23 Years

Previous Years Solved Papers

Indian Forest Service Main Examination

(2001-2023)

Mechanical Engineering

Paper-I

Topicwise Presentation

Also useful for Engineering Services Main Examination,
Civil Services Main Examination and
various State Engineering Services Examinations

MADE EASY PUBLICATIONS

MADE EASY Publications Pvt. Ltd.

Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016
E-mail: infomep@madeeasy.in
Contact: 9021300500
Visit us at: www.madeeasypublications.org

Mechanical Engineering : Indian Forest Service Main Examination (Paper-I)

First Edition: 2017
Second Edition: 2018
Third Edition: 2019
Fourth Edition: 2020
Fifth Edition: 2021
Sixth Edition: 2022
Seventh Edition: 2023

Eighth Edition: 2024

Preface

B. Singh (Ex. IES)

Our country has a vast forest cover of near about 25% of geographical area and if man doesn't learn to treat trees with respect, man will become extinct; Death of forest is end of our life. Scientific management and judicial exploitation of forest becomes first task for sustainable development.

Engineer is one such profession which has an inbuilt word "Engineer – skillful arrangement" and hence IFS is one of the most talked about jobs among engineers to contribute their knowledge and skills for the arrangement and management for sustainable development

In order to reach to the estimable position of Divisional Forest Officer (DFO), one needs to take an arduous journey of Indian Forest Service Examination. Focused approach and strong determination are the pre-requisites for this journey. Besides this, a good book also comes in the list of essential commodity of this odyssey.

I feel extremely glad to launch the revised edition of such a book which will not only make Indian Forest Service Examination plain sailing, but also with 100% clarity in concepts.

MADE EASY team has prepared this book with utmost care and thorough study of all previous years' papers of Indian Forest Service Examination. The book aims to provide complete solution to all previous years' questions with accuracy.

On doing a detailed analysis of previous years' Indian Forest Service Examination question papers, it came to light that a good percentage of questions have been asked in Engineering Services, Indian Forest Services and State Services exams. Hence, this book is a one stop shop for all Indian Forest Service Examination, CSE, ESE and other competitive exam aspirants.

I would like to acknowledge efforts of entire MADE EASY team who worked day and night to solve previous years' papers in a limited time frame and I hope this book will prove to be an essential tool to succeed in competitive exams and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

With Best Wishes

B. Singh

CMD, MADE EASY Group

Previous Years Solved Papers

Indian Forest Service Main Examination

Mechanical Engineering

Paper-I

CONTENTS

SYLLABUS

Paper - I

1. Theory of Machines : Kinematic and dynamic analysis of planar mechanisms, Cams, Gears and gear trains, Flywheels, Governors, Balancing of rigid rotors, Balancing of single and multicylinder engines, Linear vibration analysis of mechanical systems (single degree and two degrees of freedom), Critical speeds and whirling of shafts, Automatic Controls, Belts and chain drives. Hydrodynamic bearings.
2. Mechanics of Solids: Stress and strain in two dimensions, Principal stresses and strains, Mohr's construction, linear elastic materials, isotropy and anisotropy, Stress-strain relations, uniaxial loading, thermal stresses, Beams: Bending moment and shear force diagrams, bending stresses and deflection of beams, Shear stress distribution. Torsion of shafts, helical springs. Combined stresses, thick and thin walled pressure vessels. Struts and columns. Strain energy concepts and theories of failure. Rotating discs. Shrink fits.
3. Engineering Materials: Basic concepts on structure of solids, crystalline materials, Defects in crystalline materials, Alloys and binary phase diagrams, structure and properties of common engineering materials. Heat treatment of steels, plastics, Ceramics and composite Materials, common applications of various materials.
4. Manufacturing Science: Merchant's force analysis, Taylor's tool life equation, machinability and machining economics, Rigid, small and flexible automation, NC, CNC. Recent machining methods-EDM, ECM and ultrasonic. Application of lasers and plasmas, analysis of forming processes. High energy rate forming Jigs, fixtures, tools and gauges, Inspection of length, position, profile and surface finish.
5. MANUFACTURING MANAGEMENT: Production Planning and Control, Forecasting-moving average, exponential smoothing, Operations scheduling; assembly line balancing. Product development, Breakeven analysis, Capacity planning. PERT and CPM. Control Operations: Inventory control-ABC analysis, EOQ model, Materials requirement planning, Job design, Job standards, work measurement, Quality management-Quality control Operations Research: Linear programming-Graphical and Simplex methods, Transportation and assignment models, Single server queuing model.

   Value Engineering: Value analysis, for cost/ value, Total quality management and forecasting techniques. Project management.
6. ELEMENTS OF COMPUTATION: Computer Organization, Flow charting, Features of Common Computer Languages FORTRAN, d Base-III, Lotus 1-2-3, C and elementary programming.

■■■

1 Theory of Machines

1. Analysis of Plane Mechanism

1.1 Single cylinder vertical engine has a bore of 30.5 cm, a stroke of 40 cm, and a connecting rod 80 cm long. When the piston is at its quarter stroke and moving downwards, the net pressure on it is 65 N/cm^2.

(i) If the speed of the engine is 250 rpm and the total equivalent mass of the reciprocating parts is assumed to be 135 kg, find the net-turning moment on the crank-shaft at the above condition without considering the mass of the connecting rod.

(ii) If the actual mass of the reciprocating parts is 90 kg and that of connecting rod is 120 kg, determine the actual turning moment available at the crank-shaft for the same instant. The CG of the connecting rod is 50 cm from the small end and the radius of gyration about its centroidal axis is 30 cm.

(iii) Find out the percentage of error in the approximate calculation as in (i).

