MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-7 : Section A : Heat Transfer + Power Plant

Section B : Renewable Sources of Energy-1 + Industrial & Maintenance Engg-1

Production Engineering and Material Science-2

Name : ....

Roll No :

Test Centres	**Student's Signature**
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ Hyderabad ☐	

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	42
Q.2	—
Q.3	36
Q.4	—
Section-B	
Q.5	16
Q.6	18
Q.7	—
Q.8	34
Total Marks Obtained	146

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

Keep up this Consistent effort

IMPORTANT INSTRUCTIONS

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

DONT'S

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

DO'S

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

Section A : Heat Transfer + Power Plant

Q.1 (a) What are the characteristics of ideal working fluid for vapour-power cycle? Discuss properties of coal which are important in power plant applications.

[12 marks]

The characteristics of ideal working fluid for vapour-power cycles are :

- It should be able to wet the surface properly.
- Having high value of enthalpy of evaporation.
- Freezing point should be below room temp.
- Having high specific volume of vapour phase and low specific volume in liquid phase.
- It should be non corrosive, non errosive, non flamable and non poisonous.
-

The properties of coal used in power plant are.

- Having high calorific value.
- High carbon content, less sulphur and ash content
- Moisture content should be negligable.
-

6

Q.1 (b) A steam power plant operates at a boiler pressure of 5 MPa. The steam enters as dry saturated in the turbine. The condenser pressure is 5 kPa. Determine the cycle efficiency for

(i) Carnot cycle

(ii) Rankine cycle.

Also show the T-s representation for both the cycles.

From steam table:

At 5 MPa $h_{f,\,5MPa} = 1154.23$ kJ/kg, $s_{f,\,5MPa} = 2.92$ kJ/kgK

$h_{g,\,5MPa} = 2794.3$ kJ/kg, $s_{g,\,5MPa} = 5.97$ kJ/kgK

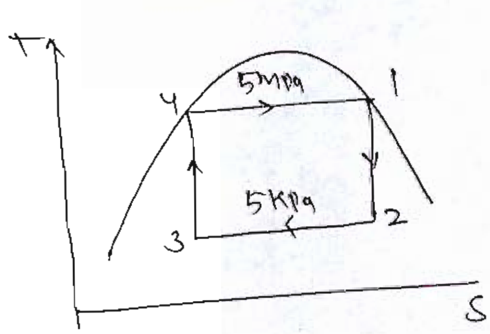
At 5 kPa $h_{f,\,5kPa} = 137.82$ kJ/kg, $s_{f,\,5kPa} = 0.4764$ kJ/kgK

$h_{g,\,5kPa} = 2561.5$ kJ/kg, $s_{g,\,5kPa} = 8.3951$ kJ/kgK

$v_{f,\,5kPa} = 0.001005\ m^3/kg$

[12 marks]

(i) For Carnot cycle.



$h_1 = h_{g,5MPa} = 2794.3$ kJ/kg

$S_1 = S_{g,5MPa} = 5.97$ kJ/kgK

$h_4 = h_{f,5MPa} = 1154.23$ kJ/kg

$S_4 = S_{f,5MPa} = 2.92$ kJ/kgK

∴ process 1-2 is isentropic

∵ $S_1 = S_2$

$5.97 = S_{f, 5kPa} + x_2 (S_{g, 5kPa} - S_{f, 5kPa})$

$= 0.4764 + x_2 (8.3951 - 0.4764)$

$\Rightarrow x_2 = 0.6937$

∵ $h_2 = h_{f, 5kPa} + x_2 (h_{g, 5kPa} - h_{f, 5kPa})$

$= 137.82 + 0.6937 (2561.5 - 137.82)$

$= 1819.1268 \frac{kJ}{kg}$

and

∴ Process 3-4 is also isentropic

∵ $S_3 = S_4$

$2.92 = S_{f, 5kPa} + x_3 (S_{g, 5kPa} - S_{f, 5kPa})$

$= 0.4764 + x_3 (8.3951 - 0.4764)$

$\Rightarrow x_3 = 0.3086$

$\Rightarrow h_3 = 137.82 + 0.3086 (2561.5 - 137.82)$

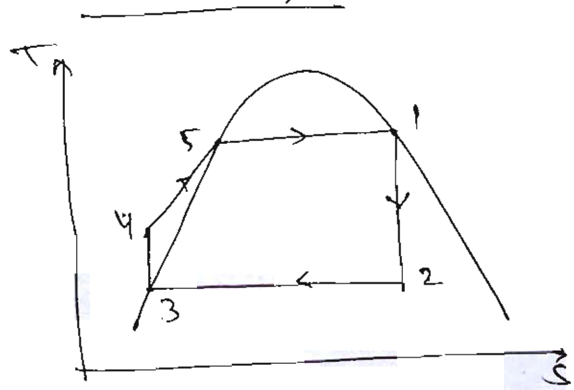
$= 885.7676 \frac{kJ}{kg}$

$\eta_{carnot\ cycle} = \frac{\text{Net work produced}}{\text{Heat supplied}} \times 100$

$= \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4} \times 100$

$= 43.0903\%$

(ii) Rankine cycle



$h_1 = 2794.3 \text{ kJ/kg}$

$h_2 = 1819.1268 \text{ kJ/kg}$

$h_3 = h_{f, 5kPa} = 137.82 \frac{kJ}{kg}$

∴ Pump work $(W_P) = v_4 \,\text{kPa} (5000 - 5)$

$= 0.001005 (5000 - 5)$

$= 5.0199$ KJ/kg

and also

$W_P = h_4 - h_3$

∴ $h_4 = 137.82 + 5.0199 = 142.8399$ KJ/kg

$\eta_{Rankine} = \frac{\text{Net work produced}}{\text{Heat supplied}} \times 100$

$= \frac{(h_1 - h_2) - W_P}{h_1 - h_4} \times 100 = \frac{2794.3 - 1819.1268 - 5.0199}{2794.3 - 142.8399} \times 100$

$= 36.5894\%$

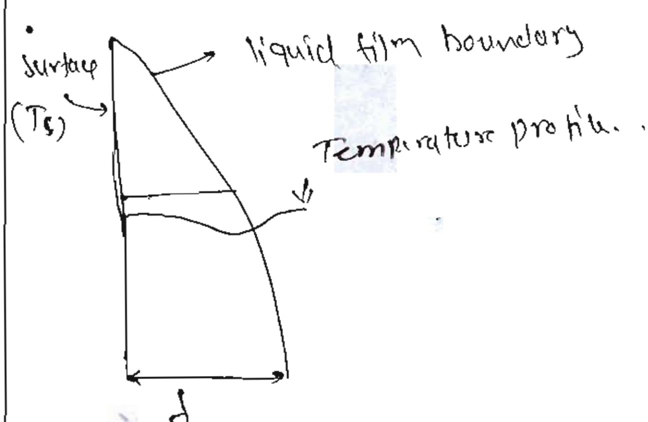
12

Q.1 (c) Explain briefly the mechanism of filmwise and dropwise condensation. Which type has a higher heat transfer film coefficient?

[12 marks]

Filmwise Condensation

- In this the condensate wet the surface and form a thin layer of liquid over the surface which slide down under the influence of gravity
- The thickness of film increased in the direction of flow
- Here, the heat transfer occur from the liquid to surface via the film.
-



Dropwise condensation

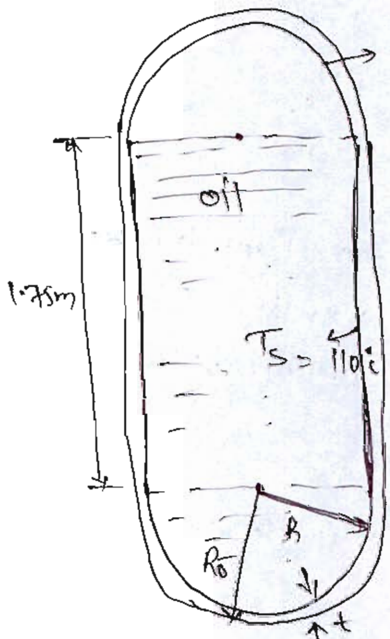
- In this the condensate form droplet of liquid on the surface instead of a layer which cover entire surface.
- It does not ~~stay~~ stay longer and converted into film wise condensation
- to promote dropwise condensation promoter chemical are added inyvapour and are provided with coating of polymer like teflon over the surface.
- Dropwise condensation having higher value of heat transfer coefficient because it will not cover the entire surface with liquid layer, therefore allow direct contact between the ~~liquid~~ vapour and surface.

Therefore dropwise condensation is most likely to preferred.

8

Q.1 (d) A cylindrical storage tank with hemispherical ends is fabricated from a 25 mm thick material having thermal conductivity of 4.14 W/mK. The cylindrical part of tank have length of 1.75 m and inner-diameter of 0.875 m. The tank is exposed to ambient air at 27°C and having convective heat transfer coefficient of 10 W/m^{2}K. The tank is used to store heated oil which keeps the inner surface of tank at 110°C. Determine the electric-power that needs to be supplied to the heater submerged in the oil so that the oil remains at steady state at the given conditions.

[12 marks]



$K = 4.14$ W/mK

air

$h_o = 10$ W/m^{2}K

$T_o = 27°C$

∴ Electrical power needed by heater should be equal to the heat released by the tank into surrounding.

