GATE 2020
Mechanical Engineering

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Questions and Solutions

Date of Exam : 01/02/2020 (Afternoon)

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GENERAL APTITUDE

Q.1 The recent measures to improve the output would ______ the level of production to our satisfaction.

(a) increase
(b) equalise
(c) decrease
(d) speed

Ans. (a)

End of Solution

Q.2 It was estimated that 52 men can complete a strip in a newly constructed highway connecting cities P and Q in 10 days. Due to an emergency, 12 men were sent to another project. How many number of days, more than the original estimate, will be required to complete the strip?

(a) 3 days
(b) 5 days
(c) 10 days
(d) 13 days

Ans. (a)

52 men can do in 10 days.

Since 12 men were sent out

Remaining men left = 52 – 12 = 40

We know $M_1D_1 = M_2D_2$

$$52 \times 12 = 40 \times x$$

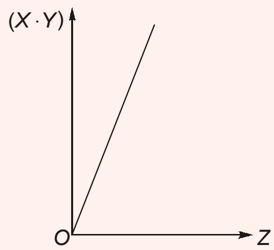
$$x = \frac{52 \times 10}{40} = 13 \text{ days}$$

Total number of days taken = 13 days

3 days more than the original estimate.

End of Solution

Q.3 An engineer measures THREE quantities X, Y and Z in an experiment. She finds that they follow a relationship that is represented in the figure below: (the product of X and Y linearly varies with Z)



Then, which of the following statements is FALSE?

(a) For fixed Y; X is proportional to Z
(b) XY/Z is constant
(c) For fixed X; Z is proportional to Y
(d) For fixed Z; X is proportional to Y

Ans. (d)

End of Solution

Q.4 While I agree ________ his proposal this time, I do not often agree ______ him.

(a) with, to
(b) to, with
(c) with, with
(d) to, to

Ans. (b)

Agree with - a person,

Agree to - an idea, proposal

End of Solution

Q.5 Select the word that fits the analogy:

White : Whitening : : Light : ________.

(a) Lightening
(b) Lightning
(c) Enlightening
(d) Lighting

Ans. (a)

End of Solution

Q.6 There are five levels {*P*, *Q*, *R*, *S*, *T*} in a linear supply chain before a product reaches customers, as shown in the figure.

P → Q → R → S → T → Customers

At each of the five levels, the price of the product is increased by 25%. If the product is produced at level *P* at the cost of Rs. 120 per unit, what is the paid (in rupees) by the customers?

(a) 292.96
(b) 187.50
(c) 234.38
(d) 366.21

Ans. (d)

P → Q → R → S → T → Customer

↓

120 at each level increased 25% price paid by customer

$$= 120 \times \frac{125}{100} \times \frac{125}{100} \times \frac{125}{100} \times \frac{125}{100} \times \frac{125}{100} = 366.21$$

End of Solution

Q.7 In one of the greatest innings ever seen in 142 years of Test history. Ben Stokes upped the tempo in a five-and-a-half hour long stay of 219 balls including 11 fours and 8 sixes that saw him finish on a 135 not out as England squared the five-match series.

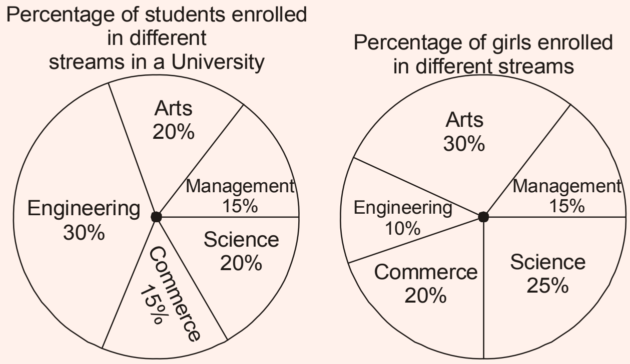
Based on their connotations in the given passage, which one of the following meanings DOES NOT match?

(a) squared = lost
(b) tempo = enthusiasm
(c) upped = increased
(d) saw = resulted in

Ans. (a)

End of Solution

Q.8 The two pie-charts given below show the data of total students and only girls registered in different streams in a university. If the total number of students registered in the university is 5000, and the total number of the registered girls is 1500; then, the ratio of boys enrolled in Arts to the girls enrolled in Management is ________.



(a) 9 : 22
(b) 11 : 9
(c) 2 : 1
(d) 22 : 9

Ans. (d)

$$\frac{(\text{Boys})_{\text{Arts}}}{(\text{Girls})_{\text{Management}}} = \frac{20\% \text{ of } 5000 - 30\% \text{ of } 1500}{15\% \text{ of } 1500}$$

$$= \frac{1000 - 450}{225} = \frac{550}{225}$$

$$= \frac{110}{45} = \frac{22}{9}$$

$$= 22 : 9$$

End of Solution

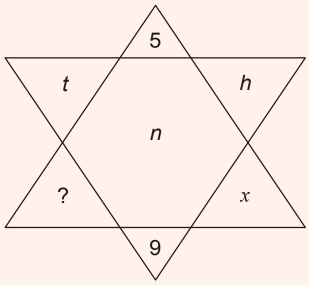
Q.9 Climate change and resilience deal with two aspects - reduction of sources of nonrenewable energy resources and reducing vulnerability of climate change aspects. The terms 'mitigation' and 'adaptation' are used to refer to these aspects, respectively.
Which of the following assertions is best supported by the above information?

(a) Mitigation deals with actions taken to reduce the use of fossil fuels.
(c) Adaptation deals with causes of climate change.
(b) Mitigation deals with consequences of climate change.
(d) Adaptation deals with actions taken to combat green-house gas emissions

Ans. (a)

End of Solution

Q.10 Find the missing element in the following figure:



(a) *d*
(b) *w*
(c) *e*
(d) *y*

Ans. (a)

This is the log i.e. (n = 4)

$5 + 4 = 9$

$t = 20,\ x = 24$

$20 + 4 = 24$

Similarly, $h = 8$

Case-1: $8 + 4 = 12(l)$

$? + 4 = 8$

$? = 4$ (d)

End of Solution

MECHANICAL ENGINEERING

Q.1 For an air-standard Diesel cycle,
(a) heat addition is at constant volume and heat rejection is at constant volume
(b) heat addition is at constant pressure and heat rejection is at constant volume
(c) heat addition is at constant pressure and heat rejection is at constant pressure
(d) heat addition is at constant volume and heat rejection is at constant pressure

Ans. (b)

End of Solution

Q.2 The number of qualitatively distinct kinematic inversions possible for a Grashof chain with four revolute pairs is
(a) 4
(b) 2
(c) 1
(d) 3

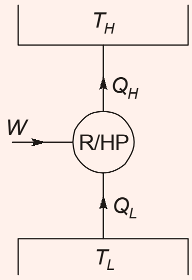
Ans. (d)

They are:
1. Double crank mechanism
2. Crank-rocker mechanism
3. Double rocker mechanism

End of Solution

Q.3 If a reversed Carnot cycle operates between the temperature limits of 27°C and –3°C, then the ratio of the COP of a refrigerator to that of a heat pump (COP of refrigerator/COP of heat pump) based on the cycle is ________ (round off to 2 decimal places).

Ans. (0.9)



$$T_H = 27°C = 300 \text{ K}$$
$$T_L = -3°C = 270 \text{ K}$$
$$\frac{COP_{ref}}{COP_{HP}} = \frac{\dfrac{T_L}{T_H - T_L}}{\dfrac{T_H}{T_H - T_L}} = \frac{T_L}{T_H} = \frac{270}{300} = 0.9$$

End of Solution

Q.4 A machine member is subjected to fluctuating stress $\sigma = \sigma_0 \cos(8\pi t)$. The endurance limit of the material is 350 MPa. If the factor of safety used in the design is 3.5 then the maximum allowable value of σ_0 is ________ MPa (round off to 2 decimal places).

Ans. (100)

Fluctuating stress, $\sigma = \sigma_o \cos(8\pi t)$

$$\sigma_{max} = \sigma_o$$
$$\sigma_{min} = -\sigma_o$$
$$\sigma_{mean} = \frac{\sigma_{max} + \sigma_{min}}{2} = 0$$
$$\sigma_v = \frac{\sigma_{max} - \sigma_{min}}{2} = \frac{2\sigma_o}{2} = \sigma_o$$
$$\sigma_e = 350 \text{ MPa}$$
$$FOS = 3.5$$

From strength criteria, $\dfrac{\sigma_v}{\sigma_e} \le \dfrac{1}{FOS}$

$$\frac{\sigma_o}{350} \le \frac{1}{3.5}$$
$$\sigma_o \le 100 \text{ MPa}$$

End of Solution

Q.5 The process, that uses a tapered horn to amplify and focus the mechanical energy for machining of glass, is

(a) electrochemical machining
(b) ultrasonic machining
(c) abrasive jet machining
(d) electrical discharge machining

Ans. (b)

End of Solution

Q.6 In Materials Requirement Planning, if the inventory holding cost is very high and the setup cost is zero, which one of the following lot sizing approaches should be used?

