MADE EASY

MADE EASY

India's Best Institute for IES, GATE & PSUs

ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-5: Production Engineering and Material Science
Strength of Materials and Mechanics-1
Fluid Mechanics and Turbo Machinery-2

Name : AAKASH VERMA

Roll No : M E 1 9 M B D L B 6 5 1

Test Centres

Delhi ☑ Bhopal ☐ Noida ☐ Jaipur ☐ Indore ☐
Lucknow ☐ Pune ☐ Kolkata ☐ Bhubaneswar ☐ Patna ☐
Hyderabad ☐

Student's Signature

Aakash Verma

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	52-1=51
Q.2	50
Q.3	—
Q.4	—
Section-B	
Q.5	26
Q.6	—
Q.7	31
Q.8	38
Total Marks Obtained	196

Signature of Evaluator: SM

Cross Checked by: Sumit Kr.

Improve the presentation.

Section A : Production Engineering and Material Science

(a) Iodine has an orthorhombic unit cell for which the *a*, *b* and *c* lattice parameters are 0.479 nm, 0.725 nm and 0.978 nm, respectively.

(i) If the atomic packing factor and atomic radius are 0.547 and 0.177 nm, respectively. Determine the number of atoms in each unit cell.

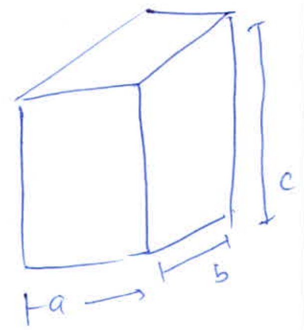
(ii) What will be the density of Iodine, if atomic weight of Iodine is 126.9 g/mol?

[12 marks]

1

Here $a = 0.479$ nm, $b = 0.725$ nm, $c = 0.978$ nm

APF = 0.547, $r = 0.177$ nm



We know, APF = $\frac{\text{vol. occupied by atoms}}{\text{vol. of unit cell}}$

$\therefore 0.547 = \frac{\text{vol of atoms}}{(abc)}$

$\therefore$ vol of atoms = 0.18578 nm^3

vol. of 1 atom = $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi (0.177)^3 = 0.02323\ nm^3$
(Assuming as sphere)

$\therefore$ No. of atoms in unit cell = $\frac{\text{vol. of atoms}}{\text{vol. of 1 atom}}$

$= 7.9982 \simeq 8$

$\therefore$ $\boxed{\text{No. of atoms / unit cell} = 8}$ (i)

(ii) At wt of iodine atom = 126.9 g/mol

$\therefore$ wt of unit cell = No. of atoms/cell × wt of one atom

$= 8 \times 126.9$ g/mol

$= 1015.2$ g/mol.

or $\frac{1015.2\ g}{6.023 \times 10^{23}}$

Vol of unit cell = $abc = 0.33963\ nm^3$

$= 0.33963 \times 10^{-27}\ m^3$

$\therefore \rho$ of iodine $= \left(\dfrac{1015.2 \times 10^{-3}\ kg}{6.023 \times 10^{23}}\right) \times \dfrac{1}{3.3963 \times 10^{-28}\ m^3}$

$$\boxed{\begin{aligned} \rho_{Iodine} &= 4962.8677\ kg/m^3 \\ \text{or } &4.963\ g/cm^3 \end{aligned}}$$

12

Q.1 (b) A 20 mm deep slot is to be cut through a workpiece of 150 mm length with the help of HSS side and face cutter whose diameter is 120 mm and has 10 teeth. The cutting speed is 40 m/min and feed is 0.20 mm per teeth. Calculate the time required to machine the slot.

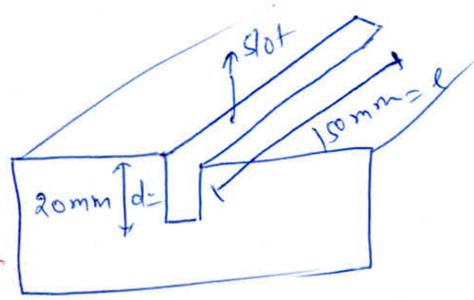
[12 marks]

Sol:
(b)

Here, $d = 20\ mm$, $l = 150\ mm$,

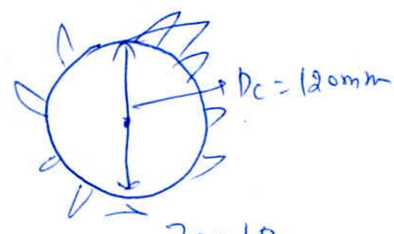
$D_c = 120\ mm$, $Z_c = 10$

$V_c = 40\ m/min$, $f_t = 0.20\ mm$



$V_c = \dfrac{\pi D_c N}{1000}$

$\therefore N = \dfrac{1000 \times V_c}{\pi D_c} = \boxed{106.103\ rpm}$



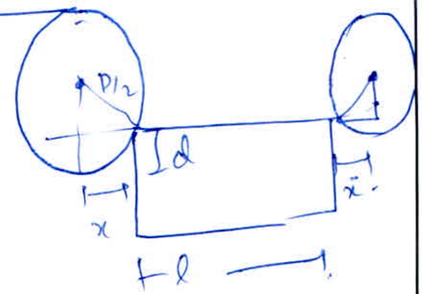
$\therefore$ ~~feed per~~ table feed $= N Z_c f_t$

$= 106.103 \times 10 \times 0.2$

table feed $= 212.206\ mm/min$

let's assume approach = overtravel (Both are present)

$\therefore x = \sqrt{d(D-d)} = \sqrt{20\times(120-20)} = 44.72\,mm$



$\therefore$ length of cutter travel $= l + 2x$

$= 150 + 2\times 44.72$

$= 239.44\,mm$

Overtravel Not required if in Question not giving anything about it approach is required only

$\therefore$ time machine $= \dfrac{\text{length of cutter travel}}{\text{table feed}}$

$= \dfrac{239.44\,mm}{212.206\,mm/min}$

$= 1.128\,mins$

do not take 2 times

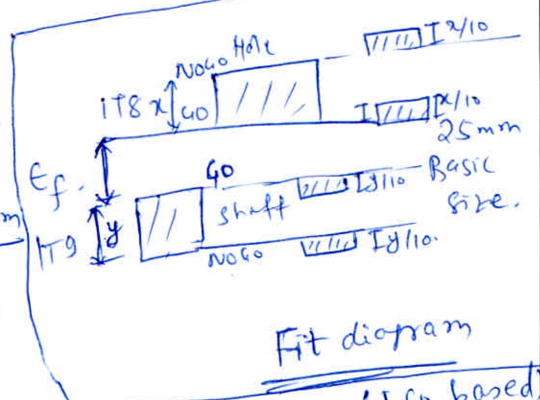
08

(c) Design general type GO and NO GO gauges for components having $25H_8f_9$ fit. The basic size falls in the diameter range of 18 – 30 mm. The fundamental deviation for 'f' shaft = $(-5.5D^{0.41})$ microns. Take gauge tolerance as 10% of work tolerance. Sketch the gauges with important values. The multipliers for 8 and 9 grades are 25 and 40 respectively.

[12 marks]

Here, We will design as per ISO gauge system.

Basic size = 25 mm



Fit diagram (ISO based)

$\therefore$ ~~$D = \sqrt{D_1 D_2}$~~

$i = 0.45D^{1/3} + 0.001D$

Here, $D = \sqrt{18\times 30} = 23.238\,mm$

$\therefore i = [0.45(23.238)^{1/3} + 0.001\times 23.238]\,\mu m$

$\boxed{i = 1.3074\,\mu m}$

fundamental deviation for hole $= 0$ (Hole basis system)

for shaft, $e_f = -5.5\times(23.238)^{0.41} = -19.976\,\mu m$

Hole tolerance $= 25i$ (IT8 grade) $= 25\times 1.3074\,\mu m = 32.685\,\mu m$

shaft tolerance $= 40i$ (IT9) $= 40\times 1.3074 = 52.296\,\mu m$

~~As per~~ gaye ~~work~~ tolerance

for ~~Go~~ Hole :- ~~work~~ gaye tolerance $= \frac{1}{10} \times$ work tolerance of hole

$= \frac{1}{10} \times 32.685 = 3.2685\ \mu m$

for shaft $= \frac{1}{10} \times$ work tolerance of shaft

$= \frac{1}{10} \times 52.296\ \mu m = 5.2296\ \mu m$

wear allowance on Go end is neglected as work tolerance for both hole & shafts is less than 0.1 mm

Hole (Plug gaye)
- Go
  - min — 25 mm
  - max — $25 + .0032 = 25.0032$ mm
- NOGO
  - min — $25 + x = 25.0326$ mm
  - max. — $25 + x + \frac{x}{10} = 25.0358$ mm

Shaft (Ring gaye)
- Go
  - min — $25 + 4 = 24.9800$ mm
  - max — $25 + 4 - \frac{y}{10} = 24.9747$ mm
- NOGO
  - ~~max~~ — 24.9277 mm
  - min. ~~max~~ — $24.9277 - \frac{y}{10}$

$= 24.9329$ mm

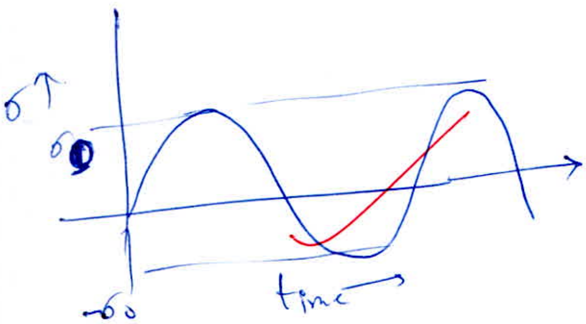
12

improve presentation

(d) What do you understand by fatigue? What are different stages of fatigue failure? What are factors which are necessary for fatigue failure?

