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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 : Bhosale Harshal Dhyaneshwar

Roll No : M E 1 9 M B D L C 6 6 0

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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	53
Q.2	—
Q.3	—
Q.4	31
Section-B	
Q.5	18
Q.6	—
Q.7	31
Q.8	55-3=52
Total Marks Obtained	185

Signature of Evaluator: SM

Cross Checked by

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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]

→ $APF = 0.547 = \frac{\text{volume of atom occupied by atom}}{\text{volume of unit cell}}$

$$0.547 = \frac{n \times \frac{4}{3}\pi r^3}{a \times b \times c} = \frac{n \times 4/3 \times \pi \times 0.177^3}{0.479 \times 0.725 \times 0.978}$$

$n = 7.998$

$\boxed{n \simeq 8}$ ← no. of atom.

→ density of Iodine

$N_A = 6.022 \times 10^{23}$ Avagadro No.

$$\rho = \frac{\text{No. of atom} \times \text{Atomic weight}}{\text{Avagadro No} \times \text{volume of unit cell}}$$

$$\rho = \frac{8 \times 126.9 \text{ g/mol}}{6.022 \times 10^{23} \times (0.479 \times 0.725 \times 0.978) \times 10^{-21}}$$

$= 4.96 \text{ gm/cm}^3$

$= 4960 \text{ kg/m}^3$.

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]

$L = 150\,mm$

$f_t = 0.2\,mm/tooth$

$D = 120\,mm$

$d = 20\,mm$

$Z = 10$

$F =$ feed in mm/min

$= f_t \times N \times Z = 0.2 \times N \times Z$

$V = \pi d N = 40 = \pi \times 0.12 \times N$

$N = 106.1\,rpm$

$F = 0.2 \times 106.1 \times 10$

$= 212.2\,mm/min$

L_T = Length of tool travelled $= L_W + L_A$

$= 150 + \sqrt{d(D-d)} = 150 + \sqrt{20 \times (120-20)}$

$= 194.72$ mm.

time Required to cut

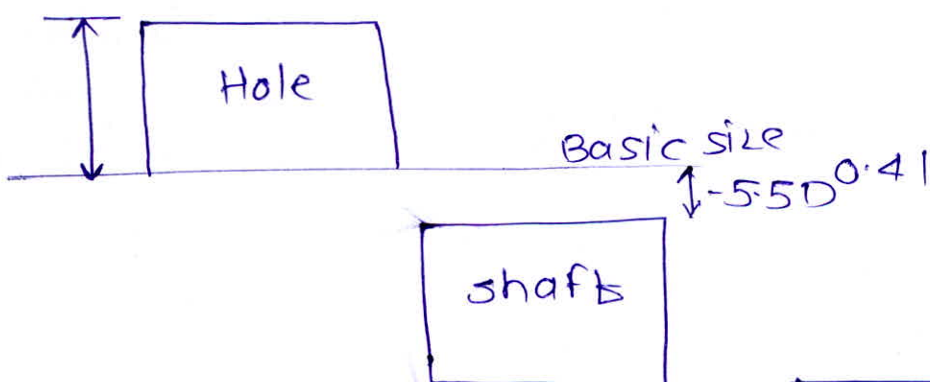
$= \frac{L}{f} = \frac{194.72}{212.2} = 0.92$ min

$= 55.06$ sec

12

(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]



$i = 0.45\sqrt[3]{D} + 0.001D$ $\quad D = \sqrt{18 \times 30} = 23.24$ mm

$i = 1.3073$ µm

Tolerance on Hole

$= 1.3073 \times 25 = 32.6844$ µm

$= 0.0326$ mm

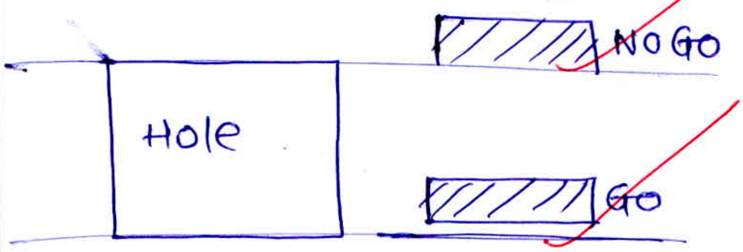
Tolerance on shaft

$= 1.3073 \times 40 = 0.0523$ mm

→ fundamental deviation of shaft.

$= -5.5(\sqrt{18\times30})^{0.41}$

$= -0.0198$ mm.



Gauge tolerance $= \frac{1}{10}$ work tolerance.

$= \frac{1}{10}\times 0.0326 = 0.00326$ mm

Neglecting wear allowance we get.

Hole. Go gauge

Lower limit = 25.00 mm

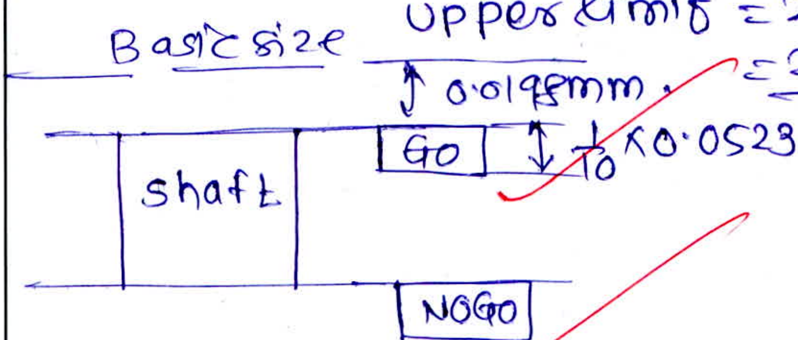
upper limit = 25.00326 mm

No. Go Gauge lower limit = 25 + 0.0326

= 25.0326 mm

upper limit = 25.0326 + 0.00326

= 25.03586 mm



$\frac{1}{10}\times 0.0523 = 0.00523$ mm

12

upper limit of Go Gauge.

$= 25 - 0.0198 = 24.9802$ mm.