[IFS (Mains) 2002 : 10+3+2 = 15 Marks]

Solution:

Given, Cylinder bore, d = 30.5 cm, Cylinder stroke, $l = 2r$ = 40 cm, Length of connecting rod, L = 80 cm

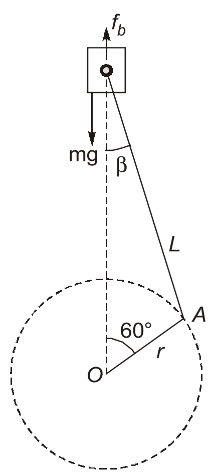
Net pressure on piston at quarter stroke,

$$P_{\text{net}} = 65 \text{ N/cm}^2$$

$$n = \frac{L}{r} = \frac{80}{20} = 4$$

$$\text{Engine speed, } N = 250 \text{ rpm} \Rightarrow \omega = \frac{(2\pi N)}{60} = \frac{2\pi \times 250}{60} = 26.179 \text{ rad/s}$$

(i) When the piston is at its quarter stroke and mass of connecting rod is neglected.



$$x = r(1 - \cos\theta)$$

$$\frac{l}{4} = r(1 - \cos\theta) \quad \text{[outer stroke]}$$

$$\frac{2r}{4} = r(1 - \cos\theta)$$

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

or $$\theta = 60^\circ$$

and $$\sin\beta = \frac{\sin\theta}{4} = \frac{\sin 60^\circ}{4} = 0.2165$$

$$\beta = 12.50$$

$$\text{Force on piston, } f_g = P_{net} \times \left(\frac{\pi}{4}d^2\right) = 65 \times \frac{\pi}{4}(30.5)^2 = 47.49 \text{ kN}$$

Accelerating force/Inertia force, $$f_b = mr\omega^2\left[\cos\theta + \frac{\cos 2\theta}{n}\right]$$

$$f_b = 135\times\left(\frac{20}{100}\right)\times\left(\frac{2\pi(250)}{60}\right)^2\left[\cos 60^\circ+\frac{\cos 120^\circ}{4}\right] = 6.939 \text{ kN}$$

$$\text{Net force on the piston, } f_p = f_g - f_b + mg = 47.46 - 6.939 + \left(\frac{135\times 9.81}{10^3}\right) = 41.845 \text{ kN}$$

$$\text{Crank effort, } f_t = \frac{F_p}{\cos\beta}(\sin(\theta+\beta)) = \frac{41.845}{\cos(12.50^\circ)}\sin(12.50^\circ+60^\circ) = 40.877 \text{ kN}$$

$$\text{Net turning moment} = f_t \times r = 40.908\times 0.2 = 8.1812 \text{ kN-m}$$

(ii) ΔT = correction torque

$$\Delta T = m_c b\,\alpha_c\,(l - L)$$

$$m_c = \text{mass of connecting rod} = 120 \text{ kg}$$

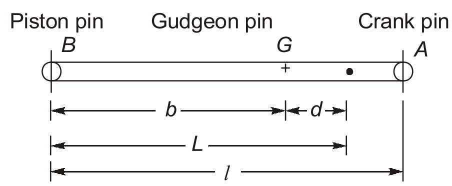
$$\text{Mass at the crank pin} = 120\times\left(\frac{50}{80}\right) = 75 \text{ kg}$$

$$\text{Mass at gudgeon pin} = 120 - 75 = 45 \text{ kg}$$

$$\text{Total reciprocating mass} = 45 + 90 = 135 \text{ kg}$$

$$\text{Inertia force, } f_b \text{ remains same} = 6.939 \text{ kN}$$

$$f_g = 47.46 \text{ kN}$$



Torque (T_1) due to net reciprocating masses remains same,

$$T_1 = 8.1816 \text{ kN-m}$$

As, α_c = Angular acceleration of connecting rod

$$\alpha_c = -\omega^2\sin\theta\left[\frac{n^2-1}{(n^2-\sin^2\theta)^{3/2}}\right] = -(26.16)^2\sin 60^\circ\left[\frac{4^2-1}{(4^2-\sin^2 60^\circ)^{3/2}}\right]$$

$$= -(592.96)\times(0.2518) = -149.307 \text{ rad/sec}^2$$

As, $L = b + d$

$$L = b+\frac{K^2}{b};\ k = \text{radius of gyration}$$

$$L = 50+\frac{(30)^2}{50} = 68 \text{ cm}$$

$$\Delta T = m\,\alpha_c\,b\,(l - L) = 120\times(-149.352)\times 0.5\,(0.8 - 0.68)$$

$$\Delta T = -1.0753 \text{ kN-m}$$

$$\text{The correction torque } (T_c),\ T_c = (\Delta T)\frac{\cos\theta}{\sqrt{n^2-\sin^2\theta}} = -1.0753\frac{\cos 60^\circ}{\sqrt{4^2-\sin^2 60^\circ}} = -0.1376 \text{ kN-m}$$

Torque due to weight of mass at crank pin,

$$T_3 = m_a g = 75\times 10\times 0.2\sin 60^\circ = 0.129 \text{ kN-m}$$

Net torque (T') on the crank shaft,

$$T' = T_1 - T_c + T_3 = 8.1816 - 0.1376 + 0.129 = 8.173 \text{ kN-m}$$

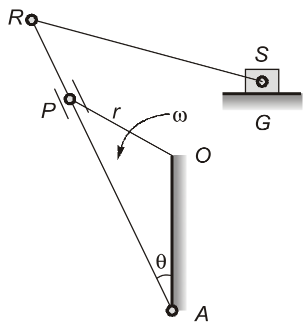
(iii)
$$\%\text{ error} = \frac{T'-T}{T}\times 100 = \frac{8.173-8.1816}{8.1816}\times 100 = 0.1051\%$$

1.2 A crank and slotted lever quick return motion mechanism has the following specifications :
Distance between fixed centres = 200 mm, Length of the driving crank = 100 mm
Sketch the mechanism. Determine the inclination of the slotted bar with the vertical in the extreme position and the ratio of cutting stroke to return stroke.

[IFS (Mains) 2004 : 10 Marks]

Solution:

Given, A crank and slotted lever mechanism



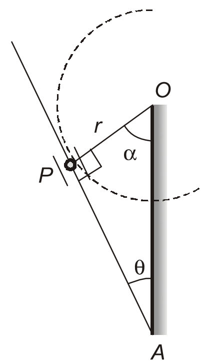
Inclination of slotted bar with the vertical in the extreme position is θ. (say)

Distance between fixed centres, OA = 200 mm

Length of crank, r = 100 mm

In the extreme position:

From Δ OPA,



$$\cos\alpha = \frac{r}{OA}$$

$$\cos\alpha = \frac{100}{200} = 0.5$$

$$\alpha = 60^\circ$$

and From triangle AOP, $\theta = 90^\circ - 60^\circ = 30^\circ$

The inclination of the slotted bar with the vertical in extreme position = 30°.