$R = 0.4375$ m, $R_o = 0.4625$ m

$t = 25$ mm

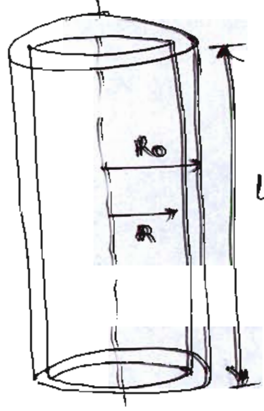
Convert the hemispherical ends into equivalent cylindrical part of insulated end having same thickness.

∴ For equivalent part, the surface area of both should be equal.

$\Rightarrow \quad 2\pi R_o^2 = 2\pi R_o \times \ell$

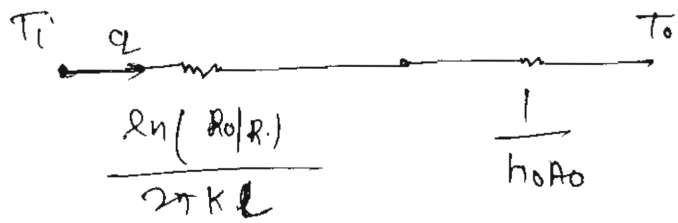
$\ell = R_o = 0.4625$ m

∴ the equivalent cylindrical tank with insulated end



$L = 1.75 + 2 \times \ell = 2.675$ m

∵ the equivalent circuit resistance is



∴ equivalent resistance $(R_e) = \frac{\ln\left(\frac{0.4625}{0.4375}\right)}{2\pi \times 4.14 \times 2.675} + \frac{1}{10 \times 2\pi R_o L}$

$= 0.01366 \ \frac{K}{W}$

∵ Heat lost $(q) = \frac{T_i - T_o}{R_e} = \frac{110 - 27}{0.01366}$

$= 6076.1347 \ W$

∵ the ~~heat~~ Electrical power supplied by heater = 6076.1347 W

Answer

12

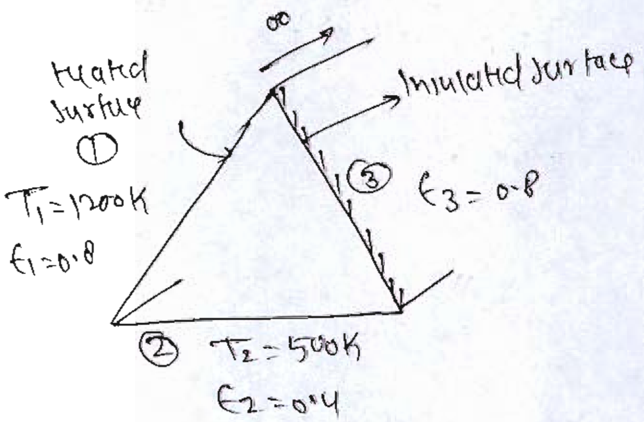
Q.1 (e) A paint baking oven consists of a long, triangular (equilateral) duct in which a heated surface is maintained at 1200 K and another surface is insulated. Painted panels, which are maintained at 500 K, occupy the third surface. The triangle is of width $W = 1$ m, and the heated and insulated surfaces have an emissivity of 0.8. The emissivity of the panels is 0.4. Determine:

(i) During steady-state operation, the rate at which energy is supplied to the heated side per unit length of the duct to maintain its temperature at 1200 K?

(ii) The temperature of the insulated surface?

[12 marks]

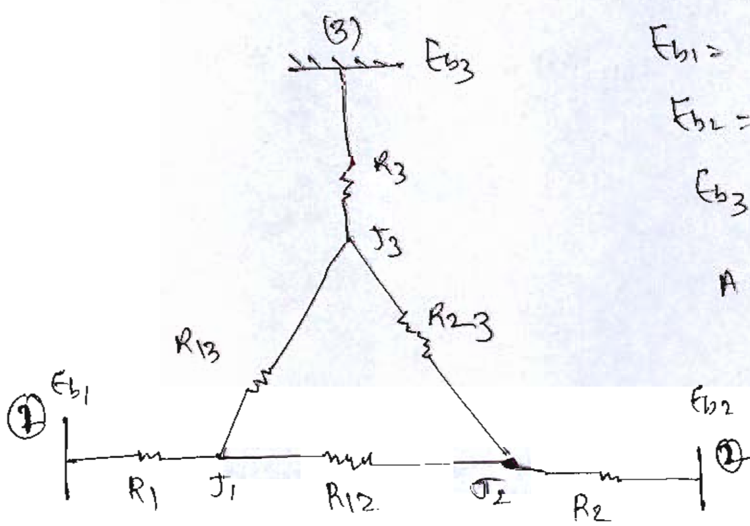
Given



∴ It is a long duct

∴ $F_{21} = F_{23} = F_{13} = \frac{1}{2}$

Resistance circuit is



where

$E_{b1} = \sigma T_1^4 = 117573.12 \ W/m^2$

$E_{b2} = \sigma T_2^4 = 3543.75 \ W/m^2$

$E_{b3} = \sigma T_3^4$

$A = W \times l = 1 \times l$

Calculate all the resistance.

$R_1 = \frac{1-\epsilon_1}{\epsilon_1 A} = \frac{1-0.8}{0.8 \times A} = \frac{0.25}{A}$

$R_2 = \frac{1-\epsilon_2}{\epsilon_2 A} = \frac{1-0.4}{0.4 A} = \frac{1.5}{A}$

$R_3 = \frac{1-\epsilon_3}{\epsilon_3 A} = \frac{1-0.8}{1-0.8 A} = \frac{0.25}{A}$

$R_{12} = \frac{1}{A_1 F_{12}} = \frac{2}{A}$

$R_{13} = \frac{1}{A_1 F_{13}} = \frac{2}{A}$

$R_{23} = \frac{1}{A_2 F_{23}} = \frac{2}{A}$

Now I apply Junction rule. (Assuming outgoing heat)

$$\frac{J_1 - E_{b1}}{R_1} + \frac{J_1 - J_2}{R_{12}} + \frac{J_1 - J_3}{R_{13}} = 0$$

$$\frac{J_1 - 11573.12}{\frac{0.25}{A}} + \frac{J_1 - J_2}{\frac{2}{A}} + \frac{J_1 - J_3}{\frac{2}{A}} = 0$$

$$8J_1 - 11573.12 \times 8 + J_1 - J_2 - J_1 - J_3 = 0$$

$$10J_1 - J_2 - J_3 = 94056.96 \quad (1)$$

Similarly

$$\frac{J_2 - J_1}{R_{12}} + \frac{J_2 - J_3}{R_{13}} + \frac{J_2 - E_{b2}}{R_2} = 0$$

$$\frac{J_2 - J_1}{\frac{2}{A}} + \frac{J_2 - J_3}{\frac{2}{A}} + \frac{J_2 - 3543.75}{\frac{1.5}{A}} = 0$$

$$3(J_2 - J_1) + 3(J_2 - J_3) + 4(J_2 - 3543.75) = 0$$

$$10J_2 - 3J_1 - 3J_3 = 14175 \quad (2)$$

4

and

$$\frac{J_3 - E_{b3}}{R_3} + \frac{J_3 - J_1}{R_{13}} + \frac{J_3 - J_2}{R_{23}} = 0$$

∴ Surface-3 is insulated

∴ Heat transfer by surface 3 is zero

⇒ $J_3 = E_{b3}$

$$\Rightarrow \frac{J_3 - J_1}{\frac{2}{A}} + \frac{J_3 - J_2}{\frac{2}{A}} = 0$$

$$2J_3 - J_1 - J_2 = 0 \quad (3)$$

On solving eqn (1), (2) and (3)

$J_1 = 11091.1712$ W/m²

$J_2 = 7539.4435$ W/m²

$J_3 = 9315.3073$ W/m²

(ii) Temperature of insulated surface

∴ $E_{b3} = J_3 = 9315.3073$

$\sigma T_3^4 = 9315.3073$

⇒ $T_3 = 636.6541$ K

(i) Heat transfer by surface-1 is

$$q_1 = \frac{E_{b1} - J_1}{R_1} = \frac{11573.12 - 11091.1712}{\frac{0.25}{A}} \Rightarrow \frac{q_1}{A} = 425927.7952 \text{ W/m}$$

Q.2 (a) Steam at 45 bar, 520°C flowing at the rate of 5800 kg/h expands in a h.p. turbine to 2 bar with an isentropic efficiency of 85%. A continuous supply of steam at 2 bar, 0.86 quality and a flow rate of 2800 kg/h is available from a geothermal energy source. This steam is mixed adiabatically with the H.P. turbine exhaust steam and the combined flow then expands in a L.P. turbine to 0.1 bar with an isentropic efficiency of 80%. Determine the power output and the thermal efficiency of the plant. Assume that 5800 kg/h of steam is generated in the boiler at 45 bar, 520°C from the saturated feedwater at 0.1 bar.

[Use Steam table attached at the end]

[20 marks]

Q.2 (b) Two large steel plates at temperature of 110°C and 65°C are separated by a steel-rod 3 cm in diameter and 25 cm long. The rod is welded to each plate. The space between the plates is filled with insulation which also insulates the circumference of the rod. Voltage difference is applied between the two plates due to which current flows through the rod and the electrical energy is dissipated at a rate of 0.17 W, The thermal conductivity for the rod material is 40W/m°C.

