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ESE 2024 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-4 : Theory of Machines [All Topics]

Fluid Mechanics & Turbo Machinery-1 [Part Syllabus]

Heat Transfer-2 + Refrigeration and Air-conditioning-2 [Part Syllabus]

Name :

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	34
Q.2	48
Q.3	–
Q.4	50
Section-B	
Q.5	20
Q.6	–
Q.7	–
Q.8	20
Total Marks Obtained	172

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

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Remarks :

- Presentation and accuracy is ~~excellent~~ excellent.
- Try to increase the attempt.

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Section : A

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

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

[6 + 6 marks]

machine → physically real unit of a theoretical mechanism (kinematic chain) which gives desired output.

Grashof's Law :-

For continuous relative motion to be possible in a 4 bar linkage, the sum of lengths smallest and largest links should be less than or equal to that of the sum of other ~~two~~ two links.

(4)

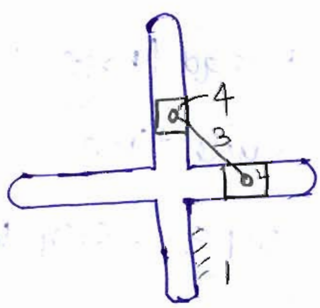
s → length of smallest link.

l → " " longest link

p, q → lengths of other two links.

$(s+l) \le (p+q)$ ⇒ condition for atleast one link to make a full revolution.

Double slider Crank mechanism



1 → slotted bar.

2, 4 → sliders.

3 → link connecting sliders.

2

Inversions of double slider

1. Elliptical Trammel → when slotted bar is fixed.

2. Scotch Yoke mechanism → when one of the sliders is fixed.

3. Oldhams coupling → when link connecting sliders is fixed

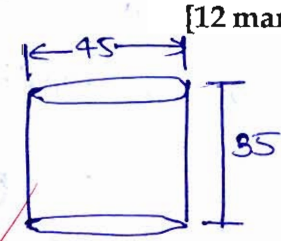
5

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

[12 marks]

8 holes per min

t_c = cycle time = 7.5s/hole



$E_{reqd}/\text{hole} = \frac{9\ J}{mm^2}(A_{sheared})$

$A_{sheared} = \pi(45\times35)$

$A_{sheared} = 4948.0084\ mm^2$

$= 44532.0758\ J.$

$P_{motor} = \frac{E_{reqd}/\text{hole}}{\text{Cycle time}}$

$= 5937.6101$ Watt

$P_{motor} = 5.9376\ KW$

stroke = 100mm.

200 mm ⟶ 7.5s.

35 mm ⟶ t_a = 1.3125s.

↓ exact operation time.

$P_{motor}(t_c - t_a)$ = Energy provided by flywheel

$= I\omega^2 C_s$.

$C_s = 3.5\% = \frac{3.5}{100}$

$5937.6101(7.5 - 1.3125) = mk^2\omega^2 C_s$.

$k\omega = 25 m/s$.

$36738.9625 = m \times (25)^2 \times \left[\frac{3.5}{100}\right]$.

$m_{flywheel} = 1679.4954 kg$.

12

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

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

[6 + 6 marks]

Fly wheel	Governor.
* Used to minimise the fluctuation of speed when the engine torque is different from load torque by storing and releasing the remaining energy.	* used to maintain the fuel supply that an maintain the mean speed of engine under variable load condition. *

4

(ii) Interfearance

when two gears are mating, if the involute portions of one gear enter in to the non involute portion of other gear there would be removal of material from the non involute portion of gear which is called as inter fearance.

methods to avoid interfearance :-

1. Undercutting of gears.
2. Increasing pressure angle.
3. stubbing of gear tooth.
4. Increasing the number of teeth.

✓ (5)

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

[12 marks]

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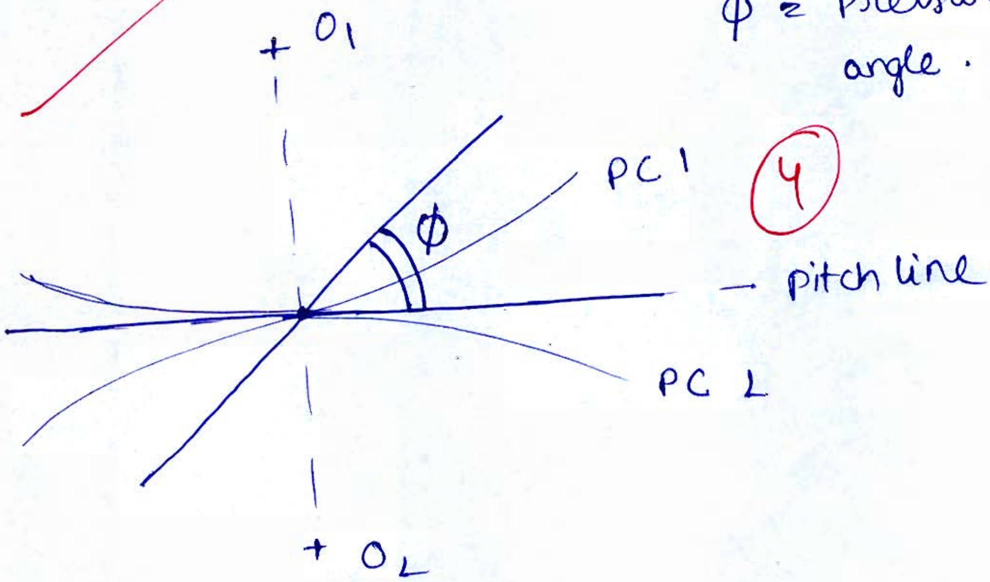
1 (e) Distinguish between the pressure angle of a radial cam and that of a spur gear with the help of neat diagram.

