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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 | T | P | L | A | 6 | 3 | 1 |

Test Centres

Delhi ☑ Bhopal ☐ Noida ☐ Jaipur ☐ Indore ☐
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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	50-3=47
Q.2	09 +5=14
Q.3	42
Q.4	
Section-B	
Q.5	50-3=47
Q.6	—
Q.7	—
Q.8	(37)
Total Marks Obtained	187

Signature of Evaluator: SM

Cross Checked by

Improve writing.

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Section A : Fluid Mechanics and Turbo Machinery

(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]

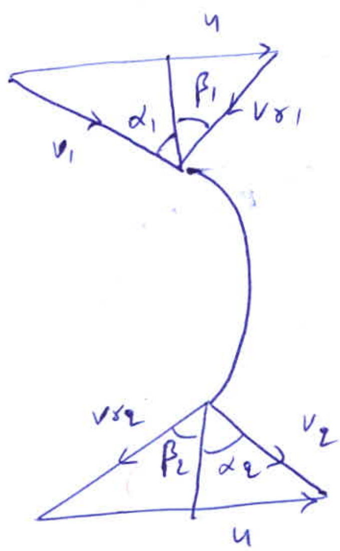
Degree of Reaction :-

effect

It is the ratio of enthalpy change due to reaction forces i.e pressure forces ~~effect~~ to the Net enthalpy change in a stage. it is defined for both turbines & compressors.

For multistage compressor

$$R_D = \frac{\Delta h_{MB}}{\Delta h_{stage}} \quad \text{or} \quad \frac{\Delta h_{MB}}{\Delta h_{MB} + \Delta h_{SB}}$$



For a stage Work done =

$$W_{in} = (V_{w_2} - V_{w_1})u \quad \frac{kJ}{kg}$$

For axial flow compressor $(u_1 = u_2)$

$$(V_{w_2} - V_{w_1})u = \frac{V_2^2 - V_1^2}{2} + \frac{V_{r_1}^2 - V_{r_2}^2}{2}$$

increase Pr. in static blade — increase Pr in moving blade

So

$$R_D = \frac{V_{r_1}^2 - V_{r_2}^2}{2(V_{w_2} - V_{w_1})u}$$

Sol

$$V_{r_1} = \frac{V_f}{\cos\beta_1} \quad -(1)$$

$$V_f = V_{r_1}\cos\beta_1 \qquad V_{r_2} = \frac{V_f}{\cos\beta_2} \quad -(2)$$

$$\frac{u - V_{w_1}}{V_f} = \tan\beta_1$$

$$V_{w_1} = u - V_f\tan\beta_1 \quad -(3)$$

$$V_{w_2} = u - V_f\tan\beta_2 \quad -(4)$$

Putting (1), (2), (3), (4) in R_D eq:

$$R_D = \frac{V_f^2\left[(\cos^2\beta_1)^{-1} - (\cos^2\beta_2)^{-1}\right]}{2(u - V_f\tan\beta_2 - u + V_f\tan\beta_1)u}$$

$$= \frac{V_f^2(\sec^2\beta_1 - \sec^2\beta_2)}{2V_f u(\tan\beta_1 - \tan\beta_2)}$$

$$= \frac{V_f}{2u}\left(\frac{1+\tan^2\beta_1 - 1 - \tan^2\beta_2}{\tan\beta_1 - \tan\beta_2}\right)$$

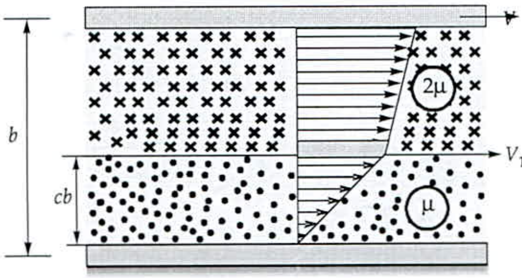
$$= \frac{V_f}{2u}\frac{(\tan\beta_1 - \tan\beta_2)(\tan\beta_1 + \tan\beta_2)}{(\tan\beta_1 - \tan\beta_2)}$$

$$\boxed{R_D = \frac{V_f}{2u}(\tan\beta_1 + \tan\beta_2)}$$

12

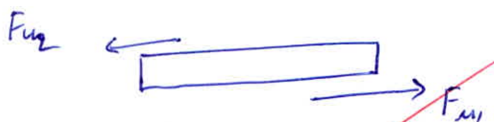
(b) Two flat plates are oriented in parallel configuration above a fixed lower plate as shown in figure. The top plate, located a distance, b above the fixed plate, is pulled along with speed V. The other thin plate is located a distance (cb) where $0 < c < 1$, above the fixed plate. This plate moves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

If draw FBD of thin plate



$\Sigma F_{net} = 0$

$$A \mu \left(\frac{V_1 - 0}{cb}\right) = A\, 2\mu \left(\frac{V - V_1}{(1-c)\, b}\right)$$

$$\frac{1-c}{2c} = \frac{V}{V_1} - 1$$

$$\frac{1-c+2c}{2c} = \frac{V}{V_1}$$

$$\boxed{\frac{V_1}{V} = \frac{2c}{c+1}}$$

$$\frac{V_1}{V} = \frac{2c}{c+1}$$

i) $c = 0$ $\quad \boxed{\frac{V_1}{V} = 0}$ Ans

ii) $c = 0.2$ $\quad \frac{V_1}{V} = \frac{2 \cdot 0.2}{1.2} = \frac{1}{3} = 0.33$

