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GATE 2019
Mechanical Engineering

Questions and Solutions of forenoon session

Date of Exam : 2/2/2019

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GENERAL APTITUDE

Q.1 - Q.5 Carry One Mark each.

Q.1 John Thomas, an _____writer, passed away in 2018.

(a) prominent (b) dominant
(c) imminent (d) eminent

Ans. (d)

Eminent means one who is famous and respected within a particular sphere; distinguished or renowned.

End of Solution

Q.2 _____I permitted him to leave, I wouldn't have had any problem with him being absent, _____I?

(a) Had, wouldn't (b) Have, would
(c) Have, wouldn't (d) Had, would

Ans. (d)

Had, I permitted him to leave, I wouldn't have had any problem

Past perfect conditional sentence pattern.

$\underbrace{\text{Had} + V_3 \text{ form,}}_{\text{If clause}}$ $\underbrace{\text{would have} + V_3 \text{ form,}}_{\text{main clause}}$

Negative statement requires affirmative question tag so would I?

End of Solution

Q.3 A worker noticed that the hour hand on the factory clock had moved 225 degrees during her stay at the factory. For how long does she stay in the factory?

(a) 8.5 hours (b) 7.5 hours
(c) 3.75 hours (d) 4 hours and 15 minutes

Ans. (b)

We know that watch hour hand complete one rotation (360°) in12 hours.

So, for 225°, corresponding time = $\left(\frac{225}{360}\right) \times 12 = 7.5$ hours

End of Solution

Q.4 The sum and product of two integers are 26 and 165 respectively. The difference between these two integers is _____.

(a) 2 (b) 6
(c) 3 (d) 4

Ans. (d)

Let two numbers are x and y

Given, $(x + y) = 26$

$xy = 165$

We know that, $(x - y)^2 = (x + y)^2 - 4xy$

$= (26)^2 - 4 \times 165$

$(x - y)^2 = 16$

$x - y = 4$

End of Solution

Q.5 The minister avoided any mention of the issue of women's reservation in the private sector. He was accused of _____ the issue.

(a) tying (b) collaring

(c) skirting (d) belting

Ans. **(c)**

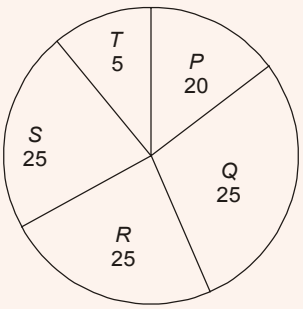
He was accused of skirting.

Skirt as a verb means to avoid discussing a subject or problem, usually because there are difficulties that you do not want to deal with.

End of Solution

Q.6 - Q.10 Carry Two Marks each.

Q.6 A firm hires employees at five different skill levels P, Q, R, S, T. The shares of employment at these skill levels of total employment in 2010 is given in the pie chart as shown. There were a total of 600 employees in 2010 and the total employment increased by 15% from 2010 to 2016. The total employment at skill levels P, Q, and R remained unchanged during this period. If the employment at skill level S increased by 40% from 2010 to 2016, how many employees were there at skill level T in 2016?



Percentage share of skills in 2010

(a) 35 (b) 30

(c) 72 (d) 60

Ans. **(d)**

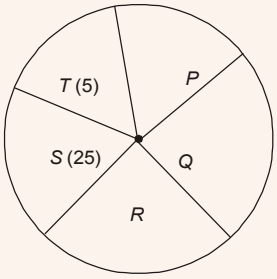
In 2010 total employees = 600

In 2016 there is 15% increment in number of employees.

In 2016 total employees = $1.15 \times 600 = 690$

Given, there is no change in *P*, *Q* and *R* type employees.

There is 40% increment in '*S*' type employees.



Now, Total employees in 2016 = $\left(600 \times \frac{25}{100}\right) \times 1.4 = 150 \times 1.4$

= 210 employees

Increase in '*S*' type employees = $210 - \left(600 \times \frac{25}{100}\right) = 60$

Initially, '*T*' type employees = $\frac{5}{100} \times 600 = 30$

In 2016, increase in '*T* ' type employees = (690 – 600 – 60) = 30

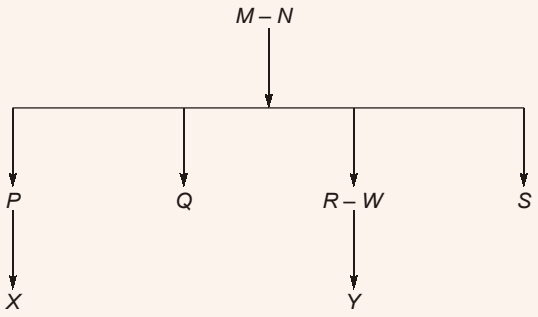
In 2016, total '*T* ' type employees = (30 + 30) = 60 employees

End of Solution

Q.7 M and N had four children P, Q, R and S. Of them, only P and R were married. They had children X and Y respectively. If Y is a legitimate child of W, which one of the following statements is necessarily FALSE?

(a) W is the wife of R
(b) R is the father of Y
(c) M is the grandmother of Y
(d) W is the wife of P

Ans. (d)



W can't be wife of *P*.
W can be husband or wife of *R*.
R can be father or mother of *Y*.
M can be grandfather of *Y*.

End of Solution

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Q.8 Congo was named by Europeans. Congo's dictator Mobuto later changed the name of the country and the river to Zaire with the objective of Africanising names of persons and spaces. However, the name Zaire was a Portuguese alternation of *Nzadi o Nzere*, a local African term meaning 'River that swallows Rivers'. Zaire was the Portuguese name for the Congo river in the 16th and 17th centuries.
Which one of the following statements can be inferred from the paragraph above?
(a) The term *Nzadi o Nzere* was of Portuguese origin
(b) As a dictator Mobuto ordered the Portuguese to alter the name of the river to Zaire
(c) Mobuto's desire to Africanise names was prevented by the Portuguese
(d) Mobuto was not entirely successful in Africanising the name of his country

Ans. **(d)**
As the paragraph states, dictator Mobuto wanted to Africanise the name of Congo but could not succeed as the new name given to the country was Portuguese alteration of some other term.

End of Solution

Q.9 Under a certain legal system, prisoners are allowed to make one statement. If their statement turns out to be true then they are hanged. If the statement turns out to be false then they are shot. One prisoner made a statement and the judge had no option but to set him free. Which one of the following could be that statement?
(a) I committed the crime
(b) You committed the crime
(c) I will be shot
(d) I did not commit the crime

Ans. **(c)**
Remaining three options would lead to the prisoner being hanged or shot. This answer choice creates two contradictory situations.

End of Solution

Q.10 A person divided an amount of Rs. 100,000 into two parts and invested in two different schemes. In one he got 10% profit and in the other he got 12%. If the profit percentages are interchanged with these investments he would have got Rs. 120 less. Find the ratio between his investments in the two schemes.
(a) 9 : 16 (b) 37 : 63
(c) 47 : 53 (d) 11 : 14

Ans. **(c)**
1st condition
Total amount = 100000
Assume, A has invested Rs.x at 10% rate and Rs (100000 – x) at 12% interest.
Total interest = $0.1x + (100000 - x) \times 0.12$
$(TI)_I = 12000 - 0.02x$
2nd condition
Assume, A has invested Rs x at 12% rate and Rs (100000 – x) at 10% interest.

$$\text{Total interest} = 0.12x + (100000 - x) \times 0.1$$

$$(\text{TI})_{II} = 10000 + 0.02x$$

Given, $(\text{TI})_{I} - (\text{TI})_{II} = 120$

$$(12000 - 0.02x) - (10000 + 0.02x) = 120$$

$$2000 - 0.04x = 120$$

$$x = \frac{1880}{0.04} = \text{Rs. } 47000$$

Now, Another part $= 100000 - x = 100000 - 47000 = \text{Rs. } 53000$

$$\frac{x}{(100000 - x)} = \frac{47}{53}$$

End of Solution

MECHANICAL ENGINEERING

Q.1 - Q.25 Carry One Mark each.

Q.1 In a casting process, a vertical channel through which molten metal flows downward , from pouring basin to runner for reaching the mould cavity is called

(a) sprue (b) blister

(c) pinhole (d) riser

Ans. (a)

End of Solution

Q.2 Consider an ideal vapour compression refrigeration cycle. If the throttling process is replaced by an isentropic expansion process, keeping all the other processes unchanged, which one of the following statements is true for the modified cycle?

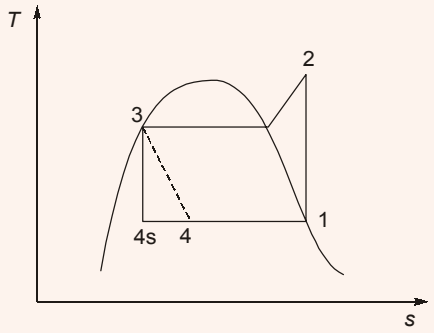
(a) Coefficient of performance is higher than that of the original cycle

(b) Coefficient of performance is the same as that of the original cycle

(c) Refrigerating effect is lower than that of the original cycle

(d) Coefficient of performance is lower than that of the original cycle

Ans. (a)



- R.E. increases.
- Work input decreases.
- COP increases.

End of Solution

Q.3 Water flows through a pipe with a velocity given by $\vec{V} = \left(\frac{4}{t} + x + y\right)\hat{j}$ m/s, where $\hat{j}$ is the unit vector in the y direction, t (> 0) is in second, and x and y are in meters. The magnitude of total acceleration at the point $(x, y) = (1, 1)$ at $t = 2$ s is _____ m/s^2.

Ans. (3)

$$\vec{V} = \left(\frac{4}{t} + x + y\right)\hat{j}$$

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

$$a = a_y$$

$$a_y = v\frac{\partial v}{\partial y} + \frac{\partial v}{\partial t} = a$$

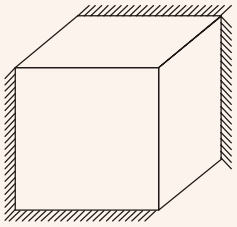
at $x = 1;\ y = 1;\ t = 2$

$$a = 3 \text{ m/s}^2$$

End of Solution

Q.4 A solid cube of side 1 m is kept at a room temperature of 32°C. The coefficient of linear thermal expansion of the cube material is 1×10^{-5}/°C and the bulk modulus is 200 GPa. If the cube is constrained all around and heated uniformly to 42°C, then the magnitude of volumetric (mean) stress induced due to heating is _____MPa.

Ans. (60)



Since block is constrained in all direction and heated uniformly. So it is the case of hydrostatic state of stress.