[12 marks]

Pressure angle in a spurgear:-

It is the angle b/w pitch line and the line of action (i-e common normal at the point of contact.)



ϕ = pressure angle.

4

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

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

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

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

[20 marks]

$m = 120\,kg$.

$M_{reci} = 2\,kg$.

$r = \frac{90}{1000\times 2} = 0.045\,m$.

$\epsilon = \frac{1}{25} = \frac{\sqrt{1+\left(\frac{2\xi\omega}{\omega_n}\right)^2}}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2+\left[\frac{2\xi\omega}{\omega_n}\right]^2}}$ = transmissibility.

neglecting damping $\Longrightarrow \xi = 0$.

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

$\omega = \frac{2\pi\times 900}{60} = 94.2477$ rad/s.

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

$$\left(\frac{\omega}{\omega_n}\right)^2 = 26. \Longrightarrow \frac{\omega}{\omega_n} = 5.09901$$

$$\boxed{\omega_n = \frac{94.2477}{5.09901} = 18.48349}$$

$\omega_n = \sqrt{\frac{S}{m}} = \sqrt{\frac{S}{120\,kg}} = 18.48349$

$$\boxed{S = 40.9967\ \frac{kN}{m}}$$

$\epsilon = \frac{1}{25}$. (when $\xi = 0$).

Given, $\frac{A_1}{A_2} = \frac{1}{0.7}$.

$e^{\xi\omega_n t_d} = \frac{1}{0.7}$ $\qquad t_d = \frac{2\pi}{\sqrt{1-\xi^2}\,\omega_n}$

$$e^{\frac{2\pi\xi}{\sqrt{1-\xi^2}}} = \frac{1}{0.7}$$

$$\frac{2\pi\xi}{\sqrt{1-\xi^2}} = \ln\left(\frac{1}{0.7}\right) = 0.35667$$

$$(2\pi)^2\xi^2 = (0.35667)^2(1-\xi^2)$$

$$310.332\,\xi^2 = 1-\xi^2$$

$$311.332\,\xi^2 = 1$$

Damping factor ← $\boxed{\xi = 0.05667}$

$$F_0 = 2 \times 0.045 \times \left(\frac{2\pi \times 900}{60}\right)^2 \Longrightarrow \text{Unbalance force.}$$

$$F_0 = 799.4385 \text{ N}$$

10

$$\frac{F_t}{F_0} = \epsilon_{actual}$$

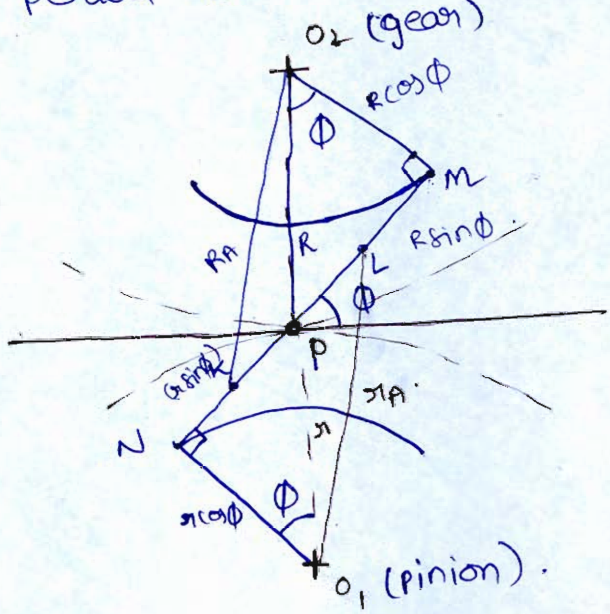
Q.2 (b) (i) Define arc of contact and deduce the expression to find its magnitude.

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

[10 + 10 marks]

Arc of contact

when two gears are mating, the distance travelled by a gear along its pitch circle in one engagement period is known as arc of contact.



$\phi \rightarrow$ Pressure angle.

we know that arc of contact $= \dfrac{\text{Path of contact}}{\cos\phi}$.

Path of contact $= KP + PL$.

from $\Delta\, O_2MK$,

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

$$\sqrt{R_A^2 - (R\cos\phi)^2} - R\sin\phi = KP \longrightarrow (1)$$

From $\Delta\, O_1NL$,

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

$$\sqrt{r_A^2 - r^2\cos^2\phi} - r\sin\phi = PL \longrightarrow (2).$$

8

* arc of contact $= \frac{① + ②}{\cos\phi}$

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

(ii) $m = \frac{d}{t} = 8mm.$

$T_g = T_p = 54.$

$P_c = \pi m = (\pi 8)mm.$

$\phi = 20°.$

$d = 54 \times 8mm.$

$r = R = 216 mm.$

∵ both gears have same # teeth, module

let, $R_A = r_A$
$R = r.$
$KP = PL.$

$$KL = PL = \sqrt{R_A^2 - (216\cos 20)^2} - (216\sin 20)$$

$$\frac{2\left[\sqrt{R_A^2 - 4198.2847} - 73.8763\right]}{\cos 20} = 2.3 \times 8\pi.$$

$$\sqrt{R_A^2 - 4198.2847} = 101.0359.$$

$R_A = 226.7301$ mm.