Determine :

(i) The maximum temperature in the rod and its location.

(ii) The heat flux at each end of the rod.

(iii) Compare the net heat flow rate of the two ends with the total heat rate of heat generation.

[20 marks]

Q.2 (c) In an oil fired boiler the fuel has an analysis by mass : Carbon 84%, Hydrogen 10%, Sulphur 3.2%, Oxygen 1.6%, remainder incombustible. The analysis of dry flue gas by volume gave : combined ($CO_2 + SO_2$) 15.72%, O_2 1%, there being no CO or SO_3. Calculate per kg of fuel

(i) Mass of air supplied.

(ii) Percentage excess air supplied.

(iii) Mass of dry flue gas formed.

(iv) Mass of water vapour formed.

[20 marks]

Do not write in this margin

Q.3 (a) Atmospheric air at 27°C flows with a velocity of 50 m/s past a flat plate 1.72 m long and 0.52 m wide. The surface of the plate is maintained at 270°C.

Estimate:

(i) The total heat transferred and total drag-force on one-side of the plate.

(ii) The heat transfer and drag-force for the laminar portion of the flow on one side of the plate.

For transition flow or Reynold's number lies between [5×10^5 to 10^7] use the following correlation.

Average Nusselt number $(\overline{Nu}) = \left(0.037\,Re_L^{0.8} - 871\right)Pr^{1/3}$

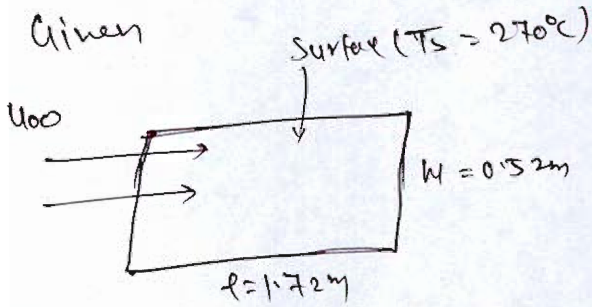
Average combined skin friction or drag coefficient, $(\overline{C_f}) = \dfrac{0.074}{Re_L^{0.2}} - \dfrac{1742}{Re_L}$

The thermophysical properties of air are

$\rho = 0.8$ kg/m^3; $\mu = 24 \times 10^{-6}$ kg/ms; $c_p = 1000$ J/kg°C; $k = 35 \times 10^{-3}$ W/m°C

[20 marks]

(i) Given



$T_\infty = 27°C$

$u_\infty = 50$ m/s

$\therefore$ Reynold's Number $(Re_L) = \dfrac{\rho u_\infty L}{\mu} = \dfrac{0.8 \times 50 \times 1.72}{24 \times 10^{-6}} = 2.8667 \times 10^6$

As $Re_L > 5 \times 10^5 \Rightarrow$ Turbulent flow

Now check for critical distance from leading edge.

$x_{cr} \longrightarrow Re_D = 5 \times 10^5$

$\because 5 \times 10^5 = \dfrac{0.8 \times 50 \times x_{cr}}{24 \times 10^{-6}} \Rightarrow x_{cr} = 0.3$ m

$\Rightarrow x \in [0, 0.3] \rightarrow$ laminar flow

$x \in [0.3, 1.72] \rightarrow$ turbulent flow

$\overline{Nu} = (0.037\,Re_L^{0.8} - 871)\,Pr^{1/3}$ | $Pr = \dfrac{\mu c_p}{k} = \dfrac{24 \times 10^{-6} \times 1000}{35 \times 10^{-3}} = 0.6857$

$\Rightarrow \overline{Nu} = 4012.5724$

and $\overline{Nu} = \frac{\bar{h} L}{k}$

∴ Average heat transfer coefficient ($\bar{h}$) is

$\bar{h} = \frac{\overline{Nu}\, k}{L} = \frac{4012.5724 \times 35 \times 10^{-3}}{1.72} = 81.6512 \frac{W}{m^2 K}$

Now

total heat transfer (q_{total}) = $\bar{h} \times A_s \times (T_s - T_\infty)$

$= 81.6512 \times 1.72 \times 0.52 (270 - 27)$

$= 11746.00$ W

and

Drag force (F_D) = drag coefficient × $\frac{1}{2} \rho A_s U_\infty^2$

∴ drag coefficient ($\bar{C}_f$) = $\frac{0.074}{Re_L^{0.2}} - \frac{1742}{Re_L}$

$= 3.1746 \times 10^{-3}$

∴ Drag force (F_D) = $3.1746 \times 10^{-3} \times \frac{1}{2} \times 0.8 \times 1.72 \times 0.52 \times (50)^2$

$= 2.8394$ N

(ii) Now for laminar portion only

∴ Reynolds Number (Re_{xcr}) = 5×10^5

∴ $\overline{Nu} = [0.037 (5\times10^5)^{0.8} - 871] (0.6857)^{1/3}$

$= 414.3146$

⇒ $\frac{\bar{h}\, x_{cr}}{k} = 414.3146$

⇒ $\bar{h} = \frac{414.3146 \times 35 \times 10^{-3}}{0.3} = 48.3367$ W/m²K

Heat transfer $(q) = \bar{h} \times A_s \times (T_s - T_\infty)$

$= 48.3367 \times (W \times 2(\alpha))(270-27)$

$= 48.3367 \times 0.52 \times 0.3 (270-27)$

$= 1832.3476\ W$

$\therefore$

Drag force(F_D) = drag coefficient $\times \frac{1}{2} \rho A_s U_\infty^2$

For laminar flow, from Blausius relation.

drag coefficient $= \frac{1.328}{\sqrt{Re_{xL}}} = \frac{1.328}{\sqrt{5 \times 10^5}}$

$= 1.878 \times 10^{-3}$

$\therefore F_D = 1.878 \times 10^{-3} \times \frac{1}{2} \times 0.8 \times 0.52 \times 0.3 \times (50)^2$

$= 0.5859\ N$

17

Q.3 (b) Steam expands in a turbine from 45 bar, 500°C to 0.10 bar isentropically. Assuming ideal conditions, determine the mean diameter of the wheel if the turbine were of

(i) single impulse stage
(ii) single 50% reaction stage
(iii) four pressure (or Rateau) stages
(iv) one two-row curtis stage
(v) four 50% reaction stages

Take the nozzle angle as 16° and N as 3000 rpm.

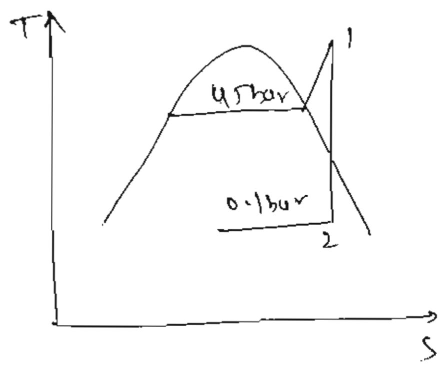
[Use steam table attached at the end]

[20 marks]

Given

Nozzle angle (α) = 16°

Speed (N) = 3000 rpm



From steam table

at 45 bar, 500°C

$h_1 = 3440.4$ kJ/kg

$S_1 = 7.0323$ kJ/kg K

at 0.1 bar (0.01 MPa)

$h_f = 191.81$ $\quad s_f = 0.64920$

$h_g = 2583.9$ $\quad s_{fg} = 7.4996$

$h_{fg} = 2392.1$

∴ process 1-2 is isentropic

∴ $S_1 = S_2$

$7.0323 = 0.64920 + x_2(7.4996)$

$x_2 = 0.8516$

$h_2 = 191.81 + 0.8516(2392.1)$

$= 2228.9224 \frac{kJ}{kg}$

Work produced by turbine (W_T) = $h_1 - h_2$

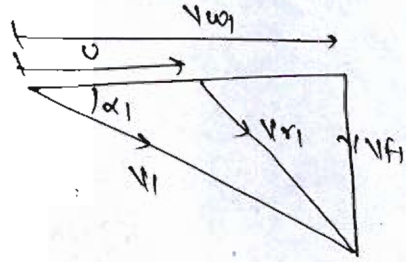
$= 1211.4776 \frac{kJ}{kg}$ (1)

$= (\Delta h_{0st})_{stage}$

(i) For single impulse stage.

∴ Work produced by turbine $(W_T) = (V_{w1} + V_{w2})U$

Inlet velocity triangle.



$\therefore \frac{V_1^2}{2000} = (\Delta h_{isen})_{stage}$

$\Rightarrow V_1^2 = 2000 \times (\Delta h_{isen})_{stage}$

$V_1 = (2000 \times 1211.4776)^{1/2}$

$= 1556.5844$ m/s

and

for optimum power

$\frac{U}{V_1} = \frac{\cos\alpha_1}{2}$

$\therefore U = \frac{V_1 \cos\alpha_1}{2}$

$\frac{\pi D_m N}{60} = \frac{V_1 \cos\alpha_1}{2}$

$\Rightarrow D_m = \frac{30 \times V_1 \cos\alpha_1}{\pi \times N}$

$D_m = 4.7628$ m

(ii) For 50% reaction stage.

