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For GATE, ESE & PSUs

GATE - 2021

Mechanical Engineering (ME)

Forenoon Session

Questions & Solutions (Memory Based)

1. * HT

Heisler chart

- Biot Number & Fourier Number

2. * ATD

Relative Humidity

$$\phi = 50\%$$

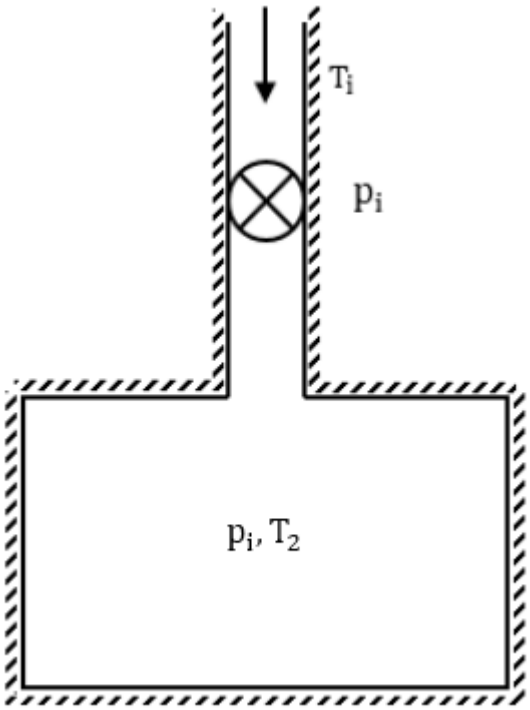
$$p_v \ \& \ p_{vs}$$

$$\phi = \frac{p_v}{p_{vs}}$$

$$0.5 = \frac{p_v}{p_{vs}}$$

$$p_v = 0.5\, p_{vs}$$

3. *ATD



$$T_i = 400\ K$$

$$\gamma = 1.4$$

$$T_2 = \gamma T_i$$

$$T_2 = 1.4 \times 400$$

$$T_2 = 560\ K$$

4. $\lim_{x\to 0} \frac{(1-\cos x)}{x^2}$ $\left(\frac{0}{0}\right)$ form

Apply L.H Rule

$$\lim_{x\to 0} 0 + \frac{\sin x}{2x}$$

$$= \frac{1}{2} \lim_{x\to 0} \frac{\sin x}{x}$$

$$= \frac{1}{2} \times 1$$

$$= \frac{1}{2}$$

5. $L\{S(t-a)\} = \int_0^\infty e^{-st} . \delta(t-a) = e^{-st}|_{t=a}$ $(\text{since } a > 0)$

$$= e^{-as}$$

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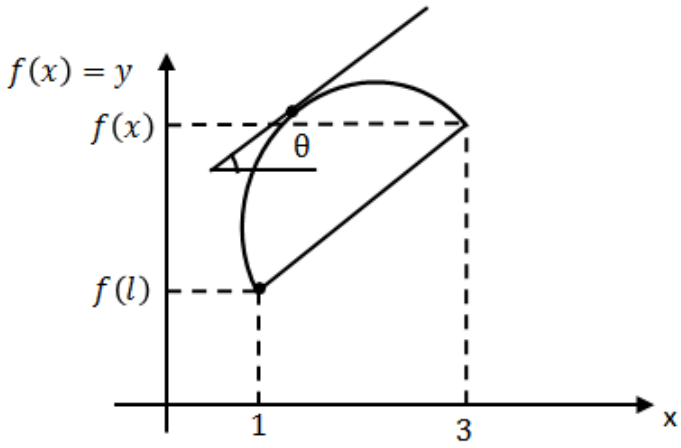
6. $f(x) = x^2 - 2x + 2$ Continuous in $[1,3]$, the point x at which the tangent to $f(x)$ lies parallel to the line segment joining $(1, f(1)), (1, f(3))$

Solution:

$$f'(c) = \frac{f(b) - f(a)}{b - a}$$



$$f'(x) = 2x - 2$$

$$f'(C) = 2C - 2$$

$$f(3) = 9 - 2 \times 3 + 2 = 11 - 6 = 5$$

$$f(1) = 1 - 2 + 2 = 1$$

$$2C - 2 = \frac{5 - 1}{3 - 1}$$

$$2(C - 1) = \frac{4}{2} = 2$$

$$C = 2$$

7. *FM

No pressure gradient

$$\rho = 800\ \text{kg/m}^3$$

$$\nu = 1.25 \times 10^{-4}\ \text{m}^2/\text{s}$$

$$\tau = ?$$

$$\tau = \mu \frac{du}{dy}$$

$$\tau = \rho\nu\ \frac{U}{Y}$$

$$\tau = 800 \times 1.25 \times 10^{-4} \times \frac{4}{5 \times 10^{-3}}$$

$$\tau = 80\ \text{N/m}^2$$

8. TD

At least one isothermal process

* Brayton & Rankine (×)

* Otto & Diesel (×)

* Carnot & stirling (Right)