$R = 216$ mm.

10

Addendum $= R_A - R.$

Add = 10.7301 mm

Q.2 (c) The driven shaft has a moment of inertia 3 g-m² and is inclined at 25° to the axes of the driving shaft. If the driving shaft rotates at 2700 rpm with a steady torque of 280 Nm, determine the maximum fluctuation of output torque. Also, determine the maximum and minimum torque at driving shaft.

[20 marks]

① → driving shaft $\quad I_2 = 3\ gm^2$

② → driven shaft $\quad = 0.003\ kgm^2$

$\alpha = 25^\circ$ (angle b/w shafts)

$N_1 = 2700$ rpm $\quad \omega_1 = \frac{2\pi \times 2700}{60} = 282.7433$ rad/s

$T_{steady} = 280$ Nm. [Both shafts connected by Hooke's joint]

$$\alpha_2 = \frac{-\omega_1^2 \cos\alpha \sin^2\alpha \sin 2\theta}{(1 - \cos^2\theta \sin^2\alpha)^2}$$

↓

angular acceleration of driven shaft.

Driven shaft

$$T_2 - T_{steady} = I_2 \alpha_2 .$$

maximum fluctuation of output torque (T_2)

$$T_2 = (T_{steady}) + (I_2 \alpha_2)$$

$$(T_2)_{max} = T_{steady} + (I_2 \alpha_2)_{max} \rightarrow (I)$$

$$(T_2)_{min} = T_{steady} + (I_2 \alpha_2)_{min} \rightarrow (II).$$

for $\alpha_2 \rightarrow$ max/min.

$$\cos 2\theta = \frac{2\sin^2\alpha}{2 - \sin^2\alpha}.$$

$$\cos 2\theta = 0.19612$$

$$2\theta = 78.6898°, 281.3101°$$

$$\theta = 39.3449°, 140.6550°$$

at $\theta = 39.3449°$, (θ_1).

$$\alpha_2 = \frac{-(282.7433)^2 \cos 25 \sin^2(25) \sin(2\theta)}{(1 - \cos^2\theta \sin^2 25)^2}.$$

$$\alpha_2 = -15905.9341 \text{ rad/s}^2. \rightarrow (III)$$

at $\theta = 140.6550° = \theta_2$

$$\alpha_2 = +15905.9341 \text{ rad/s}^2 \rightarrow (IV).$$

from (I), (II), (III), (IV)

$$(T_2)_{max} = 280 Nm + (0.003 \times 15905.9341)$$

$$= 280 Nm + 47.7178 Nm$$

at $\theta = \theta_2$ $\boxed{(T_2)_{max.} = 327.7178 N.m}$

$$(T_2)_{min} = 280 Nm + (0.003 \times (-15905.9341))$$

at $\theta = \theta_1 \Rightarrow$ $\boxed{(T_2)_{min.} = 232.28219 N.m}$

maximum fluctuation of output torque

$(\Delta T_2) = (T_2)_{max} - (T_2)_{min}$

$= 327.7178 - 232.28219$

$\boxed{(\Delta T_2)_{max} = 95.4356 \text{ N.m}}$

Power balance Equation.

at $\theta = \theta_1 = 39.3449$.

$T_1 \omega_1 = T_2 \omega_2$

$T_1 \times \cancel{(282.7433)} = (T_2)_{min} \times \frac{\cancel{\omega_1} \cos\alpha}{1-\cos^2\theta \sin^2\alpha}$

$(T_1)_{min} = (T_2)_{min} \left[\frac{\cos\alpha}{1-\cos^2\theta \sin^2\alpha}\right]$. at $\theta = 39.3449°$.

$\boxed{(T_1)_{min} = 235.6955 \text{ N.m}}$ → min torque at driving shaft.

$(T_1)_{max} = (T_2)_{max} \left[\frac{\cos\alpha}{1-\cos^2\theta \sin^2\alpha}\right]$ at $\theta = 140.655°$

$= 327.7178 \left[\frac{\cos 25}{1-\cos^2(140.655)\sin^2 25}\right]$

20

$\boxed{(T_1)_{max} = 332.5334 \text{ N.m}}$ → max. torque at driving shaft.

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

[20 marks]

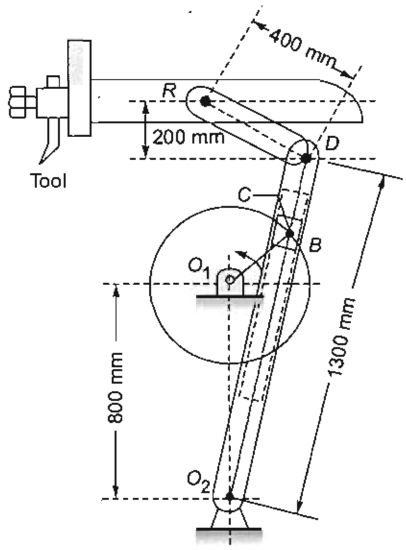
.3 (b) A quick return mechanism of the crank and slotted lever type shaping machine is shown in figure below. The links dimensions are as follows:

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

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

(i) the velocity of ram, and

(ii) the angular velocity of link O_2D



(a) Configuration diagram

[20 marks]

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

[20 marks]

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

[20 marks]

$I_W = 2.5\ kgm^2$

$R_W = \frac{640}{2}\ mm = 320\ mm = 0.32\ m$.