[12 marks]

Fatigue is the state of stress which is varying in nature. It could be alternating in nature or completely reversed stress state or could of the same kind (Tensile or compressive) but with varying magnitude.



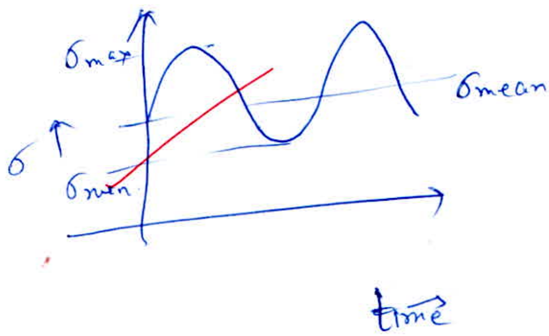


Fig. Completely reversed state of stress

Fig: Alternating state of stress

Fatigue failure occurs in stages. It starts with crack initiation when a micro crack or void appears in the material due to localized failure. This crack then propagates through the material until it becomes large enough that the failure occurs. Fatigue failure is sudden. Presence of cracks ~~and~~ fastens the process of fatigue failure.

Also, if the stress within the sample is below the endurance strength, then fatigue failure (theoretically) will never happen, i.e. infinite life of the material exists. Endurance limit is lower than the yield strength.

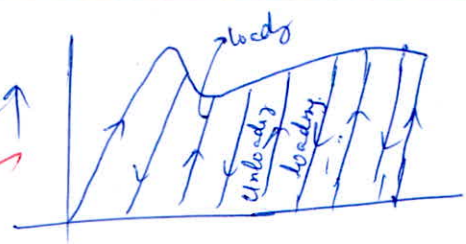
~~Factor~~ various factors affect failure by fatigue like

(a) Surface roughness & finish

(b) Size of sample

(c) Temperature (d) Type of loading (reversed, alternate)

(e) Presence of cracks, ✓



Fatigue loading diagram

To suppress fatigue failure, materials can be pre-stressed under compression.

(f) stress concentration

(g) Notch

stages ?!!

07

Q.1 (e) While machining steel with zero rake angle, prove the following expression:

$$\frac{\tau_s}{p_c} = \frac{r(1-\mu r)}{1+r^2}$$

where τ_s is shear strength of material, p_c is specific cutting power and r is chip thickness ratio $\left(\frac{t_1}{t_2}\right)$.

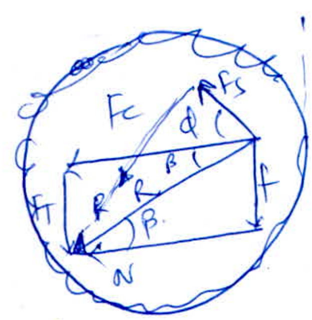
[12 marks]

Here $\alpha = 0$, the force diagram is shown

$\therefore f = F_T$ & $N = F_c$

$F_s = \frac{(\tau_s)\, b \cdot t_1}{\sin\phi} \Rightarrow \boxed{\tau_s = \frac{F_s \sin\phi}{b t_1}}$

$\mu = \tan\beta = \frac{f}{N} = \frac{F_T}{F_c}$ — (i)



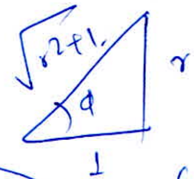
Specific cutting power $P_c = \frac{F_c V}{b t_1 V} = \frac{F_c}{b t_1}$ —

force diagram

$\therefore \frac{\tau_s}{p_c} = \frac{F_s \sin\phi}{b t_1 \times F_c} \, b t_1$

$\frac{\tau_s}{p_c} = \frac{F_s \sin\phi}{F_c}$ — (ii)

Also, $r = \frac{\sin\phi}{\cos(\phi-\alpha)} = \frac{\sin\phi}{\cos\phi}$ $(\because \alpha = 0)$



$\therefore r = \tan\phi$.

$\therefore$ $\boxed{\sin\phi = \frac{r}{\sqrt{r^2+1}} \quad \& \quad \cos\phi = \frac{1}{\sqrt{1+r^2}}}$ — (iii) $\to$ (iii) — (iv)

Also, $F_s = F_c\cos\phi - F_T\sin\phi$.

& $\frac{F_T}{F_c} = \tan\beta = \mu$ $\Rightarrow$ $F_T = F_c\,\mu$ — (v)

$\therefore$ Using (iv) & (v) & (iii))

$F_s = F_c \times \frac{1}{\sqrt{1+r^2}} - F_c\mu \times \frac{(r)}{\sqrt{r^2+1}}$

$\Rightarrow \frac{F_s}{F_c} = \frac{(1-\mu r)}{\sqrt{r^2+1}}$ — (vi)

$\therefore$ from (ii) & (vi) & (iii)

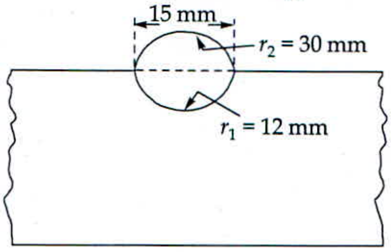
$\frac{\tau_s}{p_c} = \frac{F_s}{F_c}\sin\phi = \left(\frac{1-\mu r}{\sqrt{1+r^2}}\right) \times \frac{r}{\sqrt{r^2+1}}$

$$\boxed{\therefore \frac{\tau_s}{p_c} = \frac{r(1-\mu r)}{\left(\sqrt{r^2+1}\right)^2} = \frac{r(1-\mu r)}{1+r^2}}$$

12

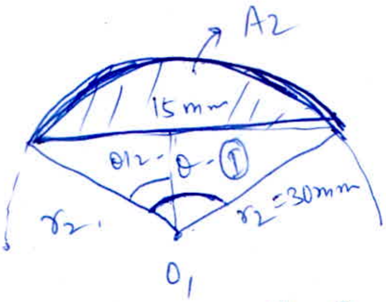
Do not write this margin

Q.2 (a) The cross-section of weld bead is shown in figure. The profile of the bead and the fusion zone are taken circular for convenience. Bead width and radii of curvature of circular profiles are shown in figure. What is percentage dilution?



[20 marks]

for reinforcement:



Using cosine rule

$$\cos\theta = \frac{r_2^2 + r_2^2 - (15)^2}{2 \cdot r_2 \cdot r_2}$$

$$= \frac{2r_2^2 - 15^2}{2r_2^2} = 1 - \frac{15^2}{2r_2^2} = 1 - \frac{15^2}{2\times 30^2} = 0.875$$

$\therefore \theta = \cos^{-1}(0.875) = 28.955^\circ$

Reinforcement area: $A_2 = \pi r_2^2 \left(\frac{\theta}{2\pi}\right) - \text{(I)}$

$\Rightarrow A_2 = \frac{1}{2} r_2^2 \theta - \text{(I)}$

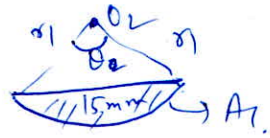
(I) = area of triangle $= \frac{1}{2} \times 15 \times r_2 \cos\frac{\theta}{2} = 217.855\ mm^2$

$\therefore A_2 = \frac{1}{2} r_2^2 \theta - 217.855\ mm^2$

$= (227.412 - 217.855)\ mm^2$

$$\boxed{A_2 = 9.557\ mm^2}$$

for penetration



Using cosine rule

$$\cos\theta = \frac{r_1^2 + r_1^2 - 15^2}{2 \cdot r_1 \cdot r_1}$$

$$\cos\theta = 1 - \frac{15^2}{2r_1^2} = 0.21875$$

$$\therefore \boxed{\theta = 77.384^\circ} \text{ or } 1.3503 \text{ radians}$$

$\therefore$ Area of penetrated weld bead (A_1)

$$A_1 = \frac{1}{2} r_1^2 \theta - \frac{1}{2} \times 15 \times r_1 \cos(\theta/2)$$

$$= (97.2216 - 70.256) \text{ mm}^2$$

$$\boxed{A_1 = 26.9656 \text{ mm}^2}$$

$$\therefore \% \text{ dilution} = \frac{A_1}{A_1 + A_2} = \frac{26.9656}{26.9656 + 9.557} \times 100\,\%$$

$$\boxed{\% \text{ dilution} = 73.8326\,\%}$$

20

(b) What are linear defects in crystal? Describe different types of linear defects.