As we know,

For hydrostatic state of stress,

$$\text{Volumetric strain, } \varepsilon_v = \frac{\sigma_v}{K} = 3\alpha\Delta T$$

$$\sigma_v = 3K\alpha\Delta T$$

$$\sigma_v = 3 \times 200 \times 10^3 \times 10^{-5} \times (42 - 32)$$

$$\sigma_v = 60 \text{ MPa}$$

End of Solution

Q.5 The lengths of large stock of titanium rods follow a normal distribution with a mean (μ) of 440 mm and a standard deviation (σ) of 1 mm. What is the percentage of rods whose lengths lie between 438 mm and 441 mm?

(a) 68.4%
(b) 86.64%
(c) 81.85%
(d) 99.75%

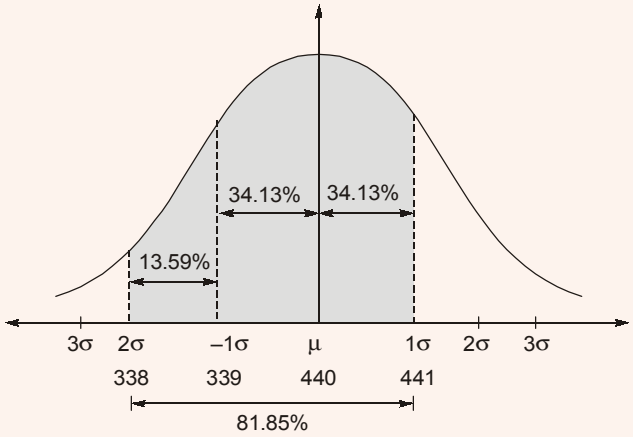
Ans. (c)

$\mu = 400$ mm,
UL = 441 mm
$\sigma = 1$ mm,
LL = 438 mm

Now, Upper limit $= \left(\frac{Z-\mu}{\sigma}\right) = \left(\frac{441-440}{1}\right) = 1$

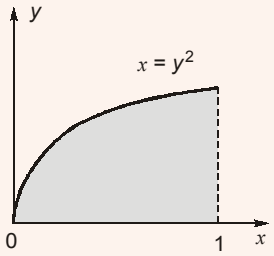
Lower limit $= \left(\frac{Z-\mu}{\sigma}\right) = \left(\frac{438-440}{1}\right) = -2$

Hence total percentage of rods in between 438 mm and 441 mm
$= P(Z - 1) - P(Z - 2)$
$= 0.3413 + (0.5 - 0.0228) = 0.81854 = 81.854\%$



End of Solution

Q.6 A parabola $x = y^2$ with $0 \le x \le 1$ is shown in the figure. The volume of the solid of rotation obtained by rotating the shaded area by 360° around the x–axis is



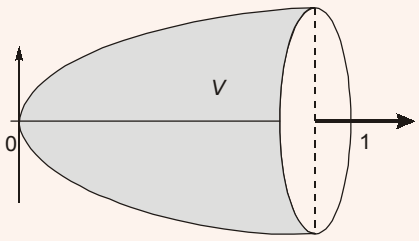
(a) $\frac{\pi}{4}$ (b) π

(c) $\frac{\pi}{2}$ (d) 2π

Ans. (c)

Since rotation is about x axis, so.

$$\text{Volume} = \int_0^1 \pi y^2 dx = \int_0^1 \pi x\, dx = \pi\left[\frac{x^2}{2}\right]_0^1 = \frac{\pi}{2}$$



End of Solution

Q.7 Air of mass 1 kg, initially at 300 K and 10 bar, is allowed to expand isothermally till it reaches a pressure of 1 bar. Assuming air as an ideal gas with gas constant of 0.287 kJ/kgK, the change in entropy of air (in kJ/kgK, round off to two decimal places) is _____.

Ans. (0.66)

$m = 1$ kg; $P_1 = 10$ bar $= 1000$ kPa; $T_1 = 300$K

$T_2 = 300$K, $P_2 = 1$ bar

$$S_2 - S_1 = mc_p \ln\frac{T_2}{T_1} - mR\ln\frac{P_2}{P_1}$$

$$S_2 - S_1 = -mR\ln\frac{P_2}{P_1} = -1\times 0.287\ln\frac{1}{10}$$

$$S_2 - S_1 = 0.66 \text{ kJ/kgK}$$

End of Solution

Q.8 Consider the matrix

$$P = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

The number of distinct eigen values of P is

(a) 2 (b) 0

(c) 1 (d) 3

Ans. (c)

$$A = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

Since given matrix is U.T.M.

So, diagonal elements are the eigen values. Hence, $\lambda = 1, 1, 1$. So matrix has only one distinct eigen value i.e.

End of Solution

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Q.9 A spur gear with 20° full depth teeth is transmitting 20 kW at 200 rad/s. The pitch circle diameter of the gear is 100 mm. The magnitude of the force applied on the gear in the radial direction is

(a) 0.73 kN (b) 2.78 kN
(c) 1.39 kN (d) 0.36 kN

Ans. (a)

$\phi = 20°$
$P = 20$ kW
$\omega = 200$ rad/s
$D = 100$ mm

We know that, power, $P = T \times \omega$

$20 \times 10^3 = T \times 200$

$T = 100$ N-m

We know that, $T = F_t \times r$

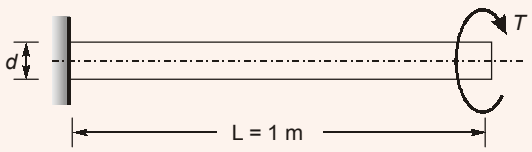
$$F_t = \frac{2T}{D} = \frac{2\times100}{100\times10^{-3}} = 2 \text{ kN}$$

Radial force, $F_r = F_t(\tan\phi) = 2 \times \tan20° = 0.72794$ kN $= 0.728$ kN
$= 0.73$ kN

End of Solution

Q.10 A cylindrical rod of diameter 10 mm and length 1.0 m is fixed at one end. The other end is twisted by an angle of 10° by applying a torque. If the maximum shear strain in the rod is $p \times 10^{-3}$, then p is equal to_____ (round off to two decimal places)

Ans. (0.8726)



$d = 10$ mm; $\theta = 10°$
$L = 1$ m, $\phi = P \times 10^{-3}$

From torsion eq. $\frac{T}{J} = \frac{\tau_{max}}{R} = \frac{G\theta}{L}$

$$\frac{\tau_{max}}{G} = \frac{R\theta}{L}$$

$\Rightarrow$ $$\phi_{max} = \frac{R\theta}{L}$$

$$P \times 10^{-3} = \frac{5\times10°}{1000} \times \frac{\pi}{180} = 0.8726 \times 10^{-3}$$

$P = 0.8726$

End of Solution

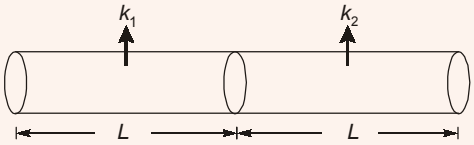
Q.11 A slender rod of length L, diameter d ($L >> d$) and thermal conductivity k_1 is joined with another rod of identical dimensions, but of thermal conductivity k_2, to from a composite cylindrical rod of length 2L. The heat transfer in radial direction and contact resistance are negligible. The effective thermal conductivity of the composite rod is

(a) $\dfrac{k_1k_2}{k_1+k_2}$ (b) $\dfrac{2k_1k_2}{k_1+k_2}$

(c) $k_1 + k_2$ (d) $\sqrt{k_1k_2}$

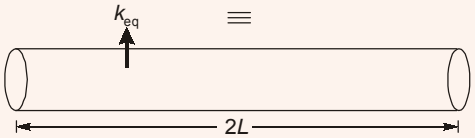
Ans. **(b)**

$$(R_{th})_I = \frac{L}{k_1A} + \frac{L}{k_2A}$$



Case I

$$(R_{th})_{II} = \frac{2L}{k_{eq}A}$$



Case II

Equivalent resistance will be same in both cases,

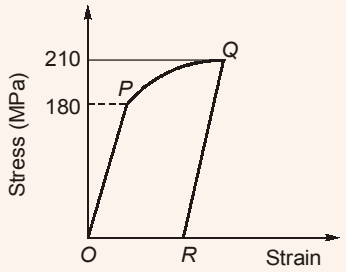
$$(R_{th})_{II} = (R_{th})_I$$

$$\Rightarrow \quad \frac{2L}{k_{eq}A} = \frac{L}{k_1A} + \frac{L}{k_2A}$$

$$\Rightarrow \quad k_{eq} = \frac{2k_1k_2}{k_1+k_2}$$

End of Solution

Q.12 Consider the stress-strain curve for an ideal elastic-plastic strain hardening metal as shown in the figure. The metal was loaded in uniaxial tension starting from O. Upon loading, the stress-strain curve passes through initial yield point at P, and then strain hardens to point Q, where the loading was stopped. From point Q, the specimen was unloaded to point R, where the stress is zero. If the same specimen is reloaded in tension from point R, the value of stress at which the material yields again is _____MPa.



Ans. **(210)**

Initial loading upto Y.P. and then unloading to zero load results in cold working of the material. As a result, Y.S. increases on immediate next reloading. Since it is ideal elastic-plastic, material Y.S. on reloading of the specimen remains at 210 MPa.

End of Solution

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Q.13 The table presents the demand of a product. By simple three months moving average method, the demand-forecast of the product for the month of September is

Month	Demand
January	450
February	440
March	460
April	510
May	520
June	495
July	475
August	560

(a) 536.67
(b) 490
(c) 530
(d) 510

Ans. **(d)**

Three month moving average forecast for month of September.

$$F_{sep} = \frac{D_{June} + D_{July} + D_{Aug}}{2} = \frac{495 + 475 + 560}{3}$$

$$\text{Forecast for September} = \frac{1530}{3} = 510$$

End of Solution

Q.14 For the equation, $\frac{dy}{dx} + 7x^2y = 0$, if $y(0) = \frac{3}{7}$, then the value of $y(1)$ is

(a) $\frac{3}{7}e^{-\frac{7}{3}}$
(b) $\frac{7}{3}e^{-\frac{7}{3}}$
(c) $\frac{3}{7}e^{-\frac{3}{7}}$
(d) $\frac{7}{3}e^{-\frac{3}{7}}$

Ans. **(a)**

$$\frac{dy}{dx} + 7x^2y = 0$$

$$\int \frac{dy}{y} = \int -7x^2dx$$

$$\ln y = \frac{-7x^3}{3} + c \qquad \text{...(i)}$$

At $x = 0,\ y = \frac{3}{7}$

$$\ln\left(\frac{3}{7}\right) = c \qquad \text{...(ii)}$$

From (i) and (ii),

$$\ln y = \frac{-7x^3}{3} + \ln\left(\frac{3}{7}\right)$$

$$\ln\left(\frac{7y}{3}\right) = \frac{-7x^3}{3}$$

$$\Rightarrow \quad y = \frac{3}{7}e^{-\frac{7}{3}x^3}$$

$$y(1) = \frac{3}{7}e^{-\frac{7}{3}}$$

End of Solution

Q.15 For a hydrodynamically and thermally fully developed laminar flow through a circular pipe of constant cross section, the Nusselt number at constant wall heat flux (Nu_q) and that at constant wall temperature (Nu_T) are related as

(a) $Nu_q = Nu_T$ (b) $Nu_q < Nu_T$

(c) $Nu_q > Nu_T$ (d) $Nu_q = (Nu_T)^2$

Ans. **(c)**

For fully developed laminar flow through pipes,

Nusselt number value corresponding to uniform heat flux is 4.36.