Lower limit of Go Gauge

$= 24.9802 - 0.00523 = 24.9749$ mm

Upper limit of No. Go Gauge

$= 25 - 0.0198 - 0.0523 = 24.9279$ mm

Lower limit of No. Go gauge

$= 24.9279 - 0.00523$

$= 24.92267$ mm

(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 → when a Reversible stresses, or fluctuating ~~stresses~~ stresses is applied on a component, then the ~~m~~ fails below this yield point due to this Repeated stresses which is known as fatigue.

Factors necessary for fatigue failure

(I) No. of cycles of operation.
→ As No. of cycles of operation increases fatigue strength decreases.

(II) Surface Irregularities of component.
– more the Surface Irregularities lesser the fatigue Resistance. Hence highly polished surface has a higher fatigue Resistance than a Rough surface

(III) Type of load:
fatigue failure also depends upon the type of load. because ~~to~~ In axial load the surface Irregularatives causes earlier failure than bending load
(Sea) = 0.8Se.

(IV) Type of operation used:
for a ~~forging~~ forged component has a higher fatigue Resistance than a casted component.

write more factors.

stages ??

06

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]

→ we know that

$$\tau_s = \frac{F_s}{t_1 b} \times \sin\phi.$$

$$P_c = \frac{F_c \times V_c}{t_1 b \times V_c} = \frac{F_c}{t_1 b}$$

$$\frac{\tau_s}{P_c} = \frac{F_s}{F_c} \times \sin\phi$$

we know that $\tan\phi = \frac{r \cdot \cos\alpha}{1 - r\sin\alpha}$

$\alpha = 0^\circ$

$\tan\phi = r.$ ϕ = shear angle

$$\frac{\tau_s}{P_c} = \frac{F_s}{F_c} \times \sin\phi.$$

$\tan(\beta - \alpha) = \frac{F_V}{F_H}$ $\qquad \frac{F_V}{F_H} = \tan\beta = \mu$

$F_V = \mu \cdot F_H$ — (1)

From Merchant circle

$F_S = F_H \cos\phi - F_V \sin\phi$ from eq^n

$= F_H \cos\phi - \mu F_H \sin\phi$

$F_S = F_H(\cos\phi - \mu \cdot \sin\phi)$ — (2)

Hence

$$\frac{\tau_s}{P_c} = \frac{F_C[\cos\phi - \mu \cdot \sin\phi]}{F_C} \times \sin\phi$$

$$\frac{\tau_s}{P_c} = (\cos\phi - \mu\sin\phi) \times \sin\phi$$

$$= \left[1 - \mu \cdot \frac{\sin\phi}{\cos\phi}\right] \times \cos\phi \cdot \sin\phi$$

$$= [1 - \mu r] \times \cos^2\phi \cdot \left[\frac{\sin\phi}{\cos\phi}\right]$$

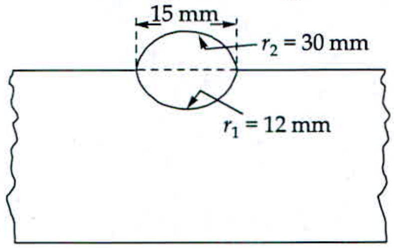
$$= \frac{\tan\phi\,[1 - \mu r]}{\sec^2\phi}$$

$$= \frac{r \cdot [1 - \mu r]}{1 + \tan^2\phi}$$

$$\boxed{\frac{\tau_s}{P_c} = \frac{r[1 - \mu r]}{1 + r^2}}$$

12

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]

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

[20 marks]

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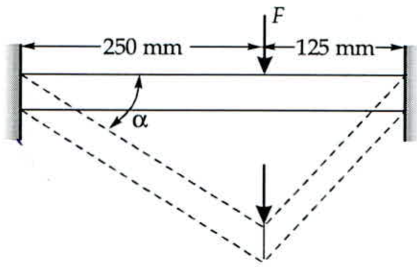
(c) Explain the principle of abrasive water-jet machining using suitable schematic diagram. Write the advantages and applications of AWJM.

[20 marks]

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



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

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

[20 marks]

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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]

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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.

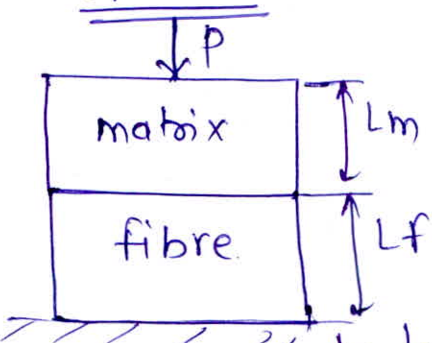
[20 marks]

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]

E_s longit $= 33$ Gpa $(E_s)_{tr} = 3.65$ Gpa

$V_f = 0.3$



In a transeverse direction. Load shared by each member is same

$P_m = P_f$

but the total deflection.

$$\delta = \delta_m + \delta_f$$

$$\left(\frac{PL}{AE}\right)_{eq} = \frac{P_m \times L_m}{A_m E_m} + \frac{P_f \times L_f}{A_f \times E_f}$$

$$\frac{L_{eq}}{E_{eq}} = \frac{L_m}{E_m} + \frac{L_f}{E_f}$$

$$\left(\frac{A L_{eq}}{E_{eq}}\right) = \frac{A_m \times L_m}{E_m} + \frac{A_f \times L_f}{E_f}$$

$$\frac{1}{E_{eq}} = \frac{\frac{A_m \times L_m}{A \times L_{eq}}}{E_m} + \frac{\frac{A_f \times L_f}{A \times L_{eq}}}{E_f}$$

$\frac{A_m \times L_m}{A \times L_{eq}} = \%$ volume of matrix

$\frac{A_f \times L_f}{A \times L_{eq}} = \%$ of volume of fibre

$$\left[\frac{1}{E_{eq}} = \frac{\% V_m}{E_m} + \frac{\% V_f}{E_f}\right] \quad \text{--- (1)}$$

similarly after deriving for a longitudinal direction.

$$E_{eq} = \% E_m + \% V_f E_f$$

$$33 = 0.7 \times E_m + 0.3 \times E_f.$$

fora transverse direction

$$\frac{1}{3.65} = \frac{0.3}{E_f} + \frac{0.7}{E_m}$$

$$\frac{33 - 0.7E_m}{0.3} = E_f$$

$$\frac{1}{3.65} = \frac{0.3 \times 0.3}{33 - 0.7E_m} + \frac{0.7}{E_m}$$

$E_m = 2.58$ GPa

$$E_f = \frac{33 - 0.7 \times 2.58}{0.3} = 103.98 \text{ GPa}$$

$E_m = 2.58$ GPa

$E_f = 103.98$ GPa.