[20 marks]

Linear defects or line defects are the defects in crystals which occur due to dislocation motion inside the crystal. These defects are categorised as

(i) Edge dislocation (ii) Screw dislocation

(iii) Mixed dislocations.

The concept of burger vector is used to describe linear defects inside crystals. Burgers vector is unit plastic in the direction of slip. Slip is defined as deformation.

Let us look at different types of dislocations / linear defects.

(i) Edge dislocation: In Edge dislocation, an extra half plane of atoms appear above/below the dislocation line.

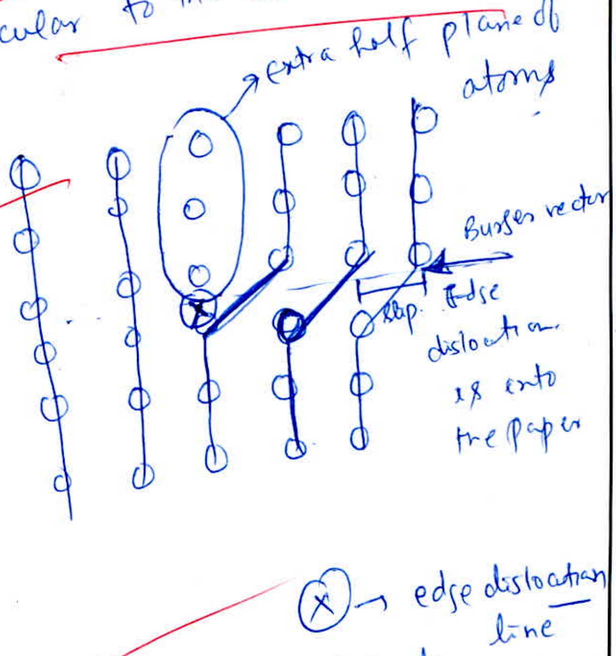
These can be positive edge dislocation or negative edge dislocation depending on whether extra half plane of atoms appears above the dislocation line or below the dislocation line. Burgers vector is perpendicular to the dislocation line in edge dislocation.

Movement of edge dislocation is called glide.

Symbols:

Positive edge dislocation $\perp$

negative edge dislocation $\top$

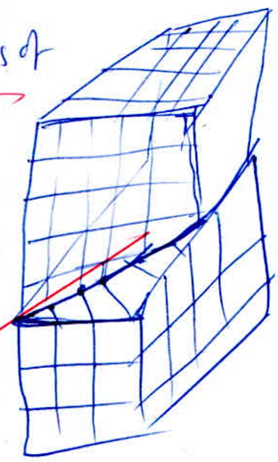


Schematic of edge dislocation.

Do not write in this margin

(ii) Screw dislocation: This type of dislocation happens when atoms move along the screw of a helix. There is no extra half plane of atoms in screw dislocation. Here, Burger vector is along the dislocation line. The movement of screw dislocation is called 'climb'.

Applying a twist can produce these kinds of dislocations.



Schematic of screw dislocat

Mixed dislocation: It consists of both edge dislocations and screw dislocations. Here, burger vector is neither parallel nor perpendicular to the dislocation line.

add few more facts about mixed dislocations

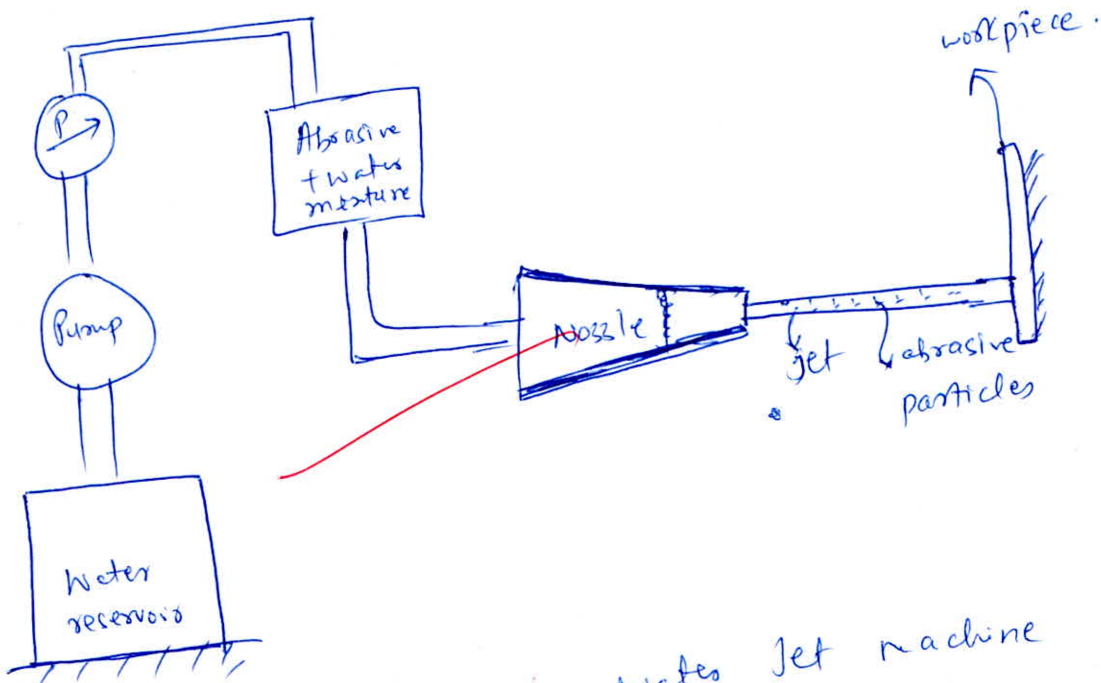
15

Do not write in this margin

(c) Explain the principle of abrasive water-jet machining using suitable schematic diagram. Write the advantages and applications of AWJM.

[20 marks]

Abrasive water jet maching is a unconventional m/c method in which a water jet with abrasives (~~----~~ in the water jet is thrown at a w/p at very high speeds of the order of 250 ~ 300 m/s. for machining operations.



Schematic of abrasive water Jet machine

Principle:

Jet containing water and abrasives comes out of the nozzle at very high speeds. When they strike the workpiece at such high momentum, machining / material removal takes place due to abrasives ~~----~~ plus high momentum or KE of water. Brittle fracture of w/p takes place called as chipping action, and chips are then carried away by water. Water also serves to cool the w/p. due to ~~--~~ heat produced from machining operation.

Advantages of AWJM

(i) Very little or less noise

(ii) Water is very easily available.

(iii) Automatic process.

(iv) High surface finish and dimensional accuracy

(v) Little or no heat generated.

(vi) Very less temperature stresses developed in w/p.

(vii) Intricate shapes & designs can be made.

Applications :-

(i) Machining of ~~fine~~ holes.

(ii) Cutting of metal sheets.

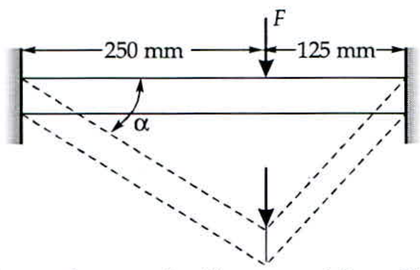
(iii) Cleaning of surfaces from oxides, etc.

(iv) Removal of burrs.

write down ~~a~~ standard data about process parameter

15

(a) A 375 mm long sheet with a cross-sectional area of $5 \times 10^{-4}\ m^2$ is stretched with a force, F, until $\alpha = 20°$. The material has a true stress-true strain relationship as, $\sigma = (700\ MPa)\epsilon^{0.3}$. Calculate:



(i) The total workdone, ignoring end effects and bending.

(ii) What is α_{max} before necking begins?

[20 marks]

Q.3 (b) Sketch the setup for spot welding and also explain about spot welding in detail. Show the pressure v/s time graph for different phases. Explain how melting efficiency is calculated? Write down major drawbacks of spot welding process and also write down process parameters for spot welding.

[20 marks]

Q.3 (c) For the lead-tin alloy 40 wt% Sn and 60 wt% Pb at 150°C. Assume that 10 wt% Sn is fully soluble in Pb at 150°C and 2 wt% Pb is fully soluble in Sn at 150°C. At 150°C densities of Pb and Sn are 11.23 g/cm^3 and 7.24 g/cm^3 respectively. Calculate the relative amount of α and β phase present in terms of (i) mass fraction and (ii) volume fraction. Also draw Pb-Sn phase diagram.