9. *TD

Compressibility Factor

$$Z = 0.95$$

$$p = 1500\ \text{kPa}$$

$$\bar{v} = 2.75\ \text{m}^3/\text{kmol}$$

$$T = ?$$

$$Z = \frac{PV/nT}{\bar{R}}$$

$$Z = PV/n\bar{R}T$$

$$Z = \frac{p\bar{v}}{\bar{R}T}$$

$$T = \frac{1500 \times 2.75}{8.314 \times 0.95}$$

$$= 522.26K$$

$$= 249.11°C$$

10. $\int_C \frac{\cosh 3z}{2z}, |z| = 1$

$$\oint f(z)dz = 2\pi i[\Sigma R]$$

$$\Rightarrow \text{ Singularity} \rightarrow z = 0$$

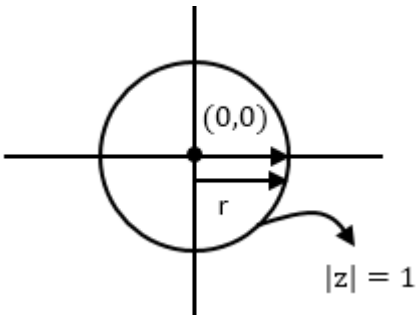
Path is $|z| = 1 \Rightarrow$

$$z = x + iy$$

$$|z| = \sqrt{x^2 + y^2}$$

$$|z| = 1$$

Equation of circle centre at origin and radius $= 1$



Singularity:-

$$z = 0 \rightarrow \text{Simple pole}$$

$$R = \lim_{z \to a}(z - a)f(z)$$

$$\Rightarrow \lim_{z \to 0} z \times \frac{\cosh(3z)}{2z}$$

$$\Rightarrow 1/2$$

$$\oint \frac{\cosh 3z}{2z} = 2\pi i \times R = 2\pi i \times \frac{1}{2} = \pi i$$

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11. $\sin x \frac{dy}{.dx} + y \cos x = 1$

$$y\left(\frac{\pi}{2}\right) = \frac{\pi}{2}$$

$$y\left(\frac{\pi}{6}\right) = ??$$

Solution:

$$\frac{dy}{dx} + y \cot x = \operatorname{cosec} x$$

$$\frac{dy}{dx} + py = Q$$

$$I.F = e^{\int p dx}$$

$$\Rightarrow e^{\cot x dx}$$

$$\Rightarrow e^{\log|\sin x|}$$

$$= \sin x$$

General Solution:

$$y(I.F) = \int Q(I.F)dx + C$$

$$y \sin x = \int \operatorname{cosec} x . \sin x \, dx + C$$

$$y \sin x = \int 1 . dx + C$$

$$y \sin x = x + C$$

Given $y\left(\frac{\pi}{2}\right) = \frac{\pi}{2}$

$$\frac{\pi}{2}\left(\sin\frac{\pi}{2}\right) = \frac{\pi}{2} + C$$

$$\frac{\pi}{2} . 1 = \frac{\pi}{2} + C$$

$$C = 0$$

$$y \sin x = x + 0$$

$$y \sin x = x$$

$$y\left(\sin\frac{\pi}{6}\right) = \frac{\pi}{6}$$

$$y\left(\frac{1}{2}\right) = \frac{\pi}{6}$$

$$y = \frac{\pi}{3}$$

12.***ATD : Reheat Rankine cycle**

$w_{01} = 750\ \text{kJ/kg}$

$w_{02} = 1500\ \text{kJ/kg}$

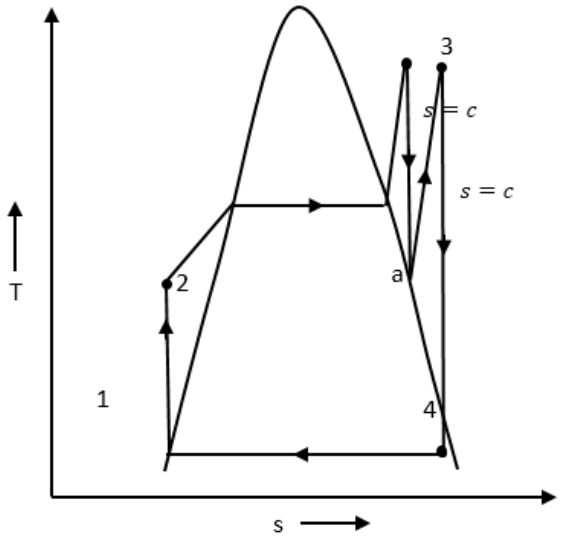
$\eta = 50\%$

$(h_f)_{P_c} = 200\ \text{kJ/kg}$

$(h_g)_{P_c} = 2600\ \text{kJ/kg}$

$w_i = 20\ \text{kJ/kg}$

$x_4 = ?$



$$\eta_{RR} = \frac{\Sigma w}{q_s}$$

$$0.5 = \frac{750+1500-20}{q_s}$$

$$q_s = \frac{2230}{0.5} = 4460 \text{ kJ/kg}$$

$$\Sigma q = \Sigma w$$

$$q_s - q_r = 2230$$

$$4460 - q_r = 2230$$

$$q_r = 2230 \text{ kJ/kg}$$

$$x_4 (h_{fg})_c = 2230 \text{ kJ/kg}$$

$$x_4 = \frac{2230}{2600-200}$$

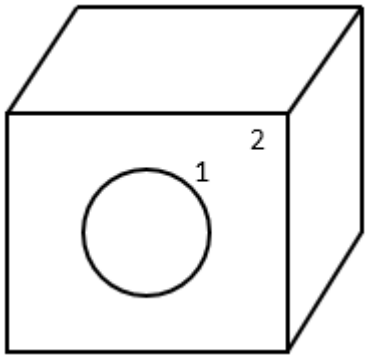
$$x_4 = \frac{2230}{2400}$$

$$x_4 = 0.929$$

$$x_4 = 92.9\%$$

Ans: 93%

13. Shape factor:



$$L = 30 \text{ mm}$$

$$r = 10 \text{ mm}$$

$$F_{22} + F_{21} = 1 \qquad F_{11} + F_{12} = 1$$

$$F_{11} + F_{12} = 1$$

$$F_{12} = 1$$

$$A_1 F_{12} = A_2 F_{21}$$

$$F_{21} = \frac{A_1}{A_2} \text{ (Since } F_{12} = 1)$$

$$F_{21} = \frac{4\pi r^2}{6a^2}$$

$$F_{21} = 0.2327$$

$$F_{22} = 1 - F_{21}$$

$$= 1 - 0.2327$$

$$F_{22} = 0.7673$$

$$F_{22} = 0.77$$

14. * HT (Fin)