Derivation incorrect

12

$\sigma_m = \sigma_f = \sigma_c$

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

[20 marks]

→ Hardening is a process of increasing hardenability of steel by converting Austenite structure into a martensite structure

(i) It increases Hardness of steel.
(ii) It also increases strength of a mtl.
(iii) It converts Austenite structure into a martensite structure
(iv) It Reduces ductility and ~~to~~ malleability of material.

→ Types of case hardening:-
(i) carburizing
(ii) Nitriding
(iii) cynaiding
(iv) Flame hardening
(v) Induction hardening

(i) carburizing:-
In a carburizing, carbon is diffused on a case or a surface.
the mtl which are Required to be hardened is placed in a $CaCO_2$ container where It is heated to Austenizing Temp. due to this carbon is diffused on the surface.
which increases hardness of a surface but core Remains tough.
It Requires longer time.

Nitriding:-

→ Hardeness of Nitriding component is more than the carburized component

→ In this a Nitrogen is diffused on a surface of a component by placing a component in a NH_3 container.

→ It makes a componet brittle hence further heat treatment is Required.

(iii) → Flame hardening:-

- Flame hardening is used for a medium carbon steel.

- In this a flame such as oxidizing is used for heating of a component this heated component cools Rapidly and converts into martensite structure.

(iv) Induction hardening:-

In a Induction harding a component which is to be hardened is placed in a coil through which current is passed.

due to this the eddy current is takes place @ surface which increases temp. of metal.

by a proper cooling, hardening is obtained.

the thickness of hardened component

$$x = 5000\sqrt{\frac{\rho}{\mu f}}$$

6 (14)

Mention temperatures !!

Cyaniding theory ??

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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.

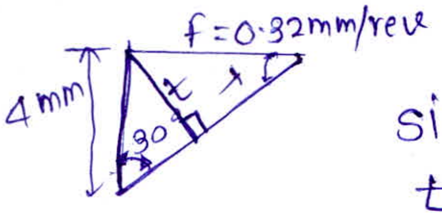
(iii) Cutting power consumption in kW.

[20 marks]

→ Approach angle $\lambda = 60^\circ$.

$\alpha = 0^\circ$ $N = 600$ rpm

$f = 0.32$ mm/rev.



$\sin\lambda = \frac{t}{0.32}$

$t_1 = 0.277$ mm

$\cos 30 = \frac{4}{b}$ $b = 4.6188$ mm

$r = \frac{t_1}{t_2} = \frac{0.277}{0.8} = 0.34625$

$\phi = 19.08^\circ$ ← shear angle.

$F_c = 1000$ N $F_t = 200$ N

α is negative

(i) friction force

$F = 200$ N

(ii) Normal force, N

$N = 1000$ N.

(iii) yield shear strength of work.

$\tau = \frac{F_s}{t_1 b} \times \sin\phi$

$F_s = F_H \cdot \cos\phi - F_V \cdot \sin\phi$

$= 1000 \times \cos 19.08 - 200 \times \sin(19.08)$

$= 879.685$ N.

$$\tau_s = \frac{879.685}{4 \times 0.32} \times \sin(19.08).$$

$$= \underline{224.65\ N/mm^2}$$

(III) cutting power consumption in kW.

$$= F_c \times V_c$$

$$V_c = \frac{\pi d N}{60} = \frac{\pi \times 0.18 \times 600}{60}$$

$$= \underline{5.65\ m/s}.$$

$$P = 1000 \times 5.65 =$$

$$= \underline{5.65\ kW}.$$

Method correct

05

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

5 (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]

$u = 4x \qquad v = 5y+3 \qquad w = 3t^2$

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

$\frac{dx}{x} = 4dt \qquad \frac{dy}{5y+3} = dt \qquad z = t^3 + c_3$

$x = e^{4t} + c_1 \qquad \frac{\ln(5y+3)}{5} = t + c_2$

~~$5y+3 = 5t$~~

~~$y = \left(\frac{5t-3}{5}\right)$~~

~~$= e^{4t} i + \left(\frac{5t-3}{5}\right) \hat{j} + t^3 \hat{k}$~~

~~$= e^4 + \left(\frac{2}{5}\right) \hat{j} +$~~

(1)

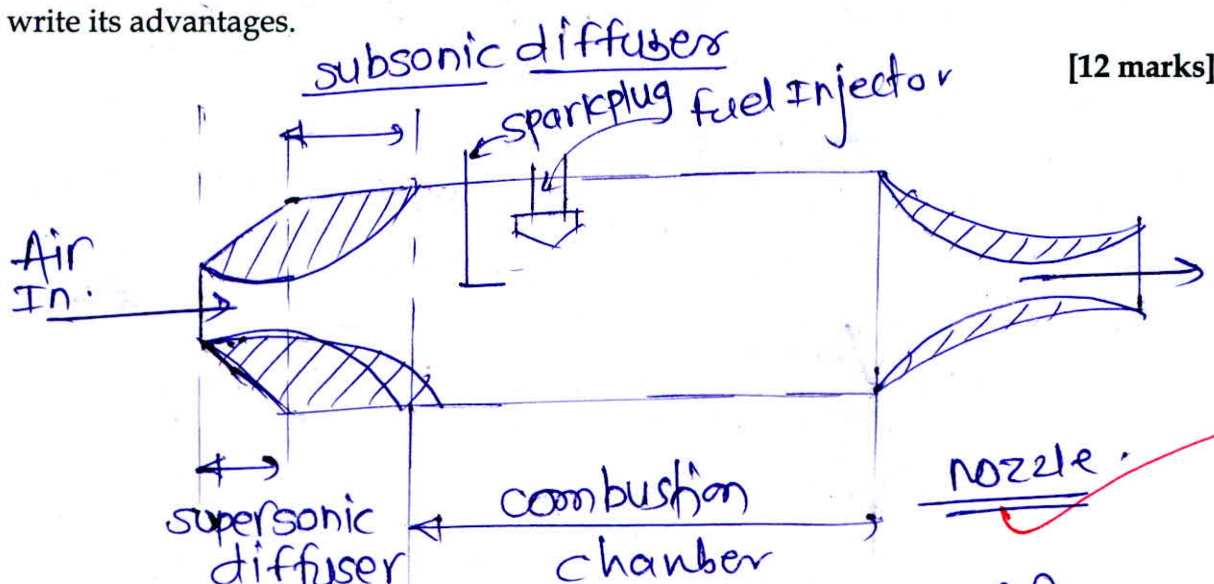
$5y+3 = e^{5t} \qquad y = \frac{e^{5t}-3}{5}$