And ratio of cutting stroke to return stroke,

$$\frac{\text{Time of cutting}}{\text{Time of return}} = \frac{360^\circ - 2\alpha}{2\alpha} = \frac{360^\circ}{2\alpha} - 1 = \frac{360^\circ}{120^\circ} - 1 = 2$$

1.3 Derive an expression for the acceleration of the piston of a reciprocating engine. The following details pertain to a single cylinder vertical engine:
Bore = 20 cm, Stroke = 40 cm, Connecting rod length = 80 cm, Mass of reciprocating part = 140 kg, Net gas pressure at the piston when the crank angle is 45° = 65 N/cm^2 and Speed of the engine = 300 rpm.
Determine the turning moment on the crank shaft when the crank angle is 45°.

[IFS (Mains) 2005 : 7+8 = 15 Marks]

or

With usual notations show that the velocity of slider of slider-crank mechanism is expressed approximately by

$$V_P = \omega r\left(\sin\theta + \frac{\sin 2\theta}{2n}\right)$$ where n = Length of the connecting rod/crank radius.

[IFS (Mains) 2008 : 10 Marks]

2 Mechanics of Solids

1. Stress, Strain and Elastic Constants

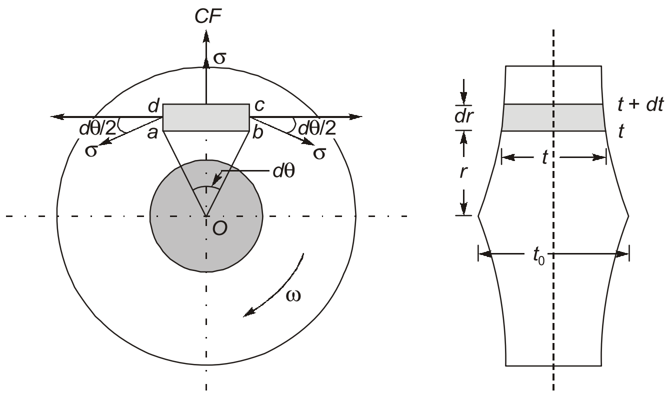
1.1 Illustrate the use of discs of uniform strength in industry. Derive an expression for the profile of disc of uniform strength. How does it differ from those for disc of uniform thickness?

[IFS (Mains) 2001 : 16 Marks]

Solution:

Use of disc: In applications such as turbine blades rotating at high speeds, it is often desirable to design for constant strength as the thickness varies exponentially which results in optimum material usage.

Rotors of steam or gas turbines, on the periphery of which blades are attached, are designed as disc of uniform strength, in which the stress developed due to centrifugal forces are equal and constant independent of radius. In order to achieve the objective of uniform strength throughout, thickness of the disc is varied along the radius. Consider a disc of radius R, rotating at angular speed ω about its axis. Take a small element *abcd* subtending an angle $d\theta$ at the centre of the disc. disc is of uniform strength. Stress on faces *ab*, *bc*, *cd* and *da* of the small element is σ. Thickness of the element at radius r, is t and at radius r + dr, thickness is $t + dt$. (ρ is assumed as specific weight i.e., N/m^3).



$$\text{Volume of element} = r d\theta\, t\, dr$$

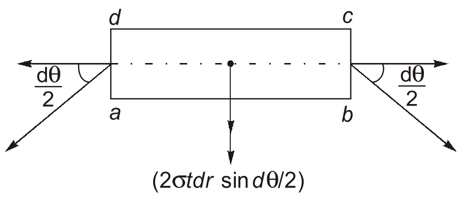
$$\text{Mass of element} = \rho \frac{r d\theta t dr}{g}$$

$$\text{Centrifugal force, CF} = \rho r t \frac{d\theta dr}{g} \times \omega^2 r = \frac{\rho \omega^2 r^2\, t d\theta dr}{g}$$

$$\text{Radial force on face } ab = r\, d\theta\, t\sigma$$

$$\text{Radial force on face } cd = (r + dr) d\theta (t + dt)\sigma$$

$$\text{Force on faces } bc \text{ and } da = \sigma\, t\, dr$$



where σ is uniform stress

Resolving all forces along the radial direction OCF.

$$\frac{\rho\omega^2 r^2}{g}(tdrd\theta) + \sigma(r + dr)(t + dt)d\theta = \sigma r d\theta t + 2\sigma t dr \sin\frac{d\theta}{2}$$

As $d\theta$ is very small $\left(\sin\frac{d\theta}{2} \approx \frac{d\theta}{2}\right)$ So, $\frac{\rho\omega^2 r^2 t}{g} dr + \sigma r t + (\sigma d r t) + \sigma r dt + \sigma dr dt = \sigma r t + \sigma t dr$

Neglecting ($dr \times dt$) as negligible,

$$\frac{\rho\omega^2 r^2 t}{g} dr + \sigma r dt = 0$$

or
$$\sigma \frac{dt}{t} = -\frac{\rho\omega^2 r}{g} dr$$

$$\int \frac{dt}{t} = -\int \frac{\rho\omega^2 r}{g\sigma} dr$$

$$\ln t = -\frac{\rho\omega^2 r^2}{2g\sigma} + \ln A \ (A = \text{constant})$$

or
$$\ln\left(\frac{t}{A}\right) = -\frac{\rho\omega^2 r^2}{2\sigma g} \quad \text{or} \quad \frac{t}{A} = e^{-\frac{\rho\omega^2 r^2}{2\sigma g}}$$

At centre, $r = 0$, and $t = t_0$
$$t_0 = A$$

and profile thickness varies as,
$$t = t_0 e^{-\frac{\rho\omega^2 r^2}{2g\sigma}}$$

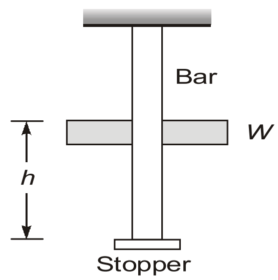
Hence, the thickness of the disc is varied along the radius to achieve the objective of uniform strength. Whereas, disc of uniform thickness has constant thickness throughout the radius.

1.2 With reference to Figure, neglect the weight of the bar and stopper. A load W is dropped from a height h. Given W = 1.0 kN, area of cross-section of the bar = 20 mm^2. Find the instantaneous stress developed in the bar when the weight W is dropped from a height h = 0.