Nusselt number value corresponding to uniform wall temperature is 3.66.

Hence, $Nu_q > Nu_T$

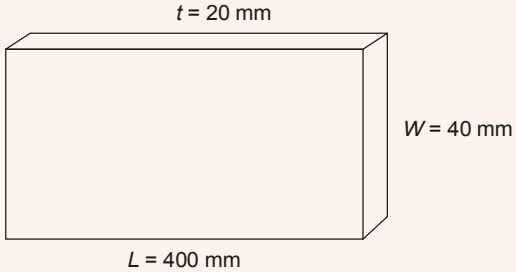
End of Solution

Q.16 The length, width and thickness of a steel sample are 400 mm, 40 mm and 20 mm, respectively. Its thickness needs to be uniformly reduced by 2 min in a single pass by using horizontal slab milling. The milling cutter (diameter: 100 mm, width: 50 mm) has 20 teeth and rotates at 1200 rpm. The feed per tooth is 0.05 mm. The feed direction is along the length of the sample. If the over travel distance is the same as the approach distance, the approach distance and time taken to complete the required machining task are

(a) 14 mm, 21.4 s (b) 21 mm, 39.4 s

(c) 14 mm, 18.4 s (d) 21 mm, 28.9 s

Ans. **(a)**



Cutter diameter, D = 100 mm

Cutter width = 50 mm that means single pass is sufficient.

Number of teeth, z = 20, Depth of cut, d = 2 mm

Rotational speed, N = 1200 rpm, f = 0.05 mm per tooth

$$\text{Approach distance, } A = \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d\right)^2} = \sqrt{d(D-d)}$$

$$= \sqrt{2(100-2)}\,\text{mm} = 14\ \text{mm}$$

Time for one pass in slab or slot milling

$$= \frac{L+A}{fzN} \text{ for rough milling} = \frac{L+2A}{fzN} \text{ for finish milling}$$

As length of approach and over travel are same

$$= \frac{L+A+A}{fzN} = \frac{400+14+14}{0.05\times 20\times 1200}\,\text{min} = 21.4\,\text{s}$$

End of Solution

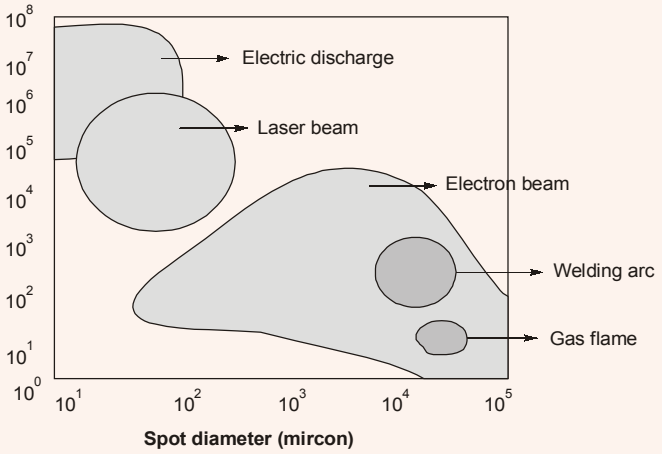
Q.17 Which one of the following welding methods provides the highest heat flux (W/mm^2)?

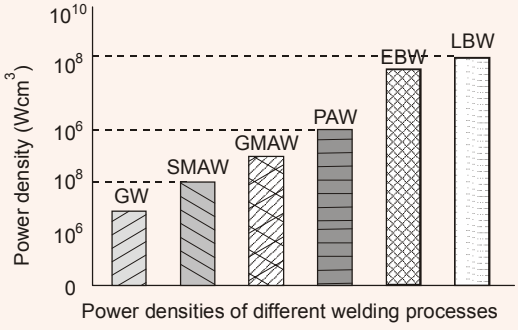
(a) Oxy-acetylene gas welding (b) Tungsten inert gas welding

(c) Plasma arc welding (d) Laser beam welding

Ans. (d)

In laser beam welding heat flux is highest upto 1 MW/mm^2.

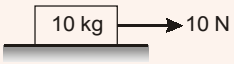




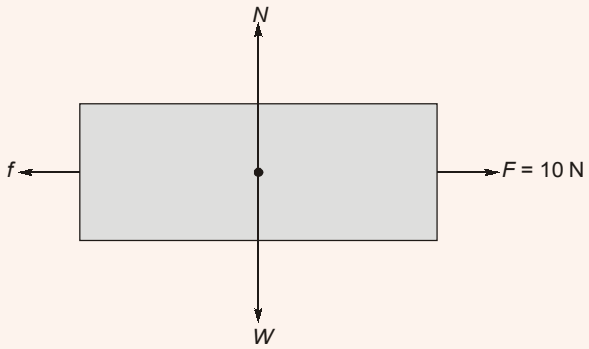
Sr.No.	Welding process	Heat density (W/cm^2)	Temperature(°C)
1	Gas welding	$10^2 - 10^3$	2500 – 3500
2	Shielded meta arc welding	10^4	> 6000
3	Gas metal arc welding	10^5	8000 – 10000
4	Plasma arc welding	10^6	15000 – 30000
5	Electron beam welding	$10^7 - 10^8$	20000 – 30000
6	Laser beam welding	$> 10^8$	> 30000

End of Solution

Q.18 A block of mass 10 kg rests on a horizontal floor. The acceleration due to gravity is 9.81 m/s^2. The coefficient of static friction between the floor and the block is 0.2. A horizontal force of 10 N is applied on the block as shown in the figure. The magnitude of force of friction (in N) on the block is _____.



Ans. (10)



$W = mg = 10 \times 9.81 = 98.1$ N

Normal force, $N = W = 98.1$ N

Now, Maximum value of static friction force

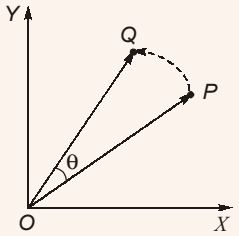
$= \mu_S N = 0.2 \times 98.1 = 19.62$ N

∵ Applied force is less than static friction force, so friction force will be same as applied force.

Hence, Friction force = 10 N

End of Solution

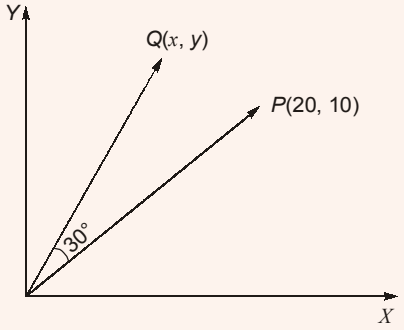
Q.19 The position vector $\overrightarrow{OP}$ of $P(20, 10)$ is rotated anti-clockwise in X-Y plane by an angle $\theta = 30°$ such that the point P occupies position Q, as shown in the figure. The coordinates (x, y) of Q are



(a) (13.40, 22.32)
(b) (18.66, 12.32)
(c) (22.32, 8.26)
(d) (12.32, 18.66)

Ans. **(d)**

From given diagram,



Rotation about x-y plane -counterclockwise $= \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} 20 \\ 10 \end{bmatrix}$

$= \begin{bmatrix} \cos 30 & -\sin 30 \\ \sin 30 & \cos 30 \end{bmatrix} \begin{bmatrix} 20 \\ 10 \end{bmatrix} = \begin{bmatrix} 0.866 & -0.5 \\ 0.5 & 0.866 \end{bmatrix} \begin{bmatrix} 20 \\ 10 \end{bmatrix} = \begin{bmatrix} 12.32 \\ 18.66 \end{bmatrix}$

End of Solution

Q.20 During a non-flow thermodynamic process (1 – 2) executed by a perfect gas, the heat interaction is equal to the work interaction ($Q_{1-2} = W_{1-2}$) when the process is

(a) Isentropic
(b) Polytropic
(c) Adiabatic
(d) Isothermal

Ans. **(d)**

End of Solution

Q.21 Evaluation of $\int_2^4 x^3 dx$ using a 2-equal segment trapezoidal rule gives a value of _____.

Ans. (63)

Step size, $h = \frac{b-a}{n} = \frac{4-2}{2} = 1$

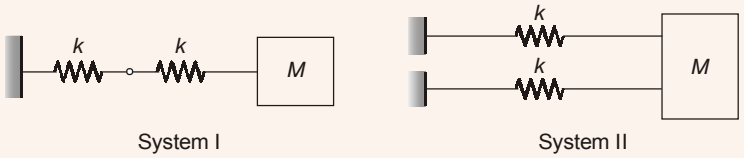
x	2	3	4
y	8	27	64

By trapezoidal rule,

$$\int_2^4 x^3 dx = \frac{h}{2}\left[(y_0 + y_2) + 2y_1\right] = \frac{1}{2}\left[8 + 64 + 2 \times 27\right] = 63$$

End of Solution

Q.22 The natural frequencies corresponding to the spring-mass systems I and II are ω_I and ω_{II}, respectively. The ratio $\frac{\omega_I}{\omega_{II}}$ is



System I System II

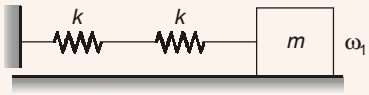
(a) 2 (b) $\frac{1}{2}$

(c) $\frac{1}{4}$ (d) 4

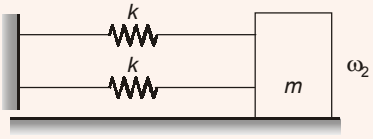
Ans. (b)

$$\frac{1}{k_{eg}} = \frac{1}{k} + \frac{1}{k} = \frac{2}{k}$$

$$k_{eg} = \frac{k}{2}$$



$$\Rightarrow \quad \omega_1 = \sqrt{\frac{(k/2)}{m}} = \sqrt{\frac{k}{2m}}$$



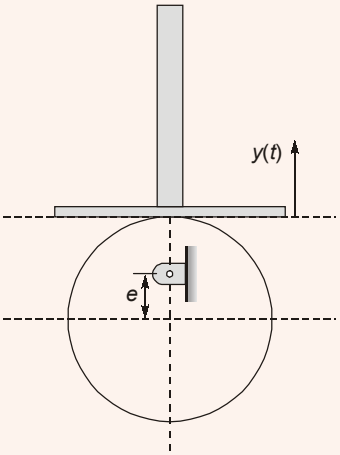
$$\omega_2 = \sqrt{\frac{2k}{m}}$$

$$\frac{\omega_1}{\omega_2} = \sqrt{\frac{k/2m}{2k/m}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

$$\frac{\omega_1}{\omega_2} = \frac{1}{2}$$

End of Solution

Q.23 A flat-faced follower is driven using a circular eccentric cam rotating at a constant angular velocity ω. At time $t = 0$, vertical position of follower is $y(0) = 0$, and the system is in the configuration shown below.