$\bar{x} = e^{4t} \hat{i} + \frac{e^{5t}-3}{5} \hat{j} + t^3 \hat{k}$

Combine x, y, z and make single eqn

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 works on the principle of Ram compression i.e. by converting a high kinetic energy of air converts into the Ram pressure in a diffuser.

→ A supersonic air M>2 to 3 is comes into a supersonic diffuser where further pressure increases due to Ramming action (As M>1 convergent diffuser is used).

→ Now the ~~at~~ this compressed air flows through a subsonic diffuser (M<1) where further pressure increases. (divergent diffuser is used because M<1).

→ This high pressurized air flows through a combustion chamber where fuel inject into ~~inf~~ it and combustion takes place.

→ This high pressure, high Temp gas exhaust through a nozzle in a backward direction which gives thrust in a forward direction.

Advantages:

→ (i) ~~Not~~ In a Ramjeet there is no compressor, turbine. It is simple in a construction.

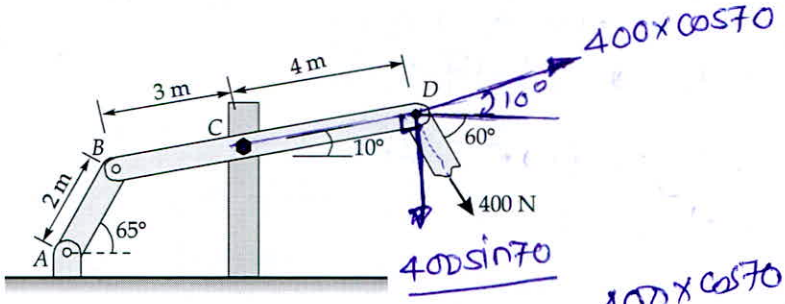
→ (ii) It is simple in a construction.

→ (iii) It can fly at a high speed as 600 m/s

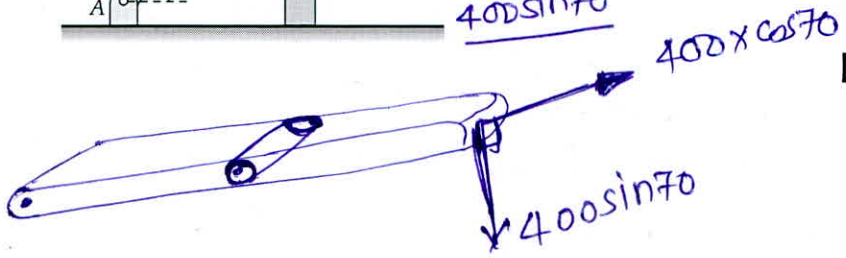
→ (iv) It can operates in a gaseous or ~~solid~~ liquid fuel also because there is no use of a turbine.

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]



$d_{bolt} = 2\text{ cm} = 20\text{ mm}.$

~~direct~~ shear stress in a bolt.

$$= \frac{400}{\frac{\pi}{4}\times 20^2} = 1.27\ \text{N/mm}^2$$

~~torsional shear stress~~

~~$$= \frac{400\times\sin70\times4000\times16}{\pi\times20^3}$$~~

* bearing stress @ C in member BD

$$= \frac{400\times\cos70}{100\times20} = 0.0684\ \text{N/mm}^2$$

(0)

See soln

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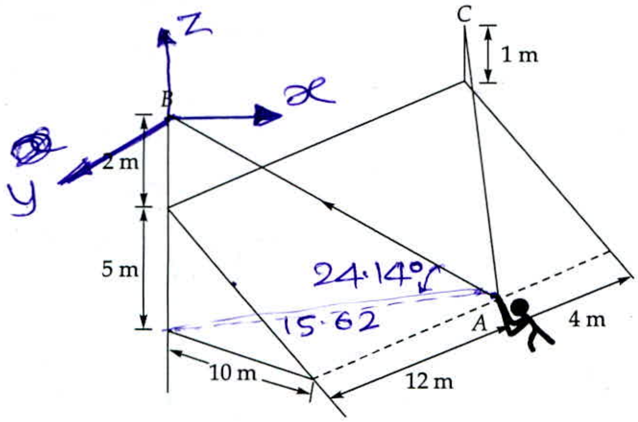
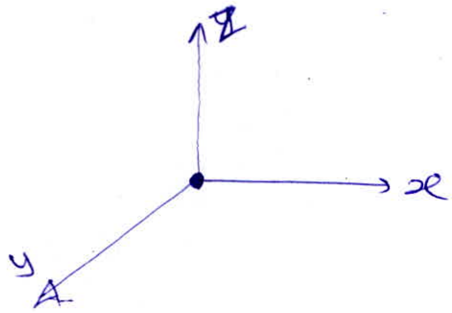
5 (d) In trying to move across a slippery icy surface, a 75 kg man uses two ropes, *AB* and *AC*. Knowing that the force exerted on the man by the icy surface is perpendicular to the icy surface, determine the tension in each rope.



[12 marks]



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 $\in_1 = +500 \times 10^{-6}$, $\in_2 = +300 \times 10^{-6}$. If $E = 200$ kN/mm², $\nu = 0.3$, what are principal stresses?

[6 + 6 marks]

→ (1) Factor of safety = $\frac{\text{Ultimate strength}}{\text{Allowable strength}}$

Allowable strength = $\frac{\sigma_{ut}}{FOS}$

- So, Allowable strength of a m/c is always less than a FOS, because the ultimate strength of a m/c is considered by Testing only one dimensional load in a universal Testing m/c Applying steady load.