(a) Lot-for-Lot
(b) Fixed Period Quantity, for 2 periods
(c) Economic Order Quantity
(d) Base Stock Level

Ans. (a)

End of Solution

Q.7 A matrix P is decomposed into its symmetric part S and skew symmetric part V. If

$$S = \begin{pmatrix} -4 & 4 & 2 \\ 4 & 3 & 7/2 \\ 2 & 7/2 & 2 \end{pmatrix}, \quad V = \begin{pmatrix} 0 & -2 & 3 \\ 2 & 0 & 7/2 \\ -3 & -7/2 & 0 \end{pmatrix}$$

then matrix P is

(a) $\begin{pmatrix} -2 & 9/2 & -1 \\ -1 & 81/4 & 11 \\ -2 & 45/2 & 73/4 \end{pmatrix}$

(b) $\begin{pmatrix} -4 & 6 & -1 \\ 2 & 3 & 0 \\ 5 & 7 & 2 \end{pmatrix}$

(c) $\begin{pmatrix} -4 & 2 & 5 \\ 6 & 3 & 7 \\ -1 & 0 & 2 \end{pmatrix}$

(d) $\begin{pmatrix} 4 & -6 & 1 \\ -2 & -3 & 0 \\ -5 & -7 & -2 \end{pmatrix}$

Ans. (c)

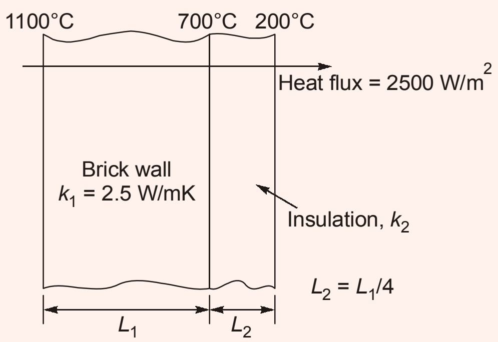
$$S = \frac{P + P^T}{2}$$

$$V = \frac{P - P^T}{2}$$

$$P = S + V = \begin{pmatrix} -4 & 2 & 5 \\ 6 & 3 & 7 \\ -1 & 0 & 2 \end{pmatrix}$$

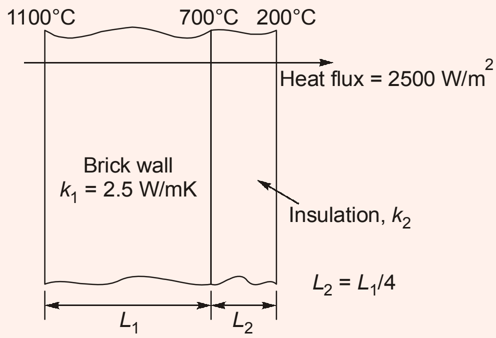
End of Solution

Q.8 In a furnace, the inner and outer sides of the brick wall (k_1 = 2.5 W/mK) are maintained at 1100°C and 700°C respectively as shown in figure.



The brick wall is covered by an insulating material of thermal conductivity k_2. The thickness of the insulation is 1/4th of the thickness of the brick wall. The outer surface of the insulation is at 200°C. The heat flux through the composite walls is 2500 W/m^2. The value of k_2 is _______ W/mK (round off to 2 decimal places).

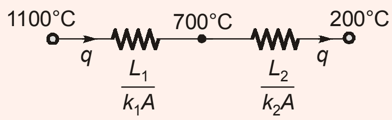
Ans. (0.5)



Given, $L_2 = \dfrac{L_1}{4}$

Assuming steady state, one-dimensional conduction heat transfer through composite slab,

Thermal circuit:



$$\Rightarrow \qquad q = \frac{1100-700}{\frac{L_1}{k_1 A}} = \frac{700-200}{\frac{L_2}{k_2 A}}$$

$$\Rightarrow \qquad \frac{400}{\frac{L_2}{2.5}} = \frac{500}{\frac{L_2}{k_2}}$$

$$\Rightarrow \qquad k_2 = 0.5 \text{ W-mK}$$

End of Solution

Q.9 Which of the following conditions is used lo determine the stable equilibrium of all partially submerged floating bodies?

(a) Centre of buoyancy must be below the centre of gravity

(b) Metacentre must be at a lower level than the centre of gravity

(c) Centre of buoyancy must be above the centre of gravity

(d) Metacentre must be at a higher level than the centre of gravity

Ans. (d)

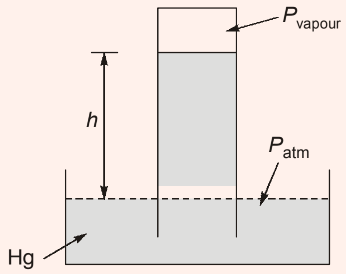
Metacentre must be higher level than the centre of gravity.

End of Solution

Q.10 In the space above the mercury column in a barometer tube, the gauge pressure of the vapour is

(a) positive, but more than one atmosphere
(b) negative
(c) zero
(d) positive, but less than one atmosphere

Ans. (b)



$$P_{vap} + \rho_{Hg}gh = P_{atm}$$

$$(P_{vap}) = P_{atm} - \rho_{Hg}gh$$

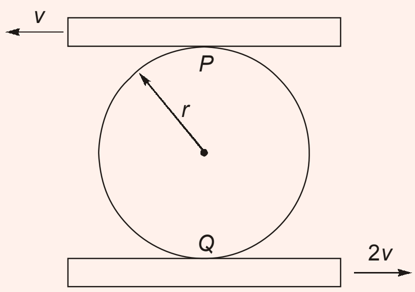
For gauge pressure $P_{atm} = 0$

$$(P_{vap})_{gauge} = -\rho_{Hg}gh$$

So, –ve gauge pressure.

End of Solution

Q.11 A circular disk of radius r is confined to roll without slipping at P and Q as shown in the figure.

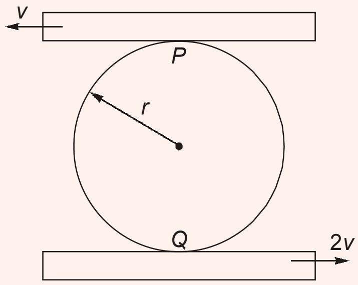


If the plates have velocities as shown, the magnitude of the angular velocity of the disk is

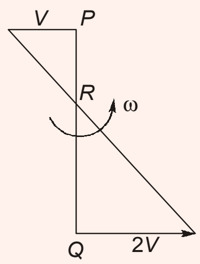
(a) $\frac{3v}{2r}$ (b) $\frac{v}{2r}$

(c) $\frac{v}{r}$ (d) $\frac{2v}{3r}$

Ans. (a)



For pure rolling



$$V_P = V = (PR)\omega \quad \text{... (i)}$$

$$V_Q = 2V = (QR)\omega \quad \text{... (ii)}$$

Divide by (ii) to (i),

$$2 = \frac{QR}{PR} \Rightarrow QR = 2(PR)$$

$$PR + QR = 2r$$

$$PR + 2(PR) = 2r$$

$$PR = \frac{2}{3}r$$

From equation (i), $V = \left(\frac{2}{3}r\right)\omega \Rightarrow \omega = \frac{3V}{2r}$

End of Solution

Q.12 The sum of two normally distributed random variables X and Y is

(a) normally distributed, only if X and Y have the same standard deviation

(b) always normally distributed

(c) normally distributed, only if X and Y have the same mean

(d) normally distributed, only if X and Y are independent

Ans. (b)

$$X_1 \sim N(\mu_1, \sigma_1)$$

and $X_2 \sim N(\mu_2, \sigma_2)$

then $X_1 + X_2 \sim N\left(\mu_1 + \mu_2, \sqrt{\sigma_1^2 + \sigma_2^2}\right)$

Always normally distributed.

End of Solution

Q.13 The solution of $\frac{d^2y}{dt^2} - y = 1$, which additionally satisfies $y\big|_{t=0} = \frac{dy}{dt}\Big|_{t=0} = 0$ in the Laplace s-domain is

(a) $\frac{1}{s(s+1)}$

(b) $\frac{1}{s(s+1)(s-1)}$

(c) $\frac{1}{s(s-1)}$

(d) $\frac{1}{s-1}$

Ans. (b)

$$y'' - y = 1$$
$$y(0) = 1$$
$$y'(0) = 1$$
$$L\{y'' - y\} = L\{1\}$$
$$s^2Y(s) - sy(0) - y'(0) - y(s) = \frac{1}{s}$$
$$y(s) = \frac{1}{s(s^2-1)} = \frac{1}{s(s+1)(s-1)}$$

End of Solution

Q.14 Let $I = \int_{x=0}^{1} \int_{y=0}^{x^2} xy^2 dy dx$. then, I may also be expressed as

(a) $\int_{y=0}^{1} \int_{x=\sqrt{y}}^{1} yx^2 dx\, dy$

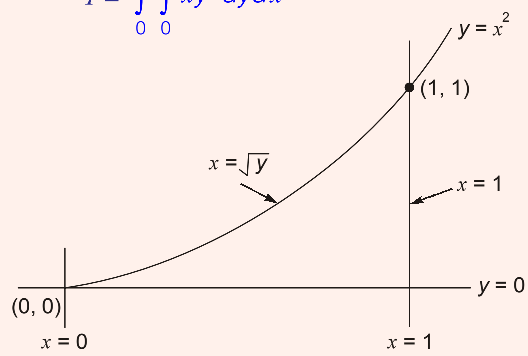
(b) $\int_{y=0}^{1} \int_{x=0}^{\sqrt{y}} xy^2 dx\, dy$

(c) $\int_{y=0}^{1} \int_{x=\sqrt{y}}^{1} xy^2 dx\, dy$

(d) $\int_{y=0}^{1} \int_{x=0}^{\sqrt{y}} yx^2 dx\, dy$

Ans. (c)

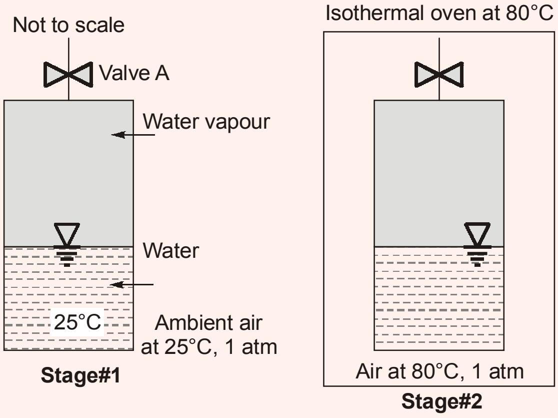
$$I = \int_0^1 \int_0^{x^2} xy^2 dy dx$$



Change on rules, $I = \int_{y=0}^{1} \int_{x=\sqrt{y}}^{1} xy^2 dx\, dy$

End of Solution

Q.15 A closed vessel contains pure water, in thermal equilibrium with its vapour at 25°C (Stage #1), as shown.



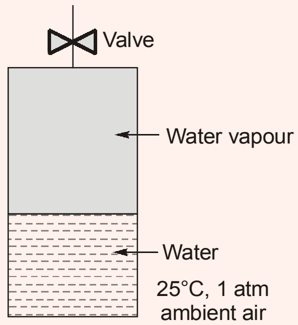
The vessel in this stage is then kept inside an isothermal oven which is having an atmosphere of hot air maintained at 80°C. The vessel exchanges heat with the oven atmosphere and attains a new thermal equilibrium (Stage #2). If the Valve *A* is now opened inside the oven, what will happen immediately after opening the valve?