$$\boxed{\frac{V_1}{V} = 0.334}$$ Ans

iii) $c = 0.5$ $\quad \frac{V_1}{V} = \frac{2 \cdot 0.5}{1.5}$

$$\boxed{\frac{V_1}{V} = 0.667}$$ Ans

iv) $c = 0.7$ $\quad \frac{V_1}{V} = \frac{2 \cdot 0.7}{1.7}$

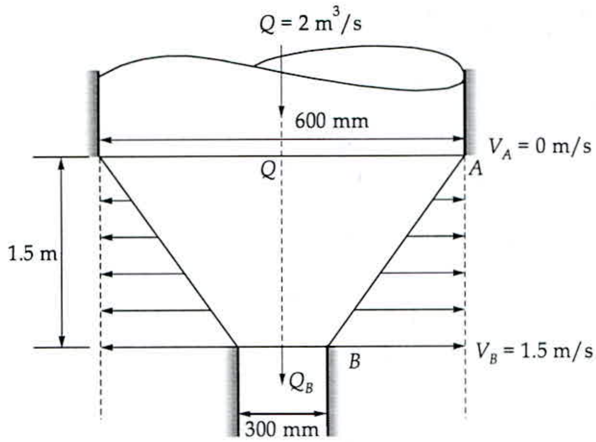
$$\boxed{\frac{V_1}{V} = 0.8235}$$ Ans

Better to make Table

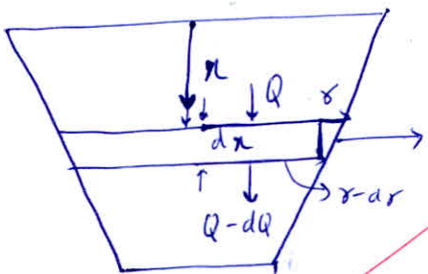
(v) $c = 1$ $\quad \boxed{\frac{V_1}{V} = 1}$ Ans

12

(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]



$V_x = 0 + \frac{1.5-0}{1.5} x$

$V_x = x$ m/s

x in metre

r → in mm

$Q - (Q - dQ) = (\pi r^2) . dx\, x$

$dQ = \pi r^2 x\,dx$ — ①

x	0	1.5
r	300	150

$r = 300 + \left(\frac{150-300}{1.5-0}\right) x$

$= 300 - \frac{150}{1.5} x$

$r = 300 - \frac{150}{1.5} x$ mm

Putting in ①

$dQ = \pi \left(300 - \frac{150}{1.5} \times 10 x\right)^2 \frac{x\,dx}{(1000)^2}$

Do not write in this margin

$$dQ = \pi \left(\frac{3-x}{10}\right)^2 x\,dx$$

$$Q = \int_0^{1.5} \pi \frac{(x-3)^2 x\,dx}{100}$$

$$\boxed{Q = 0.14579\ m^3/s}$$

$$Q_A = Q_B + Q$$

$$Q_B = Q_A - Q$$

$$\boxed{Q_B = 1.8542\ m^3/s}$$

04

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

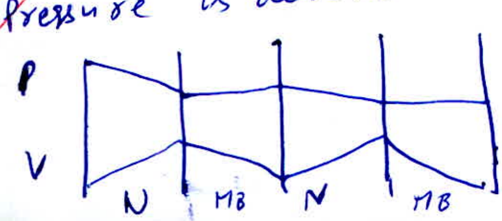
(ii) What are the differences between impulse and reaction turbine? Explain in a tabular form.

[6 + 6 marks]

In the simple impulse steam turbine ~~the~~ the total drop of Pressure from boiler to condenser takes place in nozzle only so the velocity of steam coming out of nozzle is quite high. around 20,000 - 30,000 r/m ~~so~~ and a generator is directly coupled with the turbine so decrease the rotational speed of turbine we need compounding.

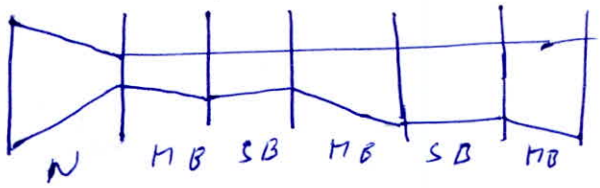
1) ~~Velocity~~ Pressure compounding (Ratean turbine)

in the compounding type Pressure is derease in set of nozzle



Velocity compounding :- (curtis)

in this compounding the ~~moving blades~~ we put a stator blade b/w the ~~Bo Parts~~ velocity decreased in



(3) Mixed Compounding

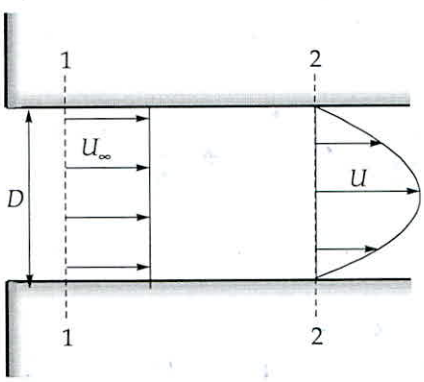
ii) impulse turbine	reaction turbine
a) only impulse forces present	a) impulse + Pressure forces
b) blade	b) Aerofoil shaped blade
c) $\eta_{max} = \cos^2\alpha$ @ $\rho = \frac{\cos\alpha}{2}$	c) $\eta_{max} = \frac{2\cos^2\alpha}{1+\cos^2\alpha}$ @ $\rho = \cos\alpha$
d) $V_{r2} < V_{r1}$ [friction]	d) $V_{r1} < V_{r2}$ (Converging type Passage)
e) Nozzle is present	e) guide Vanes are Present.

Incorrect — only for 50% rxn — don't write as generalised

eight (8)

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

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



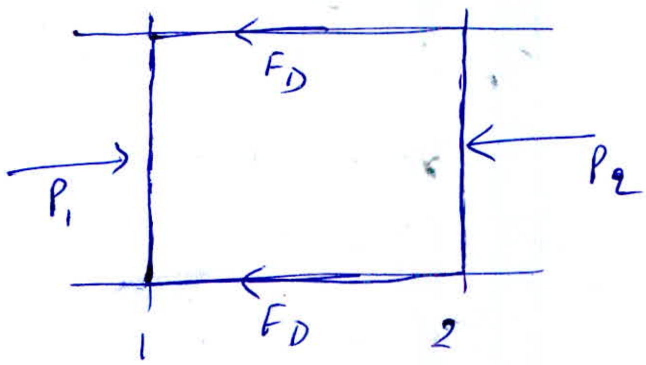
Where P_1 and P_2 are pressure at respective sections.

