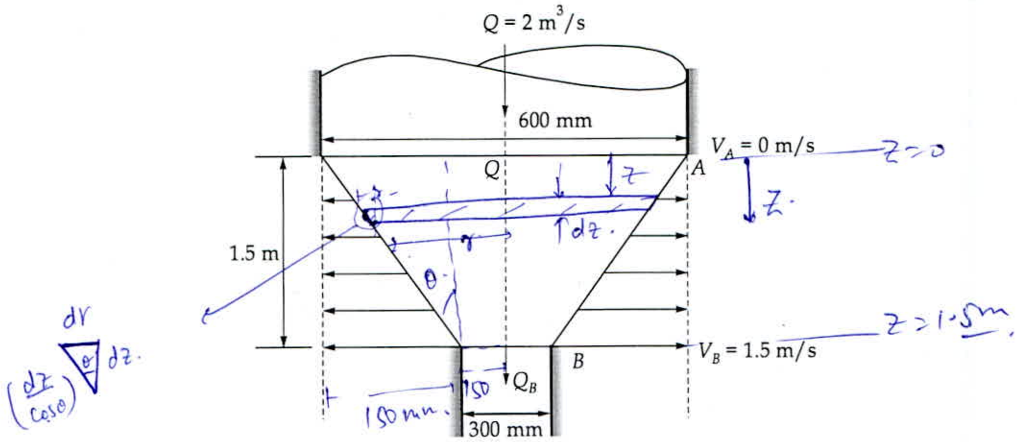
$\therefore V_1 = \frac{2C(V-V_1)}{1-C}$

$\Rightarrow V_1(1-C) = 2C(V-V_1) \Rightarrow V_1(1-C+2C) = 2CV$

$\therefore \boxed{V_1 = \frac{2CV}{1+C}}$

$\therefore C = 1 \Rightarrow \frac{V_1}{V} = \frac{2 \times 1}{1+1} = \frac{2}{2} = 1 \Rightarrow \boxed{\frac{V_1}{V} = 1}$

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.



[12 marks]

Radial velocity flow distribution

$V_{rA} = 0, \quad V_{rB} = 1.5 \text{ m/s}$

$\therefore V_{rZ} = \dfrac{(V_{rB} - V_{rA})}{1.5} \times (Z) = \dfrac{1.5}{1.5}(Z) = Z$

$\therefore \boxed{V_{rZ} = Z}$ (Z is shown in fig)

∴ let's take a small strip over cone of dz.

∴ volume flowing out $= (V_r)_Z \, (2\pi)(r) \dfrac{dz}{\cos\theta}$

• let's find r as a fn of Z

$r(z) = \left(\dfrac{600}{2}\right) - \dfrac{(600 - 300)}{2 \times 1.5} z$

$r(z) = 300 - 100z$

∴ volume flowing out from strip $= V_r(Z) \, 2\pi \dfrac{dz}{\cos\theta}$

$= (Z) \, 2\pi (300 - 100z) \dfrac{dz}{\cos\theta} \times 10^{-3}$

Here $\tan\theta = \dfrac{150 \times 10^{-3}}{1.5} = 0.1$

$\Rightarrow \boxed{\cos\theta = 0.995}$

$\therefore$ Volume out radially $= \int_0^{1.5} 2\pi (300z - 100z^2) \frac{\times 10^{-3}}{\cos\theta} dz$

$= 0.0063 \left(\frac{300z^2}{2} - \frac{100z^3}{3} \right) \Big|_0^{1.5}$

$= 1.4175 \ m^3/s.$

$\therefore$ By continuity (assuming flow as incompressible)

$Q_B = Q_A -$ Volume out radially

$Q_B = 0.5825 \ m^3/s$

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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]

(i) if we consider a simple impulse turbine (axial flow) then for optimum working condition,

$\rho = \frac{u}{V_1} = \frac{\cos\alpha}{2}$

$V_1 = \sqrt{2(\Delta h)_{stg}}$ is very high

$\Rightarrow$ This means u is very high as $\alpha \approx 15°$

also $u = \frac{\pi D N}{60}$; as and N is given by. $N = \frac{120 \times f}{P}$

P = no. of pole, f = freq. of power production which are fixed once the installation is done

$(f \approx 50, 60 \ Hz$ and $P = 2, 4, 8, \ldots)$

$\therefore$ N is fixed more or less (not much variation)

$\therefore$ for high u, D has to be very high, which is not practical,

So, compounding is done.

Types of compounding (a) Pressure compounding (Rateau)
(b) Velocity compounding (Curtis)
(c) Mixed "

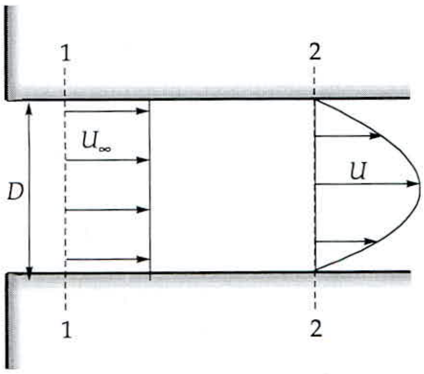
(ii)

	Impulse turbine	Reaction Turbine
(a)	Only impulse leads to power output	Both impulse & pressure are used to extract power.
(b)	Blades are symmetrical	Blades are not symmetric.
(c)	Entry of steam is only partial	Entry of steam is all around.
(d)	Blades are easy to manufacture and hence cost less	Blades are complicated & cost more
(e)	Suitable for low power production.	(Suitable for larger power production.
(f)	less efficient	More efficient

07

.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

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



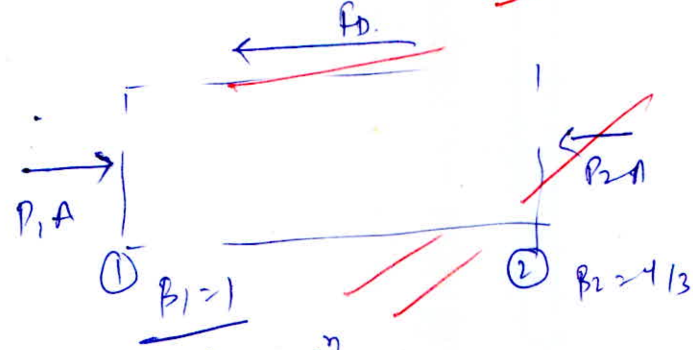
Where P_1 and P_2 are pressure at respective sections.