Engine : Back wheel :: 3 : 1 (Gear Ratio).

$I_E = 1.25\ kg\ m^2$.

Engine, wheel rotate in same sense; same plane

$m = 2500\ kg$.

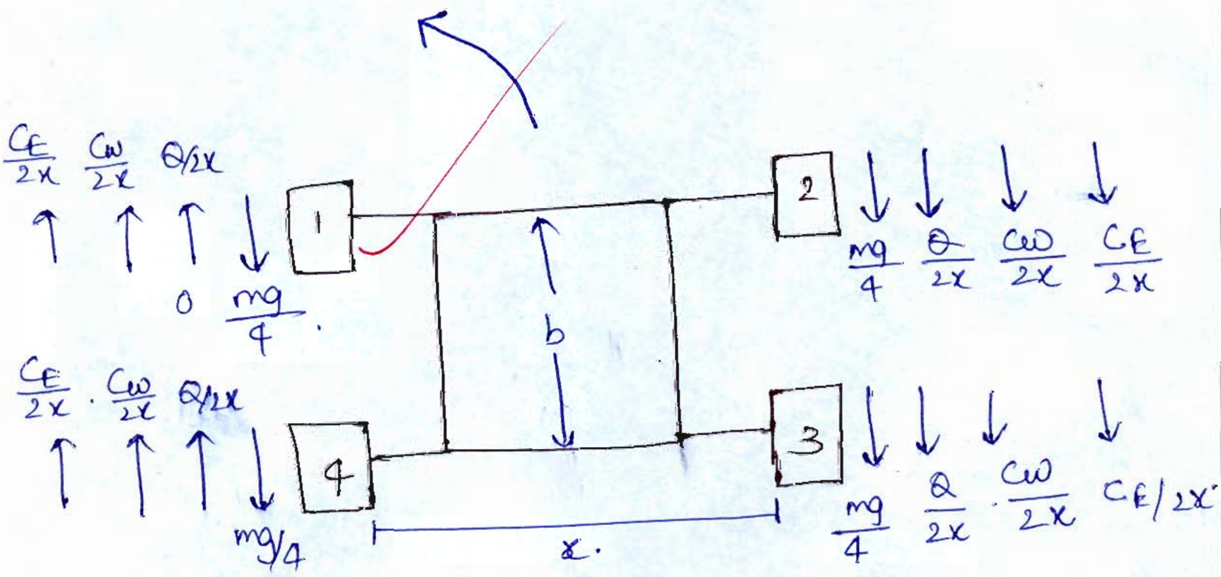
$h = 560\ mm = 0.56\ m$.

$x = 1.6\ m$. [track width.

$R_{turn} = 80\ m$.

Let v be the speed of automobile.

Forces by wheels on the ground.



wt of vehicle

$mg = 24525\ N$.

$\frac{mg}{4} = 6131.25\ N$ [on each wheel].

effect of centrifugal force

$$Q = \frac{mV^2}{R} h$$

$$= \frac{2500 \times V^2}{80} \times 0.56$$

$$Q = 17.5 V^2$$

force on to each wheel $\Longrightarrow \frac{17.5V^2}{2(x)} = 5.4687V^2$

Gyroscopic effect

from wheels

$$C_W = 4 \times I_W \times \omega_\omega \times \omega_p$$

$$C_W = 4 \times 2.5 \times \frac{V}{0.32} \times \frac{V}{80}$$

$$C_W = 0.39062 V^2$$

force on to each wheel $= \frac{0.39062V^2}{2x} = 0.12207V^2$

from Engine

$$C_E = I_E \times \omega_E \times \omega_p$$ ($\omega_E \to 3\omega_\omega$)

$$= 1.25 \times 3 \times \frac{V}{0.32} \times \frac{V}{80}$$

$$= 0.14648V^2$$

force on each wheel $= \frac{0.14648V^2}{2 \times 1.6} = 0.04577V^2$

minimum Rxn force is on wheel ①, ④, so they'll loss the contact first.

20

for $V_{limited} \Longrightarrow$ Rxn force $= 0$

$$\frac{mg}{4} - 5.4687V^2 - 0.12207V^2 - 0.04577V^2 = 0$$

$$6131.25 = 5.63654V^2$$

$$V^2 = 1087.7671$$

limited speed of vehicle ← $V = 32.9813$ m/s

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

(i) mass of each rotating ball

(ii) spring stiffness

(iii) Initial compression of the spring

Neglect the obliquity effect of arms

[20 marks]

$a = b$

$r = \frac{160}{2} = 80mm = 0.08m$.

arms are vertical in mid position.

① → lower position of sleeve.

② → top position of sleeve.

$(N_{mid})_{f=0} = 390$ rpm. $(\omega_{mid})_{f=0} = 40.8407$ rad/s

max sleeve movement = 40mm ; $f = 36N$; $M = 6kg$.