[12 marks]

momentum correction factor = $\frac{\text{Actual momentum}}{\text{Averge momentum}}$

$\frac{\text{momentum based on actual velocity}}{\text{momentum based on avg. velocity}}$

$$(\dot{P}_{act})_2 = \frac{4}{3} \times \left(\rho V_\infty \frac{\pi D^2}{4} V_\infty\right)$$



if we take fluid from section ① to section ②
and apply Newton second law

momentum

$$A P_1 - F_D - P_2 A = P_f - P_i$$

$$= P_{act_2} - P_{act_1}$$

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

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

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

hence prove

1

.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]

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

Prototype

$P = 7355$

$H = 10$

$N = 100$

$\eta_p = 1.04 \times 0.88$

$= 91.52\%$

Model

$H = 6$

$\eta_m = 88\%$

i) $\left(\frac{H}{D^2N^2}\right)_m = \left(\frac{H}{D^2N^2}\right)_p$

use effective head because $\eta_{om} \neq \eta_{op}$

$\frac{\sqrt{6}}{D_m N_m} = \frac{\sqrt{10}}{D_p N_p}$

$N_m = \sqrt{\frac{6}{10}} \frac{D_p N_p}{D_m}$

$N_m = 774.596$ rpm

ii) $Q \propto D^2\sqrt{H}$

$\frac{Q_m}{D_m^2\sqrt{H_m}} = \frac{Q_p}{D_p^2\sqrt{H_p}}$

For Prototype

$P_p = \eta_o \rho Q g H$

$Q_p = 81.921 \ m^3/sec$

$Q_m = Q_p \frac{D_m}{D_p^2} \sqrt{\frac{H_m}{H_p}}$

$Q_m = 0.6345 \ m^3/s$ Ans

→ slightly deviated

$P_m = \eta_o \rho Q g H$

$P_m = 32.868 \ kW$

iii) $(N_s)_m = \frac{N\sqrt{P}}{H^{5/4}} =$ ~~2028.4738~~ ~~479.909~~

$(N_s)_p = \frac{N\sqrt{P}}{H^{5/4}} = 482.271$

here ~~bo~~ the model & Prototype has different specific speed because the efficiency of the Prototype is higher than the model.

Method is OK

05 + 5 = 10

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]

$r_p = 4$

$D_1 = 0.3$

$V_{in} = 120$ $\quad \dot{m} = 10$ kg/s

$V_{out} = 110$ m/s $\quad u_2 = 450$ m/s $\quad N = 16000$

$\frac{\pi D_2 N}{60} = 450$

$D_2 = 0.53714$ m

$(\eta_{is})_{\text{total head}} = 80\%$

$T_{01} = 300$ K

$P_{01} = 101$ kPa

i) at inlet

$$c_p T_{01} = c_p T_1 + \frac{V_1^2}{2}$$

$$T_1 = 300 - \frac{120^2}{2000 \times 1.005}$$

$$T_1 = 292.835 \text{ K}$$

as we know stagnation state achieved in isentropic Process

$$\frac{T_{01}}{T_1} = \left(\frac{P_{01}}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$P_1 = 92.8072 \text{ kPa}$$

$P_{outlet} = 4 \times P_1$
$= 371.2288$

ii) Static Pressure ratio :-

$$(r_p)_{static} = r_p \times \frac{P_{01}}{P_1}$$

$$= 4 \times \frac{101}{92.8072}$$

$$(r_p)_{static} = 4.353$$

(iii) $$P_{in} = \frac{\dot{m} C_p T_1 \left(r_p^{\frac{\gamma-1}{\gamma}} - 1 \right)}{0.8}$$

$$P_{in} = 1921.585 \text{ kW}$$

(iv) $$\text{Mach Number} = \frac{V}{C} = \frac{V}{\sqrt{\gamma R T_0}}$$ [based on relative

$$= \frac{120}{\sqrt{1.4 \; 0.287 \times 300}}$$

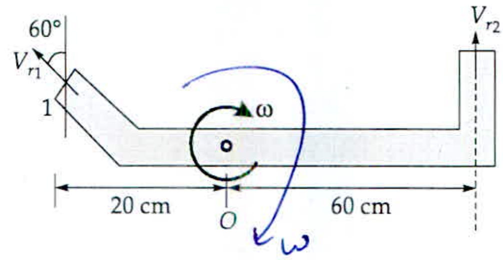
Mach Number = 0.3456

03

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,

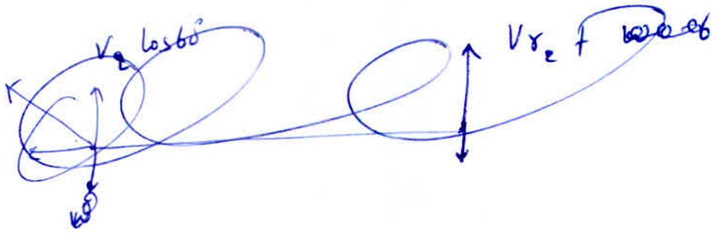
(ii) What torque is required to hold it from rotating?