[20 marks]

Q.4 (a) For a continuous and oriented fiber reinforced composite, the moduli of elasticity in the longitudinal and transverse directions are 33 GPa and 3.65 GPa, respectively. If the volume fraction of fibers is 0.30, determine the moduli of elasticity of fiber and matrix phases. Derive the relation used for modulus of elasticity in transverse direction.

[20 marks]

(b) What is hardening of materials? Briefly explain different types of case hardening process used in heat treatment.

[20 marks]

4 (c) During turning a steel rod of 180 mm diameter by a carbide tool of geometry 0°, -12°, 7°, 5°, 30°, 60°, 0 (mm) at a speed of 600 rpm, feed of 0.32 mm/rev and 4 mm depth of cut, the following observations were made:

Tangential component of the cutting force, $F_z = 1000$ N

Radial component of the cutting force, $F_y = 200$ N

Chip thickness (after cut), $t_2 = 0.8$ mm

For the above machining conditions, determine:

(i) Friction force, F and normal force, N acting at the chip-tool interface.

(ii) Yield shear strength of the work material under this machining condition.

(iii) Cutting power consumption in kW.

[20 marks]

Section B : SOM & Mechanics - 1, Fluid Mechanics and Turbo Machinery - 2

(a) The velocity field of a flow is described by $\vec{V} = (4x)\vec{i} + (5y+3)\vec{j} + (3t^2)\vec{k}$. What is the pathline of a particle at a location (1 m, 2 m, 4 m) at time $t = 1$ s?

[12 marks]

$\vec{V} = 4x\hat{i} + (5y+3)\hat{j} + (3t^2)\hat{k}$

$u = 4x = \frac{dx}{dt} \Rightarrow \frac{dx}{4x} = t \Rightarrow \ln(x) = 4t + c_1$

$\therefore$ @ $t = 1s$, $x = 1\,m \Rightarrow \ln(1) = 4 \times 1 + c_1 \Rightarrow \boxed{c_1 = -4}$

$\therefore \ln x = 4t - 4 = 4(t-1) \Rightarrow \boxed{x = e^{4(t-1)}}$

$v = (5y+3) = \frac{dy}{dt} \Rightarrow \int \frac{dy}{5y+3} = \int dt$

integrating

$\Rightarrow \ln(5y+3) = t + c_2$

IC: Conditions @ $y = 2m$, $t = 1s$

$\therefore \ln(5 \times 2 + 3) = 1 + c_2$

$\therefore c_2 = -1 + \ln(13) = 1.5649$

$\therefore \ln(5y+3) = t + c_2 = (t + 1.5649)$

$\therefore 5y + 3 = e^{(t+1.5649)}$

$$\boxed{y = \frac{1}{5}\left(e^{t+1.5649} - 3\right)}$$

again $w = \frac{dz}{dt} = 3t^2$

$\therefore \int dz = \int 3t^2\,dt$

$\Rightarrow z = t^3 + c$

Do no
write
this m

@ $t = 1s$, $z = 4m$

$\therefore 4 = (1)^3 + C \Rightarrow C = 3$

$\therefore \boxed{z = t^3 + 3}$

Position ~~v~~ coordinates

$\therefore$ Path line of particle is

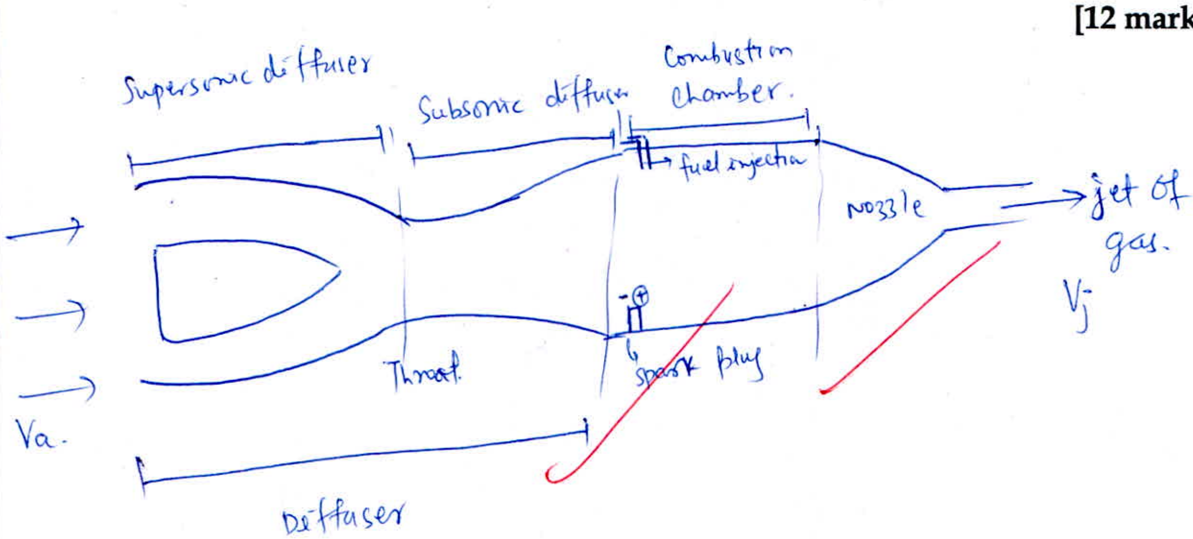
$$\boxed{\begin{aligned} x &= e^{4(t-1)} \\ y &= \frac{1}{5}\left(e^{t+1.3649} - 3\right) \\ z &= t^3 + 3 \end{aligned}}$$

combine and make single eqn

5

Q.5 (b) With the aid of a neat diagram, explain the working principle of a Ramjet engine. Also write its advantages.

[12 marks]



Ramjet Engine

A Ramjet works on the principe ~~that~~ that compressed air is readily available from the atmosphere by ram effect. This compressed air is then fed into the combustion chamber, where air & fuel mix and mixture is ignited using a spark plug.

The expansion of the hot flue gases through the nozzle produces high velocity jet which is used to propell the aircraft. ~~Ram air~~ A Ramjet engine doesn't have any turbine or compressors. ~~The~~ The temp. of hot gases reaches very high values around 3000°C. 2000°C They are not self propelling. They need to be given some initial thrust before ram air is available so as to propell the vehicle.

Advantages of Ramjet engine :-

(i) No moving parts are present. So no need for maintainence & maintainence costs are very low.

(ii) Light weight as there are no turbines or compressors.

(iii) Good efficiency.

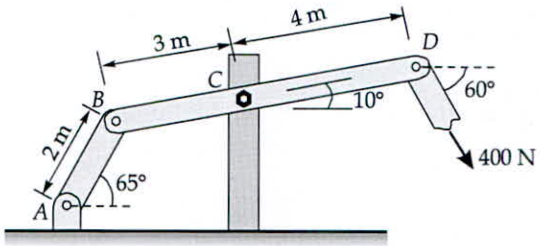
(iv) Suitable for supersonic / or high speed flights.

(v) Can be used at high altitudes.

limited to certain altitude

10

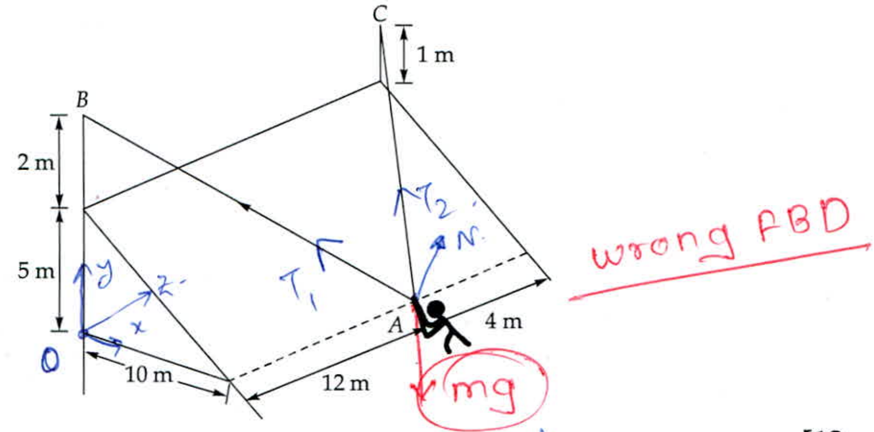
Q.5 (c) Member BD is hinged to a fixed support with the help of a bolt of diameter 2 cm. Member BD is 10 cm wide and 5 cm thick. Determine the shear stress in the bolt and bearing stress at C in member BD.



[12 marks]

Do not write in this margin

(d) In trying to move across a slippery icy surface, a 75 kg man uses two ropes, AB and AC. Knowing that the force exerted on the man by the icy surface is perpendicular to the icy surface, determine the tension in each rope.