(a) Hot air will go inside the vessel through Valve A
(b) Water vapor inside the vessel will come out of the Valve A
(c) All the vapor inside the vessel will immediately condense
(d) Nothing will happen - the vessel will continue to remain in equilibrium

Ans. (a)

Initially when water and water vapour mixture is at 25°C then the maximum vapour pressure that can be at 25°C in the saturation pressure of vapour at 25°C.

The saturation press at 25°C is very less than 1 atm (101.3 kPa). It is around 3.17 kPa.



Now when this vessel will be kept in oven at 80°C then at 80°C the saturation pressure of water is still less than 1 atm. It is around 47.2 kPa.

The vapour pressure will reach 1 atm when temperature is 100°C. Hence at 80°C also the pressure will be the than 1 atm 80 when valve is opened air will enter the valve.

End of Solution

Q.16 Let I be a 100 dimensional identity matrix and E be the set of its distinct (no value appears more than once in E) real eigenvalues. The number of elements in E is ______.

Ans. (1)

I_{100}

Eigen values of $I \rightarrow \underbrace{1, 1, \ldots\ldots\ldots, 1}_{100 \text{ times}}$

Set of distributed eigen value $E = \{1\}$

Number of elements in $E = 1$

End of Solution

Q.17 A bolt head has to be made at the end of a rod of diameter d = 12 mm by localized forging (upsetting) operation. The length of the unsupported portion of the rod is 40 mm. To avoid buckling of the rod, a closed forging operation has to be performed with a maximum die diameter of ________ mm.

Ans. (18)

If $l > 3d$ then

$$\text{Die dia} = 1.5d = 1.5(12) = 18 \text{ mm}$$

End of Solution

Q.18 The values of enthalpies at the stator inlet and rotor outlet of a hydraulic turbomachine stage are h_1 and h_3 respectively. The enthalpy at the stator outlet (or, rotor inlet) is h_2. The condition $(h_2 - h_1) = (h_3 - h_2)$ indicates that the degree of reaction of this stage is

(a) 75%
(b) 100%
(c) 50%
(d) zero

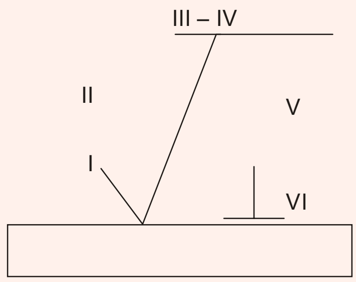
Ans. (c)

As enthalpy across stator and rotor is equal it is 50% reaction stage.

End of Solution

Q.19 The figure below shows a symbolic representation of the surface texture in a perpendicular lay orientation with indicative values (I through VI) marking the various specifications whose definitions are listed below.

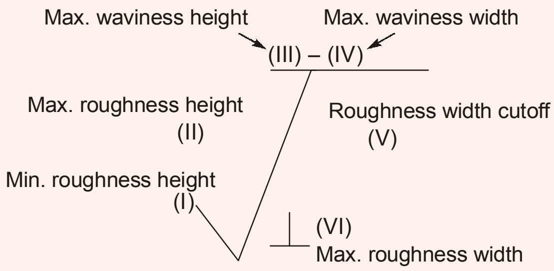
P: Maximum Waviness Height (mm); Q: Maximum Roughness Height (mm);
R: Minimum Roughness Height (mm); S: Maximum Waviness Width (mm);
T: Maximum Roughness Width (mm); U: Roughness Width (mm);



The correct match between the specifications and the symbols (I to VI) is:

(a) I-R, II-P, III-U, IV-S, V-T, VI-Q
(b) I-U, II-S, III-Q, IV-T, V-R, VI-P
(c) I-R, II-Q, III-P, IV-S, V-U, VI-T
(d) I-Q, II-U, III-R, IV-T, V-S, VI-P

Ans. (c)



I-R, II-Q, III-P, IV-S, V-U, VI-T

End of Solution

Q.20 The equation of motion of a spring-mass-damper system is given by

$$\frac{d^2x}{dt^2} + 3\frac{dx}{dt} + 9x = 10\sin(5t)$$

The damping factor for the system is

(a) 0.25
(b) 2
(c) 0.5
(d) 3

Ans. (c)

$$\frac{d^2x}{dt^2} + 3\left(\frac{dx}{dt}\right) + 9x = 10 \sin 5t$$

Comparing with standard equation:

$$\ddot{x} + (2\xi\omega_n)\dot{x} + (\omega_n^2)x = \left(\frac{F_o}{m}\right)\sin\omega t$$

$$2\xi\omega_n = 3$$
$$2\xi \times 3 = 3 \qquad \left[\begin{matrix}\omega_n^2 = 9 \\ \omega_n = 3\end{matrix}\right]$$
$$\xi = \frac{1}{2} = 0.5$$

End of Solution

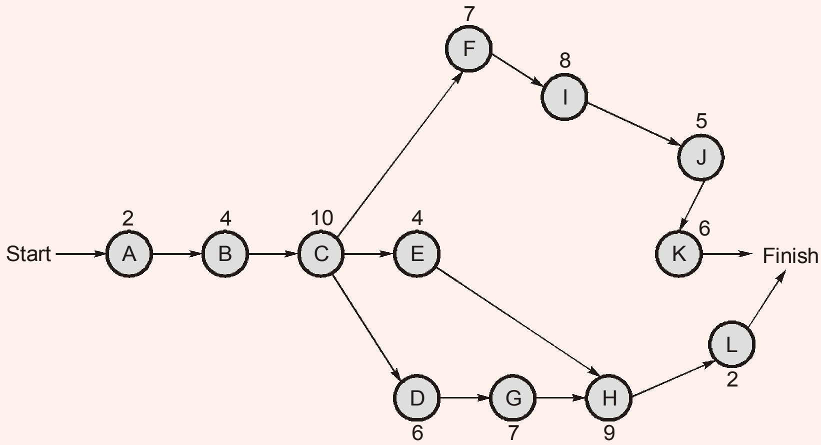
Q.21 Which one of the following statements about a phase diagram is INCORRECT?

(a) Relative amount of different phases can be found under given equilibrium conditions
(b) It gives information on transformation rates
(c) It indicates the temperature at which different phases start to melt
(d) Solid solubility limits are depicted by it

Ans. (b)

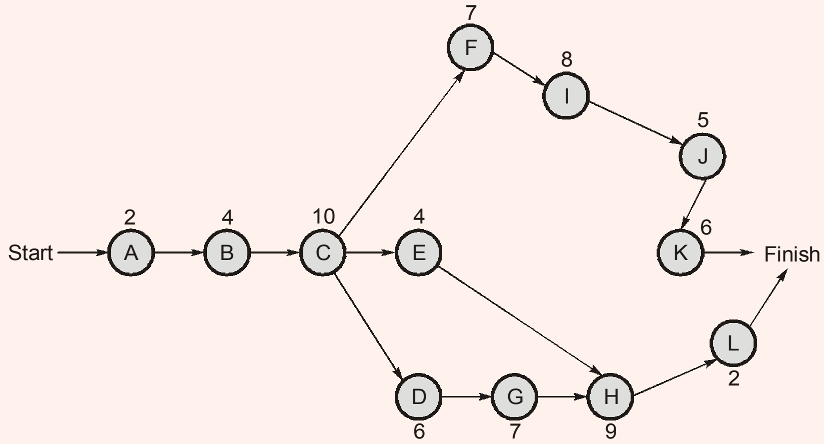
End of Solution

Q.22 Consider the following network of activities, with each activity named A–L, illustrated in the nodes of the network



The number of hours required for each activity is shown alongside the nodes. The slack on the activity L, is ________ hours.

Ans. (2)



Time along path *A-B-C-F-I-J-K* = 42 hours

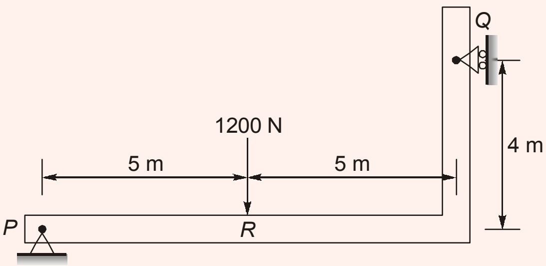
Time along path *A-B-C-E-H-L* = 31 hours

Time along path *A-B-C-D-G-H-L* = 40 hours

Slack for $L = 42 - 40 = 2$ hours

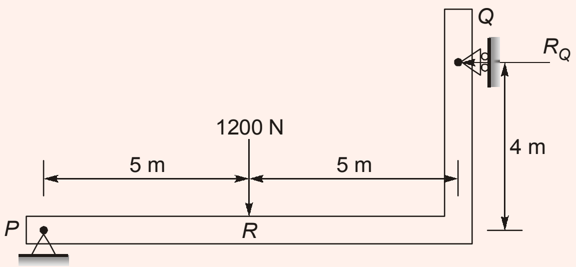
End of Solution

Q.23 A beam of negligible mass is hinged at support *P* and has a roller support *Q* as shown in the figure.



A point load of 1200 N is applied at point *R*. The magnitude of the reaction force at support Q is ________ N.

Ans. (1500)



$$\Sigma \vec{M}_P = 0$$

$$1200 \times 5 - R_Q \times 4 = 0$$

$$R_Q = \frac{1200 \times 5}{4} = 1500 \text{ N}$$

End of Solution

Q.24 Two plates, each of 6 mm thickness, are to be butt-welded. Consider the following processes and select the correct sequence in increasing order of size of the heat affected zone

1. Arc welding
2. MIG welding
3. Laser beam welding
4. Submerged arc welding

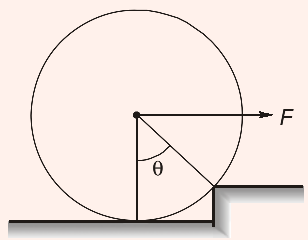
(a) 3-4-2-1 (b) 3-2-4-1
(c) 4-3-2-1 (d) 1-4-2-3

Ans. (b)

Processes with low rate of heat input (slow heating) tend to produce high total heat constant within the metal, slow cooling rates, and large heat-affected zones. high heat input process, have low total heats, fast cooling rates and small heat affected zones.