$\therefore \frac{V_1^2}{2000} = \frac{(\Delta h_{isen})_{stage}}{2}$

$\therefore V_1 = \left(\frac{2000 \times 1211.4776}{2}\right)^{1/2}$

$= 1100.6714$ m/s

For optimum power

$\frac{U}{V_1} = \cos\alpha_1$

$U = V_1 \cos\alpha_1$

$\frac{\pi D_m N}{60} = V_1 \cos\alpha_1$

$D_m = \frac{60 V_1 \cos\alpha_1}{\pi N}$

$D_m = 6.7356$ m

(iii) 4 Rateau stage

$\therefore \frac{U}{V_1} = \frac{\cos\alpha_1}{2n}$

n = stage = 4

$\Rightarrow U = \frac{V_1 \cos\alpha_1}{8}$

and $\frac{V_1^2}{2000} = (\Delta h_{isen})$

$V_1 = 1556.5844$ m/s

$\Rightarrow \frac{\pi D_m N}{60} = \frac{V_1 \cos\alpha_1}{8}$

$D_m = \frac{60 \times 1556.5844 \cos(16)}{8 \times \pi \times 3000}$

$D_m = 1.1907$ m

(iii) One two row Curtis stage.

$\therefore$ number of stage $(n) = 2$

$$\frac{U}{V_1} = \frac{\cos\alpha_1}{2n} = \frac{\cos\alpha_1}{4}$$

$$\Rightarrow U = \frac{V_1 \cos\alpha_1}{4}$$

and $\frac{V_1^2}{2000} = (\Delta h_{isen})_{stage}$

$\Rightarrow V_1 = 1556.5844$ m/s

$$U = \frac{V_1 \cos\alpha_1}{4}$$

$$\frac{\pi D_m N}{60} = \frac{V_1 \cos\alpha_1}{4}$$

$$D_m = \frac{60\, V_1 \cos\alpha_1}{\pi N \times 4}$$

$$\boxed{D_m = 2.3814 \text{ m}}$$

(iv) For 4-stage 50% reaction turbine

$\therefore$ number of stage $(n) = 4$

$$\Rightarrow \frac{U}{V_1} = \frac{\cos\alpha_1}{4}$$

$$\Rightarrow \frac{\pi D_m N}{60} = \frac{V_1 \cos\alpha_1}{4}$$

$$D_m = \frac{60\, V_1 \cos\alpha_1}{\pi 4 \times N}$$

$$\boxed{D_m = 1.6839 \text{ m}}$$

$$\frac{V_1^2}{2000} = \frac{(\Delta h_{isen})_{stage}}{2}$$

$V_1 = 1100.6714$ m/s

14

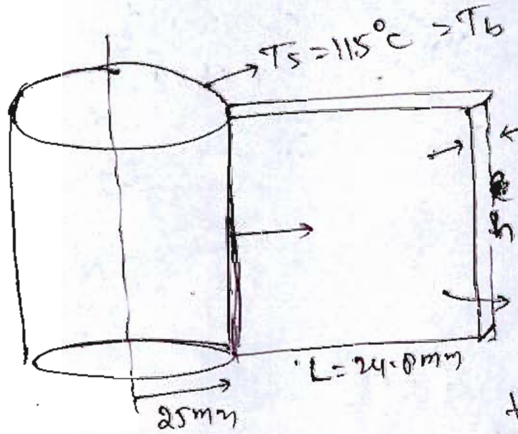
Q.3 (c) Twelve Fins having thermal conductivity $k = 73.8$ W/mK and 0.73 mm thickness protrude 24.8 mm from a cylindrical-surface of 50 mm diameter and 1.1 m length placed in an atmosphere of 40°C. If the cylindrical surface is maintained at 150°C and the heat transfer coefficient is 19 W/m^{2}K, calculate

(i) The rate of heat transfer and the percentage increase in heat transfer due to fins.

(ii) The temperature at the centre of fins.

(iii) The fin efficiencies and fin effectiveness.

[20 marks]



$T_\infty = 40°c$

$h = 19$ W/m^{2}K

$K = 73.8$ W/mK

thickness (t) = 0.73 mm.

Number of Fins (n) = 12

Assuming convected tip fin,

∴ the corrected length for insulated fin

$L_c = L + \frac{A_c}{P}$

$= 24.8 + \frac{1.1 \times 10^3 \times 0.73}{2 \times (1100 + 0.73)} = 25.1647$ mm

(i) Now heat transfer through insulated tip fin is

$q_f = \sqrt{hPKA_c}\, \theta_b \tanh mL_c$

$P = 2(h + t) = 2(1100 + 0.73) = 2201.46$ mm

$A_c = 1.1 \times 10^3 \times 0.73 = 803$ mm^2

$m = \sqrt{\frac{hP}{KA_c}} = \sqrt{\frac{19 \times 2201.46 \times 10^{-3}}{73.8 \times 803 \times 10^{-6}}} = 26.5672$ m^{-1}

$\theta_b = T_b - T_\infty = 115 - 40 = 75°c$

$\Rightarrow q_f = \sqrt{19 \times 2201.46 \times 10^{-3} \times 73.8 \times 803 \times 10^{-6}} \times 75 \tanh(26.5672 \times 25.1647 \times 10^{-3})$

$q_f = 68.9626$ W of one fin.

Heat transfer without fin ($q_{without}$) = $h\ A_s\ \theta_b$

$\Rightarrow q_{without} = 19 \times \pi D h \times (75)$

$= 19 \times \pi \times 0.05 \times 1.1 \times 75$

$= 246.2223\ W$

and

Heat transfer through all fin (q_{fin}) = $12 \times q_1$

$= 827.5512\ W$ Ans

% Increase in heat transfer = $\frac{q_{fin} - q_{without}}{q_{fin}} \times 100$

$= 70.2468\ \%$

(ii) ∴ the tempr distribution in case of Insulated tip fin is given as

$$\frac{\theta}{\theta_b} = \frac{\cosh[m(L_c - x)]}{\cosh mL_c}$$

∴ Tempr at centre of fin (T_c) i.e. $x = \frac{L_c}{2} = 12.5823\ mm$

$$\frac{T_c - T_\infty}{75} = \frac{\cosh[26.5672 \times (25.1647 - 12.5823) \times 10^{-3}]}{\cosh(26.5672 \times 25.1647 \times 10^{-3})}$$

5

$$\frac{T_c - T_\infty}{75} = 0.86515$$

$\Rightarrow T_c = 40 + 75 \times 0.86515$

$T_c = 104.886\ °C$

(iii) fin efficiency (η_{fin}) = $\frac{\tanh mL_c}{mL_c} \times 100$

$$= \frac{\tanh(26.5672 \times 25.1647 \times 10^{-3})}{25.5672 \times 25.1647 \times 10^{-3}} \times 100$$

$= 87.3043\ \%$ Ans

and

fin effectiveness $(\epsilon) = \sqrt{\frac{PK}{hA_c}} \tanh(mL_c)$

$= \sqrt{\frac{2201.46\times10^{-3}\times73.8}{19\times803\times10^{-6}}} \times \tanh(25.8647\times26.5172\times10^{-3})$

$\epsilon = 6.2808$

Q.4 (a) What is draught? What are the functions of the draught system? A boiler uses 2052 kg/h of coal. The temperature of air supplied is 300 K, and the average temperature of flue gas leaving the chimney is 650 K. The 35 m high steel chimney produces a draught of 20 mm of water column.

Determine

(i) the quantity of air supplied per kg of coal.

(ii) the draught in terms of column of hot gases.

(iii) the base diameter of the chimney.

Assume, only 10% of the theoretical draught is used for creating the flow velocity of gases through the chimney.

[20 marks]

Q.4 (b) **(i)** Discuss the working principle of cyclone separators with the help of neat diagram. Also mention its advantages and disadvantages.

(ii) The wall of a tube 3.97 m long and 19.3 mm diameter is held at constant temperature by providing a steam-jacket. A viscous fluid enters the tube at 30°C and leaves at 39°C at the rate of 178.7 kg/hr. Determine the average heat transfer coefficient wall temperature.

Use the following correlation

$$\text{Nu} = 3.65 + \frac{0.67\frac{d}{L}\text{Re.Pr}}{1 + 0.04\left[\frac{d}{L}\text{Re.Pr}\right]^{0.67}}$$

and take the following are thermophysical properties:

$\rho = 850$ kg/m^3; $k = 0.14$ W/m°C; $C_p = 2000$ J/kgK and $\nu = 5.1 \times 10^{-6}$ m^2/s

[10 + 10 = 20 marks]

Q.4 (c) 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 (d_i = 25 mm) is 0.2 kg/s, while the flow rate of oil through the outer annulus (d_o = 50 mm) is 0.15 kg/s. The inlet and outlet temperatures of oil are 95°C and 65°C, respectively. The water enters at 30°C to the exchanger. Neglecting tube wall thermal resistance, fouling factors and heat loss to the surroundings, calculate the overall heat transfer coefficient and length of the tube. [Assume uniform temperature along the inner surface of annulus].