[12 marks]

At section (1), ∵ $U = U_\infty$ at all points

∴ $\beta = 1$

also $\dot{m}_1 = \dot{m}_2 = \dot{m} = (\rho) \times \frac{\pi D^2}{4} U_\infty$ (continuity) let us consider the fluid b/w ① & ②



By momentum eq^n:

$$P_1A - P_2A - F_D = \dot{m}(\beta_2 V_2 - \beta_1 V_1)$$

$$= \dot{m}\left(\frac{4}{3}V_\infty - 1 \cdot V_\infty\right)$$

$$= \dot{m}\left(\frac{1}{3}V_\infty\right)$$

$$\therefore F_D = (P_1 - P_2)A - \frac{\dot{m}}{3}V_\infty$$

$\because A = \frac{\pi D^2}{4}$ & $\dot{m} = \rho\frac{\pi D^2}{4}V_\infty$

$$\therefore F_D = \frac{\pi D^2}{4}(P_1 - P_2) - \frac{1}{3}\rho\frac{\pi D^2}{4}V_\infty^2$$

$$\therefore F_D = \frac{\pi D^2}{4}\left[P_1 - P_2 - \frac{1}{3}\rho V_\infty^2\right]$$

10

Do not write in this margin

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]

Soln.

$L_r = \frac{L_m}{L_p} = 1/10$;

$P_p = 7355\ kW$, $H_p = 10\ m$, $N_p = 100\ rpm$,

$H_m = 6\ m$, $\eta_m = 0.88$

$\eta_p = 92\% = 0.92$

we know $P = \eta_o \rho Q g H$

for prototype: $7355 \times 10^3 = (0.92) \times 10^3 \times Q_p \times 9.81 \times 10$

$\therefore Q_p = 81.49\ m^3/s$

we know

$P = \eta_o \rho Q g H$

$\therefore \frac{P_p}{P_m} = \frac{\eta_{o,p}}{\eta_{o,m}} \frac{\rho_p}{\rho_m} \frac{Q_p}{Q_m} \frac{g_p}{g_m} \frac{H_p}{H_m}$

Take $\rho_p = \rho_m = 10^3\ kg/m^3$ & $g_p = g_m = 9.81\ m/s^2$

$\therefore \frac{P_p}{P_m} = \frac{\eta_{o,p}}{\eta_{o,m}} \times \frac{Q_p}{Q_m} \frac{H_p}{H_m}$

also $P \propto N^3 D^5$ & $Q \propto N D^3$

$$\therefore \frac{(N^3D^5)_p}{(N^3D^5)_m} = \frac{\eta_{o,p}}{\eta_{o,m}} \times \frac{(ND^3)_p}{(ND^3)_m} \times \frac{H_p}{H_m}$$

$$\left(\frac{N_p}{N_m}\right)^3\left(\frac{D_p}{D_m}\right)^5 = \frac{0.92}{0.88} \times \frac{N_p}{N_m}\left(\frac{D_p}{D_m}\right)^3 \times \frac{10}{6}$$

$$\Rightarrow \left(\frac{N_p}{N_m}\right)^2\left(\frac{D_p}{D_m}\right)^2 = 1.7424$$

Make box around ans

$$\frac{D_p}{D_m} = \frac{1}{L_r} = 10$$

$$\therefore \left(\frac{N_p}{N_m}\right)^2 = 0.017424$$

(i) $\Rightarrow N_m = 757.58$ rpm (as $N_p = 100$ rpm)

(ii) $\frac{Q_p}{Q_m} = \frac{N_p}{N_m}\frac{D_p^3}{D_m^3} \Rightarrow Q_m = Q_p \frac{N_m}{N_p}\left(\frac{D_m}{D_p}\right)^3$

(ii) $Q_m = 0.6174\ m^3/s$

(iii) $N_{s,p} = \frac{N_p\sqrt{P_p}}{H_p^{5/4}} = 482.27$ SI unit

$N_{s,m} = \frac{N_m\sqrt{P_m}}{H_m^{5/4}}$; ~~$= (N_s)_p =$ 482.27 SI units~~

$P_m = \eta_m \rho Q_m g H_m = 32$ kW

$N_{s,m} = 456.4$ SI unit

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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, γ = 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]

Sol^n:

$r_p = 4$, $D_1 = 0.3$ m, $V_{f1} = 120$ m/s, $\dot{m} = 10$ kg/s

$V_2 = 110$ m/s, $u_2 = 450$ m/s, $N = 16000$ rpm, $u_1 = \frac{\pi D_1 N}{60} = 251.33$ m/s

$\eta_{isen} = 0.80 =$ (for total head)

$T_{01} = 300$ K & $P_{01} = 101$ kPa, $C_p = 1.005$ kJ/kgK & $\gamma = 1.4$

Assume $V_{w1} = 0$ ∴ $V_1 = V_{f1} = 120$ m/s

$$T_1 = T_{01} - \frac{V_1^2}{2c_p} = 292.84 \text{ K}$$

also 1→01 is isentropic with $\gamma = 1.4$

$$\Rightarrow (P_{01}/P_1) = (T_{01}/T_1)^{\gamma/\gamma-1}$$

$\therefore P_1 = 92.81 \text{ kPa}$

Now, $\left(\frac{P_{02}}{P_{01}}\right) = 4 \Rightarrow P_{02} = 4 \times P_{01} = 404 \text{ kPa}$

$\therefore \left(\frac{T_{02s}}{T_{01}}\right) = \left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_{02s} = 445.8 \text{ K}$

$\eta_c = 0.80 = \frac{T_{02s} - T_{01}}{T_{02} - T_{01}} \Rightarrow T_{02} = T_{01} + \frac{1}{\eta_c}(T_{02s} - T_{01})$