[IFS (Mains) 2002 : 10 Marks]

Solution:

Let I.F. be the impact factor,



$$\text{I.F.} = 1 + \sqrt{1 + \frac{2h}{\delta_{static}}} \quad \left\{\delta_{Static} = \frac{WL}{EA}\right\}$$

and
$$\sigma_{impact} = \sigma_{static} \times \text{I.F.}$$

when, $(h = 0)$
$$\text{I.F.} = 1 + \sqrt{1+0} = 2$$

and
$$\sigma_{static} = \frac{W}{A}$$

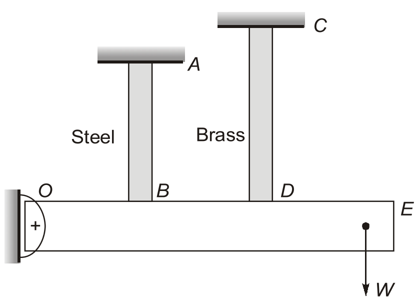
where
$$W = 1.0 \text{ kN}, \ A = 20 \text{ mm}^2$$

∴
$$\sigma_{static} = \frac{W}{A} = \frac{1 \times 10^3}{20} \text{ N/mm}^2 = 50 \text{ MPa}$$

Therefore,
$$\sigma_{instantaneous} = \sigma_{impact} = 2 \times \sigma_{static}$$
$$\sigma_{impact} = 2 \times 50 = 100 \text{ MPa}$$

Thus, instantaneous stress developed in the bar is 100 MPa

1.3 As shown in figure, OE is a rigid beam, hinged at D and kept horizontal by two vertical supports AB and CD.



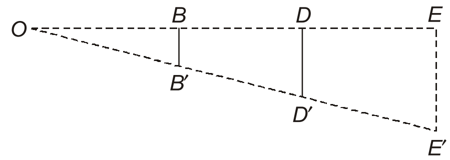
Com.	Mat.	Length	Diameter	E	α
AB	Steel	1.2 m	Solid bar of 5 mm dia.	200 GPa	12×10^{-6} /°C
CD	Brass	1.5 m	Hollow bar 10 mm internal dia & 15 mm external dia.	110 GPa	20×10^{-6} /°C

If hot gases pass through the brass tube to raise its temperature by 150°C, find the load supported by both the vertical bars, given $OB = BD = DE$. Assume that before assembly, the brass bar is 1 mm too short and $W = 10$ kN. [IFS (Mains) 2002 : 10 Marks]

Solution:

Given that, $OB = BD = DE = x$ (let)

From $\Delta OBB'$ and $\Delta ODD'$



$$\frac{OB}{BB'} = \frac{OD}{DD'} \Rightarrow \frac{x}{BB'} = \frac{2x}{DD'}$$

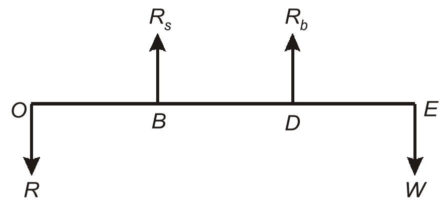
$\Rightarrow$ $DD' = 2\ BB'$

$\Rightarrow$ $\delta_{CD} = 2\,\delta_{AB}$ ...(i)

$$A_b = \frac{\pi}{4}(15^2 - 10^2) = 98.17\text{ mm}^2$$

$$A_s = \frac{\pi}{4}5^2 = 19.63\text{ mm}^2$$

FBD of beam OE:



Taking moment about O:

$$R_s \times x + R_b \times 2x = W \times 3x$$

$\Rightarrow$ $R_s + 2R_b = 3 \times 10 = 30$ kN ...(ii)

Bar CD initially 1 mm short,

Net elongation in bar CD = – 1 + Elongation due to temperature rise + Elongation due to load

$$= -1 + \alpha_b T_b L_b + \frac{R_b L_b}{A_b \times E_b}$$

$$= -1 + 20 \times 10^{-6} \times 150 \times 1.5 \times 10^3 + \frac{R_b \times 10^3 \times 1.5}{98.17 \times 110}$$

$$= -1 + 4.5 + 0.1389\,R_B$$

$\delta_{CD} = 3.5 + 0.1389\,R_B$ ...(iii)

Net elongation in bar AB $= \dfrac{R_s \times L_s}{A_s \times E_s} = \dfrac{R_s \times 1.2 \times 10^3}{19.63 \times 200} = 0.3056\,R_s$ mm

$\delta_{AB} = 0.3056\,R_s$ mm

From equation (ii), $\delta_{AB} = (30 - 2\,R_b) \times 0.3056$ ...(iv)

From equations (iii) and (iv) putting the values of δ_{AB} adn δ_{CD} in equation (i),

$$3.5 + 0.1389\,R_b = 2 \times 0.3056 \times (30 - 2R_b)$$

$\Rightarrow$ $R_b = 10.898$ kN

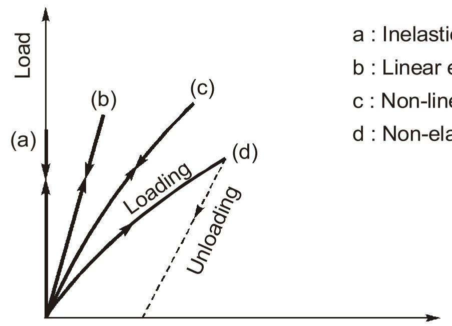
and $R_s = 30 - 2 \times 10.898 = 8.204$ kN

The load supported by brass bar = 10.898 kN

The load supported by steel bar = 8.204 kN

1.4 Explain clearly the meanings of terms:
Elastic solid, non-elastic solid, inelastic solid, linearly elastic solid, and nonlinearly elastic solid. Illustrate your answer using a diagram showing the load-deformation relationship for the above solids? [IFS (Mains) 2003 : 10 Marks]

Solution:



Elastic solid: Solids which are capable of recovering size and shape after deformations.

Non-elastic solids: Solids which can not regain their original shape and after unloading.

Inelastic solids: Solids which do not deform under the application of force.

Linearly elastic solids: Solid which deform linearly proportionally to load. They also follow Hooks law, $\sigma \propto \in$.

Non-linearly elastic solids: Elastic solids for which deformations are not linearly proportional to applied load. In these types of solid deformations follows power law.