Take the following properties at the bulk mean temperature:

Engine oil at 80°C : c_p = 2131 J/kg°C; μ = 0.0325 N-s/m^2, k = 0.138 W/m°C

Water at 35°C : c_p = 4174 J/kg°C; μ = 725 × 10^{-6} N-s/m^2, k = 0.625 W/m°C, Pr = 4.85

[20 marks]

Section B : Renewable Sources of Energy-1 + Industrial & Maintenance Engineering-1 Production Engineering and Material Science-2

Q.5 (a) During orthogonal machining using an HSS tool, the rake angle is 5°. The undeformed chip thickness is 0.2 mm and the width of cut was 5 mm. The shear strength of work-material is 350 MPa and the coefficient of friction between tool chip interface is 0.5, the cutting force and thrust forces are

[12 marks]

Given

$\alpha_0 = 5^\circ$

$t_1 = 0.2mm$

$W = 5mm$

$S_{ut} = 350$ MPa

$\mu = 0.5$

2

$\therefore \mu = \frac{\text{Friction Force (F)}}{\text{Normal force (N)}} = \frac{F_t \cos\alpha_0 + F_c \sin\alpha_0}{-F_t \sin\alpha_0 + F_c \cos\alpha_0}$

where F_c = Cutting force

F_t = thrust force.

$0.5 = \frac{F_t \cos 5 + F_c \sin 5}{-F_t \sin 5 + F_c \cos 5}$

$(-F_t \sin 5 + F_c \cos 5)\, 0.5 = F_t \cos 5 + F_c \sin 5$

$F_t (\cos 5 + 0.5 \sin 5) = F_c (0.5 \cos 5 - \sin 5)$

$F_t = 0.3952\, F_c$ —— (1)

$\therefore S_{ut} = \frac{F_s}{A_0} = \frac{\text{Shear force } (F_s)}{\text{Shear Area } (A_0)} = \frac{-F_t \sin\theta + F_c \cos\theta}{\frac{wt_1}{\sin\theta}}$

Q.5 (b) The following cost-related data has been collected from a company:

Cost Element	Variable cost	Fixed cost
Direct material	32.8	–
Direct labour	28.4	–
Factory overheads	12.6	1,89,900
Distribution overheads	4.1	58,400
General administrative overheads	1.1	66,700
Budgeted sales	–	18,50,000

Determine the following:

(i) Break even sales volume

(ii) Profit at the budgeted sales volume

(iii) Profit if the actual sales

I. Drop by 10%, and

II. Increase by 5% from budgeted sales.

[12 marks]

From given table.

total variable cost (V) = 32.8 + 28.4 + 12.6 + 4.1 + 1.1

=> ₹ 79 /unit

Total fixed cost (F) = 189900 + 58400 + 66700

=> ₹ 315000

(i) at Breakeven total sales equal to total cost ~~[struck through]~~

1850000 = 315000 + x × 79

x = 19430.3797 unit ≈ 19430 unit

↳ Sales Volume

2

(ii) Profit at budgeted sales Volume.

∴ total sales (S) = ₹185000

N

Q.5 (c) An electronically controlled system has 120 elements and each has MTBF of 15000 hours. Its cumulative operating time is one hour. Calculate the following:

(i) The probability of failure.

(ii) The probability of failure if the elements are grouped as a set of 10 each in redundant manner.

(iii) The reliability improvement factor (RIF).

[12 marks]

(i) Probability of failure $= \exp(-\lambda T)$

~~$= \exp\left(-\frac{1}{15000} \times t\right)$~~

$\therefore$ Failure rate $(\lambda) =$

0

Do not write in this margin

Q.5 (d) Determine the composition in atom per unit of an alloy. Which consists of 80% by weight of Ag and 20% by weight of Cu. Atomic weights of silver and copper are A_{Ag} = 107.87 g/mol and A_{Cu} = 63.55 g/mol.

[12 marks]

Do not write in this margin

Q.5 (e) Calculate the number of PV module required in a PV pumping system for daily requirement of 8000 litres of water from a depth of 45 m. Use following data:

Voltage at peak power, V_P = 20 V
Current at peak power, I_P = 8 A
Operating factor = 0.8
Mismatch factor due to operation at a point other that maximum power = 0.85
Efficiency of pump = 30%
Water density = 1000 kg/m^3
Sunshine hours = 5 hours/day

[12 marks]

∴ daily power requirement (P_{daily}) $= \dot{m} g H$

$= \rho Q g H$

$= 1000 \times \frac{8000 \times 10^{-3}}{5 \times 3600} \times 9.81 \times 45$

$= ~~40837.8~~ ~~watt~~$ 196.2 watt

Now for 30% efficiency of pump

actual power required (P_{act}) $= \frac{P_{daily} \times 100}{30} = 654$ watt

Now power produced by one module is

$P_{1,module} = V_P \times I_P \times 0.8 \times 0.85$

$= 20 \times 8 \times 0.8 \times 0.85$

$= 108.8$ watt

∴ Number of module required $= \frac{P_{act}}{P_{1,module}}$

$= \frac{654}{108.8}$

$= 6.011$

$\simeq$ 6 module required.

(12)

Q.6 (a) A flat plate collector tilted by 30° from horizontal plane and facing south is located at Delhi (28.7°N, 77.2°E). The standard longitude for Ist is 81.73°E. On 15th November at 1:30 PM (IST). Calculate:

(i) Declination angle (ii) Hour angle

(iii) Zenith angle (iv) Angle of incidence

(v) Number of daylight hours

[20 marks]

Given

$\beta = 30^\circ$ (tilt angle)

South facing i.e. $\gamma = 0$

latitude $(\phi) = 28.7^\circ$ N

Standard longitude $(L_{st}) = 81.73^\circ$ E

local longitude $(L_{loc}) = 72.2^\circ$ E

(i) Declination angle $(\delta) = 23.45 \sin\left(\frac{360}{365}(284+n)\right)$

$\therefore n = 365 - (15+31) = 319$

$\Rightarrow \delta = 23.45 \sin\left(\frac{360}{365} \times (284+319)\right)$

$\Rightarrow \boxed{\delta = -19.1478^\circ}$

(ii) Hour angle (ω) = [LAT − 12:00] ×15

∴ Local apparent time (LAT) = Standard time ± 4 (Lst − Lloc)

= 1:30 − 4 (81.73 − 77.2)

= 1:30 + 18.12

= 1.198 hr

$\Rightarrow \omega = (13.198 - 12) \times 15$

$\boxed{\omega = 17.97^\circ}$

(iii) Zenith angle (θ_z) = $90 - \theta_i$

∴ Angle of incidence (θ_i) is

$\cos\theta_i = \cos(\phi - \beta)\cos\delta\cos\omega + \sin(\phi - \beta)\sin\delta$

= 0.9050

$\Rightarrow \theta_i = 25.0684$

∴ $\theta_z = 90 - 25.0684$

$\boxed{\theta_z = 64.9316^\circ}$

10

(iv) Angle of incidence (θ_i) = 25.0684°

(v) Number of daylight hours = $\frac{2}{15}\omega_s$

∴ $\omega_s = \cos^{-1}(-\tan\phi\tan\delta)$

= 79.0416

$\Rightarrow$ Number of daylight hours $= \frac{2}{15} \times 79.0416$

= 10.5388 hours

Q.6 (b) (i) With the help of neat sketch, briefly explain the principle of electro slag welding process.

(ii) The volume of a weld nugget formed by spot welding process is 90 mm^3. Welding is performed using 20000A current. Energy required for melting of unit volume of metal is 15 J/mm^3. Assume that heat lost to the surrounding base metal is 750 J and contact resistance is 0.0002 ohms. Determine :

1. the time (in sec) for which the welding current is supplied, and
2. thermal efficiency of the spot welding process if other heat losses are negligible.

[12 + 8 = 20 marks]

(ii) Volume of nugget $(V_n) = 90\ mm^3$

current $(I) = 20000 A$

melting energy per unit volume $(E_m) = 15 \frac{J}{mm^3}$

Heat loss $(H_L) = 750\ J$

contact resistance $(R) = 0.0002\ \Omega$

$\therefore$ Heat supplied $(H_s) = I^2 R t$

$= 20000^2 \times 0.0002$

$= 80000\ t$

and Heat loss (H_L) = Heat supplied (H_S) − melting ice (H_m)

750 = H_s − 15 × 90

H_s = 2100 J

∵ 8000 t = 2100 J

(i) time required (t) = 0.2625 sec

(2) thermal eff = $\frac{\text{H melting } (H_m)}{\text{Heat supplied } (H_s)} \times 100$

$= \frac{15 \times 90}{2100} \times 100$

= 64.2857 %

8

Q.6 (c) (i) Write short notes on the following theories of corrosion:

1. Chemical action theory
2. Electrolytic theory
3. Galvanic-action theory
4. High-temperature oxidation theory

(ii) Explain briefly the various forms of corrosion and their causes.

[20 marks]

Q.7 (a) Discuss various types of Nanomaterials used in engineering application. What are the special properties of nanomaterials which is different from normal engineering- materials? Also explain the "Top- down" and "Bottom- up" approach for the synthesis of nanomaterials.

[20 marks]

Do not write in this margin

Q.7 (b) Discuss the different types of losses in solar cells arising due to fundamental and technological reasons. How is the electrical loss mechanism different from the optical loss mechanism in solar cells? How optical losses in solar cells be reduced?

[20 marks]

Q.7 (c) A manufacturing company needs 3000 units of a particular component every year. The company buys it at the rate of ₹32 per unit. The order processing cost for this part is estimated at ₹15 per order and the cost of carrying a part in stock comes to about ₹5 per unit per year. The company can manufacture this part internally. In that case, it save 20% of the price of the product. However, the inventory holding costs remain unchanged. The annual production rate would be 4800 units and set up cost is ₹250 per production run.