[12 marks]

Consider the co-ordinate system shown in figure

$\therefore$ B $\vec{OB} = (0\hat{i} + 7\hat{j} + 0\hat{k}) = 7\hat{j}$

A $\vec{OA} = 10\hat{i} + 12\hat{k}$; $\vec{OC} = 0\hat{i} + 6\hat{j} + 16\hat{k} = 6\hat{j} + 16\hat{k}$

$\therefore$ wt of man $= W = (+75 \times 9.81)\,N\,(-\hat{j})$

$$\boxed{W = -735.75\,\hat{j}\ N}$$

$\vec{AB} = \vec{OB} - \vec{OA} = -(10\hat{i} + 12\hat{k}) + (7\hat{j})$

$\vec{AB} = -10\hat{i} + 7\hat{j} + 12\hat{k}$

$\vec{AC} = \vec{OC} - \vec{OA} = (6\hat{j} + 16\hat{k}) - (10\hat{i} + 12\hat{k})$

$\vec{AC} = -10\hat{i} + 6\hat{j} + 4\hat{k}$

T_1 is along $\vec{AB}$ and T_2 is along $\vec{AC}$

Incomplete

2

Q.5 (e) (i) Allowable stress is determined from ultimate strength after considering factor of safety. State the rationale behind considering factor of safety.

(ii) The principal strains at a point loaded biaxially in a strained material are $\epsilon_1 = +500 \times 10^{-6}$, $\epsilon_2 = +300 \times 10^{-6}$. If $E = 200\ kN/mm^2$, $\nu = 0.3$, what are principal stresses?

[6 + 6 marks]

(i) Allowable stress is given by

$$\boxed{\sigma_{allowed} = \frac{\sigma_{UTS}}{FoS}}$$

FoS is considered to account for

(a) Stress concentrations due to presence of surface cracks, voids, etc. in the material. During operation, sometimes the actual load may exceed the design load. FoS also accounts for that. Otherwise if we design based on UTS point & load exceeds a value such that $\sigma > \sigma_{UTS}$, failure will occur instantaneously.

(i)

(ii) $\epsilon_1 = +500 \times 10^{-6}$, $\epsilon_2 = 300 \times 10^{-6}$,

$E = 200\ kN/mm^2 = 2 \times 10^5\ N/mm^2$, $\mu = 0.3$

$\therefore \sigma_1 = \frac{E}{1-\mu^2}[\epsilon_1 + \mu\epsilon_2] = \frac{2\times10^5}{1-0.3^2}[500 + 0.3 \times 300] \times 10^{-6}$

$\therefore \boxed{\sigma_1 = 129.670\ N/mm^2}$

also,

$\sigma_2 = \frac{E}{1-\mu^2}[\epsilon_2 + \mu\epsilon_1]$

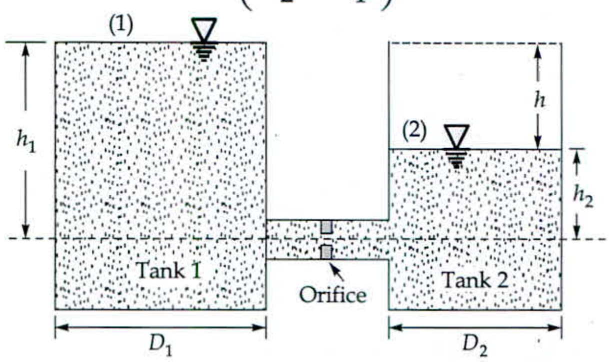
$= \frac{2\times10^5}{1-0.3^2}[300 + 0.3 \times 500] \times 10^{-6}\ N/mm^2$

$\boxed{\sigma_2 = 98.901\ N/mm^2}$

3+6 = 09

Q.6 (a) A system that consists of two interconnected cylindrical tanks with diameter D_1 and diameter D_2 is to be used to determine the discharge coefficient of a short diameter (D_0) orifice. At the beginning ($t = 0$ second), the fluid heights in the tanks are (h_1) and (h_2) as shown in figure. If it takes 't_f' second for the fluid levels in the two tanks to equalize and the flow to stop, then show that the discharge coefficient (C_d) of the orifice is:

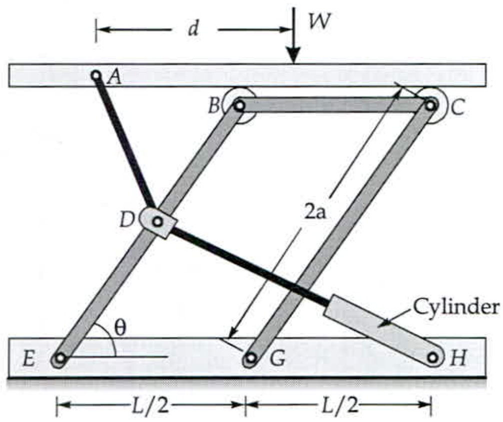
$$C_d = \frac{2\sqrt{(h_1 - h_2)}}{\left(\dfrac{D_0^2}{D_2^2} + \dfrac{D_0^2}{D_1^2}\right) \times t_f \times \sqrt{2g}}$$



Assume that the fluid is incompressible, and losses other than that associated with flow through the orifice are negligible.

[20 marks]

b) A hydraulic lift table is used to raise a 1000 kg crate. Member *EB* and *GC* are equal. Cylinder apply force in the direction *DH*. *D* is at mid point of *EB*. Determine the force exerted by the cylinder in raising the crate for $\theta = 60°$, $a = 0.7$ m, $L = 3.2$ m and $d = 1$ m.



[20 marks]

Do not write in this margin

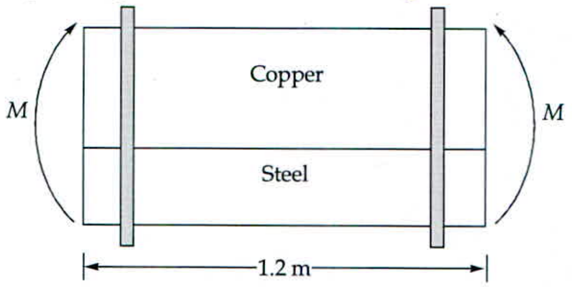
c) A helicopter gas turbine requires an overall compressor pressure ratio of 12 : 1. This is to be obtained using a two-spool layout consisting of a four stage axial compressor followed by a single stage centrifugal compressor. The polytropic efficiency of the axial compressor is 92% and that of the centrifugal compressor is 83%. The axial compressor is having a stage temperature rise of 32 K, using a 50 percent reaction design with a stator outlet angle of 25°. If mean diameter of each stage is 25.0 cm and each stage is identical, calculate the required rotational speed. Assume a work done factor of 0.85 and a constant axial velocity of 160 m/s.

Assuming an axial velocity at the eye of the impeller, an impeller diameter of 35.0 cm, a slip factor of 0.92 and power input factor of 1.04, calculate the rotational speed required for the centrifugal compressor. Ambient conditions are 1.01 bar and 288 K. Take c_p = 1.005 kJ/kgK and γ = 1.4.

[20 marks]

Do not write in this margin

Q.7 (a) Two beams are clamped together as shown in figure:



Both are of equal length and both have 5 cm width. Height of copper beam is 10 cm and that of steel beam is 6 cm. What could maximum moment that can be allowed without any failure of $E_{Cu} = 120$ GPa, $(\sigma_{allowable})_{Cu} = 150$ MPa, $E_{St} = 200$ GPa and $(\sigma_{allowable})_{St} = 250$ MPa?

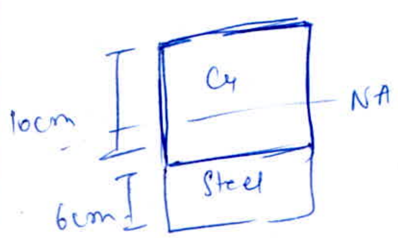
[20 marks]

(Sol^n) The BM at any section is equal to M

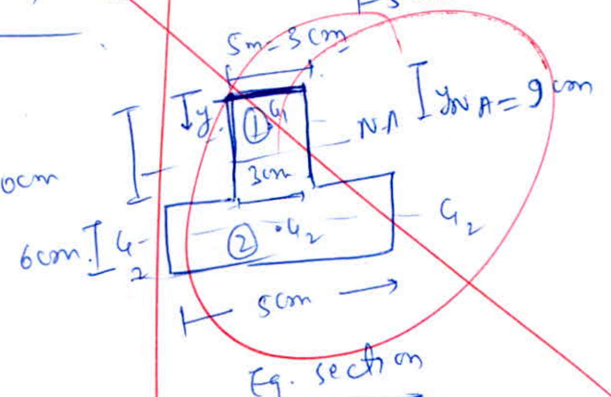
~~Let~~ the max. moment be M.