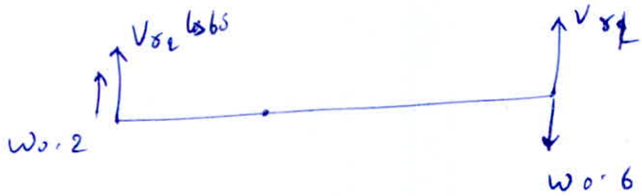


[20 marks]

$V_{r_1} = V_{r_2} = \frac{Q}{2A} = \frac{1.4 \times 100 \times 100}{1000 \times 2 \times 0.7} = 10$ m/s

(i)





$\frac{\dot m}{2}(-V_{r_2} + \omega 0.6)\, 0.6 = \frac{\dot m}{2}(V_{r_2}\cos 60° + \omega 0.2)\, 0.2$

$\omega 0.6^2 - 6 = 10 \frac{1}{2} \times \frac{0.2}{1} + \omega 0.2^2$

$\omega = \frac{7}{0.6^2 - 0.2^2}$

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$$\omega = 21.875 \text{ rad/s}$$

(ii) Torque required to hold

$$= \frac{\dot{m}}{2}\left(10\frac{1}{2} + \omega\, 0.2\right)0.2 + \frac{\dot{m}}{2}\left(-10 + \omega\, 0.6\right)0.6$$

$$= \frac{\rho Q}{2}\left[1 + \omega\, 0.2^2 - 6 + \omega\, 0.6^2\right]$$

$$= \frac{1000 \times 1.4}{2 \times 1000}\left[\omega\left(0.6^2 + 0.2^2\right) - 5\right]$$

$$\text{Torque} = 2.625 \text{ Nm}$$

0

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]

i)

$\alpha_1 = 20°$

$\beta_2 = 30°$

$u = u_1 = u_2 = 125$ m/s (Axial turbine)

$V_1 = 350$ m/s

$K = 0.9$ (blade Friction factor) $\quad \eta_{Nozzle} = 0.85$

So. in inlet velocity Δ

$V_{w_1} = 350 \cos 20° = 328.8924$ m/s

$V_{f_1} = 350 \sin 20° = 119.707$ m/s

$V_{r_1} = \sqrt{(V_{w_1} - u)^2 + V_{f_1}^2} = 236.4358$ m/s

$V_{r_2} = K V_{r_1}$

$V_{r_2} = 212.792$ m/s

in outlet velocity Δ $\quad u + V_{w_2} = V_{r_2} \cos \beta_2$

$V_{w_2} = 59.2834$ m/s (in opposite direction of V_{w_1})

Work done in stage per kg $= Q_{CP}(V_{w_1} - V_{w_2})$ in $\frac{J}{kg}$

$= (328.8727 - (-57.2834))125$

$$\boxed{W.D \text{ in a stage} = 48.5219 \ \frac{KJ}{Kg}}$$ Ans

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

$$= \frac{WD}{\frac{1}{2}V_1^2} \times \eta_{nozzle} = 0.7921 \times 0.85$$

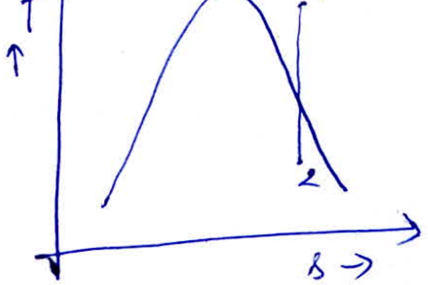
$$\boxed{\eta_{stage} = 67.336\ \%}$$ Ans

(ii) η_{stage} is equal for all stages then

$$\left[\ \eta_{overall} = \eta_{stage} \times RHF\right.$$

$$\boxed{\eta_{overall} = 70.7034\ \%}$$

From T-S diagram $(\Delta h_{so}) = h_1 - h_2$



here from 1-2 is isentropic

so $s_1 = s_2$

$s_1 = s_f + x_2 s_{fg}$

$6.5453 = 0.5582 + x_2(7.7198)$

dryness factor $x_2 = 0.7755$

$h_2 = h_f + x_2 h_{fg} = 2031.88$ KJ/Kg

$(\Delta h_{s0}) = h_1 - h_2 = 870.6184$ KJ/Kg

Net work done/Kg $= \eta_{overall} (\Delta h_{s0})$

$= 615.557$ KJ/Kg

it is given all stages have equal work done

then

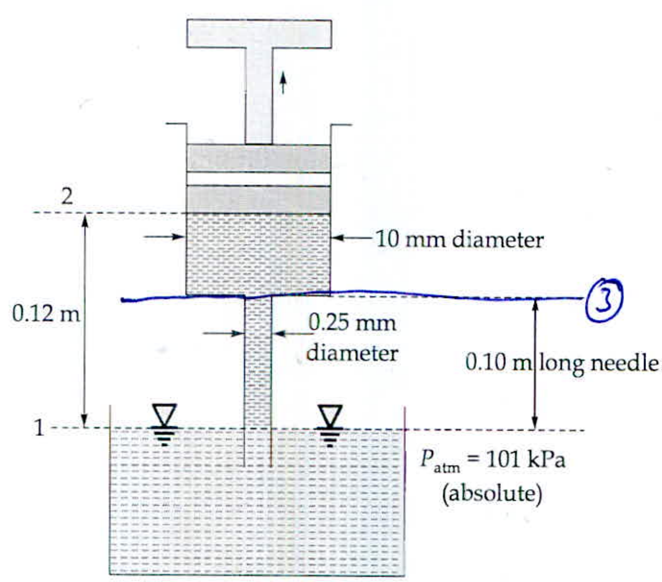
Net work done $= n W_{stage}$

$n = \frac{615.557}{48.5219} = 12.686$

$n = 13$ stages

20

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]

at 1 cross section

$P_1 = P_{atm} = 101\ kPa$

$V_1 = 0 \quad z_1 = 0$ (Datum)

at 2 cross section

$P_2 = P_v$ (For maximum flowrate)

$V_2 = V \quad z_2 = 0.12\ m$

Now applying Bernoulli eq^n b/w ① - ②

Where is head loss?