$\therefore T_{02} = 482.25 \text{ K}$

$\therefore T_2 = T_{02} - \frac{V_2^2}{2C_p} = 476.23 \text{ K}$

Show some Calculation

as $2 \rightarrow 02$ is isentropic

$\therefore \left(\frac{T_{02}}{T_2}\right) = (P_{02}/P_2)^{\frac{\gamma-1}{\gamma}} \Rightarrow P_2 = 386.62 \text{ kPa}$

(ii) Static pressure ratio

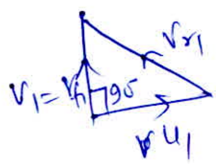
$\frac{P_2}{P_1} = \frac{386.62}{92.81} = 4.166$

(iii) Power required to drive compressor

$= \dot{m} C_p (T_{02} - T_{01})$

$= 1831.61 \text{ kW}$

(iv) @ inlet,



$V_{r1} = \sqrt{V_{f1}^2 + U_1^2}$

$V_{r1} = 278.51 \text{ m/s}$

$\therefore$ $Ma_1 = \dfrac{V_n}{\sqrt{\gamma R T_1}} = \underline{0.8119}$

~~Plot~~ Plot T-S?

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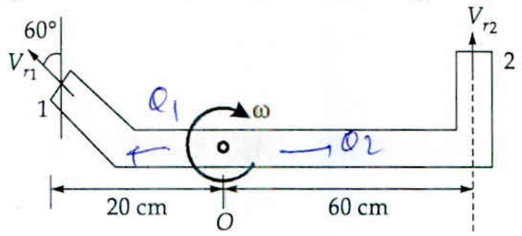
Q.2 (c) A sprinkler with unequal arms and jets of area 0.7 cm^2 is shown in figure. A flow of 1.4 l/s enters the assembly normal to the rotating arm.

(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]

Sol^n:

Area of jet = $a = 0.7\,cm^2$,

$Q = 1.4\,l/s$; $Q_1 + Q_2 = 1.4\,l/s$.

Here, $Q_1 = Q_2 = \frac{Q}{2} = 0.7\,l/s = 700\,cm^3/s$

(By momentum conservation @ inlet to the sprinkler)

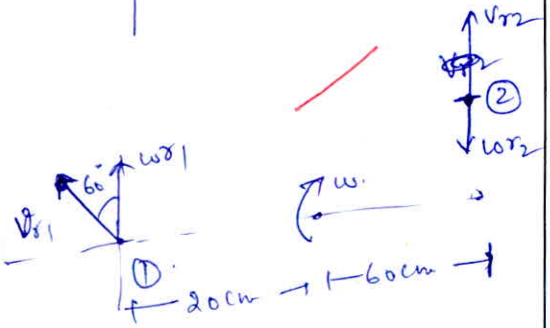
$\therefore$ $v_{r1} = \frac{Q_1}{a} = 1000\,cm/s = 10\,m/s$; $\dot m_1 = \rho Q_1$

$\dot m_2 = \rho Q_2$

& $v_{r2} = \frac{Q_2}{a} = 10\,m/s$

$\dot m_1 = \dot m_2 = \dot m$ (say)

$\therefore$ $v_{r1} = v_{r2} = 10\,m/s$



@ outlet of jet 1;

$V_{1y} = V_{r1}\cos 60° + \omega r_1$

$V_{1y} = \frac{V_{r1}}{2} + \omega r_1$

& $V_{2y} = V_{r2} - \omega r_2 =$ ~~10 ...~~

$\therefore$ (i) Net torque is zero for free rotation

$\therefore$ $\dot m_1 (V_{1y})(r_1) - \dot m_2 (V_{2y})(r_2) = 0.$

$\because V_{1y} r_1 = V_{2y} r_2$

$\Rightarrow \left(\frac{V_{r1}}{2} + \omega r_1\right) r_1 = (V_{r2} - \omega r_2) r_2$

$\therefore \frac{V_{r1}}{2} r_1 + \omega r_1^2 = -\omega r_2^2 + V_{r2} r_2$

$\therefore \omega = \frac{\left(V_{r2} r_2 - \frac{V_{r1}}{2} r_1\right)}{r_1^2 + r_2^2} = 12.5 \text{ rad/s}$

(iii) If the sprinkler is held then $\omega = 0$

Let T = torque required

$\because \omega = 0$

$\Rightarrow \therefore V_{1y} = \frac{V_{r1}}{2} = 5 \text{ m/s}$ & $V_{2y} = V_{r2} = 10 \text{ m/s}$

$\therefore$ Net torque due to fluids going out $= \dot{m}_1 (V_{1y})(r_1) - \dot{m}_2 (V_{2y}) r_2$

$= \dot{m} (5)(0.2) - \dot{m} (10)(0.6)$

$= \dot{m} - \dot{m}(6)$

$= -5\dot{m}$ N-m

$= -3.5$ N-m (net in CW direction)

$\therefore T = 3.5$ N-m in CW direction

ACW

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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,