$$\dot{Q}_{fin} = \sqrt{hpkA_c}\,\theta_b$$

$$\theta_b = T_b - T_\infty$$

$$\dot{Q}_{fin} \propto \sqrt{k}$$

$$k_2 = 2k_1$$

$$\frac{\dot{Q}_2}{\dot{Q}_1} = \sqrt{\frac{k_2}{k_1}} = \sqrt{\frac{2k_1}{k_1}}$$

$$\frac{\dot{Q}_2}{\dot{Q}_1} = \sqrt{2}$$

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15. * TD

$$z = f(x, y)$$

$$dz = Mdx + Ndy$$

$$dU = Tds + \tau dL$$

$$\left.\frac{\partial T}{\partial L}\right|_s = \left.\frac{\partial \tau}{\partial s}\right|_L$$

16. * HM

Simple Pelton Turbine

$$N = 300\ \text{RPM}, D = 2\ \text{m}, v_1 = 40\frac{\text{m}}{\text{s}} = V_{w1}$$

$$Q = 5\ \text{m}^3/\text{s}$$

$$\alpha = 165°$$

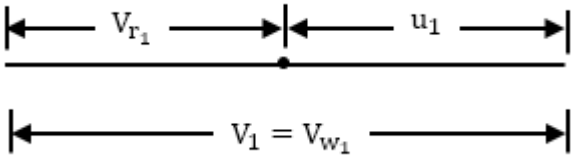
$$\text{Power output} = (\text{MW})$$

$$\text{Power} = \dot{m}\left[\bar{V}_{w_1} - \bar{V}_{w_2}\right]x^4$$

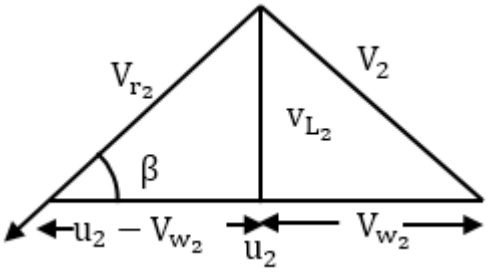
$$\dot{m} = \rho Q, u_1 = u_2 = u = \frac{\pi DN}{60}$$

$$u = 31.416\ \text{m/s}$$

Inlet vel. Diagram



$V_{r_1} = 8.584\ \text{m/s}$



$\beta_2 = 180 - 165 = 15°$

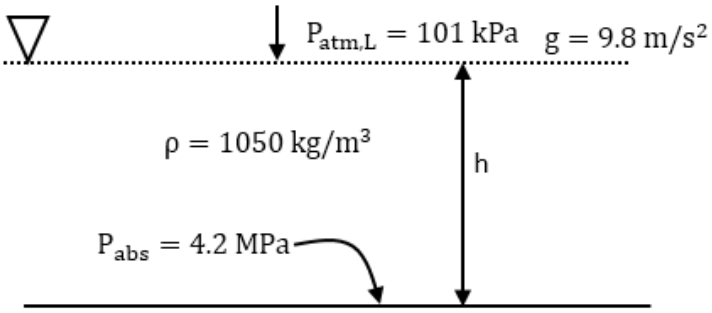
$\cos\beta_2 = \frac{u_2 - V_{w_2}}{V_{r_2}}$