Assumption
→ steady
→ irrotational
→ incompressible
→ Uniform.
→

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

$$\frac{101\times10^3}{0.96\times1000\times9.81} + 0 + 0 = \frac{1.2\times10^4}{0.96\times1000\times9.81} + \frac{V_2^2}{2g} + 0.12$$

$$\frac{V_2^2}{2g} = 9.33$$

$V_2 = 13.53\ m/s$

$Q = 1.06264\times10^{-3}\ m^3/s$

Now we have check whether at cross-section there No cavitation occuring.

So we calculate P_3 if P_3 comes to greater than P_v then cavitation will not occur.

$$V_3 A_3 = Q$$

$$V_3 \times \frac{\pi}{4}\left(\frac{0.25}{1000}\right)^2 = Q$$

$$\left[V_3 = 21648.08 \text{ m/s}\right]$$

Now applying bernoulli b/w ① - ③

$$\frac{101 \times 10^3}{0.96 \times 1000 \times 9.81} = \frac{V_3^2}{2g} + z_3 + \frac{P_3}{\rho g}$$

$z_3 \to 0.1$

P_3 comes as a negative value.

So our critical cross-section is ③ we have ~~safe~~ save it ~~first~~, from the caviation

bernouli b/w ~~① &~~ ③

$$\frac{101 \times 10^3}{0.96 \times 9.81} = 0.1 + \frac{V_3^2}{2g} + \frac{1.2 \times 10^7}{0.96 \times 1000 \times 9}$$

$$V_3 = 13.5445 \text{ m/s}$$

$$\boxed{Q = 6.64866 \times 10^{-4} \ \frac{\text{litre}}{\text{sec}}}$$

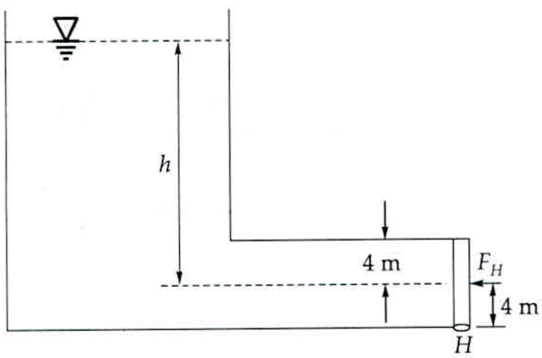
this is maximum flow rate.

Ans

02

Do not neglect major and minor losses

.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.

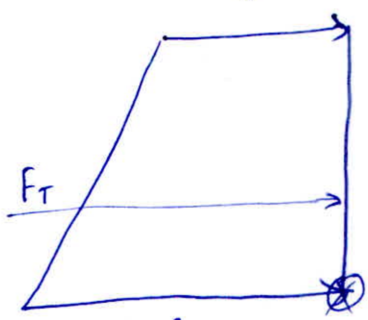


(i) Determine the maximum water depth above the centre of the gate that can exist without the gate opening.

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

[20 marks]

i) Pressure Prism of gate hinged at bottom



F_T = Volume of Pressure Prism

$= \frac{1}{2}(P_1 + P_2)\, 8 \times 3$

$F_T = \frac{1}{2}(\rho g h \times 2)\, 8 \times 3$

$F_T = 24 \rho g h$

$x_{cg} = \frac{P_1 + 2P_2}{P_1 + P_2} \cdot \frac{l}{3}$

$= \frac{\rho g(h-4) + 2\rho g(h+4)}{\rho g(h-4) + \rho g(h+4)} \cdot \frac{8}{3}$

$x_{cg} = \frac{h-4+2h+8}{2h} \times \frac{8}{3} = \frac{(3h+4)4}{3h}$

· Now the gate is hinged from bottom then

$\Sigma M_{bottom} = 0$ For equilibrium

$F_T \times (8 - x_{cg}) = F_H \times 4$

$24\rho g h \left(8 - \frac{12h+16}{3h}\right) = 3500 \times 4 \times 10^3$

$$\overset{8}{\cancel{24}} \times 9.81 \times \cancel{h}\left(\frac{24h - 12h - 16}{3\cancel{4}}\right) = 3500 \times 4$$

$$8g(12h - 16) = 3500 \times 4$$

$$\boxed{h = 16.199 \text{ m}}$$

(ii) Now in second case gate is hinged from the top everything remains same but this time we balance the Net moment from Top..

$$\sum M_{top} = 0$$

$$F_T \times x_{cy} = F_T \times 4$$

$$\overset{8}{\cancel{24}}\, \cancel{\beta} g\, h\, \frac{(12h + 16)}{3\cancel{4}} = 3500 \times 10^3 \times 4$$

$$12h + 16 = 178.399$$

$$\boxed{h = 13.532 \text{ m}}$$

No the answer will not remain same for both cases because in each case moment of F_T comes from different lengths.

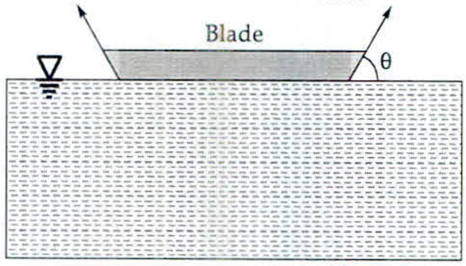
20

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 marg

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]

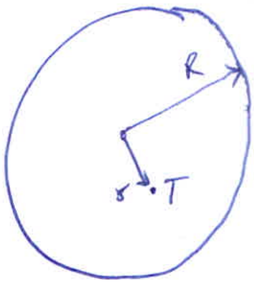
Section B : Heat Transfer - 1 + TOM - 1, Thermodynamics - 2 + RAC - 2

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]



Assumption

→ heat flow occurs in only one dimension i.e radial

→ k, h remains constant

→ radiation effect neglect

→ steady state

generalised heat conduction eqn for spherical coordinates in radial only.

$$\frac{1}{r^2}\left(\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right)\right) + \frac{\dot{q}}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau} \rightarrow 0 \text{ steady}$$