$\frac{E_C}{E_S} =$

$m = \frac{E_C}{E_S} = \left(\frac{120}{200}\right) = 0.6$



Equivalent section is shown



NOT Flitched Beam

$y_{NA} = \frac{A_1\bar{y}_1 + A_2\bar{y}_2}{A_1 + A_2}$

$A_1 = 3 \times 10 = 30\text{ cm}^2$

$\bar{y}_1 = 10/2 = 5$ cm

$A_2 = 5 \times 6 = 30\text{ cm}^2$

$\bar{y}_2 = 10 + 6/2 = 13$ cm

$\therefore \bar{y}_{NA} = \frac{A_1\bar{y}_1 + A_2\bar{y}_2}{A_1 + A_2} = 9$ cm from top as shown

~~for sect~~ for section (1) $I_1 = I_G + Ad^2 =$

$$I_1 = \frac{(3)(10)^3}{12} + (3)\times 10 \times (9-5)^2$$

$$\boxed{I_1 = 730\ cm^4} = 730\times 10^4\ mm^4.$$

for section (2) $I_2 = \frac{(9 \cdot 4 \cdot 9)^3}{2} + Ad^2$

$$= \frac{(5)(6)^3}{12} + (6\times 5)\times\left(-9+10+\frac{6}{2}\right)^2$$

$$\boxed{I_2 = 570\ cm^4}$$

Don't confused with flitched Beam for this Q. Rsteel = Rcopper Radius of curvature

$$\therefore Z_1 = \frac{I_1}{(y_{max})_1} = \frac{730}{9} = 81.111\ cm^3 = 81.111\times 10^3\ mm^3.$$

$$\therefore Z_2 = \frac{I_2}{(y_{max})_2} = \frac{570}{(-9+16)} = 81.42857\ cm^3 = 81.48\times 10^3\ mm^3$$

$\therefore$ moment resisted by copper (M_{cu}) $= Z_1(\sigma_{allowable})_{cu} = 12.1667$ kN-m $=$ ~~12.1667 kN-m~~

moment resisted by steel (M_{st}) $= (Z_2)\times(\sigma_{allowable})_{st} = 20.357$ kN-m

$\therefore$ total moment resisted $= M_{cu} + M_{st} = 32.523$ kN-m

$\therefore$ max. moment allowed $= \boxed{32.523\ kN\text{-}m}$

0

Q.7 (b) **(i)** For a multi-stage steam turbine having same stage efficiency for all stages. Prove that, $\eta_{internal} = \text{R.F.} \times \eta_{stage}$

(ii) A 20 stage 50% reaction turbine develops a diagram power of 14 MW. The total isentropic enthalpy drop is 900 kJ/kg. The stage efficiency is 76% and the reheat factor is 1.05. The exit angle of blades is 20° and the blade velocity ratio is 0.7.

Calculate:

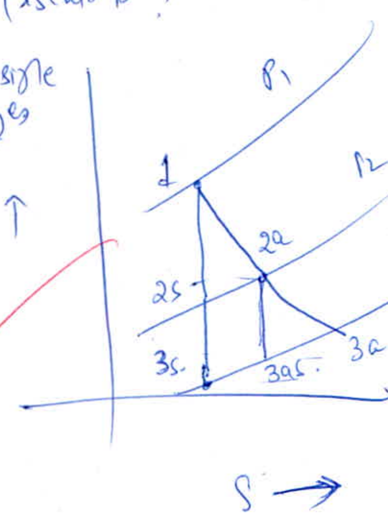
(p) Flow rate of steam required (in kg per hour) if all the stages develop equal work.

(q) Blade velocity

[10 + 10 marks]

(i)

$$R.F = \frac{\text{Heat drop in cumulative stages (isentropic)}}{\text{total isentropic Heat drop in single stages}}$$



η_{stage} = for 1-2

Isentropic Heat drop = $h_1 - h_{2s}$

& actual heat drop = $h_1 - h_{2a}$

for 2 → 3

actual heat drop = $h_{2a} - h_{3a}$

isentropic heat drop = $h_{2a} - h_{3as}$.

Let η_{stage} = stage eff. of all stages

$\therefore$

$(h_{2a} - h_{3a}) = \eta_{stage}(h_{2a} - h_{3as})$ —(i)

& $(h_1 - h_{2a}) = \eta_{stage}(h_1 - h_{2s})$ —(ii)

$\therefore$ $\eta_{internal} = \dfrac{h_1 - h_{3a}}{h_1 - h_{3s}}$ —(iii)

RF = ~~$(h_1 - h_{3a}) = \eta_{stage}(h_{2a} - h_{3as} + h_1 - h_{2s})$~~

$\therefore$ RF = η_{stage}.

$(h_1 - h_{2s}) = \frac{1}{\eta_{stage}}(h_1 - h_{2a})$

$(h_{2a} - h_{3as}) = \frac{1}{\eta_{stge}}(h_{2a} - h_{3a})$

$\therefore \left((h_1 - h_{2s}) + h_{2a} - h_{3as}\right) = \frac{1}{\eta_{stge}}(h_1 - h_{3a})$

Divide by $(h_1 - h_{3s})$ on both sides

$\Rightarrow \left\{\underbrace{\frac{(h_1 - h_{2s}) + (h_{2a} - h_{3as})}{(h_1 - h_{3s})}}_{RF}\right\} = \frac{1}{\eta_{sts}}\left\{\underbrace{\frac{(h_1 - h_{3a})}{h_1 - h_{3s}}}_{\eta_{internal}}\right\}$

$\therefore \boxed{\eta_{internal} = RF \times \eta_{stage}}$

(ii) Given $P = 14\ MW$ for 20 stages.

$(\Delta h)_{isen} = 900\ kJ/kg$, $\eta_{stge} = 76\% = 0.76$

$RF = 1.05$, $\phi = 20° = \alpha$ & velocity ratio $= 0.7$

$\therefore \eta_{internal} = RF \times \eta_{stge} = (1.05) \times 0.76 = \underline{0.798}$

$\therefore \frac{(\Delta h)_{actual}}{(\Delta h)_{isen}} = 0.798 \Rightarrow (\Delta h)_{actual} = \underline{\underline{718.2\ kJ/kg}}$

$P = 14\ MW \Rightarrow \dot{m} \times (\Delta h)_{actual} = P$

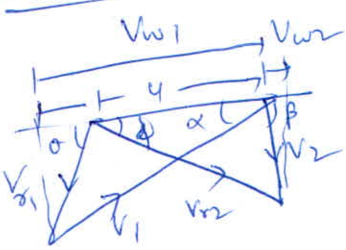
$\therefore \boxed{\dot{m} = 19.4932\ kg/s} = \underline{\underline{70175.4386\ kg/hr}}$

$\beta = 50.1 \Rightarrow 0.5 = \frac{V_f}{2u}(\tan\theta + \tan\phi)$

$\frac{V_f}{u} = 0.7$; $\frac{0.7}{2}(\tan\theta + \tan\phi) = 0.5$; $\phi = 20°$

Calculation error

$\therefore \tan\theta = 1.0648 \Rightarrow \theta = 46.792°$



$\because V_1 = V_{r2},\ V_{r1} = V_2,\ \alpha = \phi,\ \theta = \beta$

$\therefore$ Power/stage $= \dot{m}(V_{w1} + V_{w2})u.$

$V_{w1} + V_{w2} = V_1\cos\alpha + (V_1\cos\phi - u)$

$V_{w1} + V_{w2} = 2V_1\cos\alpha - u = \boxed{2.8465\,u}$

$W/\text{stage} = \dot{m}(2.84654\,u^2) = 55.4874\,u^2 = \frac{14\times10^3}{20}$

$\boxed{u = \sqrt{12.615}\ \text{m/s} = 3.55\ \text{m/s}}$

15

Q.7 (c) Air enters a 10 m long section of a rectangular duct cross section 15 cm × 20 cm made of commercial steel at 1 atm and 35°C at an average velocity of 7 m/s. Disregarding the entrance effects. Determine the fan power needed to overcome the pressure losses in this section of the duct. Assume the flow is steady and incompressible. Consider the air properties at 1 atm and 35°C.

Density, $\rho = 1.145\ \text{kg/m}^3$

Dynamic viscosity, $\mu = 1.895 \times 10^{-5}\ \text{kg/m-s}$

kinematic viscosity, $\nu = 1.655 \times 10^{-5}\ \text{m}^2/\text{s}$

The roughness of commercial steel surfaces, $\varepsilon = 0.000045$ m.