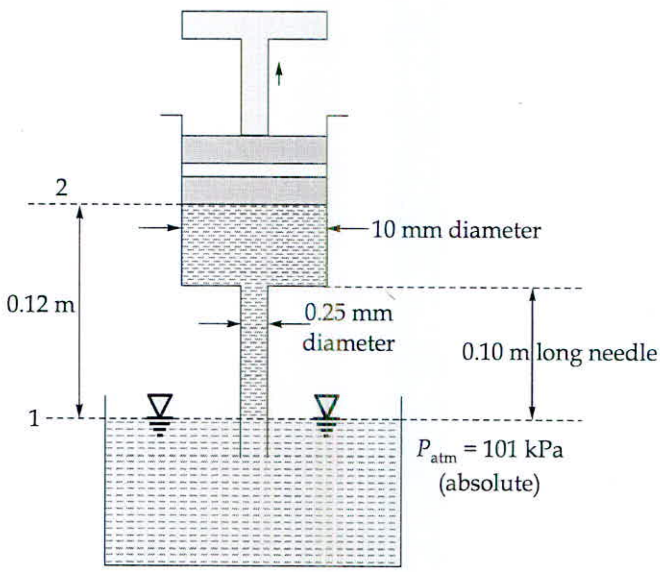
h = 2902.5 kJ/kg, s = 6.5453 kJ/kgK

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

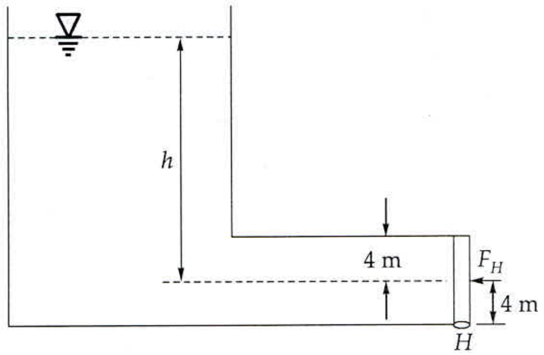
[20 marks]

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]

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.

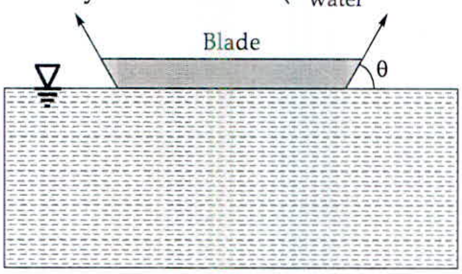
[20 marks]

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.

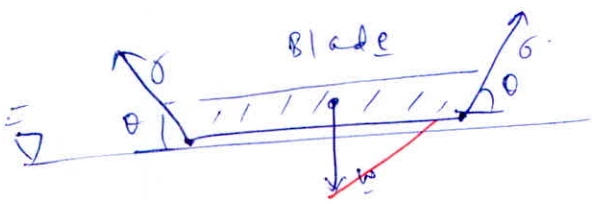
(ii) The mass of the single edge blade is 2.61×10^{-3} kg and the total length of its side is 154 mm. Explain why this blade sink.

(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]

(Sol^n)



from eq^lb^n ~~(σ sin θ)(2) × (l)~~

W = (m)(g)

from eq^lb^n : W = surface tension force

∴ mg = (σ sin θ)(l) ; l = 206 mm

∴ sin θ = $\frac{mg}{\sigma l}$ = 0.4152

∴ θ = 24.534° (i)

(ii) for a single edge blade

at $W = mg = 0.02570$ N

& surface tension force $= \sigma \sin\theta\, l = 0.01130 \sin\theta$

∴ for eq^lb^m $W =$ surface tension force.

⇒ $\sin\theta = 2.265 > 1$ not possible

∴ it will sink.

Physically this means that surface tension is unable to hold the weight of blade.

(iii) $W_{bug} = 10^{-4}$ N

∴ $W_{net} = W_{blade} + W_{bug} = 0.0063784$ N

∴ for eq^lb^m

$(\sigma l \sin\theta) = W_{net}$

∴ $\sin\theta = 0.4218$

⇒ $\theta = 24.95°$

Show some calculations?

⇒ $\Delta\theta = 24.95° - 24.534° = 0.416°$

θ will increase as expected to balance the increased weight of the bug.

18

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]

Sol^n: Here, $P_1 = 150$ bar, $T_1 = 600°C$, $P_2 = 0.1$ bar

$u_m = 220$ m/s, $\eta_{nozzle} = 0.91$, $\alpha = 20°$

all stages operate at max. η.

$(\Delta h)_{s,total} = 1400$ kJ/kg

i) All simple impulse stgs

Here $\frac{u}{V_1} = \frac{\cos\alpha}{2} = 0.4698 \Rightarrow V_1 = 468.24$ m/s

∴ ~~for isen~~ $(\Delta h)_{stage} = \frac{V_1^2}{2} =$ 109.62 kJ/kg

∴ $(\Delta h)_{isentropic} = \frac{(\Delta h)_{stage}}{\eta_{nozzle}} = 120.466$ kJ/kg

∴ no of stages $(Z) = \frac{(\Delta h)_{isen,total}}{(\Delta h)_{isen,stage}} = 11.62 \simeq 12$

(ii) → All 50% impulse-reaction stage

Here $\rho = \frac{u}{V_1} = \cos\alpha \Rightarrow V_1 = \frac{u}{\cos\alpha} = 234.12$ m/s

∴ $(\Delta h)_{FB} = \frac{V_1^2}{2} = 27.41$ kJ/kg.

~~∴ $(\Delta h)_{stage} = 2(\Delta h)_{FB} = 54.83$ kJ/kg~~

$(\Delta h)_{MB} = (\Delta h)_{FB} = 27.41$ kJ/kg

~~∴ $(\Delta h)_{isen,stage} = \frac{(\Delta h)_{stage}}{\eta_{nozzle}} =$~~

∴ $(\Delta h)_{isentropic}/stage = \frac{(\Delta h)_{FB}}{\eta_{nozzle}} + (\Delta h)_{MB}$ = (assuming $(\Delta h)_{MB}$ = isentropic drop)

= 57.53 kJ/kg

Calculation error

∴ no $Z = \frac{1400}{57.53} = 24.33 \simeq 25$

It should be 24

(iii) 2-row curtis then simple impulse

For 2-row curtis, $\rho = \frac{u}{V_1} = \frac{\cos\alpha}{2(2)} = \frac{\cos\alpha}{4}$ $\Rightarrow V_1 = \frac{4u}{\cos\alpha} = 936.48$ m/s

∴ $(\Delta h)_{nozzle} = \frac{V_1^2}{2} = 438.49$ kJ/kg

∴ $(\Delta h)_{isentropic} = (\Delta h)_{nozzle}/\eta = 481.86$ kJ/kg for remaining simple impulse stages

$\rho = \frac{u}{V_1} = \frac{\cos\alpha}{2} \Rightarrow V_1 = 468.24 \text{ m/s}$