(i) Determine the EOQ and the optimal number of order placed in a year if the company purchases the component from the supplier.

(ii) Determine the optimum production lot size and the average duration of the production run, if the company manufactures the component.

(iii) Should the company manufacture the component internally or continue to purchase it from the supplier?

[20 marks]

Q.8 (a) The time estimates (in weeks) for the activities of a PERT network are given below:

Activity	t_0	t_m	t_p
1 - 2	1	1	7
1 - 3	1	4	7
1 - 4	2	2	8
2 - 5	1	1	1
3 - 5	2	5	14
4 - 6	2	5	8
5 - 6	3	6	15

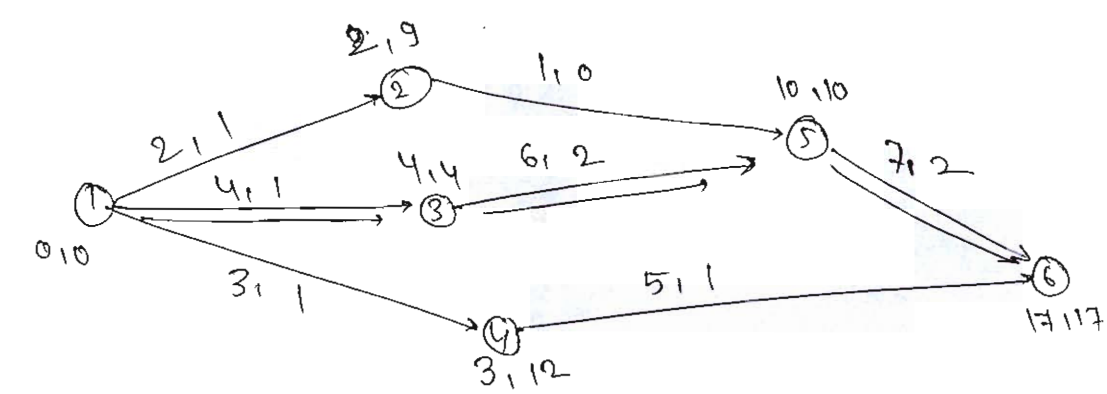
(i) Determine the expected project length.

(ii) If the project due date is 18 weeks, what is the probability of not meeting the due date?

(iii) Determine the probability that the project will be completed on schedule if the scheduled completion time is 21 weeks.

[20 marks]

Network diagram is



(i) The expected project length (T_E) = 17 weeks

(ii) if due date i.e. schedule time (T_s) = 18 week

then for probability of meeting the due date is

$\rightarrow z = \frac{T_s - T_E}{\sigma}$

$\therefore \sigma = \sqrt{1^2+2^2+2^2} = 3$ weeks

$\Rightarrow$ Normal variate (z) $= \frac{18-17}{3} = \frac{1}{3}$

$\Rightarrow$ Probability of meeting the due date $= 0.63056$

∴ probability of not meeting the due date is = 1 − 0.63056

= 0.36944

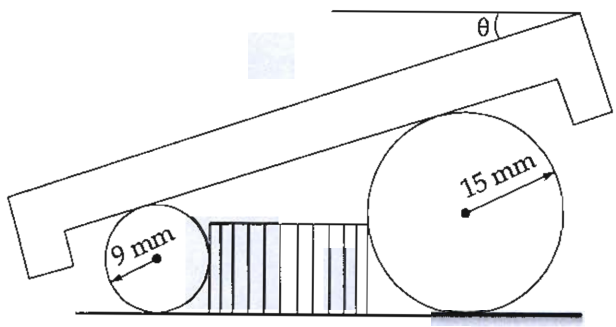
(iii) if scheduled time (T_s) = 21 week

then normal variant (Z) $= \frac{21-17}{3} = \frac{4}{3}$

∴ Probability = 0.9088

20

Q.8 (b) (i) A sine bar is used for precise measurement, if radius of the two rollers of sine bar are 9 mm and 15 mm and length of the slip gauges used in between two rollers is 23.87 mm. Determine angle of inclination (θ) measured by sine bar.



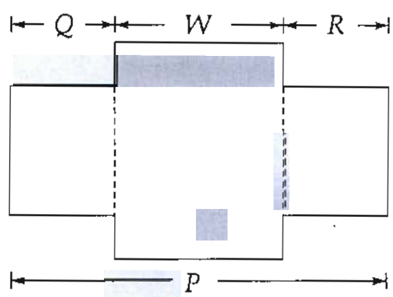
(ii) What is tolerance sink define with an example? A part as shown in figure, is machined to sizes given below:

$P = 30 \pm 0.04$ mm

$Q = 13 \pm 0.03$ mm

$R = 12 \pm 0.07$ mm

With full confidence, what will be the specification of resultant dimension W?

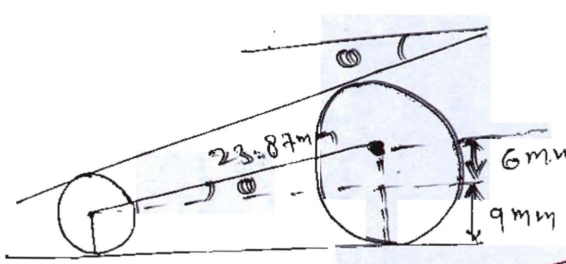


(iii) Chvorinov and Caine gave rules for solidification time and freezing ratio for a riser. Using these rules find size of a cylindrical riser of height to diameter ratio as one for a steel casting of size 300 × 300 × 100 mm^3, when casting is fed horizontally and riser is a side one, thickness of casting is 100 mm.

For steel, $a = 0.10$, $b = 0.03$, $c = 1.00$

[5 + 5 + 10 = 20 marks]

(i) Given



1

$\sin\theta = \frac{6}{23.87}$

$\Rightarrow \boxed{\theta = 14.5581°}$

(ii) Given

$P = 30 \pm 0.04$ mm

$Q = 13 \pm 0.03$ mm

$R = 12 \pm 0.07$ mm

∴ From figure,

$Q + W + R = P$

⇒ $W = P - (Q + R)$

$W_{max} = P_{max} - (Q+R)_{min}$

$= 30.04 - (13 - 0.03 + 12 - 0.07)$

$= 5.14$ mm

$W_{min} = P_{min} - (Q+R)_{max}$

$= 30 - 0.04 - (13 + 0.03 + 12 + 0.07)$

$= 4.86$ mm.

⇒ $W = 5 \pm 0.14$ mm Ans

Tolerance stack is defined as the difference between the upper and lower limit.

(iii) Given

$a = 0.1$

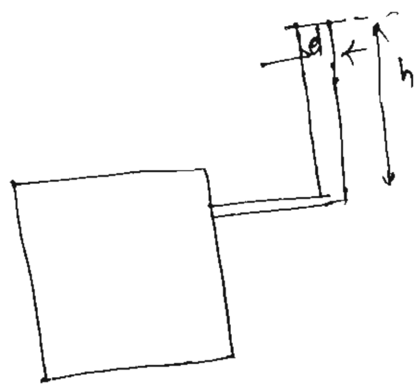
$b = 0.03$

$c = 1$

$\frac{H}{d} = 1$

Side riser

Casting dimension = $300 \times 300 \times 100$ mm³



according to Chvorinov and Caine rules

$$X = \frac{a}{Y+b} + c$$

where X = freezing ratio = $\frac{(A/V)_c}{(A/V)_r}$

$$Y = \frac{V_r}{V_c}$$

$$\therefore X = \frac{0.1}{Y+0.03} + 1$$

$\therefore$ Volume of casting (V_c) = $300 \times 300 \times 100$ = $9 \times 10^6\ mm^3$

Area of casting (A_c) = $2(300 \times 300 + 300 \times 100 + 300 \times 100)$

= $3 \times 10^5\ mm^2$

Volume of riser (V_r) = $\frac{\pi}{4} d^2 h$

$\because d = h \Rightarrow V_r = \frac{\pi}{4} d^3$

and

Area of riser (A_r) = $2\frac{\pi}{4} d^2 + \pi d h$

= $\frac{\pi}{2} d^2 + \pi d^2$

= $\frac{3}{2} \pi d^2$

$$\Rightarrow X = \frac{\left(\frac{3 \times 10^5}{9 \times 10^6}\right)}{\left(\frac{\frac{3}{2}\pi d^2}{\frac{\pi}{4} d^3}\right)} = \frac{\frac{1}{30}}{\frac{3}{2} \times \frac{4}{d}} = \frac{d}{180}$$

8

$$Y = \frac{\frac{\pi}{4} d^3}{9 \times 10^6}$$

$$\therefore \frac{d}{180} = \frac{0.1}{\frac{\pi d^3}{36 \times 10^6} + 0.03} + 1$$

on solving, $d = 203.5122\ mm = h$

Q.8 (c) Draw the current-voltage characteristic of a solar cell. Write down about fill factor and maximum efficiency of a solar cell. What are the major losses because of which photovoltaic cells have low efficiency? What are the methods of increasing efficiency of photo voltaic cell?