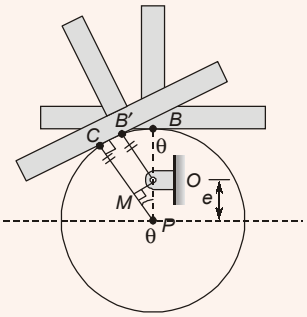


Then vertical position of the follower face, $y(t)$ is given by

(a) $e(1 - \cos \omega t)$ (b) $e(1 + \cos 2\omega t)$

(c) $e \sin \omega t$ (d) $e \sin 2\omega t$

Ans. (a)



Displacement of follower

$y = OB' - OB$ (OB' will be parallel to PC)

$= CM - OB$

$= (PC - PM) - OB$ ($OB' = CM$)

$= R - e\cos\theta - (R - e) = R - e\cos\theta - R + e$

$= e(1 - \cos\theta)$ (In time (t) $\theta = \omega t$)

$= e(1 - \cos\omega t)$

End of Solution

Q.24 During a high cycle fatigue test, a metallic specimen is subjected to cyclic loading with a mean stress of +140 MPa, and a minimum stress of –70 MPa. The R-ratio (minimum stress to maximum stress) for this cyclic loading is _____ (round off to one decimal place)

Ans. (–0.2)

$$\sigma_{min} = 70 \text{ MPa} \quad \text{(Compressive)},$$
$$\sigma_{mean} = 140 \text{ MPa}$$
$$\frac{\sigma_{min}}{\sigma_{max}} = ?$$

We know that,

$$\sigma_{mean} = \frac{\sigma_{max} + \sigma_{min}}{2}$$
$$140 = \frac{\sigma_{max} - 70}{2}$$
$$280 + 70 = \sigma_{max}$$
$$\sigma_{max} = 350 \text{ MPa (Tensile)}$$
$$\frac{\sigma_{min}}{\sigma_{max}} = -\frac{70}{350} = -0.2$$

End of Solution

Q.25 As per common design practice, the three types of hydraulic turbine, in descending order of flow rate, are

(a) Pelton, Kaplan, Francis
(b) Francis, Kaplan, Pelton
(c) Kaplan, Francis, Pelton
(d) Pelton, Francis, Kaplan

Ans. (c)

Pelton turbine is high head and low mass flow rate turbine. Kaplan turbine is low head and high mass flow rate turbine. Francis turbine is medium head, medium mass flow rate turbine.

End of Solution

Q.26 - Q.55 Carry Two Mark each.

Q.26 Five jobs (J1, J2, J3, J4 and J5) need to be processed in a factory. Each job can be assigned to any of the five different machines (M1, M2, M3, M4 and M5). The time durations taken (in minutes) by the machines for each of the jobs, are given in the table. However, each job is assigned to a specific machine in such a way that the total processing time is minimum. The total processing time is _____ minutes.

	M1	M2	M3	M4	M5
J1	40	30	50	50	58
J2	26	38	60	26	38
J3	40	34	28	24	30
J4	28	40	40	32	48
J5	28	32	38	22	44

Ans. (146)

	M1	M2	M3	M4	M5
J1	40	30	50	50	58
J2	26	38	60	26	38
J3	40	34	28	24	30
J4	28	40	40	32	48
J5	28	32	38	22	44

Subtracting minimum value of each row from corresponding row elements.

	M1	M2	M3	M4	M5
J1	10	0	20	20	28
J2	0	12	34	0	12
J3	16	10	4	0	6
J4	0	12	12	4	20
J5	6	10	16	0	22

Subtracting minimum value of each column from corresponding column.

	M1	M2	M3	M4	M5
J1	10	[0]	16	20	22
J2	[0]	12	30	~~0~~	6
J3	~~16~~	~~10~~	~~8~~	~~6~~	[0]
J4	~~0~~	12	8	4	14
J5	6	10	12	[0]	16

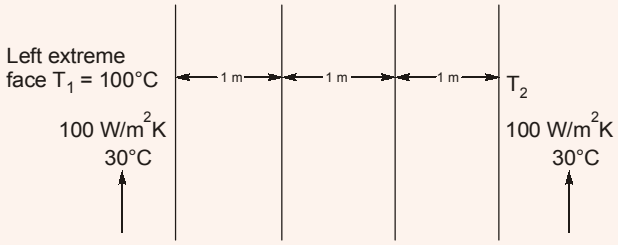
Now number of assignments is less than the number of machines. Hence current solution is not optimal. Now adding minimum uncovered value at all junctions and subtracting from uncovered values.

	M1	M2	M3	M4	M5
J1	10	[0]	10	20	16
J2	~~0~~	12	24	~~0~~	[0]
J3	22	16	[0]	6	~~0~~
J4	[0]	12	2	4	8
J5	6	10	6	[0]	10

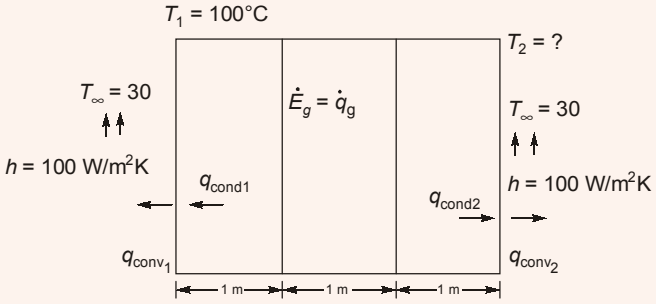
Hence,
Job 1 → Machine 2
Job 2 → Machine 5
Job 3 → Machine 3
Job 4 → Machine 1
Job 5 → Machine 4
Total time = 30 + 38 + 28 + 22 = 146

End of Solution

Q.27 Three slabs are joined together as shown in the figure. There is no thermal contact resistance at the interfaces. The center slab experiences a non-uniform internal heat generation with an average value equal to 10000 Wm^{-3}, while the left and right slabs have no internal heat generation. All slabs have thickness equal to 1 m and thermal conductivity of each slab is equal to 5 $Wm^{-1}K^{-1}$. The two extreme faces are exposed to fluid with heat transfer coefficient 100 $Wm^{-2}K^{-1}$ and bulk temperature 30°C as shown. The heat transfer in the slabs is assumed to be one dimensional and steady, and all properties are constant. If the left extreme face temperature T_1 is measured to be 100°C, the right extreme face temperature T_2 is _____°C.



Ans. (60)



$$\dot{E}_g = 10000 \times (L \times A)$$

$$= 10000 \times 1 \times 1 = 10000\text{W}$$

$$hA(T_1 - T_\infty) = q_{conv_1} = q_{cond_1}$$

$$100 \times (100 - 30) = q_{cond_1}$$

$$q_{cond_1} = 7000 \text{ W}$$

$$q_{conv_2} = hA(T_2 - T_\infty)$$

$$= 100 \times 1 \times (T_2 - 30)$$

$$q_{conv_2} = 100(T_2 - 30) = q_{cond_2}$$

At steady state:

$$\dot{E}_g = \dot{E}_{out}$$

$$\dot{E}_g = q_{cond_1} + q_{cond_2}$$

$$10000 = 7000 + 100(T_2 - 30)$$

$$T_2 = \left(\frac{3000}{100}\right) + 30 = 60°\text{C}$$

End of Solution

Q.28 Match the following sand mold casting defects with their respective causes.

Defect		Cause	
P.	Blow hole	1.	Poor collapsibility
Q.	Misrun	2.	Mold erosion
R.	Hot tearing	3.	Poor permeability
S.	Wash	4.	Insufficient fluidity

(a) P-3, Q-4, R-1, S-2 (b) P-4, Q-3, R-1, S-2
(c) P-3, Q-4, R-2, S-1 (d) P-2, Q-4, R-1, S-3

Ans. **(a)**

Blow holes → Poor permeability
Misrun → Insufficient fluidity
Hot tears → Poor collapsibility
Wash → Mold erosion

End of Solution

Q.29 A harmonic function is analytic if it satisfies the Laplace equation. If $u(x, y) = 2x^2 - 2y^2 + 4xy$ is a harmonic function, then its conjugate harmonic function $v(x, y)$ is
(a) $4y^2 - 4xy$ + constant (b) $-4xy + 2y^2 - 2x^2$ + constant
(c) $2x^2 - 2y^2 + xy$ + constant (d) $4xy - 2x^2 + 2y^2$ + constant

Ans. **(d)**

Let $f(z) = u + iv$ is an analytic function where u is harmonic then v is called its harmonic conjugate.

Here $u = 2x^2 - 2y^2 + 4xy$ i.e. real part is given, so by using Milne-Thomson method.