$(\Delta h)_{nozzle} = \frac{V_1^2}{2} = 109.62 \text{ kJ/kg}$

$\therefore (\Delta h)_{stage, isentropic} = \frac{109.62}{\eta_{nozzle}} = 120.466 \text{ kJ/kg}$

$\therefore Z = \frac{(1400 - 481.86)}{120.466} = 7.62 \simeq 8$

$\therefore$ total stages $1 + 8 = 9$ (1 2 row-curtis, 8 simple impulse)

(iv) for a 2 row curtis as done in (iii) above

$(\Delta h)_{stage\ isen} = 481.86 \text{ kJ/kg}$

$\therefore$ & isentropic enthalpy drop in remaining stages
$= 1400 - 481.86 = 918.14 \text{ kJ/kg}$

from solution of part (ii),

$(\Delta h)_{isen/stage}$ for 50% rxn stage $= 57.53 \text{ kJ/kg}$

$\therefore Z = \frac{918.14}{57.53} = 15.96 \simeq 16$

$\therefore$ total no. of stages $=$ 1 2 row curtis + 16 50% rxn stages

marks 15

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]

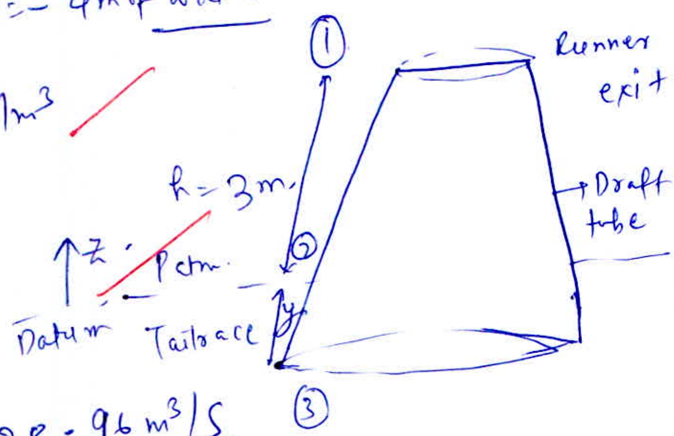
i) Draft tube allows the exit pressure at the runner of a turbine to go below the local atmospheric pressure, thereby allowing the turbine to extract more head. This increases the power output of the turbine. It also increases the efficiency of the turbine for a given head of water @ inlet as compared to a turbine with no draft tube.

(ii)

$d_1 = 2.8\,m$, $h = 3\,m$, $P_1 = -4\,m$ of water

Here $P = 1500\,kW$, $\rho = 10^3\,kg/m^3$

$H = 6\,m$, $\eta_0 = 0.88$



$\Rightarrow P = \eta_0 \rho Q g H$

$\therefore Q_0 = \dfrac{P}{\eta_0 \rho g H} = 28.96\,m^3/s$

$\therefore v_1 = \dfrac{4Q_0}{\pi d_1^2} = 4.70\,m/s$

Apply Bernoulli's eqn b/w ① and ② neglecting head loss due to friction.

$$\frac{P_1}{\gamma} + Z_1 + \frac{v_1^2}{2g} = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + Z_2$$

Here, $Z_1 = 3\,m$, $Z_2 = 0$, $v_1 = 4.70\,m/s$, $\frac{P_1}{\gamma} = -4\,m$, $\frac{P_2}{\gamma} = 0$

$$\therefore (-4) + (3) + \frac{(4.70)^2}{2\times 9.81} = (0) + \frac{v_2^2}{2g} + 0$$

Consider head loss in draft tube

$\therefore v_2 = 1.572\,m/s$

$$\therefore \eta_{draft\ tube} = \frac{\left(\frac{v_1^2 - v_2^2}{2g}\right) - h_L}{\frac{v_1^2}{2g}} = \frac{\frac{v_1^2 - v_2^2}{2g}}{\frac{v_1^2}{2g}} \quad (\text{as } h_L = 0)$$

$$= \frac{v_1^2 - v_2^2}{v_1^2}$$

$\eta_{draft\ tube} = 0.88813$ or 88.13%

Ans i dif... c

Now $P = \frac{1500}{2} = 750\ kW$, $H = 6\ m$, $\eta_0 = 0.88$

$\therefore Q = \frac{P}{\rho g H \eta_0} = \frac{Q_0}{2} = 14.48\ m^3/s$

$\therefore v_1 = \frac{4Q}{\pi d_1^2} = 2.35\ m/s$

Now $\eta_{draft\ tube} = 0.8813$

$\therefore \frac{V_1^2 - V_2^2}{V_1^2} = 0.8813$

$\therefore V_2^2 = (V_1^2 - 0.8813 V_1^2) \Rightarrow V_2 = 0.8096\ m/s$

Again Apply Bernoullis eqn b/w (1) and (2)

$\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L$ ($h_L \to 0$)

$\therefore \frac{P_1}{\gamma} = 0 + \frac{V_2^2}{2g} - \frac{V_1^2}{2g} + (0) - (3)$

$$\frac{P_1}{\gamma} = -3.248\ m$$

$\therefore$ Reading of vacuum gauge $= -3.248\ m$

this is very less

16

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

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

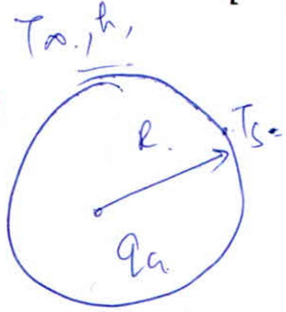
where, T_∞ = Ambient temperature.