$(N_{max})_{+f} = (N_2)_{+f} = 1.05(390) = 409.5$

$(\omega_2)_{+f} = 42.8827$ rad/s → ⓐ.

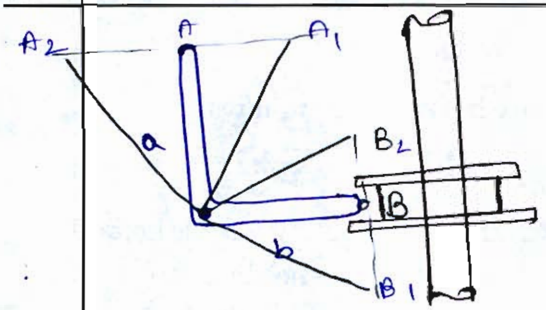
$(\omega_1)_{-f} = \frac{0.95(390)\times 2\pi}{60}$

$(\omega_1)_{-f} = \frac{370.5\times 2\pi}{60}$

$(\omega_1)_{(-f)} = 38.7986$ → ⓑ.

$(\omega_{mid})_{+f} = 1.01\times 40.8407 = 41.2491$ → ⓒ.

$(\omega_{mid})_{-f} = 0.99\times 40.8407 = 40.4322$ → ⓓ.



at mid posn;

$m \times (0.08) \times (\omega_{mid})^2_{+f} \times \phi = \left[\frac{Mg + f + F_S}{2}\right] \phi$ → ①.

~~lets neglect the mass of sleeve.~~

$m(0.08)(\omega_{mid})^2_{-f} \times \phi = \left(\frac{Mg - f + F_S}{2}\right)\phi$ → ②.

① − ②

$m \times (0.08) \times [41.2491^2 - 40.4322^2] = \frac{2f}{4} = 36N.$

$m = 6.7440 \text{ kg}$ → mass of each rotating ball.

at top position, ∵ $B_1B_2 = A_1A_2$ as $a = b$.

$r_2 = (80 + 20)$ mm.
$= 100$mm $= 0.1$m.

$(6.7440) \times 0.1 \times (\omega_2)^2_{+f} (\phi) = \left[\frac{6 \times 9.81 + 36 + F_{S2}}{2}\right] \times \phi.$

$F_{S2} = 2385.5028 N.$

at bottom position,
$r_1 = (80 - 20)$mm $= 0.06$m

$(6.7440)(0.06) \times (\omega_1)^2_{-f} \times \phi = \left[\frac{6 \times 9.81 - 36 + F_{S1}}{2}\right] \times \phi$

$F_{S1} = 1195.3745 N.$

18

S (sleevemovement) $= (F_{S2} - F_{S1})$.

$S (0.04 m) = 1190.10$

$S = 29752.72$ N/m

$S = 29.7527 \frac{kN}{m}$ → spring stiffness.

Initial compression (x_1)

$x_1 = \frac{F_{S1}}{S}$
$= 0.040176$ m

$x_1 = 40.176$ mm

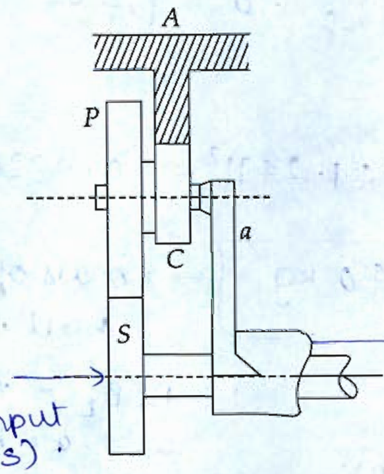
Do not write in this ma

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

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

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

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



Sign convention

+ => CW

− => ACW.

[6 + 14 marks]

$P_S = T_S \times \omega_S$ $\qquad P_S = 600W$

$\omega_S = \frac{2\pi \times 840}{60} = 87.9646 \ rad/s$

$T_S = 6.8209 N\cdot m$

motion	a (arm)	S (18T)	P (24T) / C (12T)	A (72T)
without considering the effect of arm rotation i.e $N_a = 0$, $N_S = +x$	0	$+x$	$-\left(\frac{x \times 18}{24}\right)$	$-\left(\frac{x \times 18}{24}\right) \times \frac{12}{72} = \frac{x}{8}$
considering the effect of arm $N_a = +y$	$+y$	$x+y$	$y - \frac{3x}{4}$	$y - \frac{x}{8}$

$N_S = x + y = 840$ rpm.

$\because$ A is fixed, $y - \frac{x}{8} = 0$.

$y = \frac{x}{8}$.

$x + \frac{x}{8} = 840$

$\frac{9x}{8} = 840 \implies x = 746.67$ rpm.

$y = 93.3333$ rpm.

$\therefore$ Speed of out put at 'a' = 93.3333 rpm.

$\Sigma T = \bar{T}_{in} + \bar{T}_{out} + \bar{T}_{fixing} = 0$ [$\because$ Entire gear train is in eqm].

Power balance $P_{in} + P_{out} = 0$

$(6kW \times 0.95) + \left(T_{out} \times \frac{2\pi \times 93.3333}{60}\right) = 0$

$T_{out} = -583.1891$ N·m.