Step 1: $\frac{\partial u}{\partial x} = 4x + 4y = \phi_1(x, y)$

Step 2: $\phi_1(z, 0) = 4z$

Step 3: $\frac{\partial u}{\partial y} = -4y + 4x = \phi_2(x, y)$

Step 4: $\phi_2(z, 0) = 4z$

Step 5: $f(z) = \int[\phi_1(z,0) - i\phi_2(z,0)] + c$

$$= \int(4z - i4z)dz + c = 4(1-i)\frac{z^2}{2} + c$$

$$= 2(1-i)[x^2 - y^2 + 2ixy] + c$$

$$f(z) = (2x^2 - 2y^2 + 4xy) + i(4xy - 2x^2 + 2y^2 + c) = u + iv$$

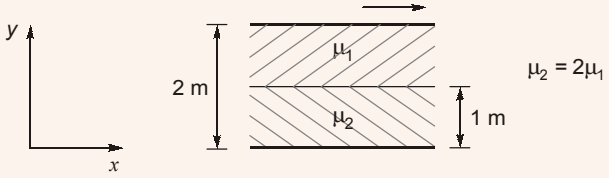
Hence harmonic conjugate, $v = 4xy - 2x^2 + 2y^2$ + constant

End of Solution

Q.30 Two immiscible, incompressible, viscous fluids having same densities but different viscosities are contained between two infinite horizontal parallel plates, 2 m apart as shown below. The bottom plate is fixed and the upper plate moves to the right with a constant velocity of 3 m/s. With the assumptions of Newtonian fluid, steady, and fully developed laminar flow with zero pressure gradient in all directions, the momentum equations simplify to

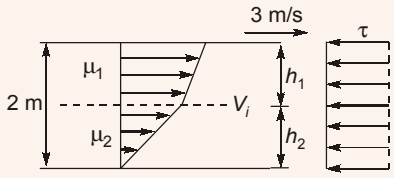
$$\frac{d^2u}{dy^2} = 0$$

If the dynamic viscosity of the lower fluid, μ_2, is twice that of the upper fluid, μ_1, then the velocity at the interface (round off to two decimal places) is _____ m/s.



Ans. (1)

Velocity profile is laminar in both fluids



$$\frac{d^2u}{dy^2} = 0$$

$$\frac{du}{dy} = c_1$$

$$u = c_1y + c_2$$

i.e. we can assume linear velocity profile.

If velocity profile is linear shear stress will be constant in gap everywhere i.e. in fluid (1) and fluid (2)

Also at the interface shear stress will be constant.

$$\tau_1 = \tau_2$$

$$\mu_2\frac{V_i}{h_2} = \mu_1\frac{(V - V_i)}{h_1}$$

where V_i is velocity at the interface.

$$2\mu_1\frac{V_i}{1} = \frac{\mu_1(3 - V_i)}{1}$$

$$2V_i = 3 - V_i$$

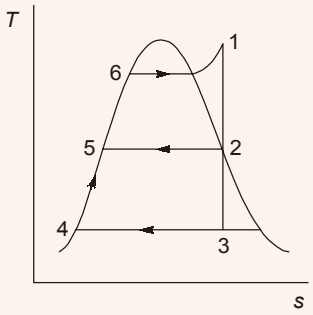
$$3V_i = 3$$

$$V_i = 1 \text{ m/s}$$

End of Solution

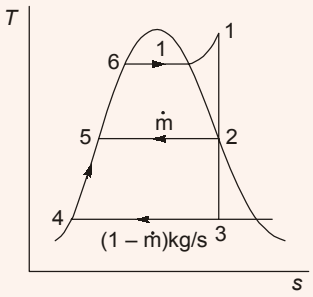
Q.31 A steam power cycle with regeneration as shown below on the T-s diagram employs a single open feedwater heater for efficiency improvement. The fluids mix with each other in an open feedwater heater. The turbine is isentropic and the input (bleed) to the feedwater heater from the turbine is at state 2 as shown in the figure. Process 3-4 occurs in the condenser. The pump work is negligible. The input to the boiler is at state 5. The following information is available from the steam tables:

State	1	2	3	4	5	6
Enthalpy (kJ/kg)	3350	2800	2300	175	700	1000



The mass flow rate of steam bled from the turbine as a percentage of the total mass flow rate at the inlet to the turbine at state 1 is _____.

Ans. (20)



From energy balance equation

$$\dot{m}h_2 + (1-\dot{m})h_4 = h_5$$

$$\dot{m}h_2 + \dot{m}h_4 + h_4 = h_5$$

$$\dot{m}(h_2 + h_4) = h_5 - h_4$$

$$\dot{m} = \frac{h_5 - h_4}{(h_2 - h_4)}$$

$$\dot{m} = \frac{700-175}{(2800-175)} \times 100 = 0.2 \text{ or } 20\%$$

End of Solution

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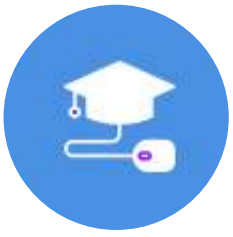

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Q.32 A circular shaft having diameter $65.00^{+0.01}_{-0.05}$ mm is manufactured by turning process. A 50 μm thick coating of TiN is deposited on the shaft. Allowed variation in TiN film thickness is ±5 μm. The minimum hole diameter (in mm) to just provide clearance fit is

(a) 64.95 (b) 65.01

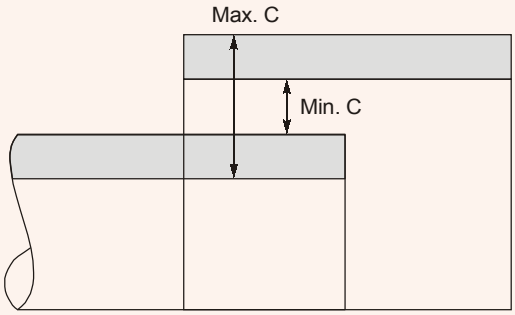
(c) 65.12 (d) 65.10

Ans. (c)

Shaft $65^{+0.01}_{-0.05}$ mm

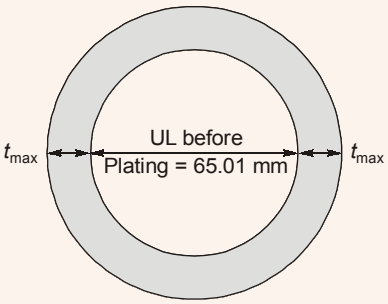
Coating thickness 50 ± 5 μm

Clearance fit



This is a question if clearance fit, for just clearance fit min. C will be zero. Therefore UL of shaft = LL of hole.

After coating largest shaft will be product if we start with largest shaft and add maximum coating.



t_{max} = 55 μm = 0.055 mm

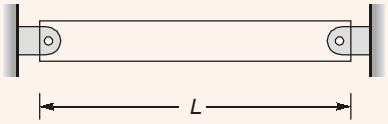
Largest shaft after plating = 0.055 + 65.01 + 0.055 mm

= 65.12 mm

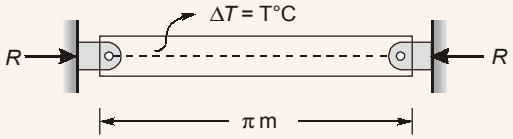
Answer is (c).

End of Solution

Q.33 Consider a prismatic straight beam of length L = π m, pinned at the two ends as shown in the figure. The beam has a square cross-section of side p = 6 mm. The Young's modulus E = 200 GPa, and the coefficient of thermal expansion $\alpha = 3 \times 10^{-6}K^{-1}$. The minimum temperature rise required to cause Euler buckling of the beam is _____K.



Ans. (1)



L = π m

Side of square, p = 6 mm

E = 200 GPa

$\alpha = 3 \times 10^{-6}/K$

For completely restricted expansion, $R = \sigma_{Th}\, A = \alpha TEA$ ...(i)

Buckling load, $P_e = \left(\dfrac{n\pi^2 EI_{min}}{L^2}\right)$

$$P_e = (1)\frac{\pi^2 Ep^4}{12L^2} \quad ...(ii)$$

Condition for buckling,

$R > P_e$

$$\alpha TE(A) > \frac{\pi^2 Ep^4}{12L^2}$$

$$\alpha T(p^2) > \frac{\pi^2 p^4}{12L^2}$$

$$T > \frac{\pi^2 p^2}{(\alpha)(12)\pi^2(1000)^2}$$

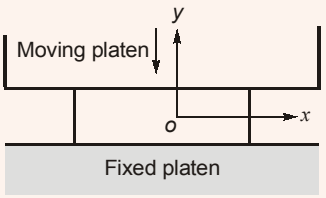
$$T > \frac{6^2}{(12)\times 3\times 10^{-6}\times 10^6}$$

$T > 1K$

or Change in temperature is 1K.

End of Solution

Q.34 A plane-strain compression (forging) of a block is shown in the figure. The strain in the z-direction is zero. The yield strength (S_y) in uniaxial tension/compression of the material of the block is 300 MPa and it follows the Tresca (maximum shear stress) criterion. Assume that the entire block has started yielding. At a point where σ_x = 40 MPa (compressive) and τ_{xy} = 0, the stress component σ_y is



(a) 340 MPa (compressive)
(b) 260 MPa (compressive)
(c) 340 MPa (tensile)
(d) 260 MPa (tensile)

Ans. **(a)**

According to Tresca's theory

$$\sigma_x + P = 2K$$

where $K = \frac{\sigma_0}{2}$ = flow shear stress

$$= \frac{300}{2} = 150 \text{ MPa}$$

and $\sigma_x = -40$ MPa

Now, $\sigma_x + P = 2K$

$$-40 + P = 2 \times 150$$

or $P = 340$ MPa

P is pressure. If P = 340 MPa, stress (σ_y) will be – 340 MPa. i.e. 340 MPa (compressive)

End of Solution

Q.35 In UTM experiment, a sample of length 100 mm, was loaded in tension until failure. The failure load was 40 kN. The displacement, measured using the cross-head motion, at failure, was 15 mm. The compliance of the UTM is constant and is given by 5×10^{-8} m/N. The strain at failure in the sample is _____%.

Ans. **(2)**

In UTM experiment under tension.

L = 100 mm

Failure load (P) = 40 kN

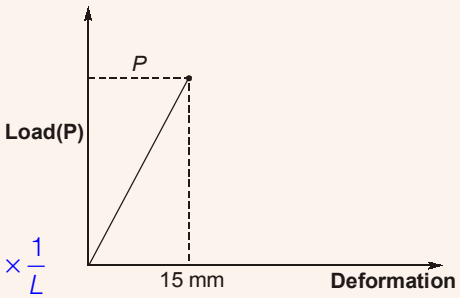
Compliance of UTM is constant = $\frac{L}{AE} = 5 \times 10^{-8}$ m/N = Constant

Strain at failure = ?

