MADE EASY

India's Best Institute for IES, GATE & PSUs

ESE 2019
Main Exam

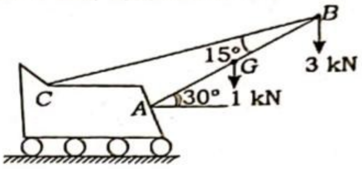
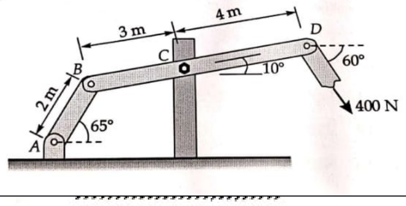
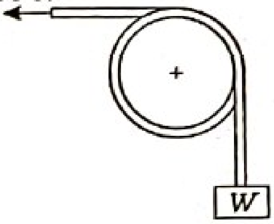
Exam held on 30.06.2019

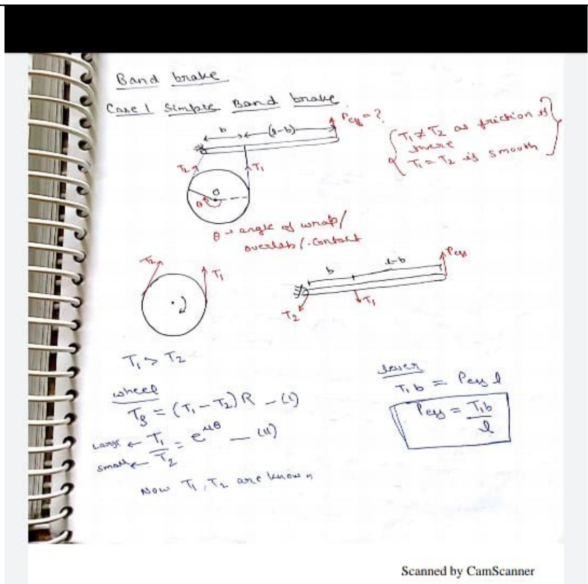
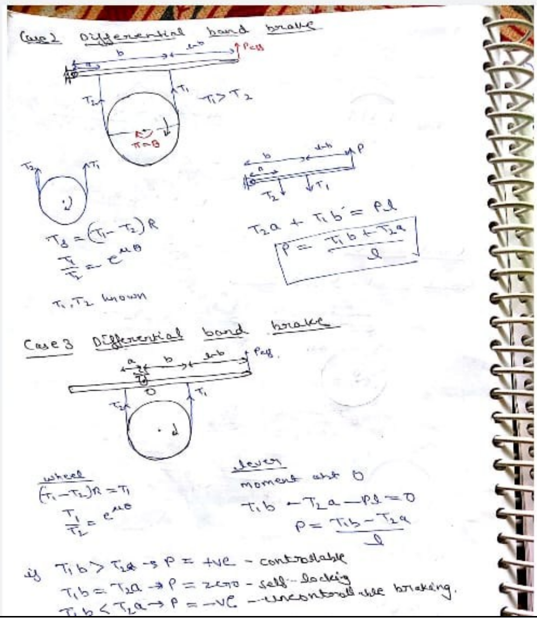
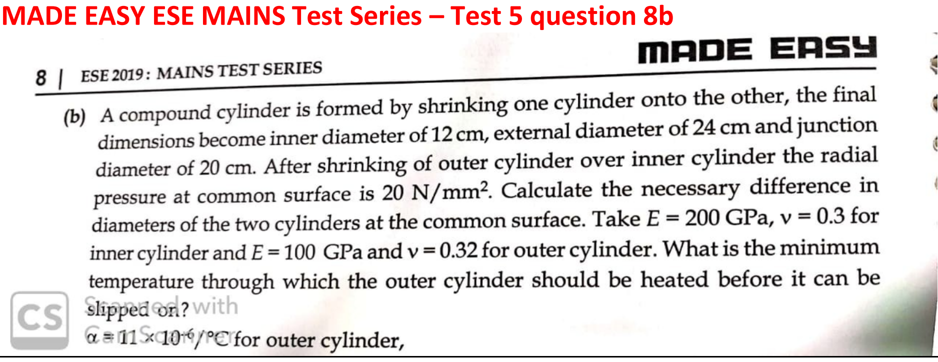
Mechanical Engineering