- But in actual practice there is a three dimensional stress with a fatigue and Impact load.

Hence, the url will be fail much below than, that of a ultimate strength of a material.

→ Hence factor of safety is provided to safeguard the url against such failure

(11) $\varepsilon_1 = 500 \times 10^{-6}$

$\varepsilon_2 = 300 \times 10^{-6}$

$E = 2 \times 10^5 \ N/mm^2$

$\nu = 0.3$.

principal strains

$$\sigma_1 = \frac{E}{1-\nu^2}(\varepsilon_1 + \nu \cdot \varepsilon_2)$$

$$= \frac{2 \times 10^5}{1-0.3^2}(500 \times 10^{-6} + 0.3 \times 300 \times 10^{-6})$$

$$= 129.67 \ N/mm^2$$

$$\sigma_2 = \frac{E}{1-\nu^2}(\varepsilon_2 + \nu \cdot \varepsilon_1)$$

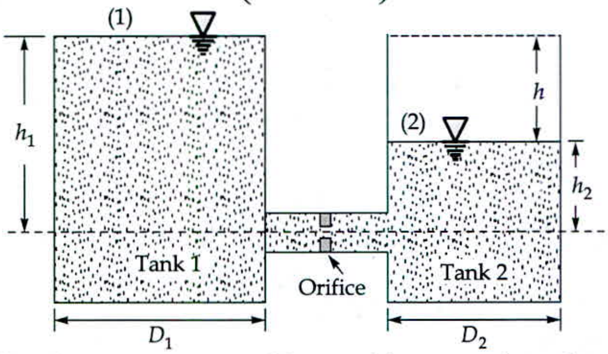
$$= \frac{2 \times 10^5}{1-0.3^2}(300 \times 10^{-6} + 0.3 \times 500 \times 10^{-6})$$

$$= 98.9 \ N/mm^2$$

7

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:

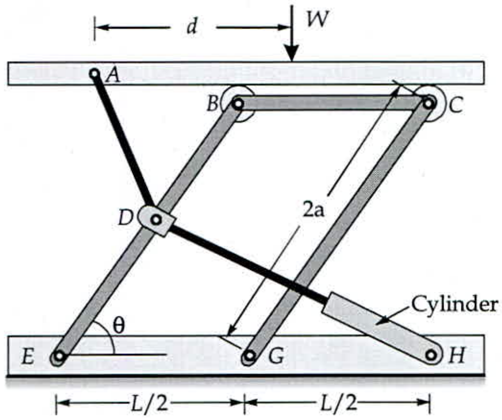
$$C_d = \frac{2\sqrt{(h_1 - h_2)}}{\left(\frac{D_0^2}{D_2^2} + \frac{D_0^2}{D_1^2}\right) \times t_f \times \sqrt{2g}}$$



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

[20 marks]

5 (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.



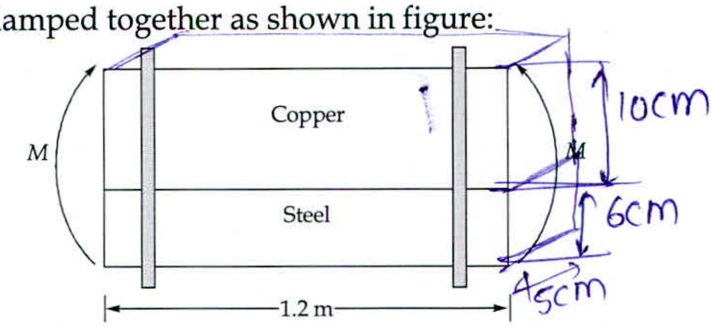
[20 marks]

5 (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 288K. Take c_p = 1.005 kJ/kgK and γ = 1.4.

[20 marks]

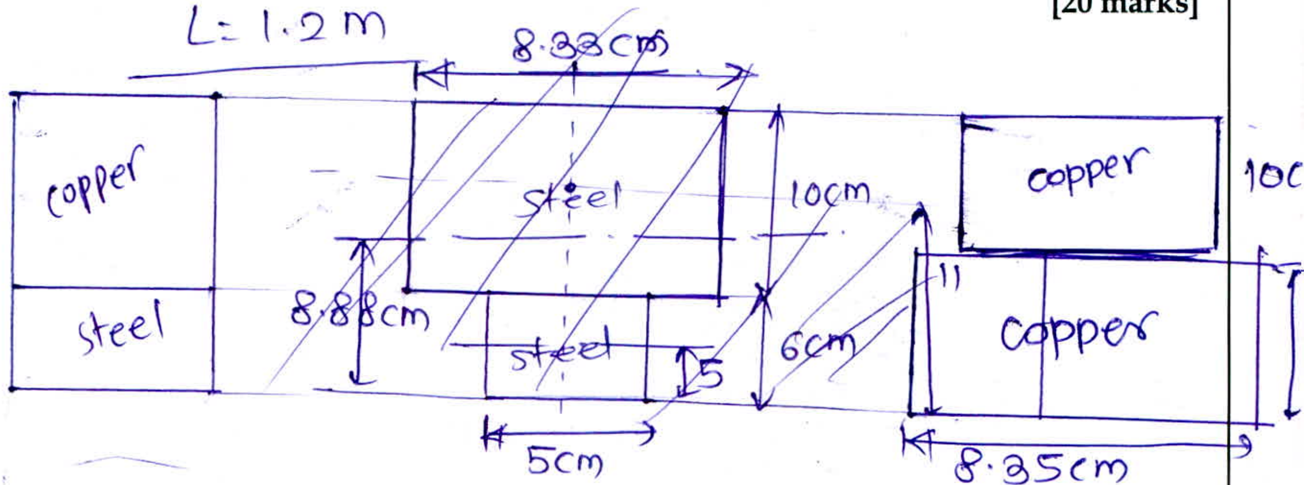
Q.7 (a) Two beams are clamped together as shown in figure:



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]