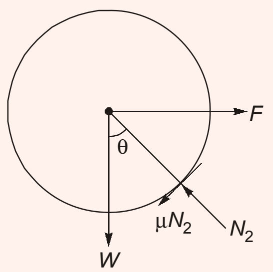
End of Solution

Q.25 An attempt is made to pull a roller of weight W over a curb (step) by applying a horizontal force F as shown in the figure.

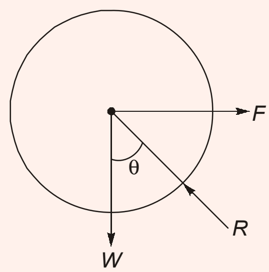


The coefficient of static friction between the roller and the ground (including the edge of the step) is μ. Identify the correct free body diagram (FBD) of the roller when the roller is just about to climb over the step.

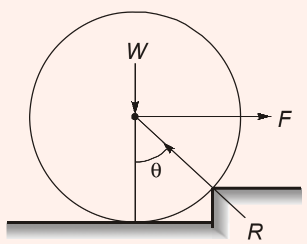
(a)



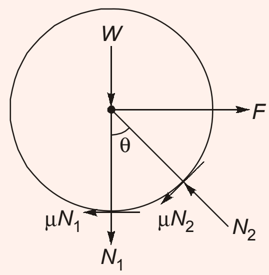
(b)



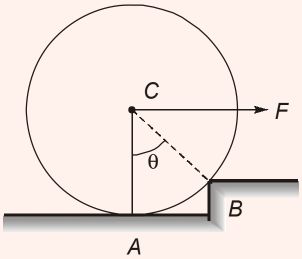
(c)



(d)



Ans. (b)



Weigh = W

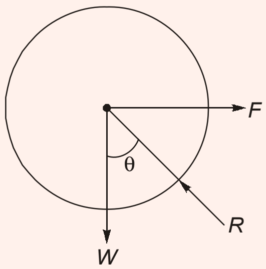
Note:

(i) When the cylinder is about to make out of the curb, it will loose its contact at point A, only contact will be at it B.

(ii) At verge of moving out of curb, Roller will be in equation under W, F and contact force from B and these three forces has to be concurrent so contact force from B will pass through C.

(iii) Even the surfaces are rough but there will be no friction at B for the said condition.

FBD

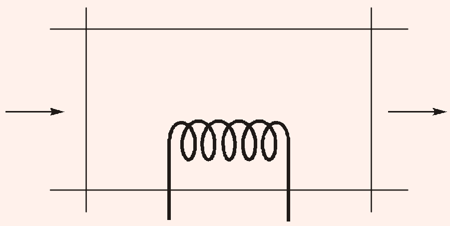


End of Solution

Q.26 Moist air at 105 kPa, 30°C and 80% relative humidity flows over a cooling coil in an insulated air-conditioning duct. Saturated air exits the duct at 100 kPa and 15°C. The saturation pressure of water at 30°C and 15°C are 4.24 kPa and 1.7 kPa respectively. Molecular weight of water is 18 g/mol and that of air is 28.94 g/mol. The mass of water condensing out from the duct is ______ g/kg of dry air (round off to 2 decimal places).

Ans. (10)

$$P_{t1} = 105 \text{ kPa},\ DBT_1 = 30°C,\ \phi_1 = 0.8$$
$$P_{t2} = 100 \text{ kPa},\ DBT_2 = 15°C,\ \phi_2 = 1$$
$$P_{vs1} = 4.24 \text{ kPa}$$
$$P_{vs2} = 1.7 \text{ kPa}$$
$$M_{water} = 18 \text{ g/mol.}$$
$$M_{air} = 28.94 \text{ g/mol.}$$



$$\omega_1 = \frac{18}{28.94} \times \frac{P_{v1}}{P_{t1} - P_{v1}}$$
$$\phi_1 = \frac{P_{v1}}{P_{vs1}}$$

$$0.8 = \frac{P_{v1}}{4.24}$$

$$\therefore \quad P_{v1} = 3.392$$

$$\therefore \quad \omega_1 = \frac{18}{28.94} \times \frac{3.392}{105 - 3.392} = 0.02076 \text{ kgV/kgd.a}$$

$$= 20.76 \text{ gv/kgd.a}$$

$$\omega_2 = \frac{18}{28.94} \times \frac{P_{v2}}{P_{t2} - P_{v2}}$$

$$\phi_2 = \frac{P_{v2}}{P_{vs2}}$$

$$1 = \frac{P_{v2}}{1.7}$$

$$\therefore \quad P_{v2} = 1.7$$

$$\therefore \quad \omega_2 = \frac{18}{28.94} \times \frac{1.7}{100 - 1.7} = 0.01075 \text{ Kgv/kgda}$$

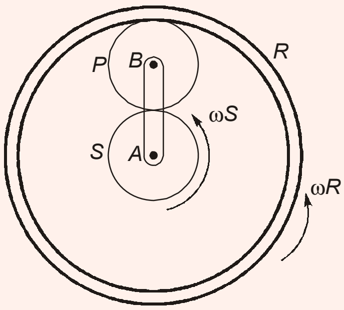
Mass of water condensing $= \omega_1 - \omega_2$

$$= 20.76 - 10.75$$

$$= 10.01 \text{ g/kgd.a}$$

End of Solution

Q.27 The sun (S) and the planet (P) of an epicyclic gear train shown in the figure have identical number of teeth



If the sun (S) and the outer ring (R) gears are rotated in the same direction with angular speed ω_S and ω_R, respectively, then the angular speed of the arm AB is

(a) $\frac{1}{4}\omega_R + \frac{3}{4}\omega_S$

(b) $\frac{3}{4}\omega_R + \frac{1}{4}\omega_S$

(c) $\frac{3}{4}\omega_R - \frac{1}{4}\omega_S$

(d) $\frac{1}{2}\omega_R - \frac{1}{2}\omega_S$

Ans. (b)

$$r_s + 2r_P = r_R$$

$$\Rightarrow \quad T_S + 2T_P = T_R \qquad (T_P = T_S)$$

$$3T_P = T_R$$

$$\Rightarrow \quad 3T_P = T_R$$

Motion	Arm	$S(T_P)$	$P(T_P)$	$R(3T_P)$
1. Let arm fixed SUN $\rightarrow +x$ rpm clock	0	$+x$	$-x\frac{T_P}{T_P}$	$-x\frac{T_P}{3T_P}$
2. Arm free	y	$(y+x)$	$(y-x)$	$\left(y-\frac{x}{3}\right)$

$$y + x = \omega_S$$

$$y - \frac{x}{3} = \omega_R$$

Substract by,

$$\frac{4x}{3} = (\omega_S - \omega_R)$$

$$x = \frac{3}{4}(\omega_S - \omega_R)$$

$$y = \omega_S - x = \omega_S - \frac{3}{4}(\omega_S - \omega_R)$$

$$= \omega_S - \frac{3\omega_S}{4} + \frac{3\omega_R}{4} = \frac{\omega_S}{4} + \frac{3\omega_R}{4}$$

End of Solution

Q.28 The forecast for the monthly demand of a product is given in the table below.

Month	Forecast	Actual sales
1	32.00	30.00
2	31.80	32.00
3	31.82	30.00

The forecast is made by using the exponential smoothing method. The exponential smoothing coefficient used in forecasting the demand is

(a) 1.00
(b) 0.50
(c) 0.40
(d) 0.10

Ans. (d)

$$F_t = F_{t-1} + \alpha(D_{t-1} - F_{t-1})$$

For 2nd month F_t = 31.8, for 1st month

$$F_{t-1} = 32 \text{ and } D_{t-1} = 30$$

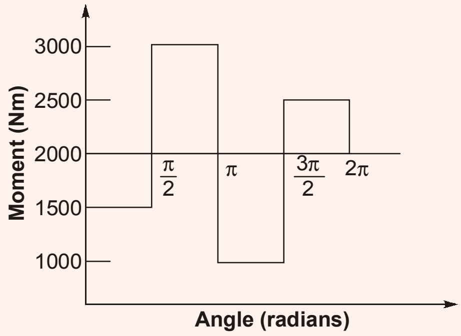
$$31.8 = 32 + \alpha(30 - 32)$$

$$2\alpha = 32 - 31.8$$

$$\alpha = 0.1$$

End of Solution

Q.29 The turning moment diagram of a flywheel fitted to a fictitious engine is shown in the figure.



The mean turning moment is 2000 Nm. The average engine speed is 1000 rpm. For fluctuation in the speed to be within ±2% of the average speed, the mass moment of inertia of the flywheel is ________ kgm^2.

Ans. (3.58)

$N = 1000$ rpm

$$\omega = \frac{2\pi \times 1000}{60} = 104.7195 \text{ rad/s}$$

$$\Delta E_{max} = \left(\pi - \frac{\pi}{2}\right) \cdot (3000 - 2000) = \left(\frac{\pi}{2} \times 1000\right) \text{J}$$

$$C_s = \pm 2\% = 4\% = 0.04$$

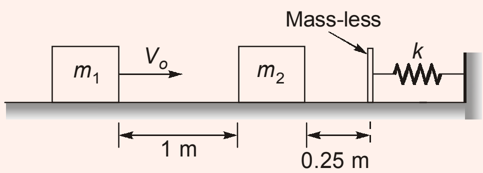
$$\Delta E_{max} = I \cdot \omega^2 \cdot C_s$$

$$\frac{\pi}{2} \times 1000 = I \times (104.7195)^2 \times 0.04$$

$$I = \frac{1570.795}{(104.7195)^2 \times 0.04} = 3.58 \text{ kg-m}^2$$

End of Solution

Q.30 A rigid block of mass m_1 = 10 kg having velocity v_0 = 2 m/s strikes a stationary block of mass m_2 = 30 kg after travelling 1 m along a frictionless horizontal surface as shown in the figure.