Paper II

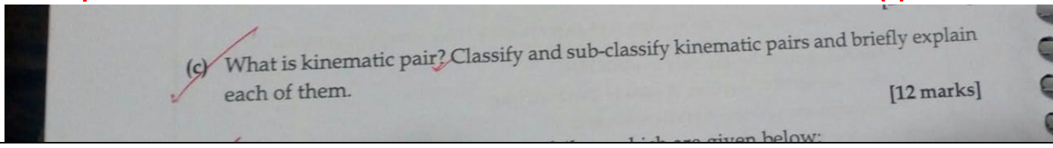
Source of Questions from MADE EASY References

(Classroom/Books/Test Series)

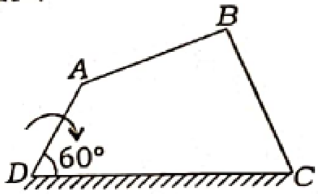
Q.No	
Q.1 a (i)	1. *(a)* *(i)* A 10 m boom *AB* weighs 1 kN. The distance of centre of gravity is 5 m from *A*. For the position shown in the figure given below, determine the tension *T* in the cable and reaction at *A* : 6 
Source	**Test 5 of MADE EASY ESE Mains test series Q. 5(c)** (c) Member BD is hinged to a fixed support with the help of a bolt of diameter 2 cm. Member BD is 10 cm wide and 5 cm thick. Determine the shear stress in the bolt and bearing stress at C in member *BD*. 
Q.1 a (ii)	*(ii)* A rope making $1\frac{1}{4}$ turns around a stationary horizontal drum is used to support a weight as shown in the figure given below. If the coefficient of friction is 0·3, what range of weight can be supported by exerting an 800 N force at the end of the rope? 
Source	**Directly from MADE EASY Class Notes**

	 
Q. 1 (b)	*(b)* A steel tube of 100 mm internal diameter and 10 mm wall thickness in a plant is lined internally with well-fitted copper sleeve of 2 mm wall thickness. If the composite tube is initially unstressed, calculate the hoop stress set up assumed to be uniform throughout the wall thickness, in a unit length of each part of the tube due to an increase in temperature of 100 °C. For steel, $E = 208$ GPa, $\alpha = 11 \times 10^{-6}$/°C For copper, $E = 104$ GPa, $\alpha = 18 \times 10^{-6}$/°C
Source	**MADE EASY ESE MAINS Test Series – Test 5 question 8b** 8 | ESE 2019 : MAINS TEST SERIES MADE EASY (b) A compound cylinder is formed by shrinking one cylinder onto the other, the final dimensions become inner diameter of 12 cm, external diameter of 24 cm and junction diameter of 20 cm. After shrinking of outer cylinder over inner cylinder the radial pressure at common surface is 20 N/mm². Calculate the necessary difference in diameters of the two cylinders at the common surface. Take $E = 200$ GPa, $\nu = 0.3$ for inner cylinder and $E = 100$ GPa and $\nu = 0.32$ for outer cylinder. What is the minimum temperature through which the outer cylinder should be heated before it can be slipped on? $\alpha = 11 \times 10^{-6}$/°C for outer cylinder,