$V_{r_2} = V_{r_1} \times k$

$k = 1$

Power $= 2.6808$ MW

17.* FM



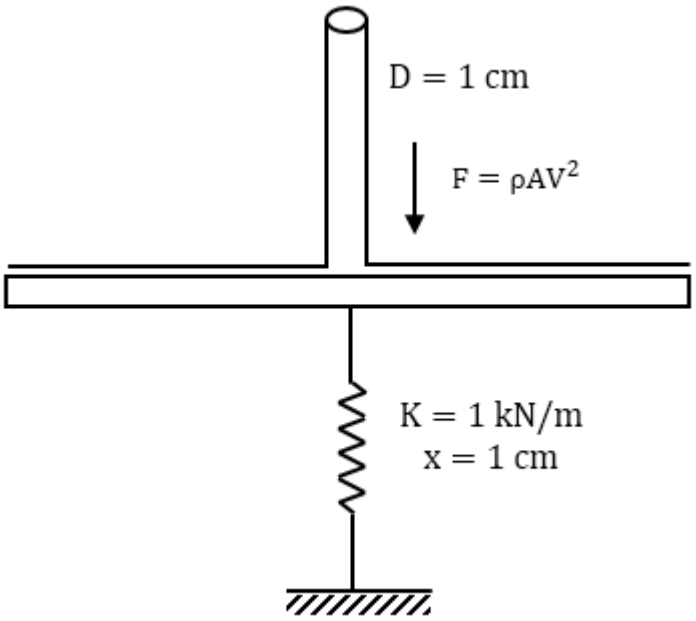
$$P_{ab} = P_{atm,L} + \rho gh$$

$$h = \frac{P_{abs} - P_{atm,L}}{\rho g}$$

$$= \frac{4200 - 101}{1.050 \times 9.8}$$

$$h = 398.34 \text{ m}$$

18. * FM



Water

$$\rho AV^2 = Kx$$

$$V^2 = \frac{Kx}{\rho A}$$

$$V^2 = \frac{10^3 \times 10^{-2}}{10^3 \times \frac{\pi}{4} \times 10^{-4}}$$

$$V^2 = \frac{400}{\pi}$$

$$V = \frac{20}{\sqrt{\pi}}$$

$$V = 11.28\ m/s$$

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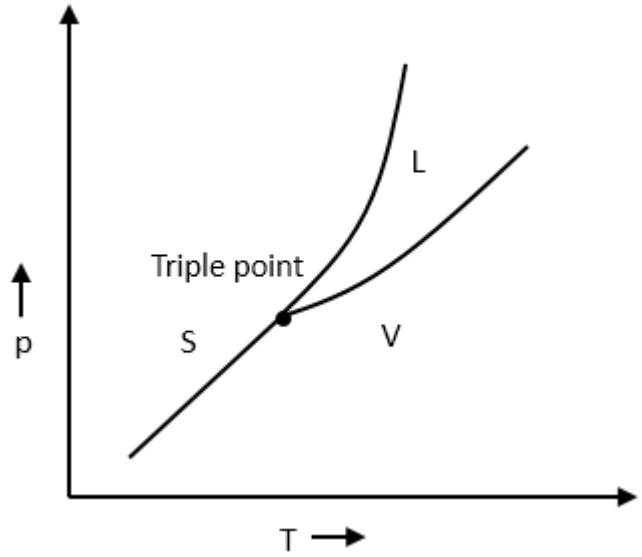
19. * NH_3



L − V:

$$\ln P = 24.38 - \frac{3063}{T}$$

S → V:

$$\ln P = 27.92 - \frac{3754}{T}$$

$$\Rightarrow 24.38 - \frac{3063}{T} = 27.92 - \frac{3754}{T}$$

$$T = 195\ K$$

20. Step size $= h$

$\frac{y_{i+1}-y_i}{h} = -\pi y_i \rightarrow$ Solution is stable

$\Rightarrow$ Forward Euler Method

$\frac{dy}{dx} = \lambda y$

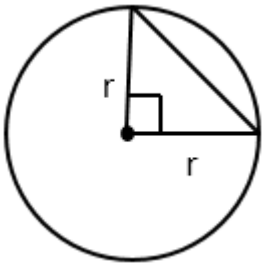
For stability of solution

$0 \leq h \leq \frac{2}{|\lambda|}$

$\lambda = -\pi$

$0 \leq h \leq \frac{2}{\pi}$

21.



Area of triangle $= 50\ \text{cm}^2$

Area of the circle=??

$\frac{1}{2} \times r \times r = 50$

$r^2 = 100$

$r = 10$

Area of the circle

$\pi \times r^2 \Rightarrow \pi \times (10)^2$

$= 100\pi$

22.

t=1.55 mm

I=10000 A

time = 0.25 sec

$$V_n = 70\ \text{mm}^3$$

$$E/\text{vol} = 12\ \text{J/mm}^3$$

$$R = 0.0001\ \Omega$$

$$\eta_{th} = \frac{\mu_{req}}{\mu_{sup}}$$

$$70 \times 12 = 840$$

$$\eta_{th} = 0.336$$

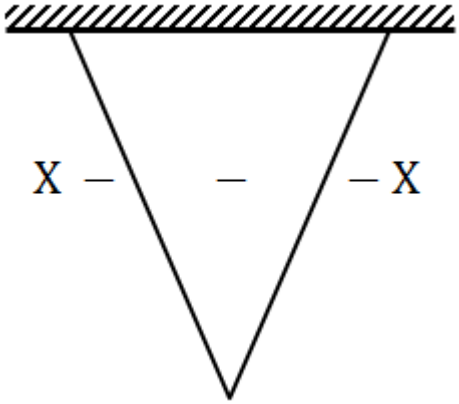
$$I^2Rt = 10000^2 \times 0.0001 \times 0.25$$

$$= 2500\ J$$

$$\eta_{th} = 0.336 \times 100 = 33.6\%$$

23.

Find deflection at mid height due to self-weight.



$$S_{(x-x)} = \frac{\gamma l^2}{6E} - \frac{\gamma (l_2)^2}{6E} = \frac{\gamma l^2}{6E}\left(1 - \frac{1}{4}\right) = \frac{\gamma l^2}{8E} = \frac{\gamma l^2}{8E}$$

24.

Deflection at mid of beam = ?

$$y_B = \frac{M(l/2)^2}{2EI} = \frac{Ml^2}{8EI}$$

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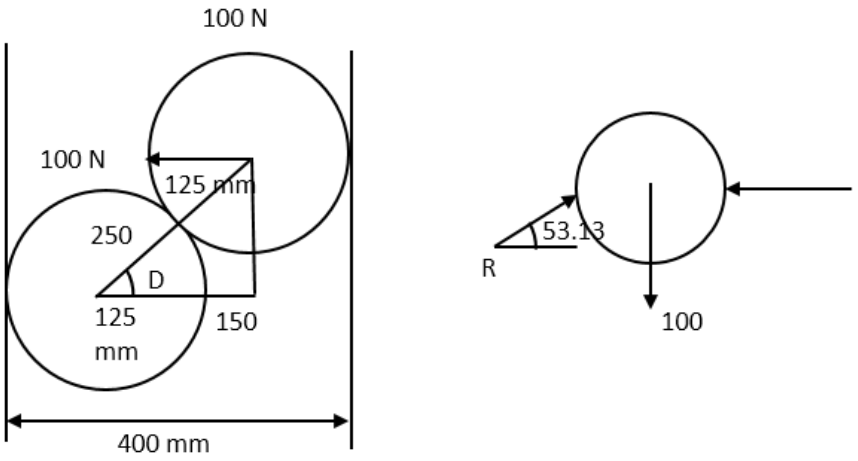
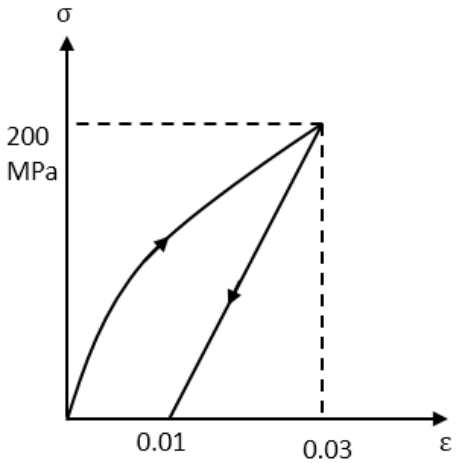
25. Reaction between spheres?