1.5 **A steel bar of diameter 60 mm and length 300 mm is subjected to an axial compressive load of 50 kN. To what diameter the middle one-third length of the bar be reduced in order to increase the stored energy by 50%?**

[IFS (Mains) 2004 : 10 Marks]

Solution:

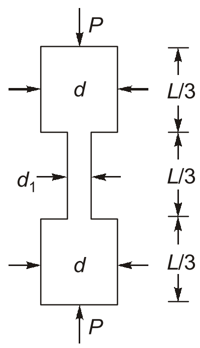
Given:

Initially, uniform steel bar,

d = 60 mm, l = 300 mm, Compressive load, P = 50 kN

$$\text{Strain energy stored, } U_1 = \frac{P^2L}{2AE}$$

Let d_1 be the new reduced diameter of $(1/3)^{rd}$ length of the bar.



$$U_2 = \frac{P^2\left(\frac{L}{3}\right)}{2AE} + \frac{P^2\left(\frac{L}{3}\right)}{2A_1E} + \frac{P^2\left(\frac{L}{3}\right)}{2AE} = \frac{P^2L}{3AE} + \frac{P^2L}{6A_1E}$$

and $$U_2 = 1.5\,U_1 \text{ (Given)}$$

$$\frac{P^2L}{3AE} + \frac{P^2L}{6A_1E} = 1.5 \times \frac{P^2L}{2AE}$$

$$\frac{1}{3A} + \frac{1}{6A_1} = \frac{1.5}{2A}$$

$$\frac{1}{6A_1} = \frac{0.4166}{A}$$

$$A_1 = 0.4\,A$$

$$d_1^2 = 0.4 \times (60)^2$$

$$d_1 = 37.947 \text{ mm}$$

Thus, the diameter of middle 1/3 length be reduced to 37.947 mm

3 Engineering Materials

1. Structure of Solids and Defects

1.1 What are dislocations in the structure of solids? Name and graphically represent the two major types of these defects. Indicate how they promote early failure of metals. How is it possible to produce metals free from these defects?

[IFS (Mains) 2001 : 10 Marks]

or

What are the various types of dislocations? Explain any two of them with the help of sketches. What is interstitial free steel and where is it used?

[IFS (Mains) 2009 : 10 Marks]

or

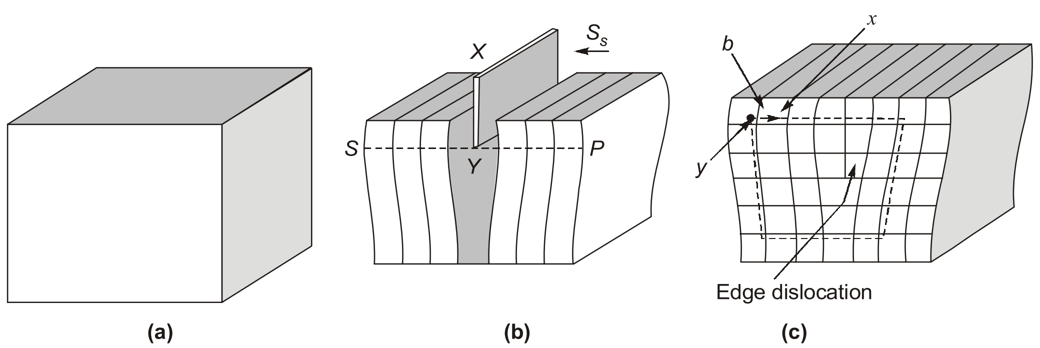
What is meant by dislocation? State different types of dislocations with neat sketches.

[IFS (Mains) 2014 : 8 Marks]

Solution:

Line Defects-Dislocations:

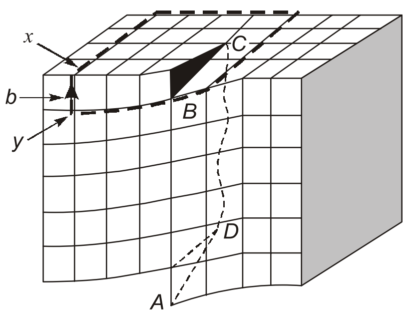
Dislocations are the defects in the orderly arrangement of a metals atomic structure. Dislocations are areas where the atoms are out of position in the crystal structure. Dislocations are generated and move when a stress is applied. The motion of dislocations allows slip-plastic deformation to occur.



(a) The perfect crystal (b) An extra plane of atoms is inserted
(c)The bottom edge of the extra plane is an edge dislocation

(i) Edge dislocation: The line marked as SP represents the slip plane of the crystal and the dashed lines represent the crystal planes perpendicular to the slip plane.
The plane marked '*X*' at the top of the figure ends at point '*Y*' on the slip plane, whereas the planes on either side of '*X*' run continuously from the top to the bottom of the figure. In such a case where a lattice plane ends inside a crystal, an edge dislocation results.
The edge dislocation shown in figure has an incomplete plane which lies above the slip plane. Such as edge dislocation is called positive edge dislocation and is represented by the symbol ⊥ where the vertical line represents the incomplete plane and the horizontal line represents the slip plane. It is also possible to have the incomplete plane below the slip plane which can be represented by the symbol *T*.

(ii) **Screw Dislocation :** The right side portion of the crystal has been sheared by one atomic distance on the downward direction relative to the left side portion. No slip has taken place to the rear portion of the line *DC* and therefore *DC* is a dislocation line. The plane *ABCD* is the slip plane The designation screw for this lattice defect is derived from the fact that the lattice planes of the crystal, spiral the dislocation line *DC*.



Representation of a screw dislocation

Interstitial Free Steel : The term 'Interstitial Free Steel or IF Steel' refers to the steel, that are having no interstitial solute atoms to strain the solid iron lattice, this results in very soft steel. If steels have interstitial free body centered cubic (BCC) ferrite matrix. These steels normally have low yield strength, high plastic strain ratio, high strain sensitivity and good formability.

- IF steel is termed as 'Clean Steel' as the total volume fraction of precipitates is very less. In spite of this, the precipitates appear to have a very significant effect on the properties of IF steels.
- Liquid steel is processed to reduce *C* and *N* to levels low enough that the remainder can be stabilized by small addition of titanium (Ti) and Niobium (Nb). Ti and Nb are strong carbide and nitride formers. They take remaining *C* and *N* out of solution in liquid iron, after which these latter two elements are no longer available to reside in the interstitial site between solidified iron atoms.
- IF steel has ultra low carbon content, achieved by removing carbon monoxide, hydrogen, nitrogen and other gases during steel making through a vacuum degassing process.
- IF steel possess typically non-ageing properties. Because of these non-ageing properties. If steels are the standard base for hot dipped galvanized products.

1.2 (i) Define allotropy. Give an example of different isotropic forms of a material.
(ii) What is edge dislocation?
(iii) Prove that the atomic packing factor of a HCP (Hexagonally Close-Packed) structure is 0.74.
[IFS (Mains) 2003 : 3+3+4 = 10 Marks]

Solution:

(i) At different temperatures, however, the same metal may form different structures, because of a lower energy requirements at that temperature. The appearance of more than one type of crystal structure is known as allotropy. For example, iron forms a BCC structure (α-iron) below 912°C and above 1394°C, but if forms an FCC structure (γ-iron) between 912°C and 1394°C.