$+6.8209$ N·m $+ (-583.1891$ N·m$) + T_{fixing} = 0$.

* Holding torque required at A. $T_{fixing} = 576.3682$ N·m

If annulus A rotates at 100 rpm in same dirn as S,

$y - \frac{x}{8} = +100 \implies y = 100 + \frac{x}{8}$.

$x + y = 840 \implies$

12

$x + \left(\frac{x}{8} + 100\right) = 840$

$\frac{9x}{8} = 740$

$x = 657.7778$.

New speed of arm 'a' $\implies y = 100 + \frac{x}{8} = 182.2222$ rpm.

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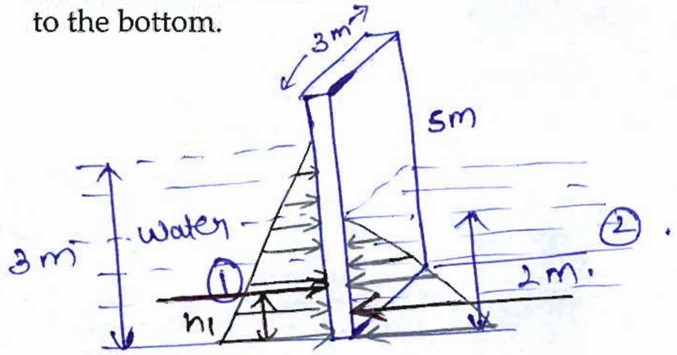
Section : B

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

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

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

[12 marks]



Due to water $F = wA\bar{x}$.

$F_1 = 9810 \times (3\times3) \times 1.5\,m$

$F_1 = 132.435$ kN. $(\longrightarrow)$.

$h_1 = \frac{3}{3} = 1m.$

Due to liquid $(S = 0.85)$

$F_2 = 0.85 \times 9810 \times (2\times3) \times 1$

$F_2 = 50.031$ kN. $(\longleftarrow)$.

$h_2 = \frac{2}{3}\,m.$

Resultant hydraulic force $= F_1 - F_2$.

$= 82.404$ kN $(\longrightarrow)$.

Let point of application of resultant pressure be at h distance from bottom.

$h(82.404) = h_1 F_1 + h_2 F_2$.

$= 1m \times (132.435) + \frac{2}{3}(50.031)$.

9

$h = 2.0119\,m$

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

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

where H_e is theoretical head generated by a centrifugal impeller.

[12 marks]

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

[12 marks]

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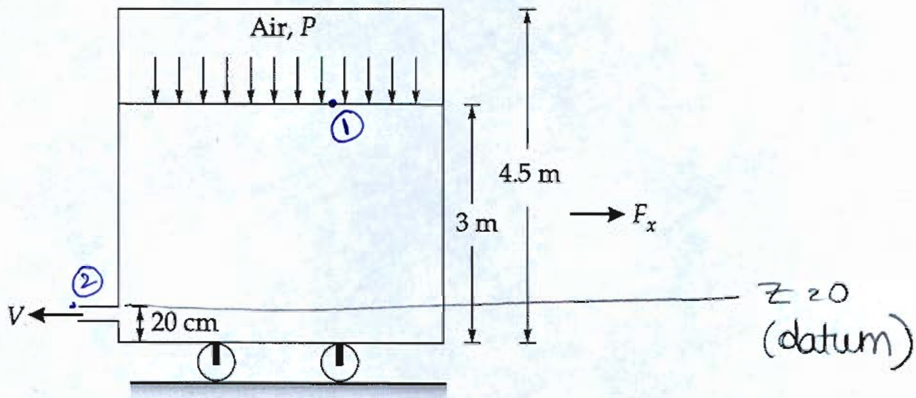
Q.5 (d) Describe briefly the working principle of the vortex tube refrigeration system. Also, write the general expression for C.O.P. of the vortex tube.

[12 marks]

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



[12 marks]

Total wt of tank = 1250 N + wt of water

$= 1250\,N + 1000 \times 9.81 \times (3 \times 2.5 \times 2)\ N$

$= 148400\ N.$

Normal Rxn at ~~each~~ wheels = 148400N.
from ground

force required to set motion = μ (Normal Rxn)

$f = 0.015\,(N)$

$= 2226\ N.$

From force balance,

$f = \rho A V^2.$

$2226\ N = 1000 \times 7.5 \times 10^{-4} \times V^2.$

$V = 54.47935\ m/s$

→ efflux velocity reqd at hole.

By applying Bernoulli Equation b/w points ①, ②;
(Flow assumed to be steady, incompressible, inviscid)

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g z_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g z_2 .$$

$$P + \left[\frac{1}{2}\rho V_1^2\right] + \rho g \times 2.8m = 101325 Pa + \frac{1}{2}\rho V_2^2 + 0.$$

~~$V_1 \to 0$ (inside tank)~~.

Let $P_2 = P_{atm} = 101.325$ KPa

$$P = 101325 + \frac{1}{2}(1000)(54.47935)^2 - (1000 \times 9.81 \times 2.8) - \frac{1}{2}(1000)(V_1^2)$$

By continuity Eqn,

$$A_1 V_1 = A_2 V_2 .$$

$$(2 \times 2.5) \times V_1 = (7.5 \times 10^{-4}) \times (54.47935)$$

$$V_1 = 8.1719 \times 10^{-3} \text{ m/s}.$$

$P = 1557837.687$ Pa

$P_{Abs} = 1557.8376$ KPa → Pressure of air required.