The two masses stick together and jointly move by a distance of 0.25 m further along the same frictionless surface, before they touch the mass-less buffer that is connected to the rigid vertical wall by means of a linear spring having a spring constant $k = 10^5$ N/m. The maximum deflection of the spring is ________ cm (round off to 2 decimal places).

Ans. (1)

Collision Theory

Conservation of momentum,

$$m_1 \times v_0 + m_2 \times 0 = (m_1 + m_2) \times v$$

$$10 \times 2 = (10 + 30)v$$

$$20 = 40v$$

$$v = 0.5 \text{ m/s}$$

Now, $$\frac{1}{2}(m_1 + m_2)v^2 = \frac{1}{2}kx^2$$

$$\frac{1}{2} \times 40 \times (0.5)^2 = \frac{1}{2} \times 10^5 \times x^2$$

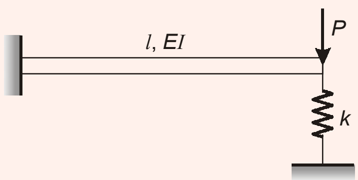
$$10 = 10^5 \times x^2$$

$$\Rightarrow \quad x^2 = \frac{1}{10^4}$$

$$x = \frac{1}{100} \text{ m} = 1 \text{ cm}$$

End of Solution

Q.31 A cantilever of length l, and flexural rigidity EI, stiffened by a spring of stiffness k, is loaded by transverse force P, as shown



The transverse deflection under the load is

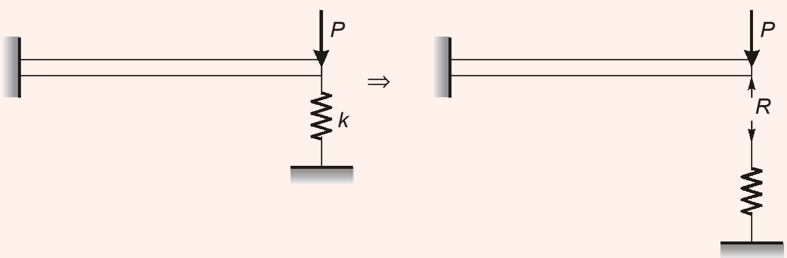
(a) $\frac{Pl^3}{3EI}\left[\frac{3EI - kl^3}{3EI}\right]$

(b) $\frac{Pl^3}{3EI}\left[\frac{3EI}{3EI + kl^3}\right]$

(c) $\frac{Pl^3}{3EI}\left[\frac{6EI - kl^3}{6EI}\right]$

(d) $\frac{Pl^3}{3EI}\left[\frac{3EI}{3EI + 2kl^3}\right]$

Ans. (b)



$$\Delta_{beam} = \Delta_{spring}$$

$$\frac{(P-R)L^3}{3EI} = \frac{R}{k}$$

$$P - R = \frac{3EI}{KL^3}R$$

$$\therefore \quad R = \frac{P}{1+\frac{3EI}{KL^3}} = \frac{PL^3K}{KL^3+3EI}$$

$$\therefore \quad \Delta_{beam} = \frac{R}{K} = \frac{PL^3}{KL^3+3EI}$$

End of Solution

Q.32 There are two identical shaping machines S_1 and S_2. In machine S_1, the width of the workpiece is increased by 10% and the feed is decreased by 10%, with respect to that of S_1. If all other conditions remain the same then the ratio of total time per pass in S_1 and S_2 will be ________ (roundoff to one decimal place).

Ans. (0.8)

$$t_1 = \frac{B_1}{f_1 N_1}$$

$$t_2 = \frac{B_2}{f_2 N_2} = \frac{1.1B_1}{0.9f_1 \times N_2}$$

$$\frac{t_1}{t_2} = \frac{B_1/f_1 N}{\frac{1.1B_1}{0.9f_1 N}} = \frac{0.9}{1.1} = 0.8$$

End of Solution

Q.33 Bars of 250 mm length and 25 mm diameter are to be turned on a lathe with a feed of 0.2 mm/rev. Each regrinding of the tool costs Rs. 20. The time required for each tool change is 1 min. Tool life equation is given as $VT^{0.2} = 24$ (where cutting speed V is in m/min and tool life T is in min). The optimum tool cost per piece for maximum production rate is Rs. ________ (round off to 2 decimal places).

Ans. (26.985)

$$\text{Optimum tool life } (T_o) = \frac{T_c(1-n)}{n} = \frac{1(1-0.2)}{0.2} = 4 \text{ min}$$

$$V_o T_o^n = C \text{ or } V_o = \frac{C}{T_o^n} = \frac{24}{4^{0.2}} = 18.19 \text{ m/min}$$

$$V = \pi DN$$

$$\Rightarrow \quad 18.19 = \pi \times 0.025 \times N$$

$\Rightarrow \quad N = 231.6$ rpm

Maching time per piece

$$(T_m) = \frac{L}{fN} = \frac{250}{0.2 \times 231.6} = 5.397 \text{ min}$$

Number of tool needed per piece work

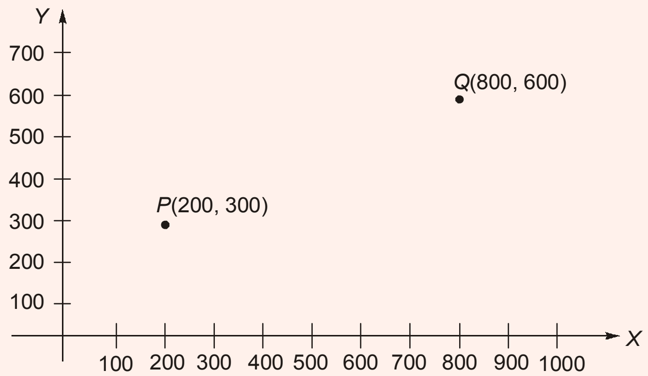
$$= \frac{5.397}{4} \text{ piece}$$

$\therefore$ The optimum tool cost per piece

$$= \frac{5.397}{4} \times 20 = 26.985$$

End of Solution

Q.34 A point P on a CNC controlled XY-stage is moved to another point 'Q' using the coordinate system shown in the figure below and rapid positioning command (G00).



A pair of stepping motors with maximum speed of 800 rpm, controlling both the X and Y motion of the stage, are directly coupled to a pair of lead screw, each with a uniform pitch of 0.5 mm. The time needed to position the point 'P' to the point 'Q' is _______ minutes. (round off to 2 decimal places).

Ans. (1.5)

$N = 800$ rpm, $P = 0.5$ mm/rev

$$V = N \times P = \text{rev/min} \times \text{mm/rev} = 400 \text{ mm/min}$$

$$\Delta t_x = \frac{600}{400} = 1.5 \text{ min}$$

$$\Delta t_y = \frac{300}{400} = 0.75 \text{ min}$$

There are two stepper motor so both will work till 0.75 min then y axis motor will stop then only x axis motor will run for 0.75 more, so total time will be 1.5 min.

End of Solution

Q.35 The spectral distribution of radiation from a black body at T_1 = 3000 K has a maximum at wavelength λ_{max}. The body cools down to a temperature T_2. If the wavelength corresponding to the maximum of the spectral distribution at T_2 is 1.2 times of the original wavelength λ_{max}, then the temperature T_2 is ________ K (round off to the nearest integer).

Ans. (2500)

From Wien's Displacement law,

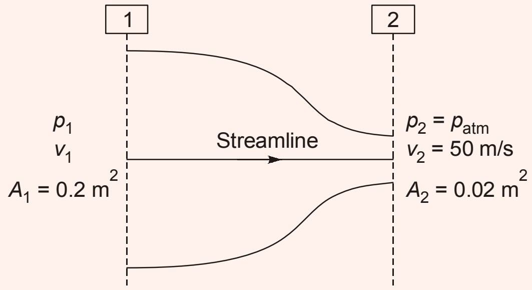
$$\lambda_m T = \text{constant} \Rightarrow \lambda_{m1} T_1 = \lambda_{m2} T_2$$

$$\lambda_{m1} \times 3000 = 1.2\lambda_{m1} \times T_2$$

$$T_2 = \left(\frac{3000}{1.2}\right) \text{K} = 2500 \text{ K}$$

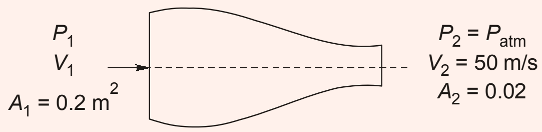
End of Solution

Q.36 Consider a flow through a nozzle, as shown in the figure below:



The air flow is steady, incompressible and inviscid. The density of air is 1.23 kg/m^3. The pressure difference ($p_1 - p_{atm}$) is _______ kPa (round off to the nearest integer).

Ans. (1.52)



$$A_1 V_1 = A_2 V_2$$

$$0.2 \times V_1 = 0.02 \times 50$$

$$V_1 = \frac{1}{10} \times 50 = 5 \text{ m/s}$$

Applying BE

$$\frac{P_1}{w} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{w} + \frac{V_2^2}{2g} + z_2 \quad (\because z_1 = z_2)$$

$$\frac{P_1 - P_2}{\rho_{air} g} = \frac{V_2^2 - V_1^2}{2g}$$

$$P_1 - P_2 = \left(\frac{50^2 - 5^2}{2}\right) \times 1.23 = 1522.125 \text{ Pa} = 1.52 \text{ kPa}$$

End of Solution

Q.37 The function $f(z)$ of complex variable $z = x + iy$, where $i = \sqrt{-1}$, is given as $f(z) = (x^3 - 3xy^2) + iv(x, y)$. For this function to be analytic, $v(x, y)$ should be

(a) $(3x^2y - y^3)$ + constant
(b) $(3x^2y^2 - y^3)$ + constant
(c) $(x^2 - 3x^2y)$ + constant
(d) $(3xy^2 - y^3)$ + constant

Ans. (a)

$$f(z) = u + iv$$
$$u = x^3 - 3xy^2,\ v = v(x, y)$$

For $f(z)$ to be Analytical,

$$u_x = 3x^2 - 3y^2 = v_y$$
$$u_y = -6xy = -v_x$$
$$v_x = 6xy \text{ by integrating w.r.t } x \Rightarrow v = 3x^2y + C_1$$
$$v_y = 3x^2 - 3y^2 \text{ by integrating w.r.t } y \Rightarrow v = 3x^2y - y^3 + C_2$$
$$v = (3x^2y - y^3) + \text{constant } (C_1 = -y^3)$$

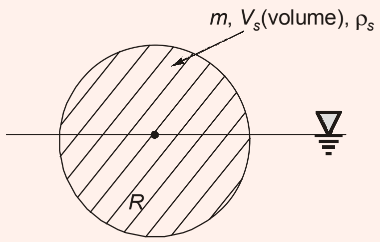
End of Solution

Q.38 A hollow spherical ball of radius 20 cm floats in still water, with half of its volume submerged. Taking the density of water as 1000 kg/m^3, and the acceleration due to gravity as 10 m/s^2, the natural frequency of small oscillations of the ball, normal to the water surface is ________ radians/s (roundoff to 2 decimal places).