(ii) An edge dislocation is a defect where an extra half-plane of atoms is introduced midway through the crystal, distorting nearby planes of atoms. When enough force is applied from one side of the crystal structure, this extra half plane passes through planes of atoms breaking and joining bonds with them until it reaches the grain boundary. In an edge dislocation, the Burger vector is perpendicular to the dislocation edge.

(iii) In HCP structure. (a = 2r)

4 Manufacturing Science

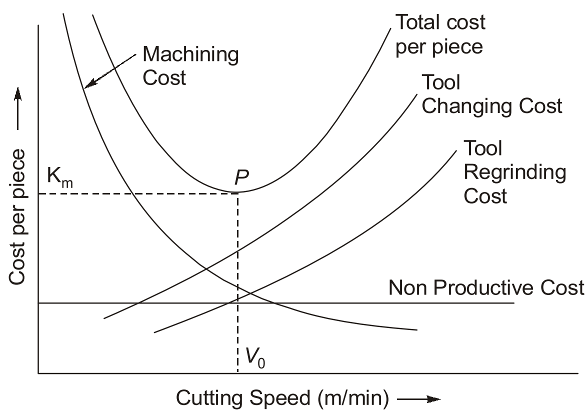
1. Metal Cutting

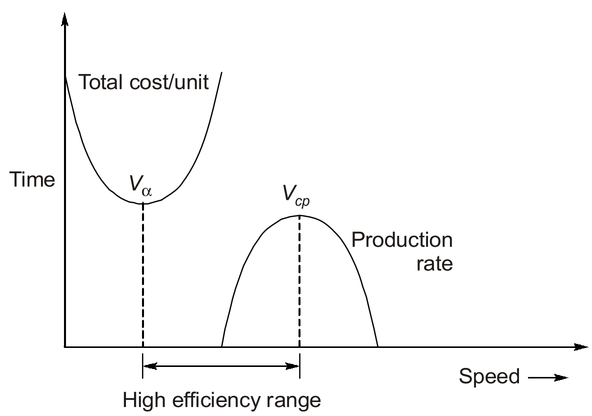
1.1 What is Hi-E range in machining economics?
Why is it called this way? How do you establish this range when simple tool-life equation is the only constraint?

[IFS (Mains) 2001 : 10 Marks]

Solution:

Hi-E or the high efficiency machining range is the speed range from V_α (the economic cutting speed) to V_{CP} (the cutting speed corresponding to the highest productivity). This means that, depending on the process demand, one could choose any cutting speed within this region and justify it on economic grounds.





The total cost is obtained and then this equation is differentiated with respect to the cutting speed V_1 to determine the optimum cutting speed (V_α). Similarly the total time required to machine the part is obtained and then this equation is differentiated with respect to the cutting speed to obtain minimum time per piece. The range between these two speeds is Hi-E range.

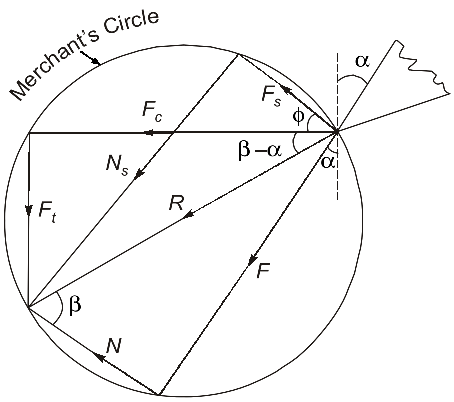
1.2 During orthogonal turning of a steel rod at a feed rate of 0.2 mm/rev. and depth of cut 3 mm by a tool with side rake angle of 10° following observations were made:
Tangential force - 180 kgf, Axial force - 90 kgf, Chip thickness - 0.6 mm
(i) Sketch the Merchant's circle diagram of forces (need not to be scale) showing all the forces concerned.
(ii) Determine by calculation shear angle, shear strain and shear force.

[IFS (Mains) 2001 : 7 + 8 = 15 Marks]

Solution:

F_s = Shear force, F_c = Cutting force, F_t = Thrust force, R = Resultant, N = Normal force,
N_s = Normal shear force, F = Friction force, ϕ = Shear angle, α = Side rake angle, β = Friction angle

(i) Merchant's circle diagram



Given: Feed rate = 0.2 mm/rev, Depth of cut = 3 mm, F_C = 180 kgf, F_t = 90 kgf, t_c(Chip thickness) = 0.6 mm
α_s = 10°

(ii) Shear angle (ϕ)

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

$$r = \frac{t_1}{t_c} = \frac{0.2}{0.6} = 0.33$$

$$\tan\phi = \frac{0.33\cos 10^\circ}{1-(0.33\sin 10^\circ)} = 0.3447$$

$$\phi = 19.02^\circ$$

$$\text{Shear strain} = \cot\phi + \tan(\phi-\alpha) = \cot 19.02^\circ + \tan(19.02 - 10^\circ)$$
$$= 2.9 + 0.1587 = 3.0587$$

$$\text{Shear force } (F_s) = F_c\cos\phi - F_t\sin\phi = 180\cos 19.02^\circ - 90\sin 19.02^\circ = 140.842 \text{ kgf}$$

1.3 Turning operation is performed with the following tool geometry and cutting conditions
Major cutting edge angle (approach angle) = 60°, Minor cutting edge angle = 10°
Rake angle = 0°, Cutting speed = 100 RPM, Feed = 0.3 mm/rev, Depth of cut = 3 mm
What is the roughness height generated? What is its R_a value?
If the tool is ground to a nose radius of 2 mm how much is the reduction in roughness height? Derive the relations used.

[IFS (Mains) 2001 : 13 Marks]

Solution:

Given: Approach angle (major cutting edge angle), ψ = 60°, Minor cutting edge angle, ψ_1 = 10°
f = 0.3 mm/rev, d = 3 mm

5 Manufacturing Management

1. Break Even Analysis and Inventory Controls

1.1 What is selective management like ABC analysis? Name and explain 3 such approaches presenting the basis on which they subgroup activities. How this improves management productivity?

[IFS (Mains) 2001 : 10 Marks]

Solution:

ABC Analysis – An *ABC* analysis is an inventory categorization technique which divides the inventory items into three groups *A*, *B*, *C* according to their annual cost volume consumption, i.e. unit cost x annual consumption.