→ Show initial steps

$$\int \frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right) = \int -\frac{q_G}{k} r^2 \, \partial r$$

$$r^2\frac{\partial T}{\partial r} = \frac{-q_G r^3}{3k} + C_1 \quad \text{— (1)}$$

$$\int \frac{\partial T}{\partial r} = \int\left(-\frac{q_G r}{3k} + \frac{C_1}{r^2}\right)\partial r$$

$$T = -\frac{q_g r^2}{6K} + \frac{c_1(-2)}{r^3} + c_2$$

boundary condition

a) at $r = 0$ $q'' = 0$

i.e $\frac{\partial T}{\partial r} = 0$

From eqⁿ ① $C_1 = 0$

b) $r = R$ $T = T_0$

$$C_2 = T_0 + \frac{q_g R^2}{6K}$$

$$T = T_0 + \frac{q_g R^2}{6K} - \frac{q_g r^2}{6K}$$

$$T = T_0 + \frac{q_g R^2}{6K}\left(1 - \frac{r^2}{R}\right)$$

at $r = R$ q''_{cond} $q_g \frac{4\pi}{3} R^3 = h\, 4\pi R^2 (T_0 - T_\infty)$

$$\frac{q_g R}{3h} + T_\infty = T_0$$

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

hence Prove

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

$P_t \rightarrow$ 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]

$P_t = 13.6\ g\ \frac{750}{1000}$

$P_t = 750$ mm of hg

$T_{DBT} = 33°c$ $T_{WBT} = 23°c$

$P_v = (P_s)_{WB} - \dfrac{(P_t - P_{sWB})(t_{DB} - t_{WB})}{1527.4 - 1.3t_{WB}}$

$= 21.06 - \dfrac{(750 - 21.06)(33 - 23)}{1527.4 - 1.3 \cdot 23}$

$P_v = 16.1922$ mm of Hg

(i) $\phi = \frac{P_v}{P_{vs}} = \frac{16.19}{37.72}$

$\phi = 42.9276\ \%$

ii) $\omega = \frac{0.622\, P_v}{P - P_v} = \frac{0.622 \times 16.19}{750 - 16.19}$

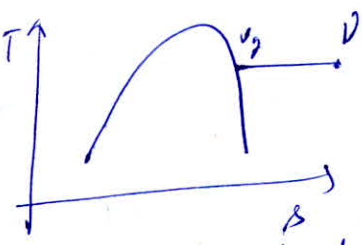
$\omega = 13.725\ \frac{gm}{kg\ of\ d.a}$

(iii) $P_v = 16.19$ mm of Hg

then corresponding ts from table is 18.7°C

Dew Point $t_{DPT} = 18.7^\circ C$

iv) For saturated vapour



$PV = RT$

$37.72 \times 28.05 = 16.19\ V$] for a constant temperature Process.

$V_{saturated\ vapour} = 63.3726\ m^3/kg$

For 1kg of d.a ~~Volume of d.a~~ $P_a V = mRT$

$(P_t - P_v) V = 1 \times 0.287 \times (33 + 273)$

$V_{d.a} = 0.897042\ m^3$

$\rho_{air} = \frac{m_{d.a} + m_{vapour}}{V_{da} + V_{vapour}}$

$V_{satur\ vapour} = \frac{V \times W}{1000} = 0.86937$

$\rho_{air} = 0.5738\ \frac{kg}{m^3}$

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 mechanism :-

The mobility of mechanism is defined no. of Minimum variables required to define the motion of mechanism or no. of input required to get a constrained motion.

For Planar mechanism

Kutzback eq :-

$$f = 3(l-1) - 2j - h$$

here for a Planar mechanism :- Any link can have maximum 3 DoF, one link is fixed

so max DoF = $3(l-1)$

j = lower pair, lower pair constrained 2 DoF

h = higher pair, higher pair constrained 1 DoF

So the Degree of freedom of mechanism = $3(l-1) - 2j - h$

10

(+) This is different from gruebler criterion because in gruebler criterion it considered only lower pair and DoF is equal to 1. h=0 no higher pair

$1 = 3(l-1) - 2j$

$$3l = 4 + 2j$$

gruebler criterion.

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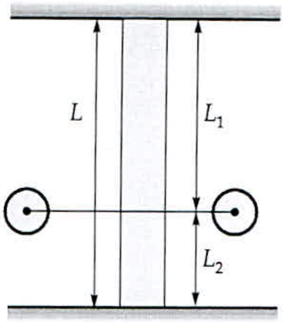
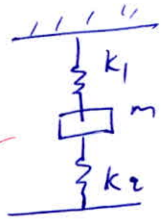
A flywheel is mounted on a vertical shaft as shown in figure. The ends of the shaft being fixed. The shaft is having 20 cm diameter, the length L_1 is 0.9 m and the length L_2 is 0.6 m. The flywheel weighs 500 kg and its radius of gyration is 50 cm, then find the natural frequencies of the longitudinal,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



[12 marks]

a) For longitudinal



$$\omega_n = \sqrt{\frac{K}{m}}$$

$$K = k_1 + k_2$$

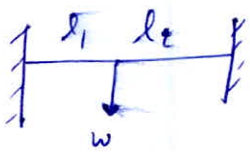
$$= \frac{EA_1}{l_1} + \frac{EA_2}{l_2}$$

$$K = EA\left(\frac{1}{l_1} + \frac{1}{l_2}\right) = 200 \times 10^9 \left(\frac{1}{0.9} + \frac{1}{0.6}\right) \times A$$

$$K = 17.453 \times 10^9 \ \frac{N}{m}$$

$$\omega_n = \sqrt{\frac{K}{m}} = 5908.179 \ \text{rad/s}$$

b) For transverse



$$\delta = \frac{W l_1^3 l_2^3}{3EIl^3}$$

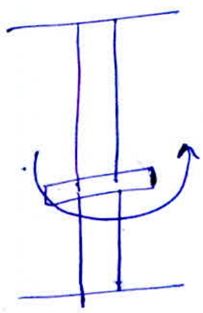
$$\frac{g}{\Delta} = \frac{3EIl^3}{l_1^3 l_2^3 m}$$