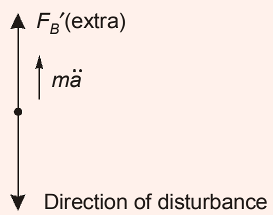
Ans. (8.66)

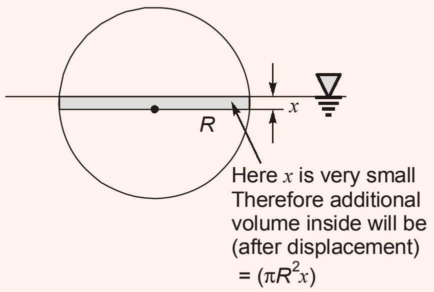
Given data:
$$R = 20 \text{ cm} = 0.20 \text{ m}$$
$$\rho = 1000 \text{ kg/m}^3$$
$$g = 10 \text{ m/s}^2$$

$$\left[\forall = \text{Volume displaced} = \frac{V_s}{2}\right]$$



$$mg = F_B = \rho \forall \cdot g$$
$$m = \rho \cdot \frac{V_s}{2}$$
$$V_s \rho_s = \rho \cdot \frac{V_s}{2}$$
$$\rho_s = \frac{\rho}{2} = \frac{1000}{2} = 500 \text{ kg/m}^3$$





$$m\ddot{x} + f'_{B\,\text{extra}} = 0$$

$$m\ddot{x} + V_{\text{extra}} \cdot \rho \cdot g = 0$$

$$\rho \cdot \frac{V_s}{2}\ddot{x} + (\pi R^2 \cdot x)\rho \cdot g = 0$$

$$\frac{4}{3}\frac{\pi R^3}{2}\hat{x} + \pi R^2 x g = 0$$

$$\ddot{x} + \frac{3g}{2R}x = 0$$

$$\omega_n = \sqrt{\frac{3g}{2R}} = \sqrt{\frac{3 \times 10}{2 \times 0.20}} = \sqrt{\frac{30}{0.4}}$$

$$\omega_n = \sqrt{\frac{300}{4}} = \sqrt{75} = 8.66 \text{ rad/s}$$

End of Solution

Q.39 A steel spur pinion has a module (m) of 1.25 mm, 20 teeth and 20° pressure angle. The pinion rotates at 1200 rpm and transmits power to a 60 teeth gear. The face width (F) is 50 mm, Lewis form factor $Y = 0.322$ and a dynamic factor $K_v = 1.26$. The bending stress (σ) induced in a tooth can be calculated by using the Lewis formula given below.

If the maximum bending stress experienced by the pinion is 400 MPa. the power transmitted is ________ kW (round off to one decimal place),

Lewis formula: $\sigma = \dfrac{K_v W^t}{FmY}$, where W^t is the tangential load acting on the pinion.

Ans. (10)

$$F_t \times c_v s = bmy[\sigma_b]_{\max}$$

$$c_v = 1.26$$

$$F_t \times 1.26 \times 1 = 50 \times 1.25 \times 0.322 \times 400$$

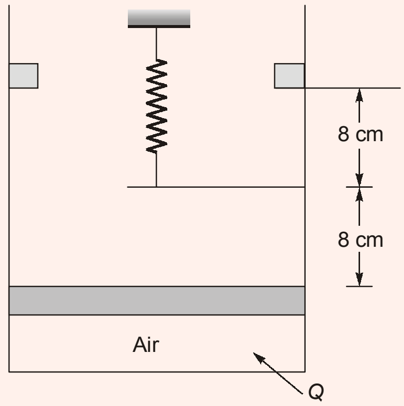
$$F_t = 6388.88 \text{ N}$$

$$P_{\text{angle}} = F_t \times v = \frac{F_t \times \pi D_p N}{60}$$

$$= \frac{6388.88 \times \pi \times 1.25 \times 20 \times 1200}{60} = 10 \text{ kW}$$

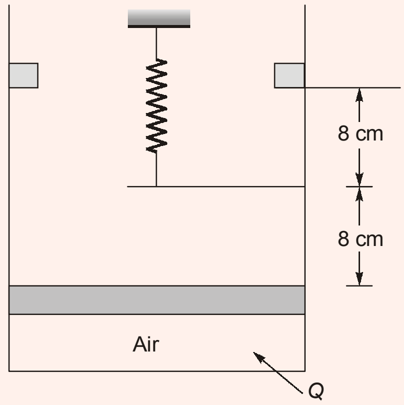
End of Solution

Q.40 Air is contained in a frictionless piston-cylinder arrangement as shown in the figure.



The atmospheric pressure is 100 kPa and the initial pressure of air in the cylinder is 105 kPa. The area of piston is 300 cm^2. Heat is now added and the piston moves slowly from its initial position until it reaches the stops. The spring constant of the linear spring is 12.5 N/mm. Considering the air inside the cylinder as the system, the work interaction is ________ J. (round off to the nearest integer).

Ans. (544)



P_0 = 100 kPa, P_1 = 105 kPa, K = 12.5 N/mm = 12.5 kN/m

$$A = 300 \text{ cm}^2 = 300 \times 10^{-4} \text{ m}^2$$

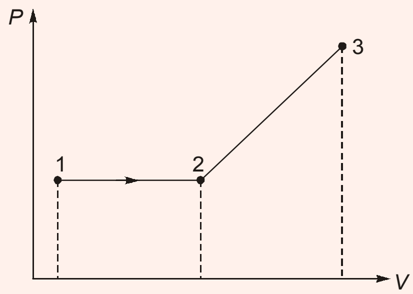
$$x = 8 \text{ cm} = 8 \times 10^{-2} \text{ m}$$

1-2 constant pressure

$$W_{1-2} = P_1 \times A \times x = 105 \times 300 \times 10^{-4} \times 8 \times 10^{-2}$$

$$= 0.252 \text{ kJ} = 252 \text{ J}$$

$$P_2 = 105 \text{ kPa}$$



$$P_3 \times A = P_2 A + Kx$$

$$P_3 = P_2 + \frac{Kx}{A} = 105 + \frac{12.5 \times 8 \times 10^{-2}}{300 \times 10^{-4}} = 138.33 \text{ kPa}$$

$$W_{2\text{-}3} = \frac{1}{2}(P_2 + P_3) \times (V_3 - V_2) = \frac{1}{2}(105 + 138.33) A \times x$$

$$= \frac{1}{2}(243.33) \times 300 \times 10^{-4} \times 8 \times 10^{-2}$$

$$W_{2\text{-}3} = 0.2919 \text{ kJ} = 291.9 \text{ J}$$

$$\therefore \quad W_{total} = W_{1\text{-}2} + W_{2\text{-}3} = 0.5439 \text{ kJ} = 543.91 \approx 544 \text{ J}$$

Alternate Solution:

Total work = Workdone because of 105 kPa pressure + Workdone against spring which is equal to energy stored in spring

$$\text{Workdone} = P_1 \times A \times 2x + \frac{1}{2} k \cdot x^2$$

$$= 105 \times 300 \times 10^{-4} \times 2 \times 8 \times 10^{-2} + \frac{1}{2} \times 12.5 \times (8 \times 10^{-2})^2$$

$$= 0.504 + 0.04$$

$$= 0.544 \text{ kJ} = 544 \text{ J}$$

End of Solution

Q.41 Keeping all other parameters identical, the Compression Ratio (CR) of an air standard diesel cycle is increased from 15 to 21. Take ratio of specific heats = 1.3 and cut-off ratio of the cycle r_c = 2.

The difference between the new and the old efficiency values, in percentage, $(\eta_{new}|_{CR\,=\,21}) - (\eta_{old}|_{CR\,=\,15})$ = _______ %. (round off to one decimal place).

Ans. **(4.8)**

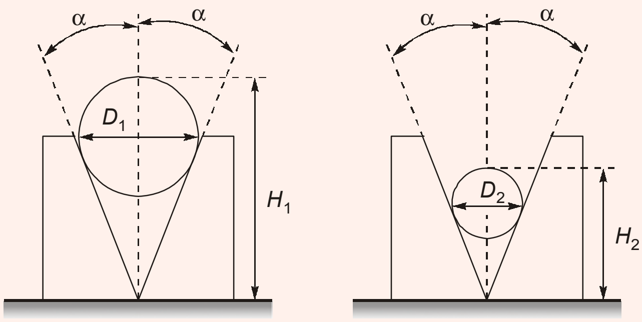
$$\eta_{d,\ r=21} = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \times \frac{(\rho^\gamma - 1)}{\gamma(\rho - 1)} = 54.87\%$$

$$\eta_{d,\ r=15} = 1 - \left(\frac{1}{r}\right)^{\gamma-1} \times \frac{(\rho^\gamma - 1)}{\gamma(\rho - 1)} = 50.08\%$$

$$\eta_{d,\ r=21} - \eta_{d,\ r=15} = 4.8\%$$

End of Solution

Q.42 Two rollers of diameters D_1 (in mm) and D_2 (in mm) are used to measure the internal taper angle in the V-groove of a machined component. The heights H_1 (in mm) and H_2 (in mm) are measured by using a height gauge after inserting the rollers into the same V-groove as shown in the figure.