[12 marks]

Governing eqⁿ is

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

→ Show initial steps



$$\therefore \frac{d}{dr}\left(r^2\frac{dT}{dr}\right) + \frac{q_G r^2}{k} = 0$$

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

Integrating w.r.t r

$$r^2\frac{dT}{dr} = -\frac{q_G r^3}{3k} + C_1$$

$$\therefore \frac{dT}{dr} = -\frac{q_G r}{3k} + \frac{C_1}{r^2}$$

again integrating r

$$T = -\frac{q_G r^2}{6k} - \frac{C_1}{r} + C_2.$$

BCs: @ $r = R$, $T = T_s$

& $r = R$, $-k\frac{dT}{dr} = h(T_s - T_\infty)$

also @ $r = 0$, T is finite

$\Rightarrow C_1 = 0$

$$\therefore T = -\frac{q_G r^2}{6k} + C_2$$

@ $r=R, T=T_s \Rightarrow T_s = -\frac{q_G R^2}{6k} + C_2$

$$\therefore C_2 = T_s + \frac{q_G R^2}{6k}$$

$$\therefore T = -\frac{q_G r^2}{6k} + T_s + \frac{q_G R^2}{6k}$$

also $-k \left.\frac{dT}{dr}\right|_{r=R} = h(T_s - T_\infty)$

$\Rightarrow +k\left(+\frac{q_G R}{3k}\right) = h(T_s - T_\infty)$

$$\therefore T_s = \frac{q_G R}{3h} + T_\infty.$$

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

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

09

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 → Barometric pressure

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

t_{WB} → Wet bulb temperature (in °C)

t_{DB} → Dry bulb temperature (in °C)

Use following table:

P_s (mm of Hg)	t_s (°C)
16.19	18.7
21.06	23 → $(P_s)_{WB}$
37.72	33 → $(P_s)_{DB}$.

At 33°C density of Hg, ρ_{Hg} = 13600 kg/m³

Assume v_g (Specific volume of saturated vapour) at 37.72 mm of Hg is 28.05 m³/kg.

[12 marks]

Sol^n.

P_t = 750 mm of HG, DBT = 33°C, WBT = 23°C

using

$\therefore P_v = (P_s)_{WB} - \frac{(P_t - (P_s)_{WB})(t_{DB} - t_{WB})}{1527.4 - 1.3 t_{WB}}$

here $(P_s)_{WB}$ = 21.06 mm of HG,

$\therefore P_v$ = 21.06 − 4.868 = 16.192 mm of Hg

$\therefore$ (i) RH: also $p_s = P_s$ @ 33°C (DB) = 37.72 mm of Hg

(i) $\therefore RH = \frac{p_v}{p_s}$ = 0.4293 ≈ 42.93%

(ii) $\phi = \frac{0.622\, p_v}{p_t - p_v} = 0.01372$ g w-v / kg of d-a

(iii) DPT: $p_v = 16.192$ mm of Hg corresponds to a saturation temp of 18.7°C (from table)

$\therefore$ DPT $= 18.7°C$

(iv) density of atmospheric air

$T = t_{DB} = 33°C = 306$ K $\quad p_t = (750$ ~~mm of Hg) × 13600~~

~~$R_{air} = 0.287$ kJ/kgK~~

Here, ~~$\frac{R_a}{m_a} + \frac{R_{wv}}{m_{wv}} =$~~

$p_v = \rho_v R_v T$

$p_a = \rho_a R_a T$

$(p_{moist\ air}) = (\rho_{moist\ air}) R_{moist\ air} \times T$

$p_{moist\ air} = p_v + p_a = p_t = 750$ mm of Hg $= (0.75)\rho_m g = 100.062$ kPa

~~$\therefore (p_v + p_a) = \rho_{moist\ air} \cdot R_{moist\ a}$~~

$R_{moist\ air} = \left(\frac{R_a}{m_a} + \frac{R_v}{m_v}\right) m_{moist\ air} =$??

$\rho_{atm\ air} = \rho_{dry\ air} + \rho_{water\ vapour}$

09

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 a mechanism is the no. of independent parameters which are necessary to completely specify the output of the mechanism. It is also called degree of freedom of mechanism (DOF).

Kutzbach eqn for planar mechanism

Let n = no. of links, h = no. of higher pairs, j = no. of lower pairs.

then as per Kutzbach eqn:

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

Explanation: → In a mechanism of n linkage, one link is grounded

∴ no. of movable links = n − 1, each has 3 DOF in plane

→ Each lower pair restricts 2 DOF ⇒ 2j is subtracted.

→ Each higher pair restricts 1 DOF ⇒ h is subtracted

∴ DOF = (Total possible movements) − restrictions

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

Grubeler's criterion: It is special case of Kutzbach eqn

for h = 0 and only single DOF,

∴ $1 = 3(n-1) - 2j - 0$

or $3n - 2j = 4$

∴ $j = \frac{3n}{2} - 2$

which implies n has to be even. for all planar single DOF mechanisms with only lower pairs.

07

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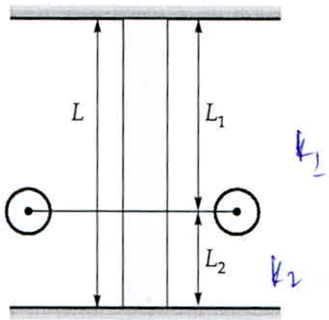
5(d) A flywheel is mounted on a vertical shaft as shown in figure. The ends of the shaft being fixed. The shaft is having 20 cm diameter, the length L_1 is 0.9 m and the length L_2 is 0.6 m. The flywheel weighs 500 kg and its radius of gyration is 50 cm, then find the natural frequencies of the longitudinal,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



[12 marks]

~~Longitudinal~~

Here, $A = \frac{\pi}{4}(d)^2 = 0.0314\ m^2 = A_1 = A_2$

$L_1 = 0.9\,m,\ L_2 = 0.6\,m,\ E = 200\,GPa$

$\therefore k_1 = \left(\frac{AE}{L}\right)_1 = (EA)/(L_1) = 6.98 \times 10^9$ N/m