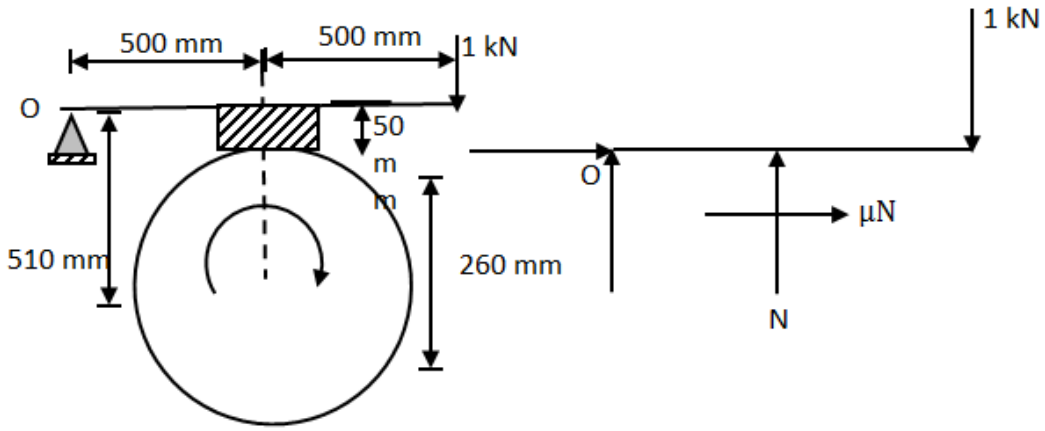
$$\Sigma F_y = 0$$
$$R \sin 53.13 = 100$$
$$R = 125 \text{ N}$$

26.



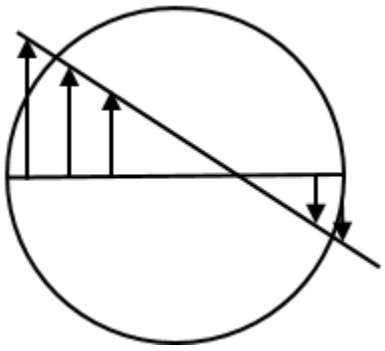
$$\varepsilon_{elastic} = 0.03 - 0.01$$
$$= 0.02$$
$$\varepsilon_{plastic} = 0.01$$

27. Breaking Torque for below shown case, when $\mu = 0.4$ is _____.



$$\mu = 0.4$$
$$T_B = ?$$
$$\sum M_o = 0$$
$$N \times 500 + 0.4N \times 50 = 1000 \times 1000$$
$$N = 1523.07$$
$$T_B = \mu N r$$
$$= 0.4 \times 1923.07 \times 0.260 = 200\ N - m$$

28.



Stress distribution in cross-section of helical spring

(A) only torsional stress

(B) only direct shear stress

(C) torsional + direct shear stress

(D) torsional + direct shear stress + curvature effects.

Answer: C

29.

$$\lambda = 12/\text{hr}$$

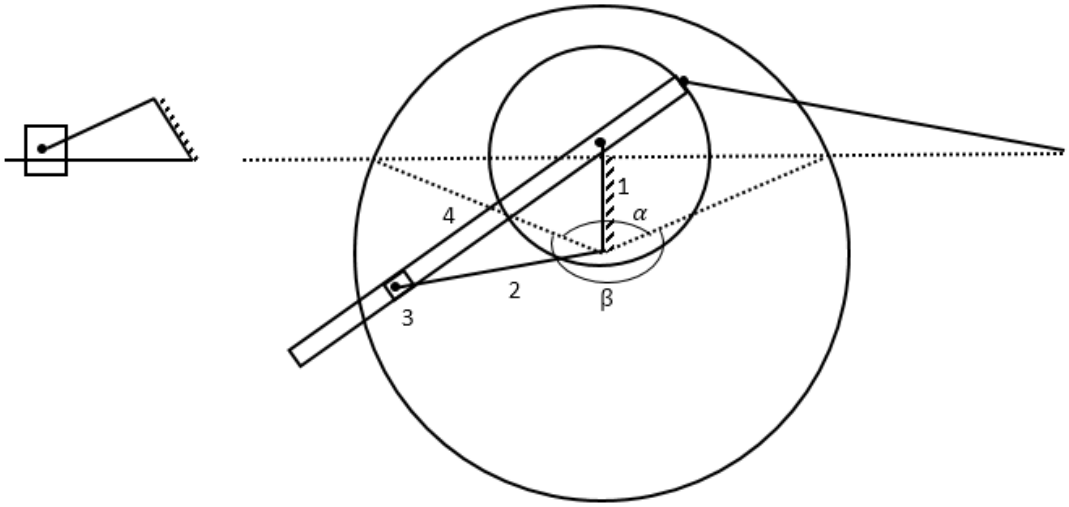
$$\mu = \text{mean}\left(4\text{ mm}\right) = \frac{60}{4} = 15/\text{hr}\Big)$$