$D_1 > D_2$

Which one of the following is the correct relationship to evaluate the angle α as shown in the figure?

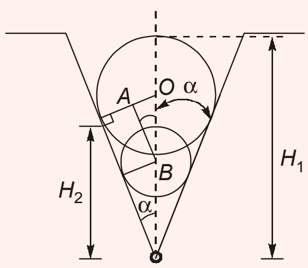
(a) $\sin\alpha = \dfrac{(H_1 - H_2)}{(D_1 - D_2)}$

(b) $\sin\alpha = \dfrac{(D_1 - D_2)}{2(H_1 - H_2) - (D_1 - D_2)}$

(c) $\cos\alpha = \dfrac{(D_1 - D_2)}{2(H_1 - H_2) - 2(D_1 - D_2)}$

(d) $\text{cosec}\,\alpha = \dfrac{(H_1 - H_2) - (D_1 - D_2)}{2(D_1 - D_2)}$

Ans. (b)



$$OB = \left(H_1 - \frac{D_1}{2}\right) - \left(H_2 - \frac{D_2}{2}\right) = (H_1 - H_2) - \left(\frac{D_1 - D_2}{2}\right)$$

$$OA = \frac{D_1 - D_2}{2}$$

$$\sin\alpha = \frac{\dfrac{(D_1 - D_2)}{2}}{(H_1 - H_2) - \dfrac{(D_1 - D_2)}{2}}$$

$$\sin\alpha = \frac{(D_1 - D_2)}{2(H_1 - H_2) - (D_1 - D_2)}$$

End of Solution

Q.43 A fair coin is tossed 20 times. The probability that 'head' will appear exactly 4 times in the first ten tosses, and 'tail' will appear exactly 4 times in the next ten tosses is ______ (round off to 3 decimal places).

Ans. (0.042)

Fair coin tossed 20 times

First 10 times probability that head will appear exactly 4 times

P[4 heads in 10 tosses] · P[4 tails in 10 tosses]

$$= 10_{C_4}\left(\frac{1}{2}\right)^4\left(\frac{1}{2}\right)^6 \cdot 10_{C_4}\left(\frac{1}{2}\right)^6\left(\frac{1}{2}\right)^4$$

$$= \frac{10_{C_4}\cdot 10_{C_4}}{2^{10}\cdot 2^{10}} = \frac{210\times 210}{2^{10}\times 2^{10}} = 0.042$$

End of Solution

Q.44 For the integral $\int_0^{\pi/2}(8+4\cos x)dx$, the absolute percentage error in numerical evaluation with the Trapezoidal rule, using only the end points, is ________. (round off to one decimal place).

Ans. (5.2)

True value

$$\int_0^{\pi/2}(8+4\cos x)dx = [8x+(4\sin x)]_0^{\pi/2}$$

$$= 4\pi + 4 = 16.566$$

By trapezoidal rule, (single step)

x	0	$\pi/2$
$f(x)$	12	8

$$h = \frac{\pi}{2}$$

Approx. $I = \frac{\pi}{4}[12+8] = 5\pi = 15.707$

Absolute error = |True value − Approximate value|

= |16.566 − 15.707| = 0.859

Absolute percentage error $= \frac{0.859}{16.566}\times 100 = 5.18\ \% \approx 5.2\%$

End of Solution

Q.45 A helical spring has spring constant k. If the wire diameter, spring diameter and the number of coils are all doubled then the spring constant of the new spring becomes

(a) $8k$
(b) $16k$
(c) k
(d) $k/2$

Ans. **(c)**

$$k_{(\text{spring})} = \frac{Gd^4}{8D^3n}$$

$$k_{\text{new}} = \frac{G(2d)^4}{8(2D)^3(2n)} = \frac{Gd^4}{8D^3n}$$

Hence, $k_{\text{new}} = k$

End of Solution

Q.46 A cylindrical bar with 200 mm diameter is being turned with a tool having geometry 0° - 9° - 7° - 8° - 15° - 30° - 0.05 inch (Coordinate system, ASA) resulting in a cutting force F_{c1}. If the tool geometry is changed to 0° - 9° - 7° - 8° - 15° - 0° - 0.05 inch (Coordinate system. ASA) and all other parameters remain unchanged, the cutting force changes to F_{c2}. Specific cutting energy (in J/mm^3) is $U_c = U_0\,(t_1)^{-0.4}$, where U_0 is the specific energy coefficient, and t_1 is the uncut thickness in mm. The value of percentage change in cutting force F_{c2}. i.e., $\left(\frac{F_{c2}-F_{c1}}{F_{c1}}\right)\times 100$, is ______ (round off to one decimal place).

Ans. **(–5.6)**

$$C_{s1} = 30°$$

$\therefore$ $$\lambda_1 = 90 - 30 = 60°$$

$$C_{s2} = 0°$$

$\therefore$ $$\lambda_2 = 90 - 0 = 90°$$

We know that specific energy consumption

$$U_c = \frac{F_c}{1000fd} = U_0(t_1)^{-0.4} \text{ (given)}$$

$\therefore$ $$F_c = U_0(f\sin\lambda)^{-0.4}\times 1000fd$$

$\therefore$ $$F_c \propto (\sin\lambda)^{-0.4}$$

$\therefore$ $$= \frac{F_{c2}-F_{c1}}{F_{c1}}\times 100 = \left[\left(\frac{\sin\lambda_2}{\sin\lambda_1}\right)^{-0.4} - 1\right]\times 100$$

$$= \left[\left(\frac{\sin 90°}{\sin 60°}\right)^{-0.4} - 1\right]\times 100 = -5.59$$

End of Solution

Q.47 The directional derivative $f(x, y, z) = xyz$ at point (–1, 1, 3) in the direction of vector $\hat{i} - 2\hat{j} + 2\hat{k}$ is

(a) $\frac{7}{3}$

(b) 7

(c) $-\frac{7}{3}$

(d) $3\hat{i} - 3\hat{j} - \hat{k}$

Ans. (a)

$$f = xyz$$

$$\nabla f = f_x\bar{i} + f_y\bar{j} + f_z\bar{k} = yz\bar{i} + xz\bar{j} + xy\bar{k}$$

$$(\nabla f)_{(-1,1,3)} = 3\bar{i} - 3\bar{j} - \bar{k}$$

$$\vec{a} = \bar{i} - 2\bar{j} + 2\bar{k}$$

Directional derivative of f in direction of $\vec{a}$

$$\underset{\vec{a}}{Df} = \nabla f \times \frac{\vec{a}}{|\vec{a}|} = \frac{3(1)+(-3)(-2)+(-1)(2)}{\sqrt{(1)^2+(-2)^2+(2)^2}} = \frac{7}{3}$$

End of Solution

Q.48 A mould cavity of 1200 cm^3 volume has to be filled through a sprue of 10 cm length feeding a horizontal runner. Cross-sectional area at the base of the sprue is 2 cm^2. Consider acceleration due to gravity as 9.81 m/s^2. Neglecting frictional losses due to molten metal flow, the time taken to fill the mould cavity is _______ seconds (round off to 2 decimal places).

Ans. (4.28)

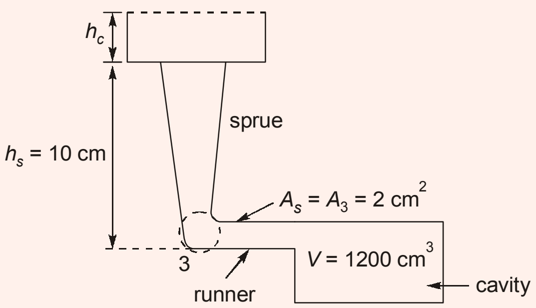
Volume of mould cavity (V) = 1200 cm^3

Height of sprue (h_s) = 10 cm

Area of sprue at the bottom (A_s) = 2 cm^2

g = 9.81 m/s^2

Sprue is feed a horizontal runner: Filling time required (t_f) = ?



By assuming top gate, $A_g = A_s = A_3 = 2\ \text{cm}^2$

$$\text{Filling time } (t_f) = \frac{V}{A_g v_g} = \frac{1200}{2\sqrt{2\times 981}} = 4.28\ \text{s}$$

$$t_f = 4.28\ \text{s}$$

End of Solution

Q.49 One kg of air in a closed system undergoes an irreversible process from an initial state of p_1 = 1 bar (absolute) and T_1 = 27°C, to a final state of p_2 = 3 bar (absolute) and T_2 = 127°C. If the gas constant of air is 287 J/kgK and the ratio of the specific heats γ = 1.4, then the change in the specific entropy (in J/kgK) of the air in the process is

(a) 172.0
(b) –26.3
(c) indeterminate, as the process is irreversible
(d) 28.4

Ans. (b)

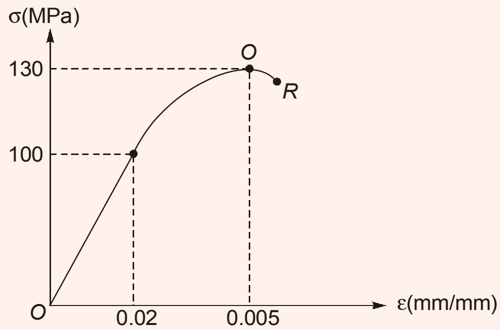
P_1 = 1 bar, P_2 = 1 bar, T_1 = 300 K, T_2 = 400 K,

$$c_p = \frac{\gamma R}{\gamma - 1} = 1005\ \text{J/kgK}$$

$$\Delta S = c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1} = 1005 \ln\frac{400}{300} - 287\ln\frac{3}{1} = -26.32\ \text{J/kgK}$$

End of Solution

Q.50 Uniaxial compression test data for a solid metal bar of length 1 m is shown in the figure.



The bar material has a linear elastic response from O to P followed by a non-linear response. The point P represents the yield point of the material. The rod is pinned at both the ends. The minimum diameter of the bar so that it does not buckle under axial loading before reaching the yield point is _______ mm (round off to one decimal place).