[20 marks]

OOOO

Attached Steam Table

Water/Steam at $p = 4.5$ MPa ($T_{sat} = 257.437$°C)

T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099793	0.04	4.53	0.00011
5	0.00099789	21.00	25.49	0.07615
10	0.00099821	41.91	46.40	0.15067
15	0.00099885	62.79	67.28	0.22377
20	0.00099979	83.64	88.14	0.29554
25	0.00100098	104.49	108.99	0.36605
30	0.00100240	125.32	129.83	0.43538
35	0.00100405	146.15	150.67	0.50356
40	0.00100590	166.98	171.51	0.57066
45	0.00100794	187.82	192.36	0.63670
50	0.00101016	208.66	213.21	0.70173
55	0.00101255	229.51	234.07	0.76579
60	0.00101511	250.37	254.94	0.82892
65	0.00101784	271.24	275.82	0.89113
70	0.00102072	292.13	296.72	0.95247
75	0.00102376	313.02	317.63	1.0130
80	0.00102696	333.94	338.56	1.0727
85	0.00103030	354.86	359.50	1.1315
90	0.00103379	375.82	380.47	1.1897
95	0.00103744	396.79	401.46	1.2471
100	0.00104123	417.78	422.47	1.3038
105	0.00104517	438.82	443.52	1.3598
110	0.00104927	459.87	464.59	1.4152
115	0.00105352	480.96	485.70	1.4699
120	0.00105793	502.08	506.84	1.5240
125	0.00106249	523.24	528.02	1.5776
130	0.00106721	544.45	549.25	1.6305
135	0.00107210	565.71	570.53	1.6830
140	0.00107716	587.00	591.85	1.7349
145	0.00108240	608.36	613.23	1.7864
150	0.00108781	629.77	634.67	1.8373
155	0.00109341	651.26	656.18	1.8879
160	0.00109920	672.80	677.75	1.9379
165	0.00110519	694.42	699.39	1.9876
170	0.00111139	716.12	721.12	2.0369
175	0.00111781	737.90	742.93	2.0859
180	0.00112445	759.77	764.83	2.1345
185	0.00113134	781.74	786.83	2.1827
190	0.00113847	803.81	808.93	2.2307
195	0.00114587	825.98	831.14	2.2784
200	0.00115355	848.28	853.47	2.3259
210	0.00116983	893.27	898.53	2.4201
220	0.00118745	938.84	944.18	2.5136
230	0.00120663	985.09	990.52	2.6067
240	0.00122763	1032.2	1037.7	2.6994
250	0.00125077	1080.2	1085.8	2.7922
257.437	0.00126965	1116.5	1122.2	2.8615
257.437	0.0440590	2599.6	2797.9	6.0197
260	0.0445720	2608.0	2808.6	6.0397
270	0.0464510	2637.7	2846.7	6.1105

T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
270	0.0464510	2637.7	2846.7	6.1105
280	0.0481860	2664.5	2881.3	6.1737
290	0.0498210	2689.4	2913.6	6.2316
300	0.0513780	2713.0	2944.2	6.2854
310	0.0528730	2735.5	2973.4	6.3359
320	0.0543170	2757.2	3001.6	6.3838
330	0.0557200	2778.2	3028.9	6.4295
340	0.0570870	2798.6	3055.5	6.4732
350	0.0584230	2818.6	3081.5	6.5153
360	0.0597330	2838.2	3107.0	6.5560
370	0.0610210	2857.5	3132.1	6.5953
380	0.0622880	2876.6	3156.9	6.6336
390	0.0635380	2895.5	3181.4	6.6708
400	0.0647720	2914.1	3205.6	6.7070
410	0.0659910	2932.7	3229.7	6.7425
420	0.0671990	2951.1	3253.5	6.7771
430	0.0683940	2969.4	3277.2	6.8111
440	0.0695800	2987.7	3300.8	6.8443
450	0.0707560	3005.8	3324.2	6.8770
460	0.0719240	3023.9	3347.6	6.9091
470	0.0730830	3042.0	3370.9	6.9406
480	0.0742360	3060.0	3394.1	6.9716
490	0.0753810	3078.0	3417.2	7.0022
500	0.0765210	3096.1	3440.4	7.0323
520	0.0787840	3132.0	3486.5	7.0912
540	0.0810270	3168.0	3532.6	7.1486
560	0.0832530	3204.0	3578.6	7.2046
580	0.0854640	3240.1	3624.7	7.2592
600	0.0876620	3276.4	3670.9	7.3127
620	0.0898480	3312.8	3717.1	7.3650
640	0.0920240	3349.3	3763.4	7.4163
660	0.0941910	3386.0	3809.9	7.4666
680	0.0963490	3422.9	3856.5	7.5161
700	0.0985000	3460.1	3903.3	7.5646
720	0.10064	3497.3	3950.2	7.6124
740	0.10278	3534.9	3997.4	7.6594
760	0.10491	3572.6	4044.7	7.7057
780	0.10704	3610.6	4092.3	7.7512
800	0.10916	3648.8	4140.0	7.7962
820	0.11128	3687.2	4188.0	7.8404
840	0.11340	3725.9	4236.2	7.8841
860	0.11551	3764.8	4284.6	7.9272
880	0.11762	3803.9	4333.2	7.9698
900	0.11972	3843.4	4382.1	8.0118
920	0.12182	3882.9	4431.1	8.0533
940	0.12392	3922.9	4480.5	8.0942
960	0.12602	3962.9	4530.0	8.1348
980	0.12811	4003.3	4579.8	8.1748
1000	0.13020	4043.9	4629.8	8.2144

Saturated Water and Steam (Pressure-based)

p_{tp} = 611.657 Pa = 0.000611657 MPa

p MPa	T_{sat} ℃	Volume, m³/kg v_f	v_g	Energy, kJ/kg u_f	u_g	Enthalpy, kJ/kg h_f	h_g	h_{fg}	Entropy, kJ/(kg K) s_f	s_g	s_{fg}
p_{tp}	0.01	0.00100021	205.991	0	2374.9	0.00	2500.9	2500.9	0	9.1555	9.1555
0.0007	1.881	0.00100011	181.217	7.89	2377.4	7.89	2504.3	2496.5	0.02878	9.1058	9.0770
0.0008	3.761	0.00100008	159.640	15.81	2380.1	15.81	2507.8	2492.0	0.05748	9.0567	8.9992
0.0009	5.444	0.00100009	142.757	22.89	2382.4	22.89	2510.9	2488.0	0.08297	9.0135	8.9305
0.0010	6.970	0.00100014	129.178	29.30	2384.5	29.30	2513.7	2484.4	0.10591	8.9749	8.8690
0.0012	9.654	0.00100032	108.670	40.57	2388.2	40.57	2518.6	2478.0	0.14595	8.9082	8.7623
0.0014	11.969	0.00100054	93.899	50.28	2391.3	50.28	2522.8	2472.5	0.18015	8.8521	8.6719
0.0016	14.010	0.00100080	82.743	58.83	2394.1	58.83	2526.5	2467.7	0.21004	8.8035	8.5935
0.0018	15.837	0.00100108	74.011	66.49	2396.7	66.49	2529.9	2463.4	0.23662	8.7608	8.5241
0.0020	17.495	0.00100136	66.987	73.43	2398.9	73.43	2532.9	2459.4	0.26056	8.7226	8.4620
0.0024	20.414	0.00100193	56.375	85.65	2402.9	85.65	2538.2	2452.5	0.30239	8.6567	8.3544
0.0028	22.935	0.00100249	48.729	96.19	2406.4	96.19	2542.8	2446.6	0.33816	8.6012	8.2631
0.0032	25.158	0.00100305	42.952	105.49	2409.4	105.49	2546.8	2441.3	0.36945	8.5533	8.1838
0.0036	27.152	0.00100358	38.430	113.83	2412.1	113.83	2550.4	2436.6	0.39729	8.5110	8.1138
0.0040	28.960	0.00100410	34.791	121.39	2414.5	121.39	2553.7	2432.3	0.42239	8.4734	8.0510
0.0045	31.012	0.00100473	31.131	129.96	2417.3	129.96	2557.4	2427.4	0.45069	8.4313	7.9806
0.0050	32.874	0.00100533	28.185	137.74	2419.8	137.75	2560.7	2423.0	0.47620	8.3938	7.9176
0.0055	34.581	0.00100590	25.762	144.87	2422.1	144.88	2563.8	2418.9	0.49945	8.3599	7.8605
0.0060	36.159	0.00100645	23.733	151.47	2424.2	151.48	2566.6	2415.2	0.52082	8.3290	7.8082
0.0065	37.627	0.00100699	22.009	157.60	2426.2	157.61	2569.3	2411.6	0.54060	8.3007	7.7601
0.0070	39.000	0.00100750	20.524	163.34	2428.0	163.35	2571.7	2408.4	0.55903	8.2745	7.7154
0.0075	40.290	0.00100800	19.233	168.74	2429.8	168.75	2574.0	2405.3	0.57627	8.2501	7.6738
0.0080	41.509	0.00100848	18.099	173.83	2431.4	173.84	2576.2	2402.4	0.59249	8.2273	7.6348
0.0085	42.663	0.00100895	17.095	178.66	2433.0	178.67	2578.3	2399.6	0.60780	8.2060	7.5982
0.0090	43.761	0.00100940	16.199	183.24	2434.4	183.25	2580.2	2397.0	0.62230	8.1858	7.5635
0.0095	44.807	0.00100984	15.396	187.62	2435.8	187.63	2582.1	2394.5	0.63607	8.1668	7.5308
0.010	45.806	0.00101027	14.670	191.80	2437.2	191.81	2583.9	2392.1	0.64920	8.1488	7.4996
0.011	47.683	0.00101110	13.412	199.64	2439.7	199.65	2587.2	2387.5	0.67372	8.1154	7.4417
0.012	49.419	0.00101188	12.358	206.90	2442.0	206.91	2590.3	2383.4	0.69628	8.0849	7.3887
0.013	51.034	0.00101263	11.462	213.66	2444.1	213.67	2593.1	2379.4	0.71717	8.0570	7.3398
0.014	52.547	0.00101335	10.691	219.98	2446.1	219.99	2595.8	2375.8	0.73664	8.0311	7.2945
0.016	55.313	0.00101471	9.4306	231.55	2449.7	231.57	2600.6	2369.1	0.77201	7.9846	7.2126
0.018	57.798	0.00101597	8.4431	241.94	2453.0	241.96	2605.0	2363.0	0.80355	7.9437	7.1402
0.020	60.058	0.00101716	7.6480	251.40	2455.9	251.42	2608.9	2357.5	0.83202	7.9072	7.0752
0.024	64.053	0.00101934	6.4453	268.13	2461.2	268.15	2615.9	2347.7	0.88191	7.8442	6.9623
0.028	67.518	0.00102131	5.5778	282.63	2465.6	282.66	2621.8	2339.2	0.92472	7.7912	6.8664
0.032	70.586	0.00102312	4.9215	295.49	2469.6	295.52	2627.1	2331.6	0.96228	7.7453	6.7830
0.036	73.345	0.00102480	4.4072	307.05	2473.1	307.09	2631.8	2324.7	0.99579	7.7050	6.7092
0.040	75.857	0.00102638	3.9930	317.58	2476.4	317.62	2636.1	2318.4	1.0261	7.6690	6.6429
0.045	78.715	0.00102821	3.5759	329.57	2480.0	329.62	2640.9	2311.2	1.0603	7.6288	6.5686
0.050	81.317	0.00102993	3.2400	340.49	2483.2	340.54	2645.2	2304.7	1.0912	7.5930	6.5018