$$f = \frac{\lambda}{\mu}$$

$$= \frac{12}{15}$$

$$L_s = \frac{f}{1-f} = \frac{0.8}{1-0.8} = 4$$

30. Whitworth quick return ratio =?



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

$$= 2$$

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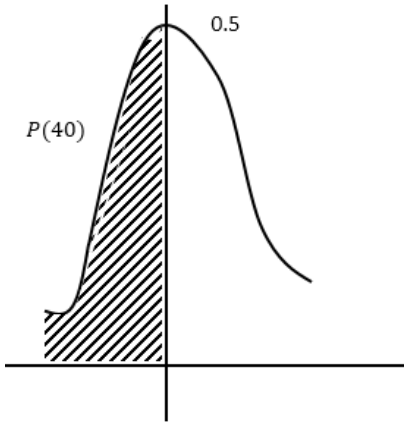
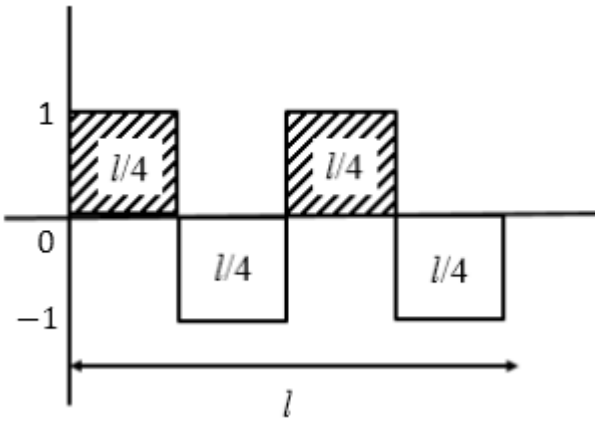
31.



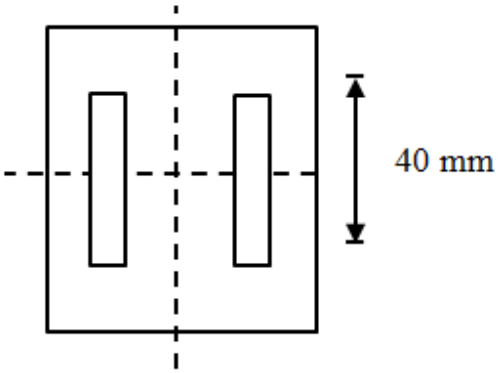
	A	B	C	D
Duration	6	11	8	15 = 40 p (40)
V	4	9	4	9

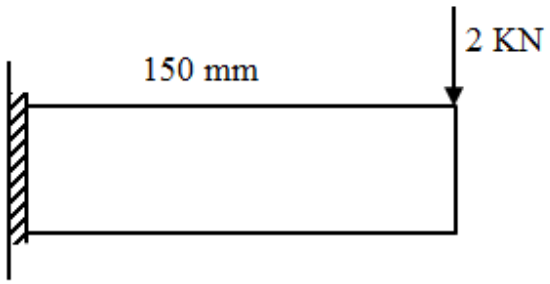
32.



$$\text{CEA} = \frac{\frac{l}{4}+\frac{l}{4}+\frac{l}{4}+\frac{l}{4}}{1}$$
$$= 1$$

33.





$\tau_{allow} = 60$ MPa

Leg of weld = ?

$$\tau = \frac{2000}{2 \times 40t} = \frac{25}{t} \text{ MPa}$$

$$\sigma_b = \frac{m.y_{max}}{f} = \frac{(2000 \times 150) \times (40/2)}{2 \times \frac{t \times 40^3}{12}} = \frac{562.5}{t}$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau^2}$$

$$60 = \frac{1}{t}\sqrt{\left(\frac{562.5}{2}\right)^2 + 25^2}$$

$$t = 4.706 \text{ mm}$$

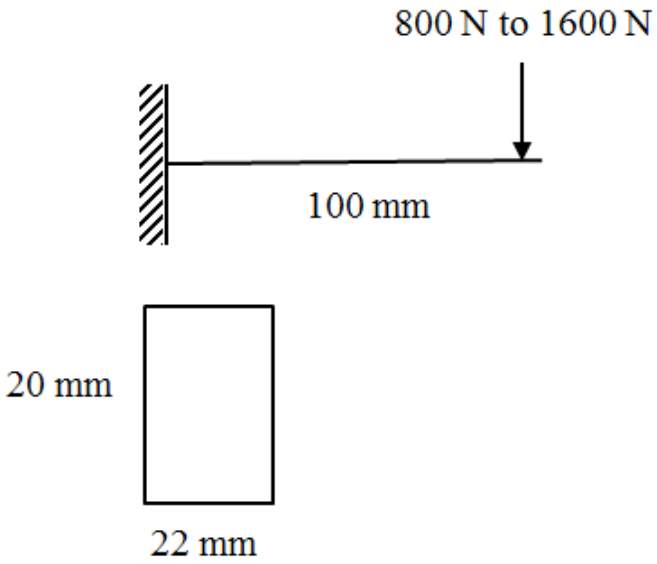
$$0.707\ h = 4.706 \text{ mm}$$

$$h = 6.656 \text{ mm}$$

34.