$k_2 = \left(\frac{AE}{L}\right)_2 = 10.47 \times 10^9$ N/m

for longitudinal vibrations

k_1 & k_2 are in parallel

$\therefore k_{eq} = k_1 + k_2 = 17.45 \times 10^9$ N/m

$\omega_n = \sqrt{\frac{k_{eq}}{m}} = \sqrt{\frac{17.45 \times 10^9}{500}}$ rad/s $= 5907.62$ rad/s

or $f_n = \frac{\omega_n}{2\pi} = 940.70$ Hz

Transverse vibrations:-

k: $\delta = \frac{Pl^3}{3EI} \Rightarrow k = \frac{3EI}{l^3}$

$\therefore k_1 = \frac{3EI_1}{l_1^3}$ & $k_2 = \frac{3EI}{l_2^3}$; Here $I = \frac{\pi d^4}{64} = 7.85 \times 10^{-5}\ m^4$

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$\therefore k_1 = \frac{3EI}{L_1^3} = 6.46\times10^7$ N/m & $k_2 = \frac{3EI}{L_2^3} = 21.8\times10^7$ N/m

Both are in parallel as well [∵ deflections are same]

$\therefore k_{eq} = k_1 + k_2 = 28.26\times10^7$ N/m

$\therefore \omega_n = \sqrt{\frac{k_{eq}}{m}} = \sqrt{\frac{28.26\times10^7}{500}} = 751.798$ rad/s

or $f_n = \frac{\omega_n}{2\pi} = 119.71$ Hz

for torsional vibrations.

$I = mk^2 = 500\times(0.5)^2 = 125$ kg-m^2

$k_{t1} = \frac{GJ_{p1}}{L_1}$, & $k_{t2} = \frac{GJ_{p2}}{L_2}$

Here $J_p = \frac{\pi d^4}{32} = 15.71\times10^{-5}$ m^4

$L_1 = 0.9$m & $L_2 = 0.6$m, $G = 80\times10^9$ N/m^2

$\therefore k_{t1} = 1.396\times10^7$ N-m/rad

& $k_{t2} = 2.094\times10^7$ N-m/rad

these are in parallel as well

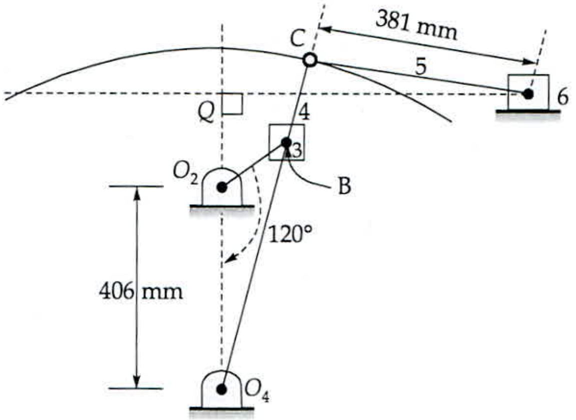
$\therefore k_{t,eq} = k_{t1} + k_{t2} = 3.49\times10^7$ N-m/rad

$\therefore \omega_n = \sqrt{\frac{k_{t,eq}}{I}} = 528.39$ rad/s

or $f_n = \frac{\omega_n}{2\pi} = 84.14$ Hz

08

(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.

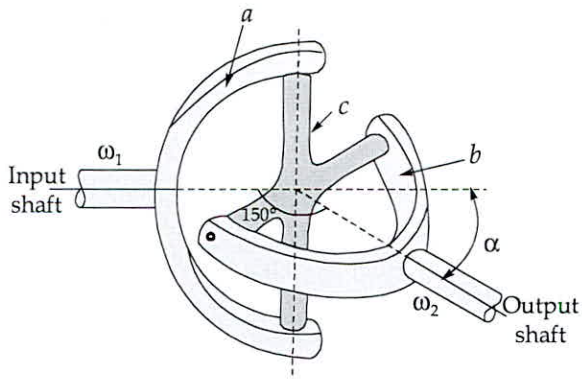


[12 marks]

(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^2K and 10 W/m^2K 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]

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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:

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

[20 marks]

(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]

Time to punch 1 hole $= \frac{60 s}{25} = 2.4 s$

Assume one hole punched per revolution.

Force required to punch 1 hole $= \times (\tau_{su} \times \pi d t) = 565.49$ kN

∴ Energy required for 1 hole punch $= \frac{1}{2} F_s \times t = 5.65$ kJ

also $\frac{t}{(25)} = \frac{\theta_2 - \theta_1}{(2\pi)} \Rightarrow \frac{\Delta\theta}{2\pi} = \frac{1}{15} \Rightarrow \frac{t}{25} = \frac{1}{15}$

∴ ~~1/15th of total~~ Energy supplied by flywheel $= \left(1 - \frac{1}{15}\right) \times 5.65$ kJ

$(\Delta E) = 5.273$ kJ

also, Power required for punching $= \frac{5.65 \text{ kJ}}{2.45} = 2.354$ kW

∴ Power of motor $= \frac{2.354}{\eta_{mech}} = \frac{2.354}{0.92} = 2.56$ kW (i)

∵ the flywheel goes 10 cycles ⇒ $(\Delta E)/\text{cycle} = \frac{5.273}{10} = 0.5273$ kJ

Now, ~~σ.~~ v for flywheel,

$v = \sqrt{\sigma/\rho} = \sqrt{\frac{6\times10^6}{7000}}$ m/s = 29.27 m/s

$q = 0.12$ ∴ $(\Delta E) = ~~\Delta q~~\, m v^2 =$

∴ $m = 51.29$ kg

Now ~~ρ(A)(πD)~~

∴ mass of flywheel = $m \times (0.9) = 46.2$ kg

∴ $m = \rho A \pi D A$

∴ $A = 0.00014$ m²

Now $A = bt = (2t^2)$

∴ $t = 0.0084$ m = 8.4 mm

& $b = 2t = 16.8$ mm

10

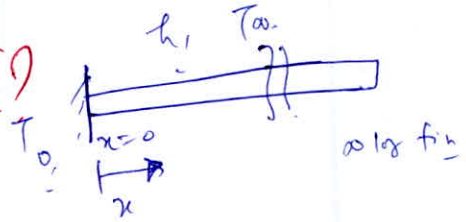
) Derive an expression for temperature distribution in case of infinite fin.