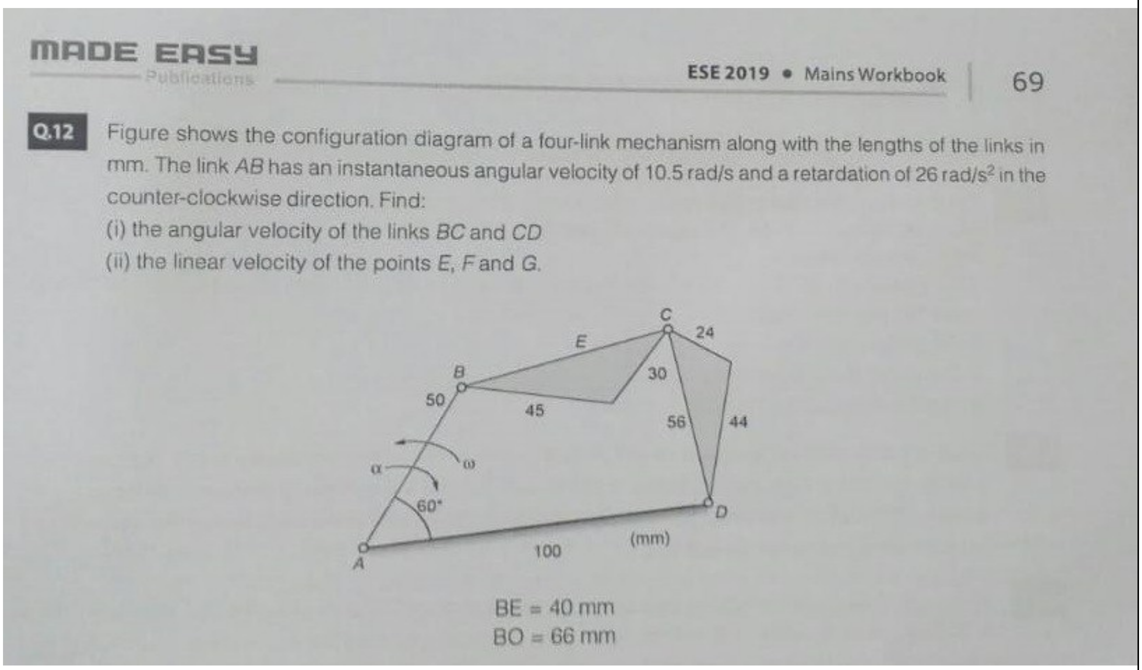
Q.1 (c) (i)	*(c)* *(i)* What is kinematic pair? How are kinematic pairs classified? Explain.
Source	**Exact question asked in MADE EASY ESE Mains test series test no 11 Q-1(c)**


(c) What is kinematic pair? Classify and sub-classify kinematic pairs and briefly explain each of them. [12 marks]

Q.1 (c)(ii)	*(ii)* A four-bar mechanism has the following dimensions : $DA = 200$ mm, $CB = AB = 300$ mm, $DC = 500$ mm. The link DC is fixed and the angle ADC is 60°. The driving link DA rotates uniformly at a speed of 100 r.p.m. clockwise and constant driving torque has the magnitude of 50 N-m. Determine the velocity of point B and angular velocity of the driven link CB. If the efficiency is 70%, calculate also the resisting torque :



Source	**Question 12 of MADE EASY ESE MAINS Workbook**


MADE EASY Publications ESE 2019 • Mains Workbook 69

Q.12 Figure shows the configuration diagram of a four-link mechanism along with the lengths of the links in mm. The link AB has an instantaneous angular velocity of 10.5 rad/s and a retardation of 26 rad/s^2 in the counter-clockwise direction. Find:

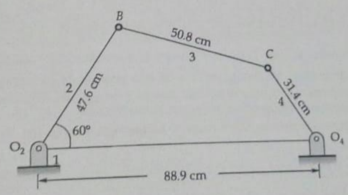
(i) the angular velocity of the links BC and CD

(ii) the linear velocity of the points E, F and G.

BE = 40 mm
BO = 66 mm

Similar question asked in Test -2 of ESE MAINS test Series

(b) The four bar chain mechanism as shown below and link '2' rotate with angular speed of 120 rev/min in CCW, then determine the angular velocity of link 3 in revolution per minute and also locate all possible I-centres for mechanism.