$S_{ut} = 600$ MPa
$S_{yt} = 500$ MPa
$S_z = 200$ MPa

Find FOS by Modified Goodman's Criteria



$$\sigma_{max} = \frac{(1600\times100)}{\left(\frac{12\times20^2}{6}\right)} = 200 \text{ MPa}$$

$$\sigma_{min} = \frac{(800\times100)}{\left(\frac{12\times20^2}{6}\right)} = 100 \text{ MPa}$$

$$\sigma_m = \frac{200+100}{2} = 150 \text{ MPa}, \quad \sigma_g = \frac{200-100}{2} = 50 \text{ MPa}$$

Goodman's

$$\frac{\sigma_m}{S_{yt}} + \frac{\sigma_a}{S_e} = \frac{1}{FOS}$$

$$\frac{150}{600} + \frac{50}{200} = \frac{1}{FOS}$$

$$FOS = 2$$

$FOS \leq 2.5$

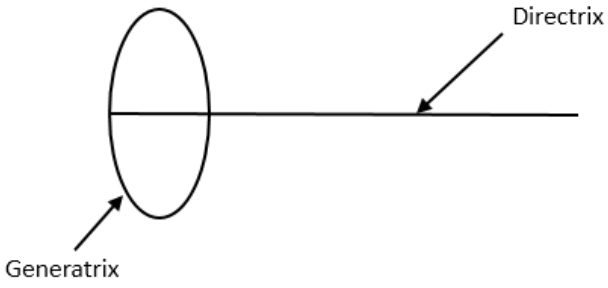
Langer's

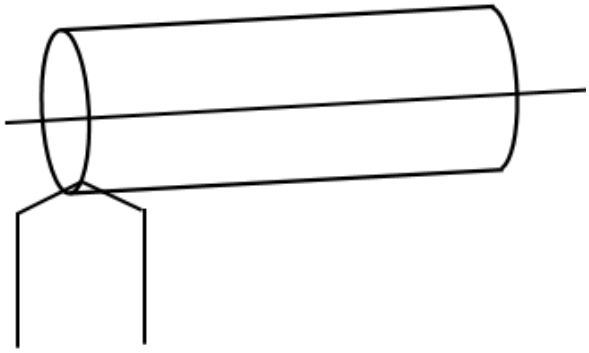
$$\sigma_m + \sigma_a = \frac{S_{yt}}{FOS}$$

$$150 + 50 = \frac{500}{FOS}$$

$$FOS = 2.5$$

35.





A. Cylinder

36.

Finishing Job (Hole)

↓

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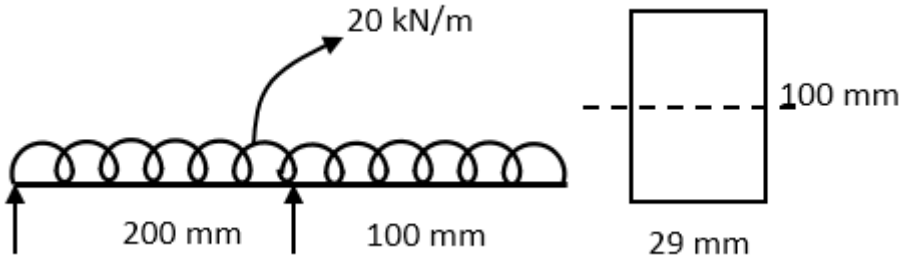
37.



$$(\sigma_b)_{max} = ?$$

$$\frac{M}{I} = \frac{\sigma_0}{y}$$

$$\sigma_b = \frac{MY}{I} = \frac{M}{(\frac{I}{y})} = \frac{M}{Z}$$

$$Z = \frac{bd^2}{6}$$

$$Z = \frac{24 \times (100)^2}{6}$$

$$Z = 4 \times (10)^4$$

$$(\sigma_m)_{max} = \frac{M}{Z} = \frac{10\ kN - m}{4 \times (10)^4 (mm)^3}$$

$$= \frac{10 \times 1000 \times 1000}{4 \times (10)^4\ mm^3}\ N - mm$$

$$= 250\ N/mm^2$$

38.

	A	B	C	D	E	F	G	H
M – 1	2	4	8	9	7	6	5	10
M – 2	6	1	3	7	9	5	2	4

A	E	D	F	H	C	G	B

39.

Machining

$$\alpha = 12$$

$$F_C = 1000\ N$$

$$F = 600\ N$$

$$t_1 = 0.75\ mm$$

$$t_2 = 15\ mm$$

$$F_s = ?$$

$$F_s = R\cos(\phi + \lambda - \alpha)$$

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

$$r = 0.5$$

$$\phi = \tan^{-1}\left(\frac{0.5\cos 12}{1 - 0.5 \times \sin 1\,2}\right)$$

$$\phi = 28.62$$

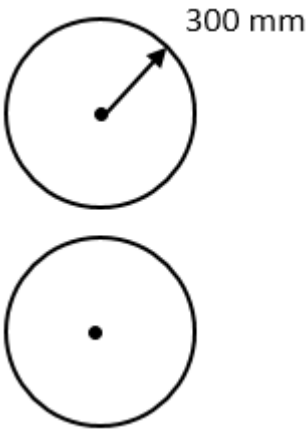
$$2\phi + \lambda - \alpha = \frac{\pi}{2}$$

$$\lambda = 44.76$$

$$R = 1848.01\ N$$

$$F_s = R\cos(\phi + \lambda - \alpha) = 885.19\ N$$

40.



20 mm 18 mm

h_1 h_2

$k = 300\ \text{MPa}$

$n = 0.2$

$\sigma_f = 300\ e^{0.2}$

$F = \bar{\sigma}_f \times W \times L_p$

$\Rightarrow F = \frac{k}{n+1} e_{max}^{n} \times W \times \sqrt{R\Delta h}$

$\Rightarrow F = \frac{k}{n+1} \ln\left(\frac{h_2}{h_1}\right) \times W \times \sqrt{R\Delta h}$