$$\omega_n = \sqrt{\frac{g}{\Delta}}$$

$$\omega_n = \sqrt{\frac{3EI\,l^3}{l_1^3 l_2^3\, m}}$$

$$\boxed{\omega_n = 1421.287 \text{ rad/s}}$$

Torsional



$$(K_T)_{net} = \frac{GJ_1}{l_1} + \frac{GJ_2}{l_2}$$

$$= 80\times10^9 \frac{\pi d^4}{32}\left(\frac{1}{0.4} + \frac{1}{0.6}\right)$$

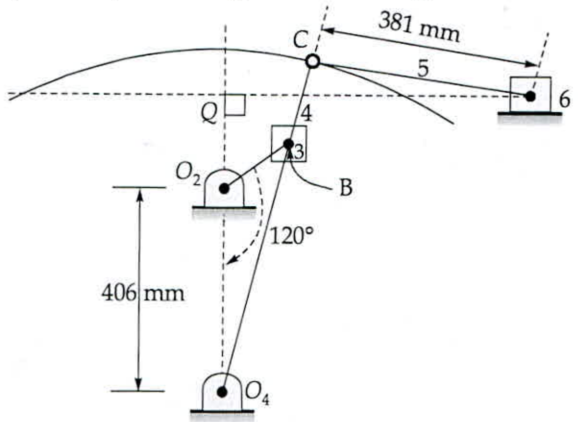
$$I\ddot{\theta} + K_T\theta = 0$$

$$\omega_n = \sqrt{\frac{K_T}{mk^2}}$$

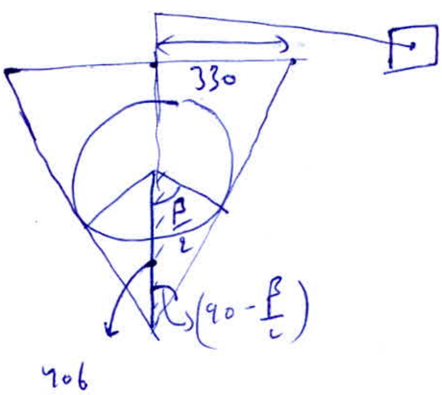
$$\boxed{\omega_n = 528.4436 \text{ rad/s}}$$

12

(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]



$1.75 = \frac{\alpha}{\beta}$

$1.75 = \frac{360-\beta}{\beta}$

$\beta = \frac{360}{2.75} = 130.91^\circ$

$406 \cos\frac{\beta}{2} = O_2B$

$O_2B = 168.6585$ mm Ans

$O_4C \sin\left(90-\frac{\beta}{2}\right) = 330$

$O_4C = 794.4$ mm

$1.75 = \frac{t_1}{t_2}$ — (1)

$(t_1+t_2) = \frac{\omega}{2\pi}$ $t_1+t_2 = \frac{40 \times 2\pi}{60 \times 2\pi}$

$t_1+t_2 = \frac{2}{3}$ — (2)

From eq^n (1) (3) (2)

$t_1 = 1.75 t_2$

$2.75 t_2 = \frac{2}{3}$

$t_2 = \frac{8}{33}$ sec $t_1 = \frac{14}{33}$

Average speed of slider in working stroke $= \frac{660}{14/33} \times 10^{-3}$

$= 1.5557$ m/s Ans

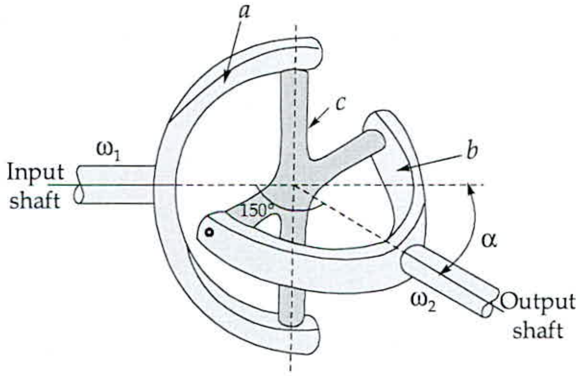
Average speed of slider in Returning stroke $= 2.7225$ m/s Ans

06

) 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 $Pr = 3.26$.

[20 marks]

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Q.) 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.

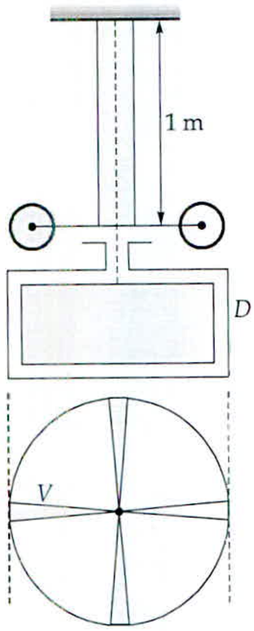
Assume the hub and the spokes of the flywheel delivers 10% of the rotational inertia of the wheel.

[20 marks]

(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/m^{2}K. Find the ratio of the rate of heat transfer for rods A and B.