[12 marks]

(c) A 1 mm diameter electric wire is covered with 2 mm thick layer of insulation ... at 25°C and $h = 10$ W/m²K. The wire

Q.1 (d) (ii)

(ii) A vibrating system has the following constants :

$W = 19{\cdot}62$ kg, $K = 8$ kg/cm, $C = 0{\cdot}08$ kg-s/cm

Determine—

(1) damping factor;

(2) natural frequency of damped oscillations;

(3) logarithmic decrement.

Here, W = Weight of mass

K = Spring stiffness

C = Damping coefficient

2×3=

Source **MADE EASY Mains Workbook solved Q 69**

166 | Mechanical Engineering • Theory of Machines MADE EASY Publications

Question-69 A vibrating system is defined by the following parameters:

$m = 3$ kg, $k = 100$ N/m $C = 3$ N-sec/m

Determine (a) the damping factor, (b) the natural frequency of damped vibration, (c) logarithmic decrement, (d) the ratio of two consecutive amplitudes and (e) the number of cycles after which the original amplitude is reduced to 20 percent.

Solution :

Critical damping is determined as

$$c_c = 2\sqrt{km} = 2\sqrt{100\times 3} = 34.64 \text{ N-sec/m}$$

(a) $$\varepsilon = \frac{c}{c_c} = \frac{3}{34.64} = 0.086$$

(b) $$\omega_d = \omega\sqrt{1-\varepsilon^2} = \sqrt{\frac{k}{m}(1-0.086)^2} = \sqrt{\frac{100}{3}(1-0.086)^2} = 5.75 \text{ rad/sec}$$

$$f_d = \frac{\omega_d}{2\pi} = \frac{5.75}{2\pi} = 0.92 \text{ Hz}$$

(c) $$\delta = \frac{2\pi\varepsilon}{\sqrt{1-\varepsilon^2}} = \frac{2\pi\times 0.086}{\sqrt{1-0.086^2}} = 0.542$$

(d) The ratio between two consecutive amplitudes say $\frac{x_1}{x_2}$

$$\delta = \ln\frac{x_1}{x_2} \text{ or } e^{\delta} = \frac{x_1}{x_2}$$

$$\frac{x_1}{x_2} = e^{0.542} = 1.72$$

(e) $$\delta = \frac{1}{n}\ln\frac{x_1}{x_{n+1}}$$

$$n = \frac{1}{\delta}\ln\frac{x_1}{x_{n+1}} = \frac{1}{0.542}\ln\left(\frac{x_1}{x_1/5}\right) = \frac{1}{0.542}\ln 5 = 2.96 \text{ cycles}$$

Question-70 A single-cylinder vertical diesel engine has a mass of 400 kg and is mounted on a steel chassis frame. The static deflection owing to the weight of the chasis is 2.4 mm. The reciprocating masses of the engine amounts to 18 kg and the stroke of the engine is 160 mm. A dashpot with a damping coefficient of 2 N/mm/s is also used to dampen the vibrations. In the steady-state of the vibrations determine the ... of the vibrations if the driving shaft rotates at 500 rpm ... resonance occurs

Q.1 (e)

(e) Differentiate between 'shaft' and 'axle'. A solid shaft of diameter d is used in power transmission. Due to the modification of existing transmission system, the solid shaft is required to be replaced by a hollow shaft of the same material and equally strong in torsion. The weight of the hollow shaft per unit length is to be half of the solid shaft. Determine the outer diameter of the hollow shaft in terms of d.

Source **Similar question solved in MADE EASY Class Notes Regular batch**

11) A solid shaft is to transmitted 300 KW at 120 rpm. If the shear stress is not to exceed 100 MPa, find dia of the shaft. What percent saving in weight would be obtained if this shaft was replaced by hollow one whose internal dia is 0.6 times the external dia. The length, material and max. shear stress is being same.

$$= \frac{32 T \cdot L}{\pi G (D_2 - D_1)} \left[\frac{1}{D_1^3} - \frac{1}{D_2^3} \right]$$ Ans

11.