Ans. (56.94)

For both end pin,

$$P = \frac{\pi^2 EI}{L^2} = \frac{\pi^2 EA \cdot \frac{d^2}{16}}{L^2}$$

$$\frac{P}{AE} = \frac{\pi^2 d^2}{16L^2}$$

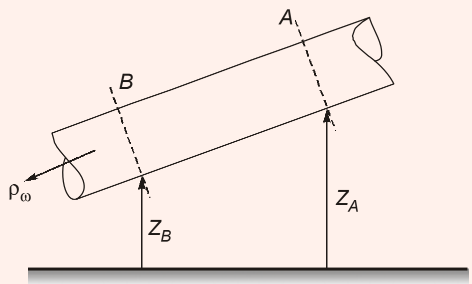
$$\varepsilon_y = \frac{\pi^2 d^2}{16L^2}$$

$$d = \sqrt{\frac{16L^2\varepsilon_y}{\pi^2}} = \sqrt{\frac{16 \times 1000^2 \times 0.002}{\pi^2}} = 56.94 \text{ mm}$$

End of Solution

Q.51 Water (density 1000 kg/m^3) flows through an inclined pipe of uniform diameter. The velocity, pressure and elevation at section A are V_A = 3.2 m/s, p_A =186 kPa and z_A = 24.5 m respectively, and those at section B are V_B = 3.2 m/s, p_B = 260 kPa and z_B = 9.1 m, respectively. If acceleration due to gravity is 10 m/s^2 then the head lost due to friction is ________ m (round off to one decimal place).

Ans. (8)



$$\text{Energy at 'A' head} = \frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{186 \times 10^3}{1000 \times 10} + \frac{3.2^2}{2 \times 10} + 24.5$$

$$= 18.6 + 0.512 + 24.5 = 43.612$$

$$\text{Energy at 'b' head} = \frac{P_b}{\rho g} + \frac{V_b^2}{2g} + Z_b = \frac{286 \times 10^3}{1000 \times 10} + \frac{3.2^2}{2 \times 10} + 9.1$$

$$= 26 + 0.512 + 9.1 = 35.612$$

$E_A > E_B$, so flow from 'A' to 'B'.

Heat loss = $E_A - E_B$ = 43.612 – 35.612 = 8 m of water head

End of Solution

Q.52 In a steam power plant, superheated steam at 10 MPa and 500°C, is expanded isentropically in a turbine until it becomes a saturated vapour. It is then reheated at constant pressure to 500°C. The steam is next expanded isentropically in another turbine until it reaches the condenser pressure of 20 kPa. Relevant properties of steam are given in the following two tables. The work done by both the turbines together is ______ kJ/kg (roundoff to the nearest integer).

Superheated Steam Table:

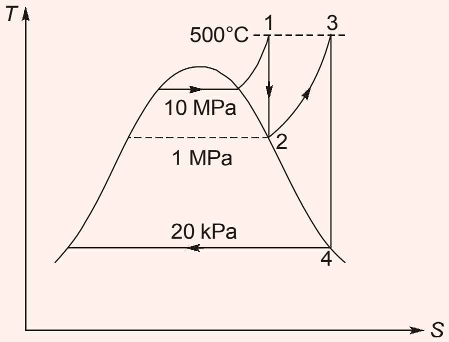
Pressure, *p* (MPa)	Temp, *p* (°C)	Enthalpy, *h* (kJ/kg)	Entropy, *s* (kJ/kg.K)
10	500	3373.6	6.5965
1	500	3478.4	7.7621

Saturated Steam Table:

Pressure, *p*	Sat. Temp, T_{sat}(°C)	Enthalpy, *h* (kJ/kg)		Entropy, *s* (kJ/kg)	
		h_f	h_g	s_f	s_g
1 MPa	179.91	762.9	2778.1	2.1386	6.5965
20 kPa	60.06	251.38	2609.7	0.8319	7.9085

Ans. (1513)

Given data: h_1 = 3373.6 kJ/kg, h_3 = 3478.4 kJ/kg, h_2 = 2778.1 kJ/kg, $s_1 = s_2$ (as from table)

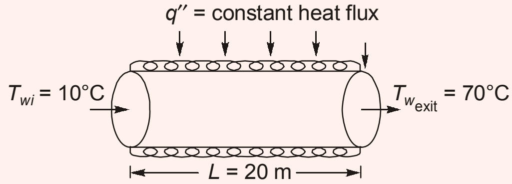


$$s_3 = s_4$$
$$s_3 = 7.7621 = 0.8319 + x + (7.9085 - 0.8319)$$
$$x_4 = 0.9793$$
$$h_4 = h_f + x_4 \times (h_g - h_f) = 2560.91 \text{ kJ/kg}$$
$$W_T = (h_1 - h_2) + (h_3 - h_4) = 1512.95 \text{ kJ/kg}$$

End of Solution

Q.53 Water flows through a tube of 3 cm internal diameter and length 20 m, The outside surface of the tube is heated electrically so that it is subjected to uniform heat flux circumferentially and axially. The mean inlet and exit temperatures of the water are 10°C and 70°C, respectively. The mass flow rate of the water is 720 kg/h. Disregard the thermal resistance of the tube wall. The internal heat transfer coefficient is 1697 W/m^{2}K. Take specific heat C_p of water as 4.179 kJ/kgK. The inner surface temperature at the exit section of the tube is __________ °C (round off to one decimal place).

Ans. (85.7)



$$h = 1697 \text{ W/m}^2\text{K}$$

From energy balance equation,

$$\text{Heat flux} \times \text{Area of } HT = \dot{m}_w \times C_{pw}(T_{w_{exit}} - T_{w_{inlet}})$$

$$q'' \times \pi DL = \dot{m}_w \times C_{pw}(70 - 10)$$

$$q'' = \frac{720}{3600} \times \frac{4.179 \times 10^3 \times 60}{\pi \times \left(\frac{3}{100}\right) \times 20} \text{ W/m}^2$$

$$q'' = 26604.34 \text{ W/m}^2$$

Applying Newton's law of cooling at exit

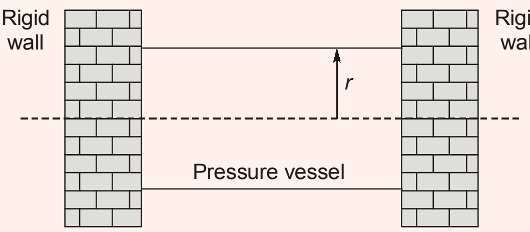
$$q'' = h \times (T_{\substack{tube\\ at\ exit}} - T_{\substack{water\\ at\ exit}}) \text{ W/m}^2$$

$$26604.34 = 1697 \times (T_{\text{tube at exit}} - 70) \text{ W/m}^2$$

$$T_{\text{tube at exit}} = 85.67°\text{C}$$

End of Solution

Q.54 A thin-walled cylinder of radius r and thickness t is open at both ends, and fits snugly between two rigid walls under ambient conditions, as shown in the figure



The material of the cylinder has Young's modulus E, Poisson's ratio ν, and coefficient of thermal expansion α. What is the minimum rise in temperature ΔT of the cylinder (assume uniform cylinder temperature with no buckling of the cylinder) required to prevent gas leakage if the cylinder has to store the gas at an internal pressure of p above the atmosphere?

(a) $\Delta T = \left(\nu - \frac{1}{4}\right)\frac{pr}{\alpha tE}$

(b) $\Delta T = \left(\nu + \frac{1}{2}\right)\frac{pr}{\alpha tE}$

(c) $\Delta T = \frac{\nu pr}{\alpha tE}$

(d) $\Delta T = \frac{3\nu pr}{2\alpha tE}$

Ans. (c)

Since cylinder is open at both end.

$\therefore \quad \sigma_L = 0$

For no leakage, $\varepsilon_{L_{P_r}} = \varepsilon_{L_{temp}}$

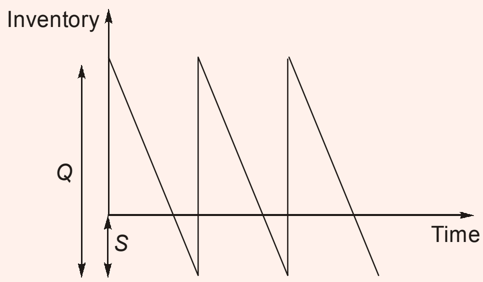
$$\frac{\nu\sigma_n}{E} = \alpha\Delta T$$

$$\frac{\nu Pr}{tE} = \alpha\Delta T$$

$$\Delta T = \frac{\nu pr}{\alpha tE}$$

End of Solution

Q.55 For a single item inventory system, the demand is continuous, which is 10000 per year. The replacement is instantaneous and backorders (S units) per cycle are allowed as shown in the figure.



As soon as the quantity (Q units) ordered from the supplier is received, the backordered quantity is issued to the customers. The ordering cost is Rs. 300 per order. The carrying cost is Rs. 4 per unit per year. The cost of backordering is Rs. 25 per unit per year. Based on the total cost minimization criteria, the maximum inventory reached in the system is ________ (round off to nearest integer).

Ans. (1137.147)

Given data: D = 10000 items/year, C_o = ₹300/order,

C_h = ₹4/unit/year, C_b = ₹25/unit/year,

For minimum tool cost,

$$\text{Quantity ordered, } Q = \sqrt{\frac{2DC_o}{C_h} \times \left(\frac{C_b + C_h}{C_o}\right)} = \sqrt{\frac{2 \times 10000 \times 300}{4} \times \left(\frac{25+4}{25}\right)}$$

$$Q = 1319.09 \text{ unit}$$

Now, for minimum cost, optimum units backordered

$$(Q - S) \times C_h = (S) \times C_b$$

$$S(C_b + C_h) = Q \times C_h$$

$$S = \frac{1319.09 \times 4}{(25+4)} = 181.94 \text{ units}$$

Maximum inventory in the system, $Q_{max} = Q - S$

$$= 1319.09 - 181.94$$
$$= 1137.15 \text{ unit}$$
$$\approx 1137 \text{ units}$$

Alternate:

$$\text{Maximum inventory in system} = \sqrt{\frac{2DC_o}{C_h} \times \left(\frac{C_b}{C_b + C_h}\right)}$$

$$Q_{max} = \sqrt{\frac{2 \times 10000 \times 300}{4} \times \left(\frac{25}{29}\right)} = 1137.147 \text{ units}$$

End of Solution

■■■■