[20 marks]

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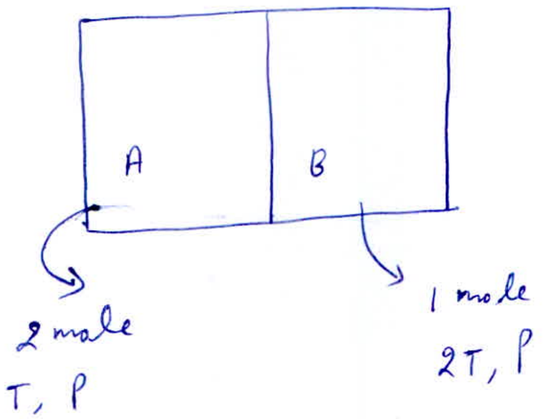
Q.8 (a) Two moles of an ideal gas at temperature T and pressure P are contained in a compartment. In an adjacent compartment one mole of an ideal gas is at temperature 2T and pressure P. The gases mix adiabatically but do not react chemically when a partition separating the compartments is withdrawn.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

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

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]



Assumption

→ gas mix adiabatically then $\Delta Q = 0$

→ Final temperature will same for both the gases let T'

$$2C_{v_A}T + 1C_{v_B}2T = (2C_{v_A} + 1C_{v_B})T'$$

$$T' = \frac{2(C_{vA}+C_{vB})T}{2C_{vA}+C_{vB}}$$

00

) 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

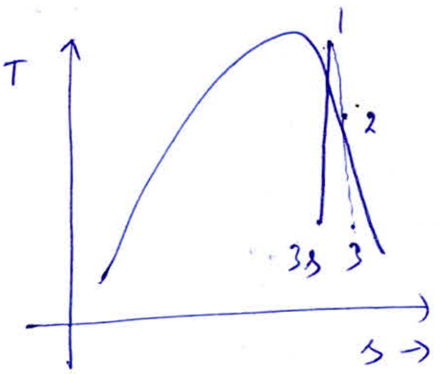
At 30°C, h_0 = 125.79 kJ/kg; $s_0 = s_{f30°C}$ = 0.4369 kJ/kgK

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]



From the data we know

$s_2 > s_1$

$s_3 > s_1$

the turbine expands as irreversible.

i) Energy entering of steam turbine / kg steam entering

$$= \frac{600 \times h_1}{600}$$

$$= h_1 = 3125.87 \ \frac{KJ}{Kg}$$

$\frac{\text{Energy leaving the turbine}}{\text{Kg of steam entering}} = \frac{(600-150)}{600} \times h_3$

$$= \frac{450}{600} \times (251.4 + 0.92 \times 2358.3)$$

$$= 1815.777 \ \frac{KJ}{Kg}$$

(ii) Maximum Work $= \phi_1 - \phi_3$

$$= \frac{(h_1 - h_2) - T_0(s_1 - s_2) \times 600 + [(h_2 - h_3) - T_0(s_2 - s_3)] \times 450}{600}$$

$$= (3125.87 - 2865.5) - 303(6.8481 - 7.3115) + \frac{450}{600}\left[[2865.5 - (h_3)] - T_0(7.3115 - s_3)\right]$$

$h_3 \rightarrow 2421.036$, $s_3 \rightarrow 7.34238$

$= 400.7802 + 340.36548$

Maximum Work $= \phi_1 - \phi_3$

$= 741.14568$ KJ (Kg of steam entering)

(iii) Irreversibility $= W_{max} - W_{actual}$

$$W_{actual} = \frac{600}{3600}(h_1 - h_2) + \frac{450}{3600}(h_2 - h_3) - 10$$

$= 88.953$ KW

$W_{act} = 533.718 \frac{KJ}{Kg \text{ of steam entering}}$

Do not write in this margin

$I = W_{max} - W_{actu}$

$$I = 207.427 \ \frac{KJ}{Kg \text{ of stem entering}}$$

19

(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

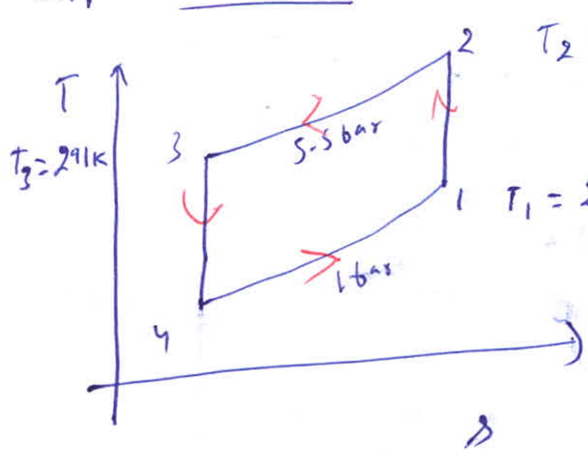
(ii) the expansion follows the law $PV^{1.25}$ = constant.

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

[20 marks]

(i) expansion is entropic

$T_2 =$



$r_p = 5.5$ if both the compressor & expander is isentropic then COP of bell coleman cycle is

$$COP = \frac{1}{r_p^{\frac{\gamma-1}{\gamma}} - 1}$$

Don't use objective method

$$COP = \frac{1}{5.5^{\frac{1.4-1}{1.4}} - 1}$$

$$\boxed{COP = 1.5935}$$ Ans

(ii) when expansion follows $PV^{1.25} = Const$

then $T_4 \Rightarrow \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{1.25-1}{1.25}}$

$$\boxed{T_4 = 206.928 \text{ K}}$$

Work done of expander / kg $= \frac{n}{n-1} R T_3 [$

$$= \frac{n}{n-1}[P_3V_3 - P_4V_4)$$

$$= \frac{n}{n-1} RT_3 \left[1 - \frac{T_4}{T_3}\right)$$

$$= 420.357\, R \ \frac{KJ}{Kg}$$

Work done to compress $= h_2 - h_1$

$$= \frac{\gamma}{\gamma-1} R T_1 \left[\frac{T_2}{T_1} - 1\right)$$

$$= 584.271\, R \ \frac{KJ}{Kg}$$

$$Q_{extract} = h_1 - h_4$$

$$= c_p (T_1 - T_4)$$

$$= \frac{\gamma}{\gamma - 1} R (266 - 206.728)$$

$$\boxed{Q_{ext} = 206.752 R \ \frac{kJ}{kg}}$$

$$COP = \frac{Q_{desired}}{(W_{net})_{input}}$$

$$= \frac{206.752 R}{587.241 R - 420.357 R}$$

$$\boxed{COP = 1.2615}$$

Ans

18

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Space for Rough Work

Space for Rough Work