L = 1.2 m



$m = \frac{E_{st}}{E_{cu}} = \frac{200}{120} = \cancel{8.33} \; 1.67$

→ position of N.A

$\bar{y} = \frac{A_1 y_1 + A_2 y_2}{A_1 + A_2} = \frac{5\times6\times3 + 8.33\times10\times(11)}{8.33\times10 + 5\times6}$

$\bar{y} = 8.88\text{cm}$

Moment of Inertia about the N.A :-

$I = I_1 + I_2$

$I = \frac{5\times6^3}{12} + 5\times6\times(8.33-5)^2 + \frac{8.33\times10^3}{12} + 8.33\times10\times(11-8.33)^2$

$= 1710.67 \text{ cm}^4$

$\bar{y} = \frac{8.35\times6\times3 + 10\times5\times11}{8.35\times6 + 50} = 7\text{cm}$ from bottom

$I = I_1 + I_2$

$= \frac{8.35\times6^3}{12} + 8.35\times6\times(7-3)^2 + \frac{5\times10^3}{12} + 5\times10\times(11-7)^2$

$= 2166.65 \text{ cm}^4$

$(\sigma_{max})_{steel} = \frac{M}{I} \times y$

$(250) = \frac{M}{1710.67 \times 10^4} \times 88.8$

$M = 48.16 \times 10^6$ N·mm

we know that at junction.

$\varepsilon_s = \varepsilon_{copper}$

we know that strain at a junction

$(\varepsilon_c) = (\varepsilon_s)$

$\left(\frac{\sigma_c}{E_c}\right) = \left(\frac{\sigma_s}{E_s}\right)$

$(\sigma_c) = \frac{M}{I} y_{max} = 150 = \frac{M \times 90}{2166.65 \times 10^4}$

$M_{max} = 36.11 \times 10^6$ N·mm

This is case of two beams, not composite beam

checking

$\frac{150}{120} = \frac{\sigma_s}{200}$

$\sigma_s = 250$ MPa.

Hence maximum bending moment

$M_{max} = 36.11$ kN·m

00

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

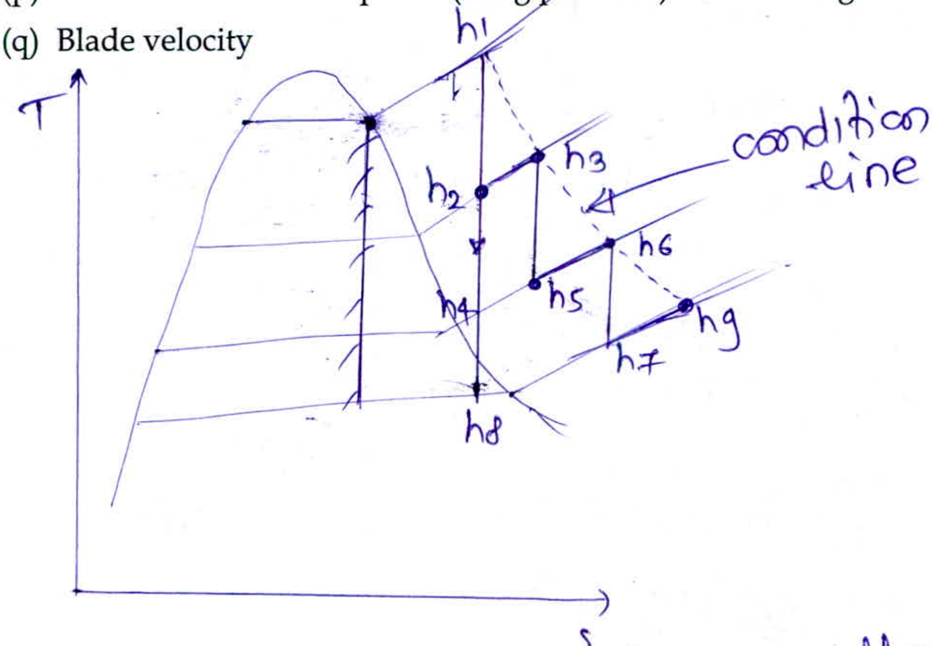
(ii) A 20 stage 50% reaction turbine develops a diagram power of 14 MW. The total isentropic enthalpy drop is 900 kJ/kg. The stage efficiency is 76% and the reheat factor is 1.05. The exit angle of blades is 20° and the blade velocity ratio is 0.7.

Calculate:

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

(q) Blade velocity

[10 + 10 marks]



Reheat factor = $\frac{\text{cumulative enthalpy drop}}{\text{total Isentropic drop}}$ in each stage

$$R.F = \frac{(h_1-h_2)+(h_3-h_5)+(h_6-h_7)}{(h_1-h_8)}$$

$$\eta_{stage} = \frac{h_1-h_3}{h_1-h_2} \qquad h_1-h_2 = \frac{h_1-h_3}{\eta_{stage}}$$

$$RF = \frac{\frac{h_1-h_3}{\eta_{stage}} + \frac{h_3-h_6}{\eta_{stage}} + \frac{h_6-h_9}{\eta_{stage}}}{h_1-h_8}$$

$$RF = \frac{\frac{1}{\eta_{stage}}[h_1-h_9)}{h_1-h_8}$$

$$RF = \frac{1}{\eta_{stage}} \times \left(\frac{h_1-h_9}{h_1-h_8}\right)$$

$$\eta_{internal} = \frac{\text{Actual enthalpy drop}}{\text{Isentropic enthalpy drop}} = \frac{h_1-h_9}{h_1-h_8}$$

$RF = \frac{1}{\eta_{stage}} \times \eta_{Internal}$

$\boxed{\eta_{Internal} = R \cdot F \times \eta_{stage}}$ $\eta_{Internal} > \eta_{stage}$

because as Reheating increases the pressure line diverges from each other.

10

(ii)

$\eta_{Internal} = 1.05 \times 0.76$

$= 0.798 = \frac{900}{(\Delta h)_{Total}}$

total isentropic enthalpy is given

$(\Delta h)_{Total} = 1127.81$ kJ/kg ← Isentropic

(i) Flow Rate of steam Required

$1127.81 \times \dot{m}_{steam} = 14 \times 10^3$

$\dot{m}_{steam} = 12.41$ kg/sec

$\dot{m}_{steam} = 44688.36$ kg/hr

(q) blade velocity

$\rho = \frac{U_b}{V_1} = 0.7$

$U_b = 0.7 V_1$

1

enthalpy drop per stage $= \frac{1127.81}{20}$

$= 56.3905$ kJ/kg.