As we know, $\delta = \frac{PL}{AE}$

$$a = \delta\frac{AE}{L}$$

P = Constant (δ)



Linear relationship. So,

$$\frac{\delta}{L} = \frac{P}{AE}$$

$$\text{Strain} = \frac{P}{AE}\times\frac{L}{L} = P\times\left(\frac{L}{AE}\right)\times\frac{1}{L}$$

$$\text{Strain} = P \times \text{compliance} \times \frac{1}{L}$$

$$= \frac{40\times10^{3}\times5\times10^{-8}}{100\times10^{-3}} = 2\times10^{-2}$$

$$= 2 \times 10^{-2} \times 100\% = 2\%$$

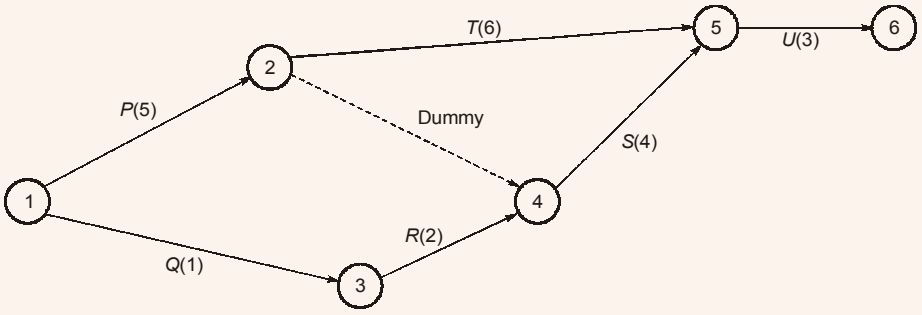
End of Solution

Q.36 A project consists of six activities. The immediate predecessor of each activity and the estimated duration is also provided in the table below:

Activity	Immediate predecessor	Estimated duration (weeks)
P	-	5
Q	-	1
R	Q	2
S	P,R	4
T	P	6
U	S,T	3

If all the activities other than S take the estimated amount of time, the maximum duration (in weeks) of the activity *S* without delaying the completion of the project is _____.

Ans. (6)



Hence different paths are:

P - T - U = 5 + 6 + 3 = 14 weeks ← Critical path

P - Dummy - S - U = 5 + 4 + 3 = 12 weeks

Q - R - S - U = 1 + 2 + 3 + 4 = 10 weeks

∵ Only 'S' is delayed and no other activity is delayed.

So, maximum activity time for activity 'S' can be 6 weeks without delaying the project.

End of Solution

Q.37 A gas turbine with air as the working fluid has an isentropic efficiency of 0.70 when operating at a pressure ratio of 3. Now, the pressure ratio of the turbine is increased to 5, while maintaining the same inlet conditions. Assume air as a perfect gas with specific heat ratio $\gamma = 1.4$. If the specific work output remains the same for both the cases, the isentropic efficiency of the turbine at the pressure ratio of 5 is _____ (round off to two decimal places)

Ans. **(0.514)**

$$\frac{P_3}{P_{4s}} = 3$$

$$\frac{P_3'}{P_{4s}} = 5$$

$$w_{net_1} = c_p T_3 \left\{1 - \frac{1}{3^{\gamma-1/\gamma}}\right\} 0.7$$

$$w_{net_1} = c_p T_3 \left\{1 - \frac{1}{5^{\gamma-1/\gamma}}\right\} \eta$$

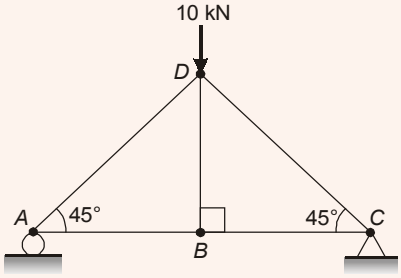
$$w_{net_1} = w_{net2}$$

$$\Rightarrow \quad \eta = \frac{(0.7)\left\{1 - \frac{1}{3^{\gamma-1/\gamma}}\right\}}{\left\{1 - \frac{1}{5^{\gamma-1/\gamma}}\right\}} = 0.514$$

Consider it is asked only for turbine portion as for full cycle, data is not sufficient.

End of Solution

Q.38 A truss is composed of members AB, BC, CD, AD and BD, as shown in the figure. A vertical load of 10 kN is applied at point D. The magnitude of force (in kN) in the member BC is _____.

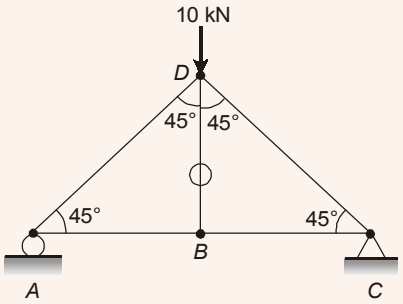


Ans. (5)

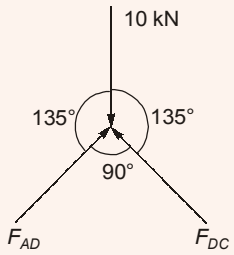
By symmetry, force in member *AB* and *CD* will be same

By symmetry, $R_A = R_C = 5$ kN

At joint *D*,



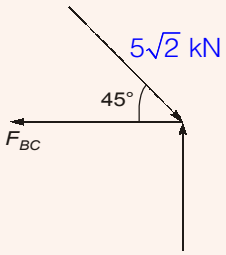
Joint *D*,



$$\frac{F_{AD}}{\sin 135°} = \frac{10}{1} = \frac{F_{DC}}{\sin 135°}$$

$$F_{DC} = 10\sin 135° = 5\sqrt{2} \text{ kN (Compressive)}$$

Joint *C*,



$$5\sqrt{2}\cos 45° = F_{BC}$$

$$F_{BC} = 5 \text{ kN (Tensile)}$$

End of Solution

Q.39 In orthogonal turning of a cylindrical tube of wall thickness 5 mm, the axial and tangential cutting forces were measured as 1259 N and 1601 N, respectively. The measured chip thickness after machining was found to be 0.3 mm. The rake angle was 10° and axial feed was 100 mm/min. The rotational speed of the spindle was 1000 rpm. Assuming the material to be perfectly plastic and Merchant's first solution, the shear strength of the material is closest to

(a) 875 MPa (b) 920 MPa

(c) 722 MPa (d) 200 MPa

Ans. (c)

Orthogonal turning, $\lambda = 90°$,

wall thickness = depth of cut, (d) = 5 mm (assumed)

Axial force, $F_x = 1259$ N, $F_t = \dfrac{F_x}{\sin 90} = F_x = 1259$ N

Tangential force, $F_z = 1601$ N, $F_c = F_t = 1601$N

$t_c = 0.3$ mm

$\alpha = 10°$

$fN = 100$ mm/min

$N = 1000$ rpm or $f \times 1000 = 100$ or $f = 0.1$ mm/rev.

$t = f\sin\lambda = 0.1 \sin 90° = 0.1$ mm

$$b = \frac{d}{\sin\lambda} = \frac{5}{\sin 90} = 5 \text{ mm}$$

$$r = \frac{t}{t_c} = \frac{0.1}{0.3} = 0.33$$

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} = \frac{0.33\cos 10°}{1 - 0.33\sin 10°} \text{ or } \phi = 19.02°$$

$$\tau_s = \frac{F_s}{A_s} = \frac{F_s \sin\phi}{bt}$$

$$= \frac{(F_c\cos\phi - F_t\sin\phi)\times\sin\phi}{bt}$$

$$= \frac{(1601\cos 19.02 - 1259\sin 19.02)\times\sin 19.02}{5\times 0.1}$$

$$= 719.12 \text{ MPa} \simeq 722 \text{ MPa}$$

Option (c) is correct.

End of Solution

Q.40 A cube of side 100 mm is placed at the bottom of an empty container on one of its faces. The density of the material of the cube is 800 kg/m^3. Liquid of density 1000 kg/m^3 is now poured into the container. The minimum height to which the liquid needs to be poured into the container for the cube to just lift up is _____ mm.

Ans. (80)

To just lift the block from the bottom,

Weight of cube = F_B

$\Rightarrow \quad \rho g \times V = \rho_l g \times \forall$

$\Rightarrow \quad 800 \times a^3 = 1000 \times a^2 \times h$

$\Rightarrow \quad h = 0.8 \times a$

$= 0.8 \times 100 = 80$ mm

End of Solution

Q.41 If one mole of H_2 gas is occupies a rigid container with a capacity of 1000 litres and the temperature is raised from 27°C to 37°C, the change in pressure of the contained gas (round off to two decimal places), assuming ideal gas behaviour, is _____ Pa. (R = 8.314 J/mol-K)

Ans. (83.14)

V = Volume of rigid container

T_1 = Initial temperature of the gas

T_2 = Final temperature of the gas

$$P_1V = n\bar{R}T_1$$

$$P_2V = n\bar{R}T_2$$

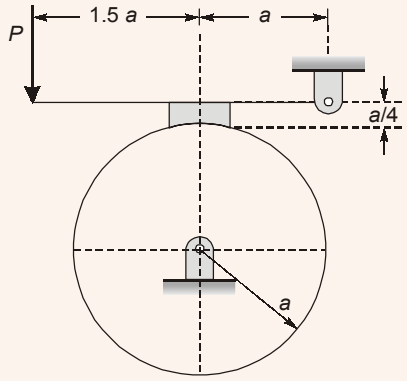
$$(P_2 - P_1)V = n\bar{R}(T_2 - T_1)$$

$$\Delta P \times 1 = 1 \times 8.314(37 - 27)$$

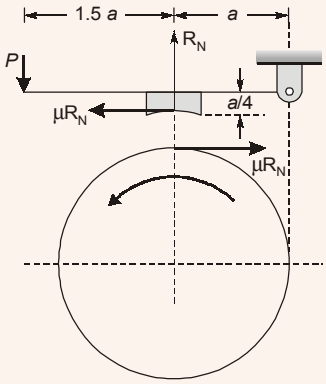
$$\Delta P = 83.14 \text{ Pa}$$

End of Solution

Q.42 A single block brake with a short shoe and torque capacity of 250 Nm is shown. The cylindrical brake drum rotates anticlockwise at 100 rpm and the coefficient of friction is 0.25. The value of a, in mm (round off to one decimal place), such that the maximum actuating force P is 2000 N, is _____.



Ans. (212.5)



Drum eq.: $T_f = \mu R_N . a$

$$250 = 0.25 \times R_N \times a \quad \ldots(i)$$

Lever eq.

$$P \times 2.5a - \mu R_N \times \frac{a}{4} - R_N \times a = 0$$

$$R_N\left(1+\frac{0.25}{4}\right) = 2000 \times 2.5$$

$$R_N = 4705.882\ \text{N} \quad \ldots(ii)$$

By eq. (i)

$$250 = 0.25 \times 4705.882 \times a$$

$$a = 212.5\ \text{mm}$$

End of Solution

Q.43 The set of equations

$x + y + z = 1$

$ax - ay + 3z = 5$

$5x - 3y + az = 6$

has infinite solution if a =

(a) -4 (b) -3

(c) 3 (d) 4

Ans. **(d)**

Given system is non-homogeneous system when augmented matrix

$$c = [a/B]$$

$$c = \left[\begin{array}{ccc|c} 1 & 1 & 1 & 1 \\ a & -a & 3 & 5 \\ 5 & -3 & a & 6 \end{array}\right]$$

$R_2 \div a$ and $R_3 \to R_3 - 5R_1$

$$c = \left[\begin{array}{ccc|c} 1 & 1 & 1 & 1 \\ 1 & -1 & 3/a & 5/a \\ 0 & -8 & a-5 & 1 \end{array}\right]$$

$R_2 \to R_2 - R_1$,

$$c = \left[\begin{array}{ccc|c} 1 & 1 & 1 & 1 \\ 0 & -2 & \frac{3}{a}-1 & \frac{5}{a}-1 \\ 0 & -8 & a-5 & 1 \end{array}\right]$$

$R_3 \to R_3 - 4R_2$,

$$c = \left[\begin{array}{ccc|c} 1 & 1 & 1 & 1 \\ 0 & -2 & \frac{3}{a}-1 & \frac{5}{a}-1 \\ 0 & 0 & a-\frac{12}{a}-1 & 5-\frac{20}{a} \end{array}\right]$$

This system will have infinitely many solution only.