11

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

(i) diameter of the runner at entry surface.

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

(iii) specific speed of the turbine runner.

[20 marks]

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

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

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

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

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

where, Δt_e denotes the excess temperature.

[8 + 12 marks]

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

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

(ii) Latent heat gain of space in kW;

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

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

[*Use Psychrometric chart attached*]

[20 marks]

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

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

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

[20 marks]

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

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

(ii) Total heating required.

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

(iv) Humidifying efficiency of the air washer.

[*Use Psychrometric Chart Attached*]

[20 marks]

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

[20 marks]

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

Hydraulic efficiency = 92%

Overall efficiency = 88%

Outer diameter = 5 m

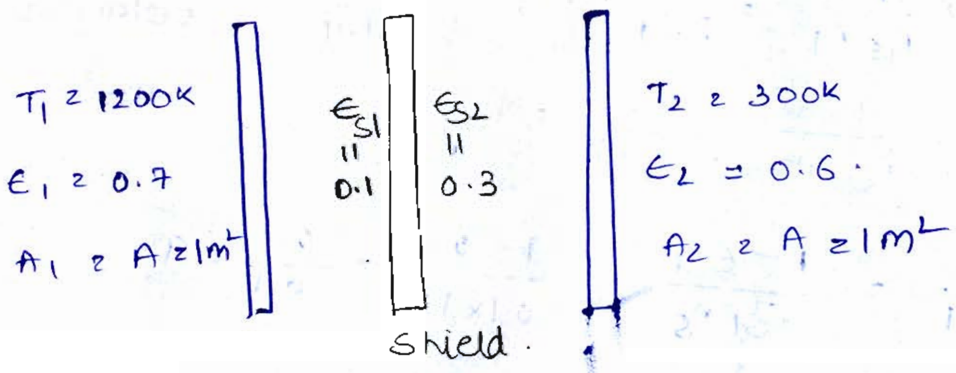
Hub diameter = 2 m

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

[20 marks]

Q.8 (b) Consider two large parallel plates, one at 1200 K with emissivity 0.7 and other at 300 K having emissivity 0.6. A radiation shield is placed between them. The shield has emissivity as 0.1 on the side facing hot plate and 0.3 on the side facing cold plate. Calculate the percentage reduction in radiation heat transfer as a result of radiation shield.

[20 marks]

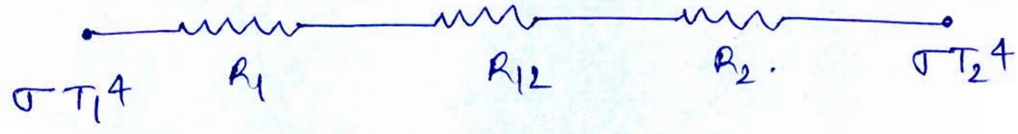


Without Radiation shield

(surface) Resistance $R_1 = \frac{1-\epsilon_1}{\epsilon_1 A_1} = \frac{1-0.7}{0.7\times 1} = 0.42857$

(Shape) Resistance $R_{12} = \frac{1}{F_{12} A_1} = \frac{1}{1\times 1} = 1$

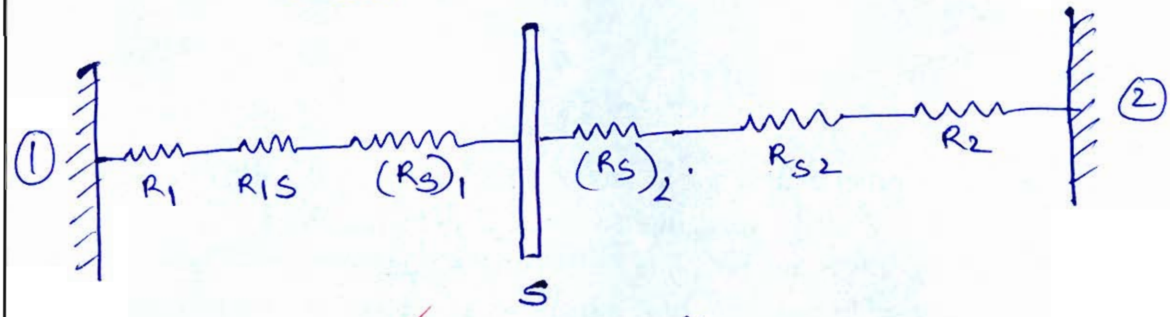
$R_2 = \frac{1-\epsilon_2}{\epsilon_2 A_2} = \frac{1-0.6}{0.6\times 1} = 0.6666$



$$Q = \frac{\sigma T_1^4 - \sigma T_2^4}{R_1 + R_{12} + R_2}$$

$$Q = \frac{5.67\times10^{-8}\,(1200^4 - 300^4)}{0.42857 + 1 + 0.6666}$$

$$Q_{\substack{w/o\\ shield}} = 55897.0632 \text{ Watt}$$



$$\left.\begin{aligned} R_{1S} &= \frac{1}{F_{1S} A_1} = \frac{1}{1\times1} = 1 \\ R_{S2} &= \frac{1}{F_{S2} A_S} = \frac{1}{1\times 1} = 1 \end{aligned}\right\} \text{shape resistances}$$