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Saturated Water and Steam (Pressure-based), Contd.

p	T_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
MPa	°C	v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
0.050	81.317	0.00102993	3.2400	340.49	2483.2	340.54	2645.2	2304.7	1.0912	7.5930	6.5018
0.055	83.709	0.00103154	2.9635	350.53	2486.2	350.59	2649.2	2298.6	1.1194	7.5606	6.4412
0.060	85.926	0.00103307	2.7317	359.85	2489.0	359.91	2652.9	2292.9	1.1454	7.5311	6.3857
0.065	87.993	0.00103452	2.5346	368.53	2491.6	368.60	2656.3	2287.7	1.1696	7.5040	6.3345
0.070	89.932	0.00103590	2.3648	376.68	2493.9	376.75	2659.4	2282.7	1.1921	7.4790	6.2869
0.075	91.758	0.00103723	2.2170	384.36	2496.1	384.44	2662.4	2277.9	1.2132	7.4557	6.2425
0.080	93.486	0.00103850	2.0871	391.63	2498.2	391.71	2665.2	2273.5	1.2330	7.4339	6.2009
0.085	95.125	0.00103972	1.9720	398.53	2500.2	398.62	2667.8	2269.2	1.2518	7.4135	6.1617
0.090	96.687	0.00104091	1.8694	405.11	2502.1	405.20	2670.3	2265.1	1.2696	7.3943	6.1246
0.095	98.178	0.00104205	1.7772	411.38	2503.9	411.48	2672.7	2261.2	1.2866	7.3761	6.0895
0.10	99.606	0.00104315	1.6939	417.40	2505.5	417.50	2674.9	2257.4	1.3028	7.3588	6.0561
0.11	102.292	0.00104527	1.5495	428.73	2508.8	428.84	2679.2	2250.3	1.3330	7.3269	5.9938
0.12	104.784	0.00104727	1.4284	439.23	2511.7	439.36	2683.1	2243.7	1.3609	7.2977	5.9367
0.13	107.109	0.00104917	1.3253	449.05	2514.3	449.19	2686.6	2237.5	1.3868	7.2709	5.8840
0.14	109.292	0.00105099	1.2366	458.27	2516.9	458.42	2690.0	2231.6	1.4110	7.2461	5.8351
0.15	111.349	0.00105273	1.1593	466.97	2519.2	467.13	2693.1	2226.0	1.4337	7.2230	5.7893
0.16	113.297	0.00105440	1.0914	475.21	2521.4	475.38	2696.0	2220.7	1.4551	7.2014	5.7463
0.17	115.148	0.00105600	1.0312	483.04	2523.5	483.22	2698.8	2215.6	1.4753	7.1812	5.7059
0.18	116.911	0.00105756	0.97747	490.51	2525.5	490.70	2701.4	2210.7	1.4945	7.1621	5.6676
0.19	118.596	0.00105906	0.92924	497.65	2527.3	497.85	2703.9	2206.0	1.5127	7.1440	5.6313
0.20	120.210	0.00106052	0.88568	504.49	2529.1	504.70	2706.2	2201.5	1.5302	7.1269	5.5967
0.21	121.759	0.00106193	0.84614	511.07	2530.8	511.29	2708.5	2197.2	1.5469	7.1106	5.5638
0.22	123.250	0.00106330	0.81007	517.40	2532.4	517.63	2710.6	2193.0	1.5628	7.0951	5.5323
0.23	124.686	0.00106464	0.77704	523.50	2534.0	523.74	2712.7	2188.9	1.5782	7.0803	5.5021
0.24	126.072	0.00106594	0.74668	529.38	2535.4	529.64	2714.6	2185.0	1.5930	7.0661	5.4731
0.25	127.411	0.00106722	0.71866	535.07	2536.8	535.34	2716.5	2181.1	1.6072	7.0524	5.4452
0.26	128.708	0.00106846	0.69273	540.59	2538.2	540.87	2718.3	2177.4	1.6210	7.0394	5.4184
0.27	129.965	0.00106968	0.66865	545.95	2539.5	546.24	2720.0	2173.8	1.6343	7.0268	5.3925
0.28	131.185	0.00107086	0.64624	551.14	2540.8	551.44	2721.7	2170.3	1.6471	7.0146	5.3675
0.29	132.370	0.00107203	0.62533	556.19	2542.0	556.50	2723.3	2166.8	1.6596	7.0029	5.3433
0.30	133.522	0.00107317	0.60576	561.11	2543.2	561.43	2724.9	2163.5	1.6717	6.9916	5.3199
0.31	134.644	0.00107429	0.58741	565.89	2544.3	566.22	2726.4	2160.2	1.6835	6.9807	5.2972
0.32	135.737	0.00107539	0.57017	570.56	2545.3	570.90	2727.8	2157.0	1.6949	6.9701	5.2752
0.33	136.802	0.00107647	0.55395	575.10	2546.5	575.46	2729.3	2153.8	1.7060	6.9598	5.2538
0.34	137.842	0.00107753	0.53864	579.54	2547.5	579.91	2730.6	2150.7	1.7168	6.9498	5.2330
0.35	138.857	0.00107857	0.52418	583.88	2548.5	584.26	2732.0	2147.7	1.7274	6.9401	5.2128
0.36	139.849	0.00107960	0.51050	588.13	2549.4	588.52	2733.2	2144.7	1.7377	6.9307	5.1931
0.37	140.819	0.00108061	0.49753	592.28	2550.4	592.68	2734.5	2141.8	1.7477	6.9216	5.1739
0.38	141.769	0.00108161	0.48522	596.34	2551.3	596.75	2735.7	2139.0	1.7575	6.9126	5.1551
0.39	142.698	0.00108259	0.47352	600.32	2552.2	600.74	2736.9	2136.2	1.7671	6.9040	5.1369
0.40	143.608	0.00108355	0.46238	604.22	2553.1	604.65	2738.1	2133.4	1.7765	6.8955	5.1190

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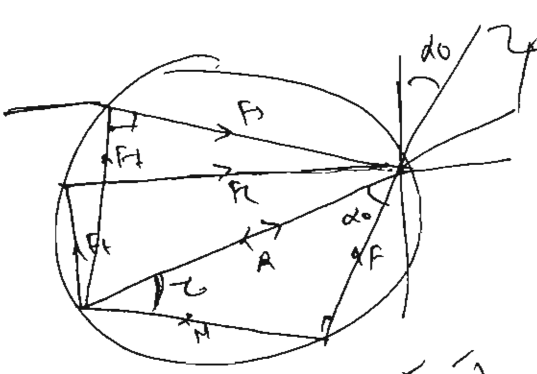
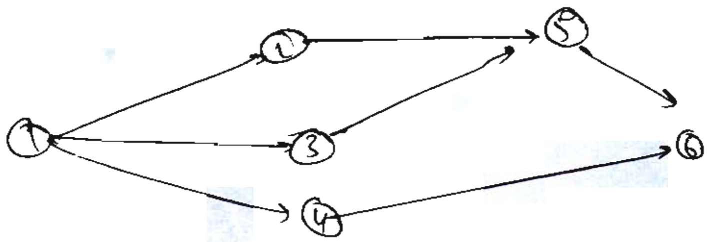
Space for Rough Work

Space for Rough Work



$F_3 = R\cos(\alpha + \tau - \alpha_0)$

$= \sqrt{F^2 + N^2}$



Space for Rough Work