For the friction factor, the governing equation is Colebrook equation:

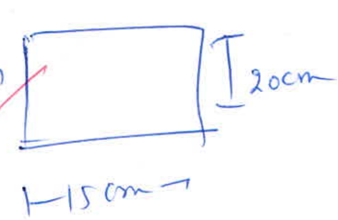
$$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left(\frac{\frac{\varepsilon}{D_h}}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}}\right)$$

where, ε = Roughness of surface, D_h = Hydraulic diameter, Re = Reynolds number, f = Friction factor, $\frac{\varepsilon}{D_f}$ = Relative roughness

[20 marks]

Here, $D_h = \frac{4A}{P}$

$= \frac{4\times(15\times20)}{2(15+20)} = 17.143\ \text{cm}$



c/s of duct

$Re = \frac{\rho D_h V}{\mu} = \frac{D_h V}{\nu} = \frac{(17.143\times10^{-2})\times(7)}{(1.655\times10^{-5})}$

$\therefore \boxed{Re = 72508.157}$

$\therefore$ Using the Rel^n given

$$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left(\frac{\frac{\epsilon}{D_h}}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

$$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left(\frac{\frac{0.000045}{0.17143}}{3.7} + \frac{2.51}{\sqrt{f}\times 72508.157}\right)$$

$$\therefore \frac{1}{\sqrt{f}} = -2.0\log_{10}\left(+7.0945\times10^{-5} + \frac{3.4616\times10^{-5}}{\sqrt{f}}\right)$$

$\therefore \boxed{f = 0.02}$ (solved using calculator) write upto 4 decimal

$\therefore$ head loss $= \frac{f l v^2}{2g d_h} = \frac{(0.02)\times 10\times(7)^2}{2\times 9.81\times(0.17143)}$ m $= \boxed{2.9137 \text{ m}}$

$\therefore \boxed{\Delta P = (\rho_w g)(\gamma_w)(\text{head loss}) = 28.5834 \text{ kPa}}$

$\therefore$ Power required $= (\Delta P)Q$; $Q = V\times(15\times20)\times10^{-4}$ m^3/s

$\Rightarrow Q = 0.21$ m^3/s

$\therefore$ Power required $= (28.5834)\times 0.21$ kW

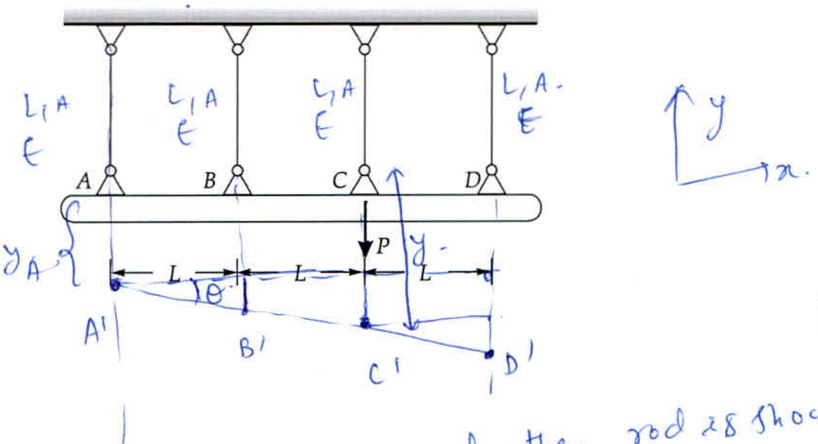
$\boxed{\text{Power} = 6.0025 \text{ kW}}$

16

Not accurate

Do not write in this margin

[redacted]) The rigid rod *ABCD* is hinged with the help of 4 wires of equal length and cross-section area. Determine tension in each wire if force *P* is applied at *C* in downward direction. All the wires have same Young's modulus.



[20 marks]

The final position at equilibrium for the rod is shown

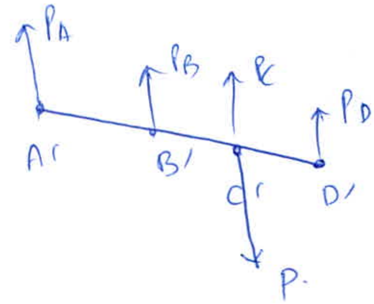
A', B', C', D' are the final positions of wires A, B, C, D.

Let θ = angle of tilt and y = downward deflection at C.

Let P_A, P_B, P_C & P_D be the forces in each wire.

$\therefore \sum F_y = 0 \Rightarrow -P + P_A + P_B + P_C + P_D = 0.$

$$\boxed{P_A + P_B + P_C + P_D = P \quad -(i)}$$



as θ is very small

deflection at A: $y_A = y_C - 2L\theta$

Similarly

$y_B = y_C - L\theta$ $\quad -(ii)$

$y_D = y + L\theta$

$\therefore P_A = $ ~~δ_A = deflection/ length change~~

$\therefore P_A$ = we know

$\delta = \frac{PL}{AE} \Rightarrow y_A = \frac{P_A L}{AE}.$

$\therefore P_A = \left(\frac{AE}{L}\right) y_A - (iii) = \frac{AE}{L}(y_C - 2L\theta) \quad -(iii)$

[redacted]

$P_B = \left(\frac{AE}{L}\right) y_B = \frac{AE}{L}(y_C - L\theta)$ — (iv)

$P_C = \frac{AE}{L} y_C$ — (v)

$P_D = \frac{AE}{L} y_D = \frac{AE}{L}(y_C + L\theta)$ — (vi)

also $\Sigma M_A = 0.$

$\Rightarrow P_B(L) + P_C(2L) - P(2L) + P_D(3L) = 0$

$P_B + 2P_C + 3P_D = 2P$ — (vii)

Improve presentation

(iii) can be written as:

$P = \frac{AE}{L}(y_C - 2L\theta) + \frac{AE}{L}(y_C - L\theta) + \frac{AE}{L} y_C + \frac{AE}{L}(y_C + L\theta)$

$$\boxed{\frac{PL}{AE} = y_C - 2L\theta + y_C - \cancel{L\theta} + y_C + y_C + \cancel{L\theta} = 4y_C - 2L\theta}$$ — (viii)

and (vii) can be written as:

$\frac{AE}{L}(y_C - L\theta) + 2\frac{AE}{L} y_C + \frac{3AE}{L}(y_C + L\theta) = 2P$

$\therefore \frac{2PL}{AE} = (y_C + 2y_C + 3y_C) - L\theta + 0 + 3L\theta$

$\frac{2PL}{AE} = 6y_C + 2L\theta$ — (ix)

19

$\therefore$ Adding (viii) & (ix) we have

$10y_C = \frac{3PL}{AE} \Rightarrow \boxed{y_C = \frac{3}{10}\frac{PL}{AE}}$ $\Rightarrow$ from (viii); $L\theta = \frac{-\frac{PL}{AE} + 4y_C}{2}$

$\boxed{L\theta = \frac{PL}{10AE}}$

$\therefore P_A = \frac{AE}{L}\left(0.3\frac{PL}{AE} - \frac{0.1PL \times 2}{AE}\right)$

$\boxed{P_A = 0.1P}$

$P_B = \frac{AE}{L}(y_C - L\theta) = 0.2P$

$P_C = \frac{AE}{L} y_C = 0.3P$

$P_D = \frac{AE}{L}(y_C + L\theta) = 0.4P$

Check: $P_A + P_B + P_C + P_D = P$ ✓ holds

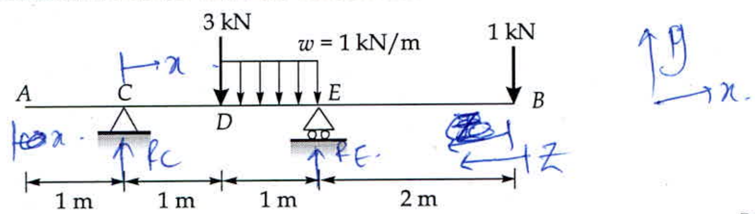
) A compound cylinder is formed by shrinking one cylinder onto the other, the final dimensions become inner diameter of 12 cm, external diameter of 24 cm and junction diameter of 20 cm. After shrinking of outer cylinder over inner cylinder the radial pressure at common surface is 20 N/mm^2. Calculate the necessary difference in diameters of the two cylinders at the common surface. Take $E = 200$ GPa, $\nu = 0.3$ for inner cylinder and $E = 100$ GPa and $\nu = 0.32$ for outer cylinder. What is the minimum temperature through which the outer cylinder should be heated before it can be slipped on?
$\alpha = 11 \times 10^{-6}/°C$ for outer cylinder,

[20 marks]

[redacted]

Do not write in this margin

(c) A beam is loaded as shown in figure. Determine the distance of point of contraflexure from point A and maximum moment and its location.



[20 marks]

at eqlb^m.