$P = 300 \text{ KW}$

$N = 120 \text{ rpm}$

$\tau_{max} = 100 \text{ MPa}$

$\tau_{max} = \frac{16 T}{\pi d^3}$

$100 = \frac{16 \times 23.87}{\pi \times d^3}$

$d = 0.106 \text{ m}$

$P = \frac{2\pi N T}{60}$

$\frac{300 \times 60}{2 \times \pi \times 120} = T$

$T = 23.87 \text{ KNm}$

$d_o = 0.106$, $d_i = 0.6 \times 0.106$

$T = 23.87$ kN-m

$\tau_{max} = 100$ MPa

$\frac{d_i}{d_o} = 0.6$

$$\frac{16T}{\pi d_o^3}\left[1 - \left(\frac{d_i}{d_o}\right)^4\right] = 100$$

$$\frac{16 \times 23.87}{\pi (d_o)^3}\left[1 - (0.6)^4\right] = 10$$

$d_o = 0.111$ m

$d_i = 0.067$ m

$$\% \text{ Saving in wt.} = \frac{W_S - W_H}{W_S} \times 100\%$$

$$= \frac{V_S - V_H}{V_S} \times 100\%$$

$$= \frac{A_S - A_H}{A_S} \times 100\%$$

$$= \frac{d^2 - (d_o^2 - d_i^2)}{d^2} \times 100\%$$

$= 30.29\%$ Ans

$l = 12$m

Similar question in ESE MAINS Workbook

$M_b = \sqrt{(810000)^2 + (250000)^2} = 847703$ N-mm

For Shaft diameter,

From equation

$$d^3 = \frac{16}{\pi\tau_{max}}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

$$= \frac{16}{\pi(85.5)}\sqrt{(1.5 \times 847703)^2 + (1.0 \times 225000)^2}$$

or $d = 42.54$ mm

Question-29 Compare the weight, strength and stiffness of a hollow shaft of the same external diameter as that of solid shaft. The inside diameter of the hollow shaft being half the external diameter. Both the shafts have the same material and length.

Q.2 (a)

2. (a) The turbine rotor of a ship has a mass of 3000 kg. It has a radius of gyration of 0·45 m and a speed of 2000 r.p.m. clockwise when looking from stern. Determine the gyroscopic couple and its effect on the ship—

(i) when the ship is steering to the left on a curve of 100 m radius at a speed of 30 km/hr;

(ii) when the ship is pitching in a simple harmonic motion, the bow falling with its maximum velocity. The period of pitching is 40 seconds and the total angular displacement between the two extreme positions of pitching is 12 degrees.

Source	Pg No 77, Question 56 of MADE EASY MAINS WORKBOOK Question 22 , of Gyroscope Chapter of MADE EASY ESE Prelims Workbook

Q.56 The rotor of the turbine ship has a mass of 2500 kg and rotates at a speed of 3200 rpm in anticlockwise direction when viewed from stern. The rotor has a radius of gyration of 0.4 m. Determine the gyroscopic effect and couple when:

(i) The ship steers to left in a curve of 80 m radius at a speed of 15 knots. (1 knot = 1860 m/h)

(ii) The ship pitches 5 degree above and 5 degree below the normal position and bow is descending with maximum velocity with S.H.M. of time period 40 sec.

Q.57 A four wheeled troller car has a total mass of 3000 kg. Each axle with its two wheel and gears has a total moment of inertia of 32 kg-m^2. Each wheel is of 450 mm radius. The centre distance between two wheels on an axle is 1.4 m. Each axle is driven by a motor with a speed ratio of 1 : 3. Each motor along with its gear has a moment of inertia 16 kgm^2, and rotates in the opposite direction to that of the axle. The centre of mass of the car is 1 m above the rails. Calculate the limiting speed of the car when it has to travel around a curve of 250 m radius without the wheels leaving the rails.