A – items – High value : These are relatively few items whose value accounts for 60-70% of the total value of the inventory. These will usually be 10-15% of the total items.

B – items – Medium value : A large number of items in the middle of the list, usually about 20-25% of the items whose total value accounts for about 20-25% of the total value.

C – items – Low value : The bulk of items usually about 60-70% whose total inventory values are almost negligible. They account for 10-15% of the total value.

Other similar approaches are:

1. HML: (High, Medium, Low) – Materials are classified according to their unit price in three categories.
2. VED : (Vital, Essential, Desirable) – Materials are classified according to their operational characteristics.
3. SDE : (Scarce, Difficult, Easy) – Materials are classified on the basis of availability of inventory items for the production system.

Advantages of such approaches are:

1. Better control of High-priority inventory.
2. It reduces the cost of inventory items in storage.
3. It ensures control over the costly items in which a large amount of capital is invested.
4. It helps in regular monitoring of critical items and prevents stock out to avoid loss in production.

1.2 Following data relate to the operating costs of 2 possible locations for a manufacturing plant:

	Location 1	Location 2
Fixed cost, ₹	110000	125000
Direct material, ₹/unit	8.5	8.4
Direct labour, ₹/unit	4.2	3.9
Variable overhead, ₹/unit	1.2	1.1
Transportation cost ₹/1000 units	800	1100

(i) Which location would minimise the total costs, given an annual production of 50,000 units.

(ii) What is the break even between the locations.

[IFS (Mains) 2001 : 6+6 = 12 Marks]

Solution:

For annual Production of 50,000 units.

Let C_1 be the total cost with location (1).

C_2 be the total cost with location (2).

$$C_1 = 1,10,000 + (8.5 \times 50,000) + (4.2 \times 50,000) + (1.2 \times 50,000) + \left(800 \times \frac{50,000}{1000}\right) = 8,45,000$$

Similarly, $C_2 = 1,25,000 + (8.4 \times 50,000) + (3.9 \times 50,000) + (1.1 \times 50,000) + \left(1100 \times \frac{50,000}{1000}\right) = 8,50,000$

As $C_1 < C_2$, location (1) will minimise the total costs for production of 50,000 units.
Let q be the annual units produced for break even.
Total variable cost for location (1),

$$= (8.5 + 4.2 + 1.2)/\text{unit} + (800/1000)$$
$$= 13.9/\text{unit} + (800/1000)/\text{unit} = 14.7/\text{unit}$$

Total variables cost for location (2),

$$= (8.4 + 3.9 + 1.1)/\text{unit} + (1100/1000)$$
$$= 13.4/\text{unit} + (1100/1000)/\text{unit} = 14.5/\text{unit}$$

Let q be the number of units at break-even

The total cost are C_1' and C_2' and at break even C_1' and C_2' should be same.

Therefore, $C_1 = C_2$ (Total cost should be same)

$$1,10,000 + 14.7q = 1,25,000 + 14.5q$$

$$q = \frac{1,25,000 - 1,10,000}{14.7 - 14.5} = 75000 \text{ units}$$

1.3 ABC company has to supply 30,000 switches per year to its customer. This demand is fixed and known. The customer uses its items in assembly operations and has no storage place/space. A storage cost of ₹10/ unit is incurred if the company fails to deliver the required units. The set-up cost per run in ₹3,500.00. Determine:

(i) the optimum run size, q
(ii) the optimum level of inventory at the beginning of any period
(iii) the optimum scheduling period
(iv) the minimum total expected annual cost

[IFS (Mains) 2002 : 10 Marks]

Solution:

Given; Demand, D = 30,000 switches/year
Storage cost, C_h = 10/unit
Setup cost, C_0 = ₹ 3,500 per run

Optimum run size, $$q = \sqrt{\frac{2DC_0}{C_h}} = \sqrt{\frac{2 \times 30000 \times 3500}{10}}$$

(i) q = 4582.57 or 4583 switches

(ii) Optimum level of inventory at the beginning of any period

$$= \frac{Q^*}{2} = \frac{4583}{2} = 2292 \text{ switches}$$

(iii) Re-order cycle time, $$t^* = \frac{Q^*}{D} = \frac{4583}{30000} = 0.1527 \text{ year} = 0.1527 \times 365 = 55.75 \simeq 55 \text{ days}$$

(iv) Number of runs $$= \frac{30,000}{4583} = 6.45 \approx 7$$

Storage cost of each switch = ₹ 10 per unit

Minimum Annual inventory cost $$= D \times C + \frac{D}{Q^*} \times C_0 + \frac{Q^*}{2} C_h$$
$$= D \times C + \sqrt{2DC_0C_h}$$
$$= 30000 \times 10 + \sqrt{2 \times 30000 \times 3500 \times 10} = 345825.7569 \text{ ₹/year}$$

1.4 An automobile instrument manufacturer has identified the following options for obtaining a machined component. They can out-source component at ₹220/- per unit (including materials). They can manufacture the component on a semi-automatic lathe at ₹80/- per component (including material); or they can manufacture the components on a CNC turning centre at ₹18/-per component including materials. There is negligible fixed if the items are out-sourced, a semi-automatic lathe costs ₹3.5 Lacs and CNC turning centre costs ₹9.5 Lacs. Suggest your optimal choices for minimizing cost and maximizing profit, if the component is sold at ₹310/- each.

[IFS (Mains) 2004 : 15 Marks]

Solution:

With the three options given::

Option I : Out-source component

$$\text{Variable cost, V.C.} = ₹\ 220/\text{- per unit}$$
$$\text{Fixed cost, F.C.} = \text{Negligible}$$

For 'x' number of units.

$$\text{Total cost, T.C} = 220x$$
$$\text{Selling price, } P_1 = 310/\text{unit}$$
$$\text{Profit/unit} = (310 - 220)/\text{unit} = 90/\text{unit}$$
$$P_1 = 90x \text{ (Profit with option I)}$$

Option II: On a semi-automatic lathe

$$\text{V.C} = ₹\ 80 \text{ per unit}$$
$$\text{F.C} = ₹\ 3.5 \text{ lacs}$$
$$\text{Total cost (T.C)} = 3.5 \times 10^5 + 80x$$
$$= 3,50,000 + 80x$$
$$P_2 = 310x - [3,50,000 + 80x]$$

Option III: CNC turning centre

$$\text{V.C.} = ₹\ 18 \text{ per unit}$$
$$\text{F.C.} = ₹\ 9.5 \text{ lacs}$$
$$\text{Total cost, T.C.} = 9,50,000 + 18x$$
$$P_3 = 310x - [9,50,000 + 18x]$$