$V_1 = \sqrt{\left(\frac{\Delta h}{2}\right) \times 2 \times 1000}$

$V_1 = \sqrt{\left(\frac{56.39}{2}\right) \times 2 \times 1000}$

$V_1 = 237.47$ m/s.

nozzle efficiency is not known

$U_b = 0.7 \times 237.47$

$U_b = 166.23$ m/s

stage efficiency is given

11

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, $\mu = 1.895 \times 10^{-5}$ 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]

→ $DH = \frac{4A_c}{P}$ = Hydraulic dia

$DH = \frac{4 \times 15 \times 20}{2[15+20]} = 17.14\text{ cm} = 0.1714\text{ m}$

$Re = \frac{\rho \bar{V} DH}{\mu} = \frac{1.145 \times 7 \times 0.1714}{1.895 \times 10^{-5}}$

$= 72494.51 > 2300$ → Hence flow is turbulent

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$$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left[\frac{\frac{0.000045}{0.1714}}{3.7} + \frac{2.51}{Re\sqrt{f}}\right]$$

$f = 0.02036$ friction factor

→ Head loss in a duct

$$h_f = \frac{fLV^2}{2gD_H} = \frac{0.02036 \times 10 \times 7^2}{2 \times 9.81 \times 0.1714}$$

$h_f = 2.97$ m

so fan power needed to suct the air

$= \rho g Q h_f$

$= 1.145 \times 9.81 \times 0.15 \times 0.2 \times 7 \times 2.97$

$= 7.006$ Watt

$= 7$ watt

20

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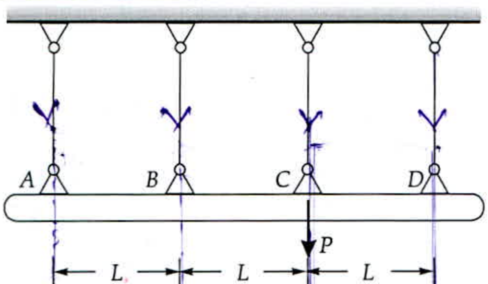
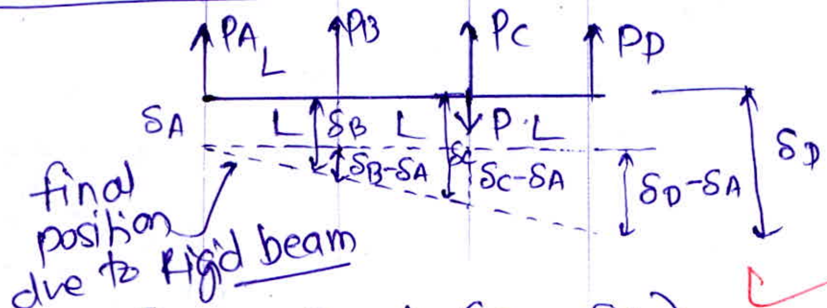
(a) The rigid rod *ABCD* is hinged with the help of 4 wires of equal length and cross-section area. Determine tension in each wire if force *P* is applied at *C* in downward direction. All the wires have same Young's modulus.



[20 marks]

$P = P_A + P_B + P_C + P_D$ for equ balance



$$(\delta_B - \delta_A) = \frac{1}{2}(\delta_C - \delta_A)$$

$$\delta_B - \delta_A = \frac{1}{2}\delta_C - \frac{1}{2}\delta_A$$

$$\delta_B = \frac{1}{2}\delta_C + \frac{1}{2}\delta_A = \frac{1}{2}(\delta_C + \delta_A)$$

$$\frac{P_B L}{A_b E} = \frac{1}{2}\left[\frac{P_C L_c}{A_c E_c} + \frac{P_A L_A}{A_A E_A}\right)$$

$$P_B = \frac{1}{2}(P_C + P_A) \qquad P_C + P_A = 2P_B \quad \text{— (1)}$$

from a geometry

$$\frac{\delta_D - \delta_A}{3L} = \frac{\delta_C - \delta_A}{2L}$$

$$\delta_D - \delta_A = \frac{3}{2}\delta_C - \frac{3}{2}\delta_A$$

$$\delta_D = \frac{3}{2}\delta_C - \frac{3}{2}\delta_A + \delta_A$$

$$\delta_D = \frac{3}{2}\delta_C - \frac{1}{2}\delta_A$$

Hence $P_D = \frac{3}{2}P_C - \frac{1}{2}P_A$ — (2)

$$P_B = \frac{1}{2}P_C + \frac{1}{2}P_A$$

$$P_B + P_D = \left(\frac{3}{2} + \frac{1}{2}\right)P_C = 2P_C$$

$$P_B + P_D = 2P_C.$$

Also $P_D = 3P_B - 2P_A$

putting in $P = P_A + P_B + P_C + P_D$

$P = 2P_B + P_B + P_D$

$P = 3P_B + P_D = 3P_B - P_B + 2P_C$

$P = 2P_B + 2P_C$

$P_B + P_C = P/2$ —— (3)

from eqn (1)

and $P_A + P_D = P/2$ —— (4)

~~$P_A + 2P_C - P_B = P/2$~~

~~$2P_B - P_C + 2P_C - P_B = P/2$~~

$P_A + 3P_B - 2P_A = P/2$

$3P_B - P_A = P/2$

$3P_B - (-2P_B - P_C) = P/2$

$P_B + P_C = P/2$

~~$P_B = \frac{1}{2}P_C$~~ ~~$\frac{3}{2}P_C = P/2$~~

~~$P_C = P/3$~~

~~$P_B = P/6$~~

~~$P_D = \frac{1}{2}\{P/6 + P/3$~~

~~$P_D = P/4$~~

~~$P_A = P/4$~~

Taking moment about A

$2P = P_B + 2P_C + 3P_D$

$8P_B - 2P_C = P$ —— (5)

from eqn (3) and (5)