If $a-\frac{12}{a}-1=0$ and $5-\frac{20}{a}=0$

$a = -3,\ 4$ and $a = 4$

for $a = 4$, the system has infinite many solution.

End of Solution

Q.44 At a critical point in a component, the state of stress is given as σ_{xx} = 100 MPa, σ_{yy} = 220 MPa, $\sigma_{xy} = \sigma_{yx}$ = 80 MPa and all other stress components are zero. The yield strength of the material is 468 MPa. The factor of safety on the basis of maximum shear stress theory is _____ (round off to one decimal place).

Ans. (1.8)

As per given data

σ_{xx} = 100 MPa

σ_{yy} = 220 MPa

$\sigma_{xy} = \sigma_{yx}$ = 80 MPa

Principal stresses are

$$\sigma_{1,2} = \left(\frac{\sigma_x+\sigma_y}{2}\right) \pm \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2+\sigma_{xy}^2}$$

$$= \left(\frac{100+220}{2}\right) \pm \sqrt{\left(\frac{100-220}{2}\right)^2+80^2} = 160 \pm 100$$

σ_1 = 160 + 100 = 260 MPa

σ_2 = 160 – 100 = 60 MPa

Both principal stresses are like in nature.

According to maximum shear stress theory.

$$\text{Maximum shear stress} = \left[\max\left(\frac{\sigma_1-\sigma_2}{2}\right),\left(\frac{\sigma_1}{2}\right),\left(\frac{\sigma_2}{2}\right)\right]$$

$$\tau_{max} = \frac{\sigma_1}{2}$$

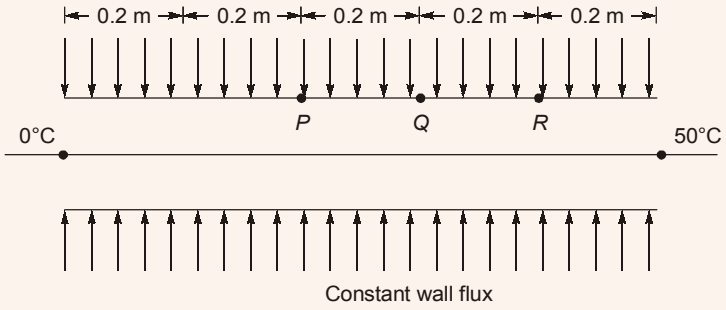
$$\frac{\sigma_{yt}}{FOS \times 2} = \frac{\sigma_1}{2}$$

$$FOS = \frac{\sigma_{yt}}{\sigma_1} = \frac{468}{260} = 1.8$$

End of Solution

Q.45 The wall of a constant diameter pipe of length 1 m is heated uniformly with flux q'' by wrapping a heater coil around it. The flow at the inlet to the pipe is hydrodynamically fully developed. The fluid is incompressible and the flow is assumed to be laminar and steady all through the pipe. The bulk temperature of the fluid is equal to 0°C at the inlet and 50°C at the exit. The wall temperatures are measured at three locations, P, Q and R, as shown in the figure. The flow thermally develops after some distance from the inlet. The following measurements are made:

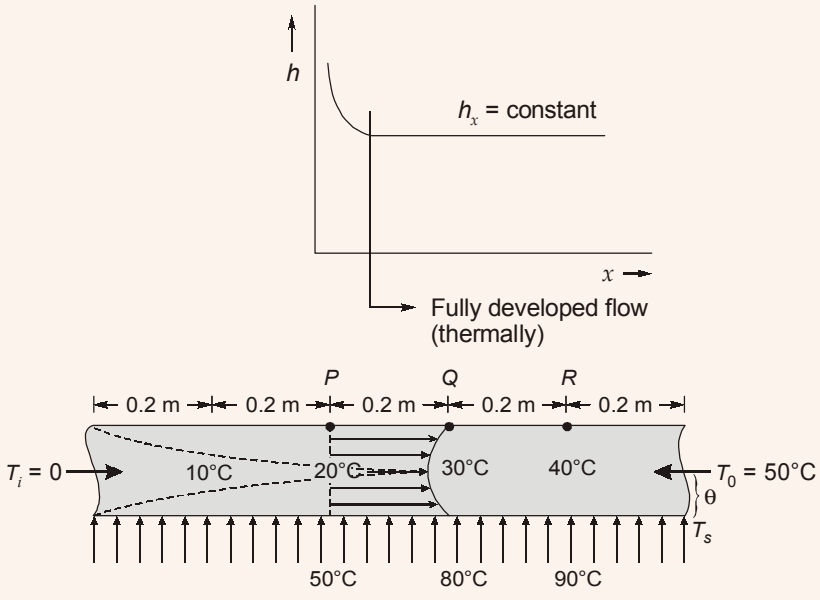
Point	P	Q	R
Wall Temperature(°C)	50	80	90



Among the locations P, Q and R the flow is thermally developed at

(a) P, Q and R
(b) Q and R only
(c) R only
(d) P and Q only

Ans. **(b)**



$$dq = h_x \times 1 \times (T_w - T_b)\ \text{W/m}^2$$

Since dq = constant

and h_x = constant

$\Rightarrow$ $T_w - T_b$ = constant

Also $dq = \dot{m}c_p dT_b$

If $dq = c$

$\Rightarrow$ dT_b = constant

T_b varies linearly with respect to x

$\Rightarrow$ T_w also varies linearly with respect to x.

Hence, Q, R in fully developed region.

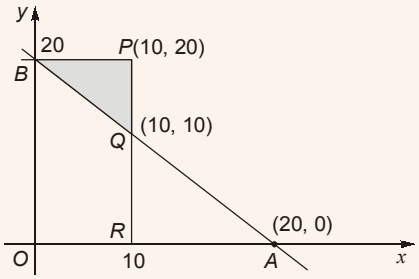
End of Solution

Q.46 The variable x takes a value between 0 and 10 with uniform probability distribution. The variable y takes a value between 0 and 20 with uniform probability distribution. The probability of the sum of variables $(x + y)$ being greater than 20 is

(a) 0.25 (b) 0.33

(c) 0.50 (d) 0

Ans. **(a)**



$0 \le x \le 10$ and $0 \le y \le 20$.

Here x and y together constitute a rectangle given by OBPR.

Where AB: $x + y = 20$

$$\text{Req. probability} = P\left[(x+y) > 20\right] = \frac{\text{Shaded area}}{\text{Total area}} = \frac{50}{200} = \frac{1}{4} = 0.25$$

End of Solution

Q.47 The value of the following definite integral is _____ (round off to three decimal places)

$$\int_1^e (x \ln x)\, dx$$

Ans. **(2.097)**

$$I = \int_1^e x \ln x\, dx$$

Put $x = e^t$, $dx = e^t dt$ (when $x = 1$, $t = 0$; when $x = e$, $t = 1$)

$$I = \int_0^1 t \cdot e^t e^t dt = \int_0^1 t \cdot e^{2t}\, dt$$

$$= \left[t\frac{e^{2t}}{2} - \int \frac{e^{2t}}{2} dt\right]_0^1 = \left(t\frac{e^{2t}}{2} - \frac{e^{2t}}{4}\right)_0^1$$

$$= \left(\frac{e^2}{2} - \frac{e^2}{4}\right) - \left(0 - \frac{1}{4}\right) = \frac{e^2+1}{4} = 2.097$$

End of Solution

Q.48 In ASA system, the side cutting and end cutting edge angles of a sharp turning tool are 45° and 10°, respectively. The feed during cylindrical turning is 0.1 mm/rev. The centre line average surface roughness (in μm, round off to one decimal place) of the generated surface is _____.

Ans. **(3.75)**

Side cutting edge angle (SCEA) = 45°

End cutting edge angle (ECEA) = 10°

Feed (f) = 0.1 mm/rev

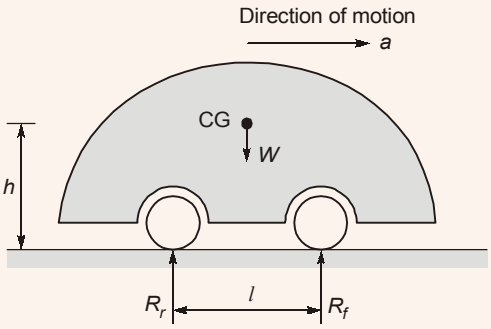
We have to consider nose radius is zero i.e. Ideal surface peak to valley surface roughness, $h = \dfrac{f}{\tan SCEA + \cot ECEA}$

The centre line average (CLA) = $\dfrac{h}{4} = \dfrac{f}{4(\tan SCEA + \cot ECEA)}$

$= \dfrac{0.1}{4(\tan 45° + \cot 10°)}$ mm = 0.00375 mm = 3.75 μm

End of Solution

Q.49 A car is having weight W is moving in the direction as shown in the figure. The centre of gravity (CG) of the car is located at height h from the ground, midway between the front and rear wheels. The distance between the front and rear wheels, is l. The acceleration of the car is a, and acceleration due to gravity is g. The reactions on the front wheels (R_f) and rear wheels (R_r) are given by



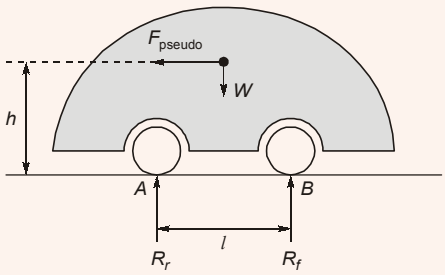
(a) $R_f = \dfrac{W}{2} + \dfrac{W}{g}\left(\dfrac{h}{l}\right)a;\ R_r = \dfrac{W}{2} - \dfrac{W}{g}\left(\dfrac{h}{l}\right)a$