Break even points:

1. Between option I and II:

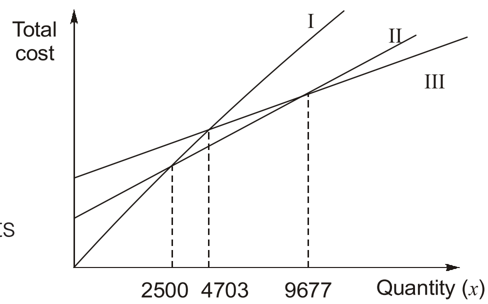
$$220x = 3,50,000 + 80x$$
$$x = 2500$$

2. Between options II and III:

$$3,50,000 + 80x = 9,50,000 + 18x$$
$$x = 9677.4 \quad \text{or} \quad 9677 \text{ units}$$

3. Between options I and III:

$$220x = 9,50,000 + 18x$$
$$x = 4702.9 \quad \text{or} \quad 4703 \text{ units}$$



Optimal Choices are:

For
$$x < 2500 \rightarrow \text{Option I i.e. Out source the component}$$
$$2500 < x < 9677 \rightarrow \text{Option II i.e. Manufacture on a semi-automatic lathe}$$
$$x > 9677 \rightarrow \text{Option III i.e. Manufacture on an CNC turning centre}$$

1.5 In the past, an 'MNC industries' has used a fixed time period inventory system that involved taking a complete inventory count of all items each month. However increasing labour costs are forcing the industry to examine alternative ways to reduce the amount of labour involved in inventory stockrooms, yet without increasing other costs, such as shortage costs. Here is a random sample of 10 items.

6 Miscellaneous

1.1 **What do you understand by a rotating disc of uniform strength?**
A turbine disc is required to have a uniform stress of 150 MPa at a speed of 3200 rpm. The disc is to be of 30 mm thick at the centre. What will be its thickness at a radius of 40 mm?
Assume density of disc material = 7800 kg/m^3.

[IFS (Mains) 2012 : 10 Marks]

Solution:

In rotating disc of uniform strength, the circumferential and radial stresses, developed due to centrifugal forces on account of high angular speed ω are equal and constant and independent of radius. Both radial and circumferential stresses are maximum at the centre of the disc, while radial stresses becomes zero at outer radius but circumferential stress reduces to a minimum at the outer radius. So, as, the stresses increase towards the centre of the disc, thickness of the disc also increases to maintain constant stress $(\sigma_r = \sigma_\theta = \sigma)$.

The thickness t at any radius r and thickness t_0 at the centre is

$$\left(t = t_0 e^{-\frac{\rho\omega^2 r^2}{2g\sigma}} \right)$$

Given: r = 40 mm, ρ = 7800 kg/m^3 = $\dfrac{7800 \times 9.8}{10^9} = 0.07644 \times 10^{-3}$ N/mm^2, t_o = 30 mm

$$\omega = \frac{2\pi N}{60} = \frac{2 \times \pi \times 3200}{60} = 335.10 \text{ rad/s}$$

$$\sigma = 150 \text{ N/mm}^2, \text{ g} = 9810 \text{ mm/s}^2$$

As,
$$\frac{\rho\omega^2 r^2}{2g\sigma} = \frac{0.07644 \times 10^{-3} \times 335.1^2 \times 40^2}{2 \times 9810 \times 150} = 0.004666$$

$$e^{-\frac{\rho\omega^2 r^2}{2g\sigma}} = e^{-0.004666} = 0.99534$$

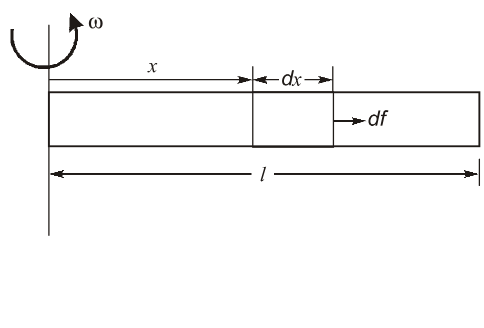
$$t = t_0 \times 0.99534 = 30 \times 0.99534 = 29.86 \text{ mm}$$

1.2 **A bar of length L, material density S and modulus of elasticity E is rotating about one end with an angular speed of ω radians per second. Find the maximum stress set up in the bar and its extension due to rotation.**

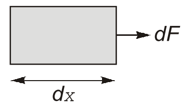
[IFS (Mains) 2016 : 8 Marks]

Solution:

Given: A bar of length L, density S and modulus of elasticity E rotating about one end with an angular speed ω radians per second.



Let us consider small element dx at a distance x from the end.



$$dm = \text{mass} = SAdx$$

$$A = \text{Area of cross-section}$$

$$dF = \text{centrifugal force due to rotation}$$

$$dF = (\text{dm})\omega^2 x = SA\,\omega^2 x\,\text{d}x$$

$$F = \int_0^L SA\omega^2 x dx = \frac{SA\omega^2 L^2}{2}$$

$$\sigma_{max} = \text{Maximum stress developed.}$$

$$\sigma_{max} = \frac{F}{A} = \frac{S\omega^2 L^2}{2}$$

Let ($d\delta$) be the elongation due to force

$$d\delta = \frac{(dF)x}{AE} = \frac{S\omega^2 x^2 dx}{E}$$

Let (δ) be the total elongation
$$\delta = \int_0^L \frac{S\omega^2 x^2 dx}{E} = \frac{S\omega^2 L^3}{3E}$$

1.3 Explain the following terms with respect to 'C' programming language :

1. Functions

2. Arguments

3. Declarations

[IFS (Mains) 2021 : 8 Marks]

Solution:

1. A function is a group of statements that together perform a task. Every C program has at least one function, which is main(), and all the most trivial programs can define additions functions. We can divide our code into separate functions.
2. An argument is a way to provide more information to a function. The function can then use that information as it runs, like a variable. Also, when we create a function, we can pass in data in the form of an argument, also called a parameter.
3. A declaration is a C language construct that introduces one or more identifiers into the program and specifies their meaning and properties.

1.4 Write 'C' program to find the product of two integers and print the result.

[IFS (Mains) 2021 : 10 Marks]

Solution:

```
#include <stdio.h>
int main ()
{
    int x, y, result;
    printf (“\n Input the first integer :”);
    scanf (“%d”, &x);
    printf (“\n Input the second integer:”);
```