Sol^n - $\Sigma F_y = 0 \Rightarrow R_C - 3 - 1\times(1) - 1 + R_E = 0.$

$\therefore \boxed{R_C + R_E = 5 \text{ kN} - (i)}$

$\Sigma M_E = 0 \Rightarrow R_C(1+1) - 3\times(1) - 1\times\frac{1}{2}\times 1 + 1\times(2) = 0.$

$\therefore R_C(2) - 3 - 0.5 + 2 = 0$

$\therefore R_C = 0.75$ kN

from (i) $\boxed{R_E = 5 - R_C = 4.25 \text{ kN}}$

BM: for AC, $BM = 0$; $M_x = 0$ (as no shear & $M_A = 0$)

$S_x = 0$

for CD: $S_x = R_C = 0.75$ kN

$M_x = R_C x = 0.75 \times x$ kN-m

for DE: $S_x = \cancel{R_C - 3 - w(x-1)} \quad \cancel{2.25\,x}$ (kN)

$= R_C - 3 - w(x-1) = -2.25 - (x-1)$

M_x ~~$R_C(x-1) - 3(x-1) - w($~~

$= R_C(x-1)$

$M_x = 0.75x - 3(x-1) - w\frac{(x-1)^2}{2}$ kN-m

$= 0.75x - 3x + 3 - \frac{(x-1)^2}{2}$

$= 3 - 2.25x - \frac{(x-1)^2}{2}$

for BE: Consider from the right side

$M_x = -(1) \times (z) = -z$ kN-m.

Point of contraflexure is the point where BM changes sign i.e. it becomes zero.

lets Check for DE (as it cannot change sign in AD)

$\therefore M_x = 0 \Rightarrow 3 - 2.25x - \frac{(x-1)^2}{2} = 0$

$\therefore 2(3 - 2.25x) - (x^2 + 1 - 2x) = 0$

$\Rightarrow -x^2 - 2.5x + 5 = 0$

$\therefore x = -3.8117$ m or 1.3117 m

$\therefore x > 0$ and $1 m < x < 2$ m

$\therefore \boxed{x = 1.3117\text{ m}}$

Similarly for BE, $M_x \neq 0$ always -ve

$\therefore$ only point of contraflexure: $x = 1.3117$ m from C

$\boxed{\therefore \text{Distance from A} = (1 + 1.3117) = 2.3117 \text{ m}}$

Max. moment: in AC = 0

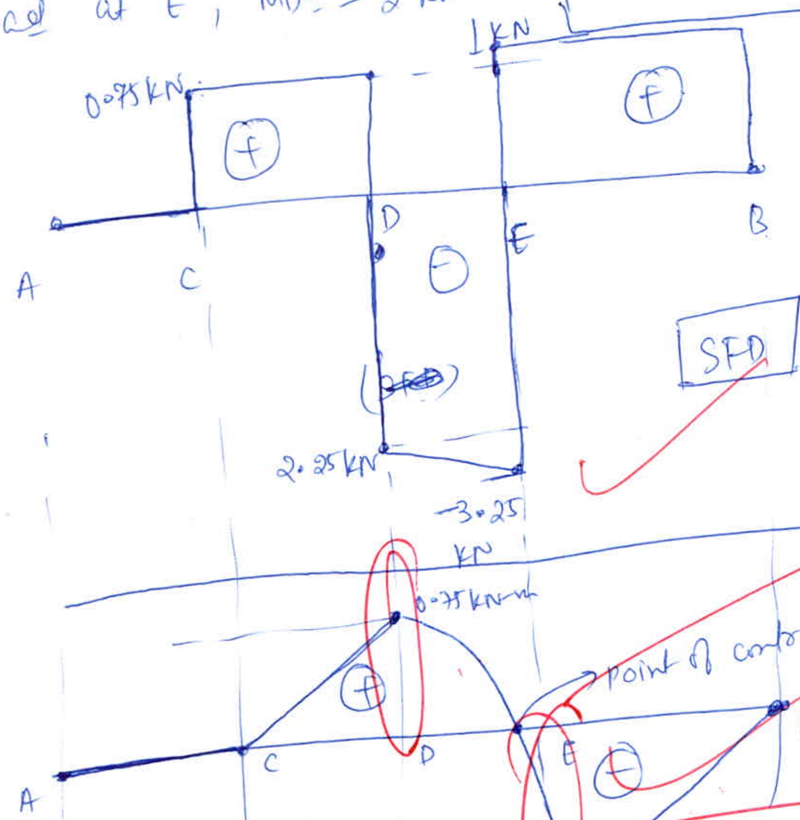
in CD, $M|_{max} = 0.75 \times (1) = 0.75$ kN-m.

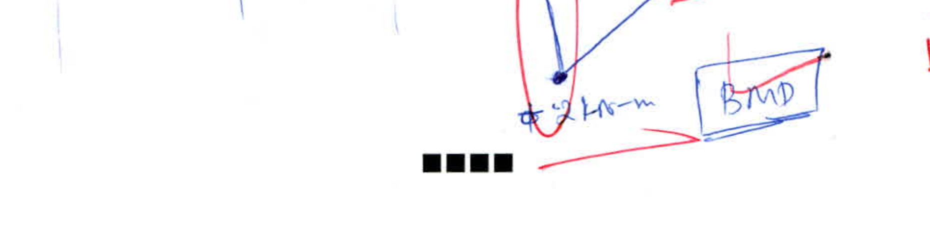
in DE: ~~$\frac{dm}{dx} = 0, S_x = 0 \Rightarrow -2.25 - x + 1 = 0$~~

at D, S_x changes sign,

$\therefore M_D = M_{max}$ in DE $= M_x|_{x=1m} = 0.75$ kN-m.

and at E, $M_D = -2$ kN-m $\Rightarrow$ $\boxed{\text{Max. BM} = -2 \text{ kN-m @ } x = 3m \text{ from A}}$





(19)

height of diagrams seems incorrect ~~diagram~~ should be corresponding to given values

■■■■

$\cancel{u = 4x + \dots}$

$u = 4x = x'$; $4t + c_1 = \ln(x)$

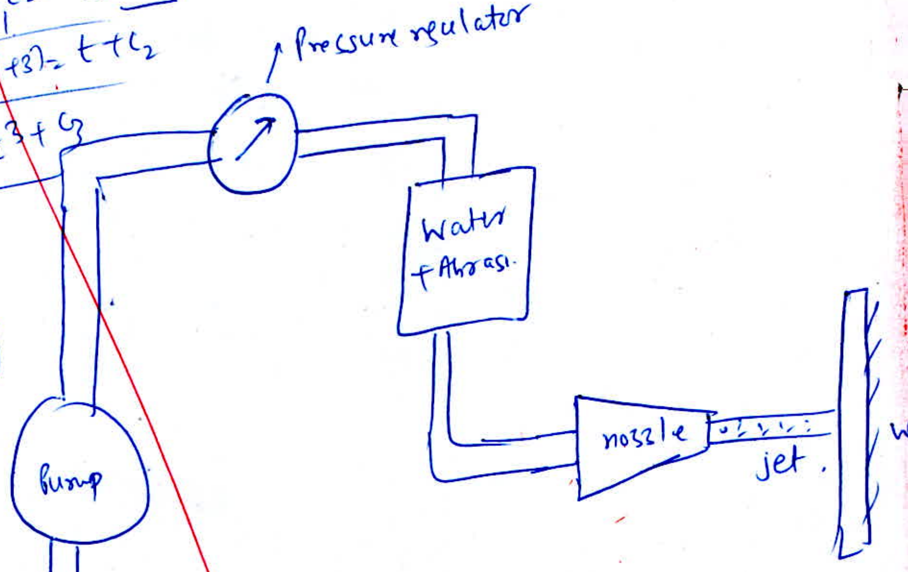
$v = 5y + 3 = y'$ $\Rightarrow$ $\ln(5y+3) = t + c_2$

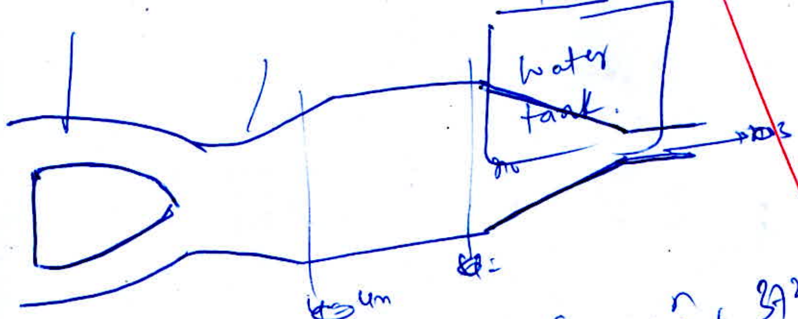
$w = 3t^2 = \frac{dz}{dt}$; $z = t^3 + c_3$

$4 + c_1 = \ln(1)$

$\boxed{\ln x = 4t - 4}$

$x = e^{4t-4}$





$\vec{V} = 4x\hat{i} + (5y+3)\hat{j} + 3t^2\hat{k}$

$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w}$

$\frac{dx}{4x} = \frac{dy}{5y+3} = \frac{dz}{3t^2} = k$

$\cancel{x = 2x^2 k + c_1}$ (1)

$\frac{dx}{dt} = 4x$

$\frac{dy}{dt}$

$\frac{dz}{dt}$