$P_B = P/5 = 0.2P$

$P_C = \frac{3}{10}P = 0.3P$

Also

$P_B + P_D = 2P_C$

$0.2P + P_D = 0.6P$

$P_D = 0.4P$

$P_A + P_D = P/2$

$P_A = 0.1P$

$P_A = 0.1P$ $P_B = 0.2P$ $P_C = 0.3P$ $P_D = 0.4P$

20 Good

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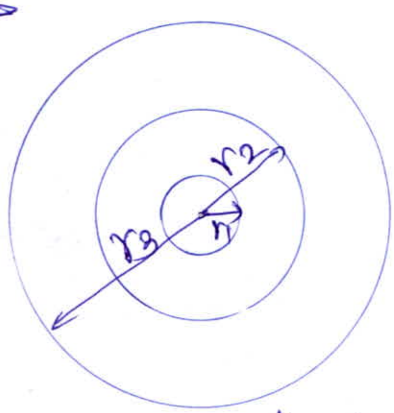
(b) A compound cylinder is formed by shrinking one cylinder onto the other, the final dimensions become inner diameter of 12 cm, external diameter of 24 cm and junction diameter of 20 cm. After shrinking of outer cylinder over inner cylinder the radial pressure at common surface is 20 N/mm^2. Calculate the necessary difference in diameters of the two cylinders at the common surface. Take E = 200 GPa, ν = 0.3 for inner cylinder and E = 100 GPa and ν = 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]



$2r_1 = 12\,cm = 120\,mm$

$2r_2 = 20\,cm = 200\,mm$

$2r_3 = 24\,cm = 240\,mm$

$r_1 = 60\,mm$

$r_2 = 100\,mm$

$r_3 = 120\,mm$

$P = 20\ N/mm^2$

Radial displacement of a Jacket cylinder

$$\delta_j = R_2\left[\frac{\sigma_{ho}}{E} + \nu.\frac{P_r}{E}\right]$$

$$= \frac{100}{E_o}\left[\frac{P(R_3^2+R_2^2)}{R_3^2-R_2^2} + \nu_o . P\right]$$

$$= \frac{100}{1\times10^5}\left[\frac{20\times(120^2+100^2)}{120^2-100^2} + 0.32\times20\right]$$

$$= 0.117\,mm.$$

Radial displacement of Inner cylinder.

$$\delta_I = R_2\left[\frac{\sigma_{hi}}{E_i} + \nu.\frac{P_r}{E_i}\right]$$

$$= \frac{R_2}{E_i}\left[\frac{-P(r_2^2+r_1^2)}{r_2^2-r_1^2} + \nu_i P_r\right]$$

$$= \frac{100}{2\times10^5}\left[\frac{-20\times(100^2+60^2)}{100^2-60^2} + 0.3\times20\right]$$

$$= -0.01825\,mm$$

so difference in a dia. of two cylinder

$= |\delta j| + |\delta i|$

$= 0.117 + (-0.01825)$

$= \underline{0.13525}$ mm.

→ Temp. increase of a outer cylinder so that slipping just occurs.

$(\delta j) = \alpha \Delta T R_2$

$0.117 = 11 \times 10^{-6} \times 100 \times (\Delta T)$

$\boxed{\Delta T = 106.36°C}$

Should take total for slip to begin b/c if outer cyl. expand, inner will try to come to its original dimension.

15

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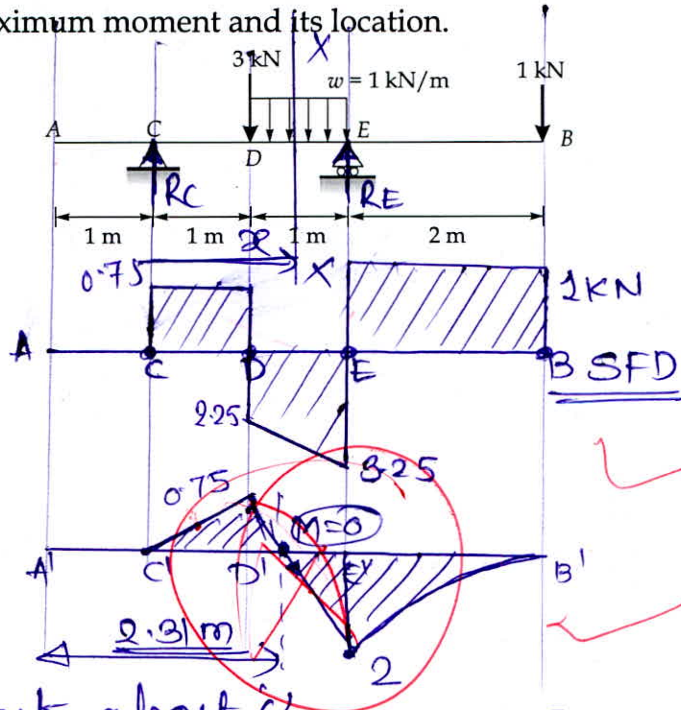
(c) A beam is loaded as shown in figure. Determine the distance of point of contraflexure from point A and maximum moment and its location.



[20 marks]

Taking moment about C

$R_E \times 2 = 3\times1 + 1\times4 + 1\times1\,[0.5+1]$

$R_E = \underline{4.25\ KN}$

$R_C + R_E = 3+1+1 = 5\ KN$

$R_C = 5 - 4.25 = \underline{0.75\ KN}$

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$M_C = 0$. $M_B = 0$ & Bending moment at B.

bending moment at D.

$M_D = 0.75 \times 1 = 0.75$ kN·m +ve

bending moment at E.

$M_E = -1 \times 2 =$

$= -2$ kN·m.

for a point of contraflexure BM = 0

so Bending Moment is zero from D to E

considering a section x-x from a support C

$M_{xx} = 0 = 0.75 \times x - 3(x-1) - \frac{1 \times (x-1)^2}{2}$

$x = 1.31$ m from a support C.

so point of contraflexure from point C

is $x_A = 1.31 + 1 = 2.31$ m.

Maximum bending moment occurs at point E.

$M_E = -2$ kN·m.

17

Draw correct BMD

■■■■

Space for Rough Work