$$(R_S)_1 = \frac{1-\epsilon_{S1}}{\epsilon_{S1} A_S} = \frac{1-0.1}{0.1\times1} = \frac{0.9}{0.1} = 9$$

$$(R_S)_2 = \frac{1-\epsilon_{S2}}{\epsilon_{S2} A_S} = \frac{1-0.3}{0.3\times1} = \frac{0.7}{0.3} = 2.3333$$

$$Q_{\substack{with\\ shield}} = \frac{\sigma\,(T_1^4 - T_2^4)}{R_1 + R_{1S} + (R_S)_1 + (R_S)_2 + R_{S2} + R_2}$$

$$= \frac{5.67\times10^{-8}\,(1200^4 - 300^4)}{14.42853}$$

$Q_{with shield} = 8116.8248$ Watt.

% Reduction in radiation heat transfer $= \dfrac{Q_{w/o\ shield} - Q_{with shield}}{Q_{w/o\ shield}}$

$= \dfrac{55897.0632 - 8116.8248}{55897.0632}$

% Reduction in Radiation heat transfer $= 85.4789\%$.

20

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

[20 marks]

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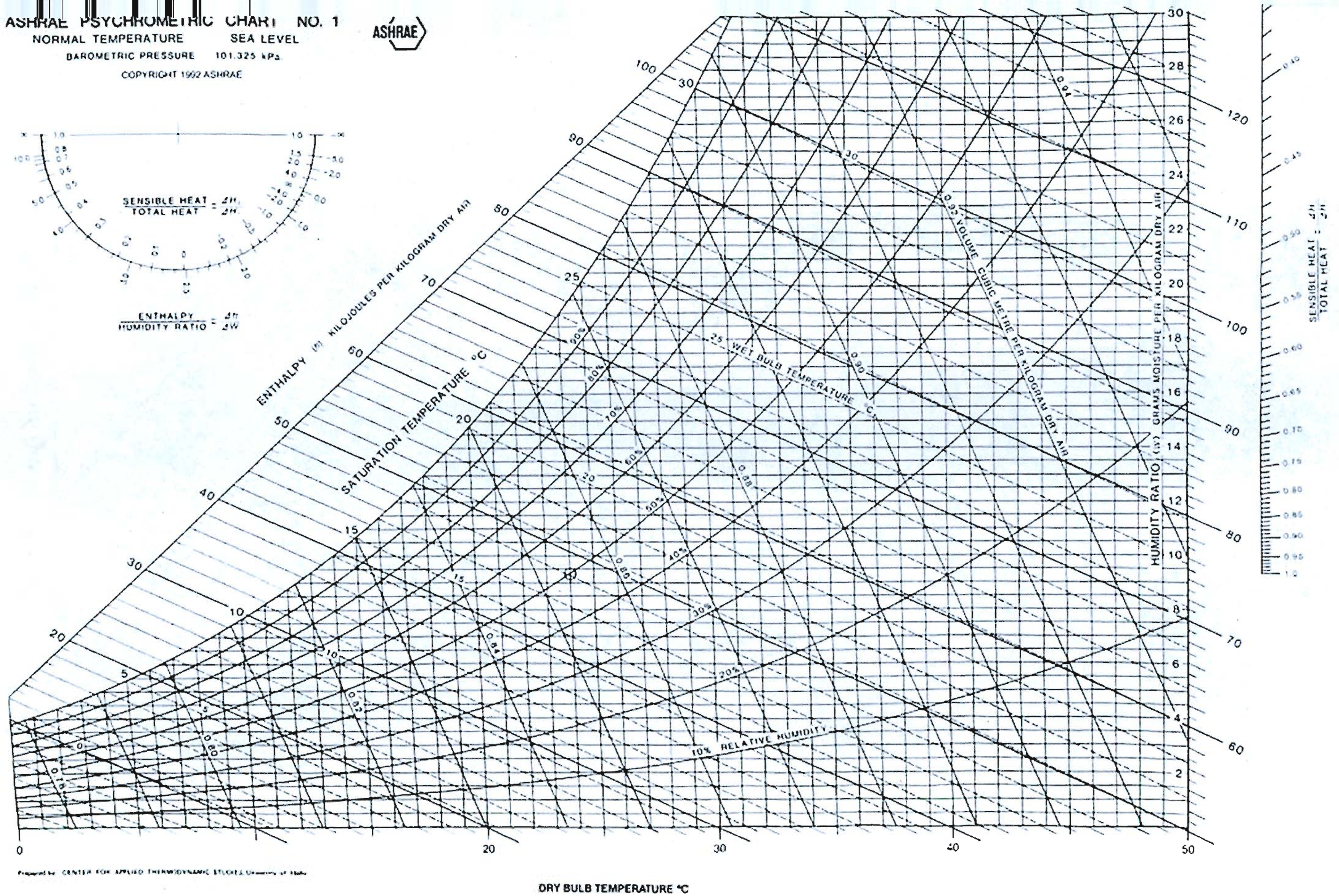
ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa
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SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔHt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO (W) GRAMS MOISTURE PER KILOGRAM DRY AIR
DRY BULB TEMPERATURE °C
Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho

Space for Rough Work

Space for Rough Work