k = 300, (n+1) = 1.2, $h_2 = 18$, $h_1 = 20$

$R = 300$, h = 2

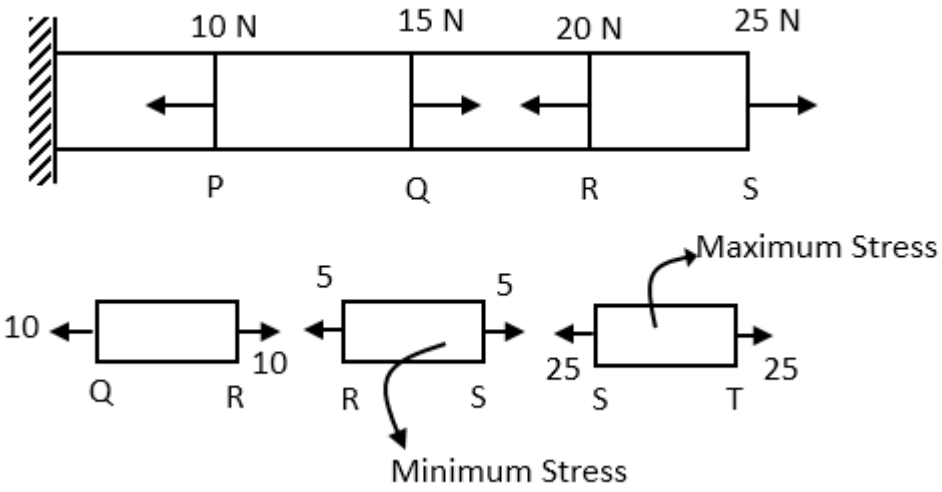
$F = 955.92\ \text{kN}$

41.

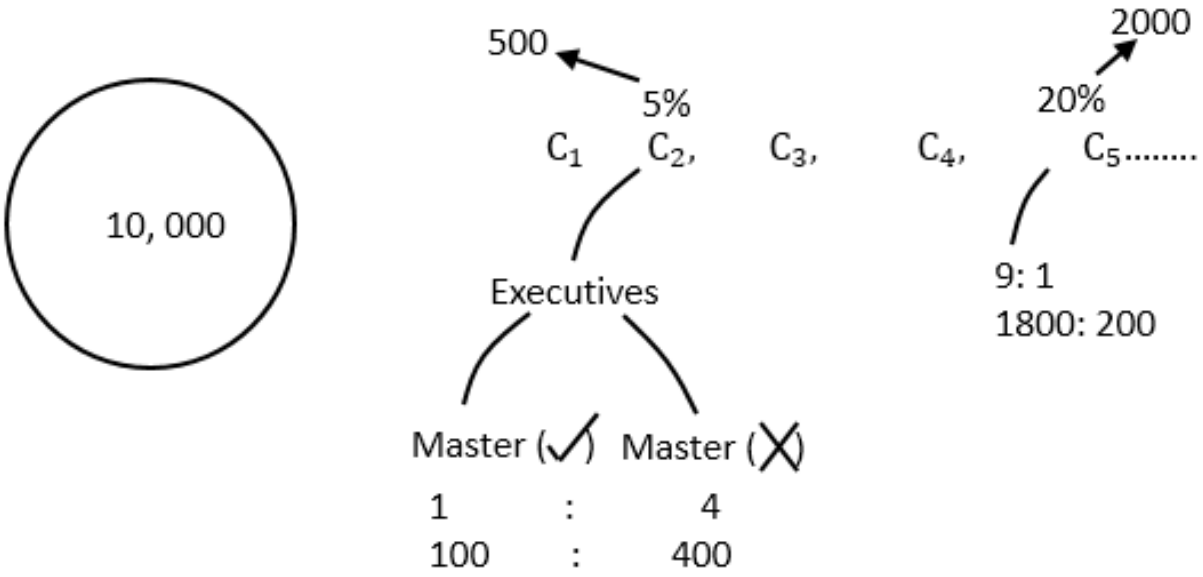
Area length

Max stress = ?

Min stress = ?



42.



$$1800 + 100 = 1900$$

43.

P, Q, R, S, T

Q P/T R P/T S
Q P/T R S P/T } 4

R T/P Q P/T S } 2

T/P Q P/T R S } 2

S R P/T Q T/P } 2

S P/T Q T/P R } 2

P/T S R T/P Q
S T/P R P/T Q } 4

Answer is 16

44.

Farm P

Hen Ducks Goats

13 (65 91 169)

Farm Q

416

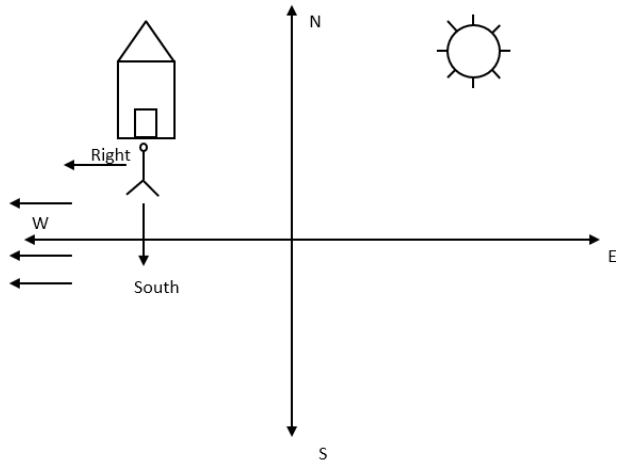
Coprimes

5: 14: 13

5: 7: 13

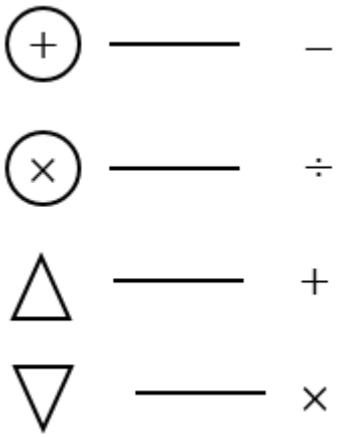
10: 21: 26

45.



South facing.

46.



$+2-3+(4\div 2\times 4)$

$-1+(8)$

$=7$