Q.58 Each wheel of a motor cycle is 600 mm diameter and has M.I. 1.2 kg-m^2. The total mass of the motorcycle and the rider is 180 kg and the combined centre of mass is 580 mm above the ground level when the motor cycle is upright. The M.I. of the rotating parts of engine is 0.2 kg-m^2. The engine speed is 5 times in the speed of the wheel and is in the same sense. Determine the angle of wheel necessary when the motorcycle takes a turn of 35 m radius at a speed of 54 km/h.

8. Vibrations

Q.59 A vertical shaft 20 mm in diameter and 100 cm long is mounted in long bearing and carries a rotor of mass 10 kg midway between the bearings. The centre of the rotor is 0.5 mm away from the axis of the shaft. Neglect the weight of the shaft and take E = 200 GPa for shaft material. Determine the whirling speed of the shaft and the bending stress induced in it when it is rotating at 200 rpm.

Q.60 A disc of mass 4 kg is mounted midway between bearings which may be assumed to be simple supports. The bearing span in 50 cm. The steel shaft is of 10 mm diameter and is horizontal. The centre of gravity of the disc is displaced 2 mm from the geometric centre. The equivalent viscous damping at the centre of the disc-shaft may be assumed as 50 N-sec/m. If the shaft rotates at 250 rpm, determine the maximum stress in the shaft. Also find the power required to derive the shaft, at this speed.
Take $E = 1.96 \times 10^{11}$ N/m^3.

Q.61 A rotor of mass 12 kg is mounted in the middle of 25 mm diameter shaft supported between two bearing placed at 900 mm from each other. The rotor is having 0.02 mm eccentricity. If the system rotates at 3000 rpm, determine the amplitude of steady state vibrations and the dynamic force on the bearings.
Take $E = 2 \times 10^5$ N/mm^2.

Q.62 A shaft 1.5 cm dia and 1 m long is held in long bearings. The weight of the disc at the centre of the shaft if 15 kg. The eccentricity of the centre of gravity of the disk from centre of rotor is 0.03 cm. The modulus of elasticity of the material of shaft is 2×10^6 kg/cm^2. The permissible stress in the shaft material is 700 kg/cm^2. Find:

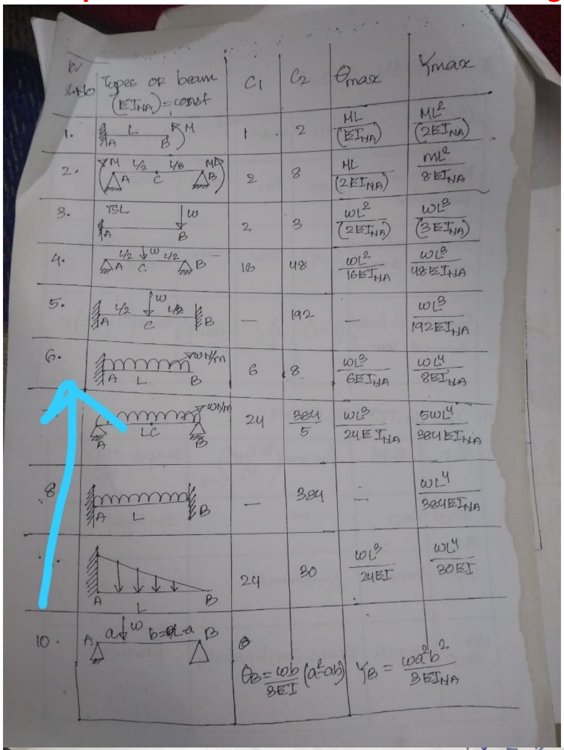
r.p.m. clockwise when viewed from the nose end (front end). Determine the gyroscopic couple on the aircraft and state its effect whether the nose end is raised or depressed.