(b) $R_f = R_r = \dfrac{W}{2} + \dfrac{W}{g}\left(\dfrac{h}{l}\right)a$

(c) $R_f = R_r = \dfrac{W}{2} - \dfrac{W}{g}\left(\dfrac{h}{l}\right)a$

(d) $R_f = \dfrac{W}{2} - \dfrac{W}{g}\left(\dfrac{h}{l}\right)a;\ R_r = \dfrac{W}{2} + \dfrac{W}{g}\left(\dfrac{h}{l}\right)a$

Ans. (d)



Pseudo force, $F_{pseudo} = ma$ in opposite direction of motion of car.

$$\Sigma F_V = 0$$

$$R_r + R_f = W \quad ...(1)$$

Taking moment about A

$$(F_{pseudo})h + (R_f)l = \frac{Wl}{2}$$

$$m_a h + R_f l = \frac{Wl}{2}$$

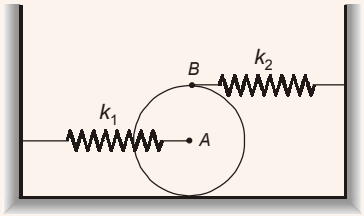
$$R_f = \frac{W}{2} - \frac{W}{g}\left(\frac{h}{l}\right)a \quad ...(2)$$

from (1) and (2)

$$R_r = \frac{W}{2} + \frac{W}{g}\left(\frac{h}{l}\right)a$$

End of Solution

Q.50 A uniform thin disk of mass 1 kg and radius 0.1 m is kept on a surface as shown in the figure. A spring of stiffness k_1 = 400 N/m is connected to the disk center A and another spring of stiffness k_2 = 100 N/m is connected at point B just above point A on the circumference of the disk. Initially, both the springs are unstretched. Assume pure rolling of the disk. For small disturbance from the equilibrium, the natural frequency of vibration of the system is _____ rad/s (round off to one decimal place)



Ans. (23.094)

As per given data

Disc mass, m = 1 kg

radius, r = 0.1m

torque equation about point 'o'

$$I\ddot{\theta} + (k_1 \times r \times \theta)r + (k_2 \times 2r \times \theta)2r = 0$$

$$I \text{ about } 'o' = \frac{mr^2}{2} + mr^2$$

$$I = \frac{3}{2}mr^2$$

$$\frac{3}{2}mr^2\ddot{\theta} + \left(k_1r^2 + k_2(4r^2)\right)\theta = 0$$

$$\ddot{\theta} + \left(\frac{k_1r^2 + 4k_2r^2}{\frac{3}{2}mr^2}\right)\theta = 0$$

$$\omega_n = \sqrt{\frac{k_1r^2 + 4k_2r^2}{\frac{3}{2}mr^2}} = \sqrt{\frac{400(0.2)^2 + 4\times100\times0.2^2}{1.5\times1\times0.2^2}}$$

$$\omega_n = 23.094 \text{ rad/s}$$

End of Solution

Q.51 Taylor's tool life equation is given by $VT^n = C$, where V is in m/min and T is in min. In a turning operation, two tools X and Y are used. For tool X, $n = 0.3$ and C = 60 and for tool Y, $n = 0.6$ and $C = 90$. Both the tools will have the same tool life for the cutting speed (in m/min, round off to one decimal place) of _____.

Ans. (40)

For tool x, $VT^{0.3} = 60$

For tool y, $VT^{0.6} = 90$

Let x is the cutting speed for same tool life in m/min.

Then $$xT_x^{0.3} = 60 \text{ or } T_x = \left(\frac{60}{x}\right)^{1/0.3}$$

$$xT_y^{0.6} = 90 \text{ or } T_y = \left(\frac{90}{x}\right)^{1/0.6}$$

Now $$T_x = T_y$$

$$\left(\frac{60}{x}\right)^{1/0.3} = \left(\frac{90}{x}\right)^{1/0.6}$$

or $$\left(\frac{60}{x}\right)^{0.6} = \left(\frac{90}{x}\right)^{0.3}$$

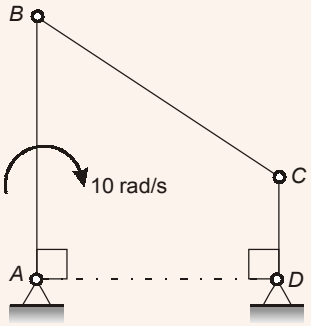
$$\frac{x^{0.3}}{x^{0.6}} = \frac{90^{0.3}}{60^{0.6}}$$

or $$x^{-0.3} = 0.33066$$

or $$x = (0.33066)^{1/-0.3} = 40 \text{ m/min}$$

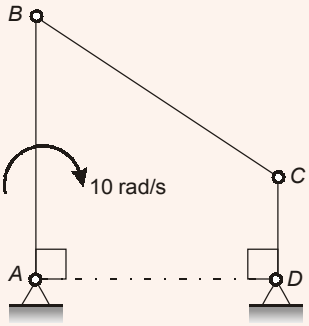
End of Solution

Q.52 In a four bar planar mechanism shown in the figure, *AB* = 5 cm, *AD* = 4 cm and *DC* = 2 cm. In the configuration shown, both *AB* and *DC* are perpendicular to *AD*. The bar *AB* rotates with an angular velocity of 10 rad/s. The magnitude of angular velocity (in rad/s) of bar *DC* at this instant is

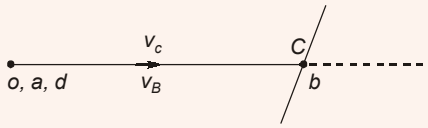


(a) 10 (b) 25
(c) 15 (d) 0

Ans. **(b)**



Velocity diagram:



$$V_C = V_B = (AB) \times \omega_{AB} = (0.05 \times 10) \text{ m/s}$$

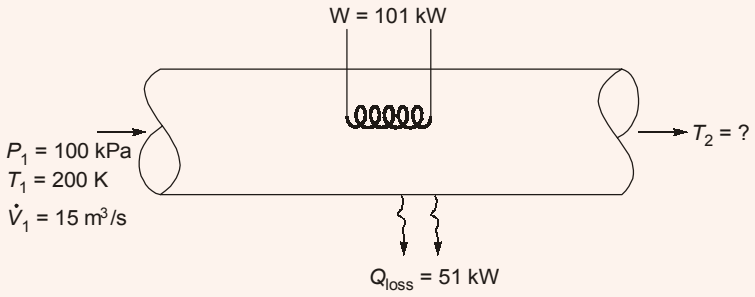
$$\omega_{CD} = \frac{V_C}{CD} = \frac{0.05 \times 10}{0.02} = 25 \text{ rad/s}$$

End of Solution

Q.53 A gas is heated in a duct as it flows over a resistance heater. Consider a 101 kW electric heating system. The gas enters the heating section of the duct at 100 kPa and 27°C with a volume flow rate of 15 m^3/s. If heat is lost from the gas in the duct to the surroundings at a rate of 51 kW, the exit temperature of the gas is
(Assume constant pressure, ideal gas, negligible change in kinetic and potential energies and constant specific heat; C_p = 1 kJ/kgK; R = 0.5 kJ/kgK)

(a) 32°C (b) 37°C
(c) 76°C (d) 53°C

Ans. (a)



Since it is given an ideal gas

and $c_p = 1$ kJ/kgK

$R = 0.5$ kJ/kgK

at inlet $P_1\dot{V}_1 = \dot{m}RT_1$

$$\dot{m} = \frac{P_1\dot{V}_1}{RT_1} = \frac{100\times 15}{0.5\times 300} = 10 \text{ kg/s}$$

Using SFEE

$$\dot{m}h_1 + Q = \dot{m}h_2 + W$$

$$h_1 + \frac{Q}{\dot{m}} = h_2 + \frac{W}{\dot{m}}$$

$$c_pT_1 - \left(\frac{51}{10}\right) = c_pT_2 - \frac{101}{10}$$

$$(T_2 - T_1)c_p = \frac{101-51}{10} = 5$$

$$T_2 - T_1 = \frac{5}{c_p} = 5\text{K}$$

$$T_2 = 300 + 5 = 305\text{K or } 32°\text{C}$$

End of Solution

Q.54 The rotor of a turbojet engine of an aircraft has a mass 180 kg and polar moment of inertia 10 kg m^2 about the rotor axis. The rotor rotates at a constant speed of 1100 rad/s in the clockwise direction when viewed from the front of the aircraft. The aircraft while flying at a speed of 800 km per hour takes a turn with a radius of 1.5 km to the left. The gyroscopic moment exerted by the rotor on the aircraft structure and the direction of motion of the nose when the aircraft turns, are

(a) 162.9 N.m, the nose goes up
(b) 1629.6 N.m, the nose goes down
(c) 1629.6 N.m, and the nose goes up
(d) 162.9 N.m, and the nose goes down

Ans. (b)

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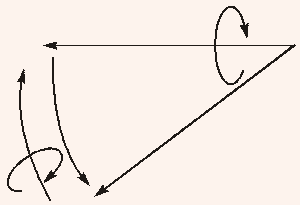


m = 180 kg

I = 10 kg – m^2

ω = 1100 rad/s

R = 1.5 km = 1500 m

$$v = 800 \text{ km/hr} = 800 \times \frac{5}{18} = 222.222 \text{ m/s}$$

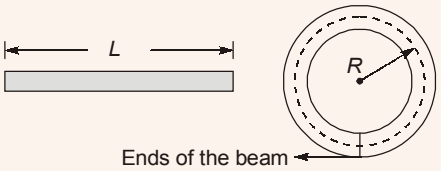
$$\omega_p = \frac{V}{R} = 0.14814 \text{ rad/s}$$

Gyroscopic couple = $I.\omega.\omega_p$ = 10 × 1100 × 0.14814 = 1629.629 Nm

Active gyroscopic couple direction clockwise in vertical plane looking from the left side of the aircraft.

End of Solution

Q.55 Consider an elastic straight beam of length L = 10π m, with square cross-section of side a = 5 mm, and Young's modulus E = 200 GPa. This straight beam was bent in such a way that the two ends meet, to form a circle of mean radius R. Assuming that Euler-Bernoulli beam theory is applicable to this bending problem, the maximum tensile bending stress in the bent beam is _____ MPa.



Ans. (100)

L = 10 π m

a = 5 mm

E = 200 GPa

Perimeter of wire = Length of wire

$2\pi R = 10\pi$

R = 5 m

We know that,

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

Now,

$$\frac{\sigma}{y} = \frac{E}{R}$$

$$\sigma_b = \frac{200 \times 10^3 \times 2.5 \times 10^{-3}}{5} = 100 \text{ MPa}$$

End of Solution

■■■■