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]

Here T_0 = base temp., T_∞ = Surroundings temperature

Governing eqn — show initial steps of this relation?



$$\frac{d^2\theta}{dx^2} - m^2\theta = 0$$

Here $\theta = T - T_\infty$

& $m = \sqrt{\frac{hP}{kA_c}}$; A_c = Area of C/S, P = perimeter @ x

h = conv. heat transfer coeff

& k = thermal conductivity of fin material

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

on assumptions: (i) Ac, P, h and k are constant throughout

(ii) There is no heat generation inside the fin rod.

(iii) Steady state conditions.

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

BCs @ $x=0$, $T = T_0 \Rightarrow \theta_0 = T_0 - T_\infty$.

& @ $x \to \infty$, $T \to$ some finite value

$\therefore \lim_{x \to \infty} \theta$ = finite $\Rightarrow C_1 = 0$

$\therefore \theta = C_2 e^{-mx}$.

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

$\therefore \theta_0 = (C_2) e^{-(0)} \Rightarrow C_2 = \theta_0$

$\therefore \theta = \theta_0 e^{-mx}$ or $\frac{\theta}{\theta_0} = e^{-mx}$

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

Rod A

$d_A = 12$ mm

$l = 1$ m

$T_0 = 100°C$

$T_\infty = 20°C$

$K_A = 60$ W/mK

Rod B

$d = 12$ mm

$l = 1$ m

$T_0 = 100°C$

$T_\infty = 20°C$

$k_B = ?$

$\theta_A|_{x=15cm} = \theta_B|_{x=7.5cm}$

$\therefore \theta_0 = T_0 - T_\infty$ = same for A & B → Please write down clearly

$\therefore \theta_A|_{x=15\,cm} = \theta_B|_{x=7.5\,cm} \Rightarrow (e^{-mx})_A = (e^{-mx})_B$

$\Rightarrow m_A x_A = m_B x_B$

Here $m = \sqrt{\frac{hP}{kA_c}}$; $h = 5\ W/m^2k$ for both

$\therefore m_A = \sqrt{\frac{h P_A}{k_A A_{c,A}}} = \sqrt{\frac{5 \times \pi \times 0.012}{60 \times \frac{\pi}{4} \times (0.012)^2}} = \sqrt{\frac{5 \times 4}{60 \times (0.012)}}$

$m_A = 5.27$

$\therefore m_A x_B = m_B x_B$

$\therefore m_B = 2 m_A = 10.54 = \sqrt{\frac{hP}{k_B A_c}} = \sqrt{\frac{5000}{3 k_B}}$

$\therefore k_B = 15.00\ W/mK$

Also $\dot{Q}_A = \sqrt{hPk_A A_c}\,(T_0 - T_\infty)$

$\dot{Q}_B = \sqrt{hPk_B A_c}\,(T_0 - T_\infty)$

$\therefore \frac{\dot{Q}_A}{\dot{Q}_B} = \sqrt{\frac{k_A}{k_B}}$ ($\because h, P, A_c$ & $T_0 - T_\infty$ are same)

$\frac{\dot{Q}_A}{\dot{Q}_B} = \sqrt{\frac{60}{15}} = 2$

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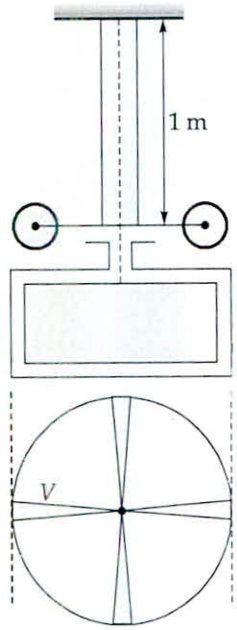
Q.7(c) A flywheel of moment of inertia 25 kg.m^2 is fixed to one end of a vertical shaft diameter 2.54 cm and the length 1 m. The other end of the shaft is fixed. The torsional oscillations of the flywheel are damped by means of a vane as shown in figure, which moves in a dashpot D filled with oil. The 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]

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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:

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

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]

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) 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]

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■■■■

$P \propto N^3 D^5$ – (1)

$Q \propto N D^3$

$\frac{P_1}{P_2} = \frac{N_1}{N_2} \times \frac{D_1}{D_2} \quad \frac{H_1}{H_2}$

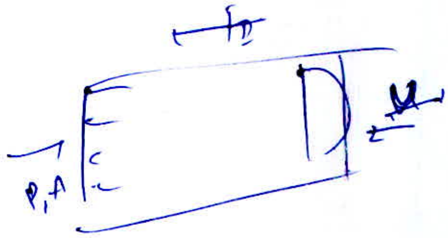
$\frac{N^3 D^5 D^2}{N^3 D^5 D^2} \quad \frac{N D^3}{N D^3} \quad N(D)^2$

Space for Rough Work

$v_1 +$

$v_1 + \frac{Cb\,v - Cb\,v_1}{b - cb}$

$v = v_1$



$\left(\frac{4}{3}\right) \times 1.$

$\dot{m} = (\rho)(U_\infty) \times \left(\frac{\pi D^2}{4}\right)$

$\dot{m}$ (Force) =

$(P_1 A - P_2 A) - F_D = \dot{m}(\beta)(U_\infty) - \dot{m}(1) \times (U_\infty)$

$= (\rho U_\infty A)\left(\frac{1}{3} U_\infty\right)$

$F_D = A \cdot \left(P_1 - P_2 - \frac{1}{3} \rho U_\infty^2\right)$

$\theta = \frac{TL}{GJ}$ $\quad k_t = \frac{T}{GJ/L}$

$P = \eta_o \rho Q g H$

$Q \propto N D^3$

$\frac{P_1}{P_2} = \frac{\eta_1}{\eta_2} \times \frac{Q_1 H_1}{Q_2 H_2}$

$P = \eta_o \rho Q H$

$\frac{P_1}{P_2}$ $\quad P \propto N^3 D^5$ $\quad$ & $P = \rho Q g H \eta_o$

$= N_1$

$\frac{Q_1}{Q_2}$ $\quad H_1$

$\frac{P_1}{P_2} = \frac{N^3 D^5}{N}$