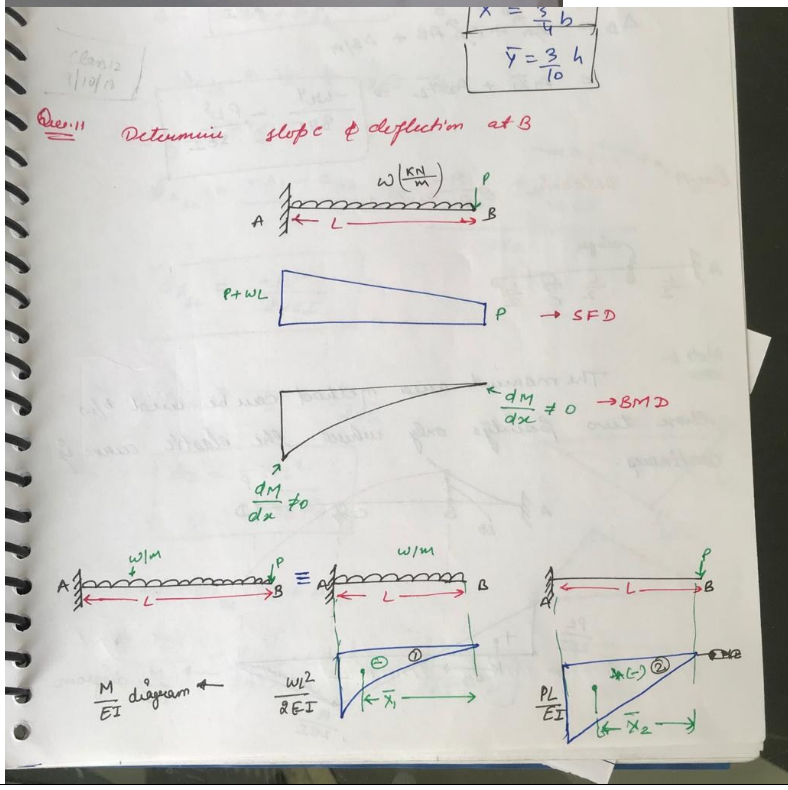
Q.22 The mass of turbine rotor of a ship is 3500 kg. It has a radius of gyration of 45 cm & a speed of 3000 rpm clockwise, when looking from the stern. Estimate the gyroscopic couple & its effects upon the ship under the following two conditions:

(a) When the ship is steering to the left in a curve of 100 m radius at a speed of 36 km/hr.

(b) When the ship is pitching in a simple harmonic motion, the bow falling with its maximum velocity. The period of pitching is 40 seconds & total angular displacement between the two extreme positions of pitching is 12 degrees.

Q.2 (b)	*(b)* A steel cantilever of length 2 m of circular cross-section, 50 mm in diameter, carries uniformly distributed load of intensity w. What is the maximum value of w so that deflection at free end is not to exceed 1 mm? Find out the slope at free end. Take $E = 200$ GPa.
Source	**Directly from MADE EASY CLASS Notes – using formula 6**





	$A_1 = -\frac{1}{3} \times L \times \frac{wL^2}{2EI} = -\frac{wL^3}{6EI}$ $A_2 = -\frac{1}{2} \times L \times \frac{PL}{EI} = \frac{PL^2}{2EI}$ $\bar{x}_1 = \frac{3}{4}L \; ; \; \bar{x}_2 = \frac{2}{3}L$ $\theta_B - \theta_A^{\,0} = A_1 + A_2 = \boxed{-\frac{wL^3}{6EI} - \frac{PL^2}{2EI}}$ $\Delta_B = \Delta_A^{\,0} + \theta_A^{\,0} AB + \Delta_{B/A}$ $= A_1\bar{x}_1 + A_2\bar{x}_2 \Rightarrow \boxed{-\frac{wL^4}{8EI} - \frac{PL^3}{3EI}}$ Do this by conjugate beam
Q.2 (c)	(c) A thick cylinder is subjected to both internal and external pressure. The internal diameter of the cylinder is 200 mm and the external diameter is 250 mm. If the maximum permissible stress is 30 N/mm^2 and the external pressure is 8 N/mm^2, determine the intensity of internal radial pressure.
Source	**MADE EASY SOM Class Notes case – 3 (Mains Class Notes)**

Case III :- Internal pr. 'P_r' and external Pr. 'P_R'

Boundary cond^n

at $x = R_i$, $P_x = P_r$ and $x = R_o$, $P_x = P_R$

$\therefore P_r = \frac{B}{R_i^2} - A$ and $P_R = \frac{B}{R_o^2} - A$

$\therefore B = (P_r - P_R) \cdot \frac{R_i^2 R_o^2}{R_o^2 - R_i^2}$ and $A = \frac{P_r R_i^2 - P_R R_o^2}{R_o^2 - R_i^2}$

In this case also max. Hoop stress will occur at $x = R_i$

$$\sigma_{h_{max}} = \frac{P_r(R_o^2 - R_i^2) - 2P_R \cdot R_i^2}{R_o^2 - R_i^2}$$

Case IV :- Solid circular shaft subjected to external radial pr. 'P'.

$P_x = \frac{B}{x^2} - A$, $\sigma_{h_x} = \frac{B}{x^2} + A$.

now at $x = 0$, $P_x = \infty$, which is not possible $\therefore$ $B = 0$.

hence $P_x = -A = P = -\sigma_{h_x}$

It means intensity of radial pr is constant everywhere and its value is equal to 'P'. Also the intensity of hoop stress is const. everywhere and is compressive.

MADE EASY MAINS Workbook Solved Question

$$\frac{\pi^2 \times 6.9\times10^4}{\left[\frac{2000\sqrt{3}}{b}\right]^2} = \frac{56.25\times10^3}{0.3535b^2}$$

$$b^4 = \frac{(2000)^2\cdot 3}{\pi^2\times6.9\times10^4}\cdot\frac{56.25\times10^3}{0.3535} = 2803919$$

∴ $b = 40.92$ mm

and $a = 0.3535\times40.92 = 14.47$ mm

8. Pressure Vessels

Question-34 The internal and external radii of a thick cylinder are 200 mm and 300 mm respectively. The external pressure on the cylinder is 4 N/mm². Find the internal pressure that can be applied if the maximum hoop stress is limited to 15 N/mm². Sketch also the distribution of radial pressure and hoop stress across the wall section.

Solution :

Let the radial pressure and the hoop stress at any radius x be given by,

$$P_x = \frac{b}{x^2} - a$$

and $$f_x = \frac{b}{x^2} + a$$

At $x = 300$ mm, $p_x = 4$ N/mm²

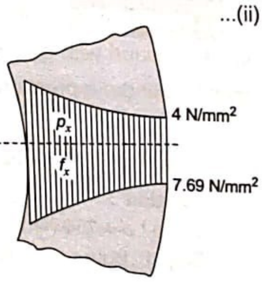
∴ $$4 = \frac{b}{300^2} - a \qquad ...(i)$$

At $x = 200$ mm, $f_x = 15$ N/mm²

∴ $$15 = \frac{b}{200^2} + a \qquad ...(ii)$$

Solving the above equations, we get,

$a = 1.846$ and $b = 526153.85$



∴ $$P_x = \frac{526153.85}{x^2} - 1.846$$

and $$f_x = \frac{526153.85}{x^2} + 1.846$$

At $x = 200$ mm, $p_{200} = \frac{526153.85}{200^2} - 1.846$

$= 11.31$ N/mm²

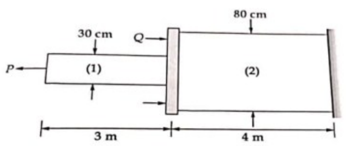
At $x = 300$ mm, $f_{300} = \frac{526153.85}{300^2} + 1.846 = 7.69$ N/mm²

Figure shows the distribution of radial pressure and hoop stress across the section of the wall.

Similar Question asked in MADE EASY ESE Mains test Series test 4 question 1b

Section A : Strength of Materials & Mechanics

Q.1 (a) Two solid cylindrical rods are joined together with help of a disk as shown in the figure.



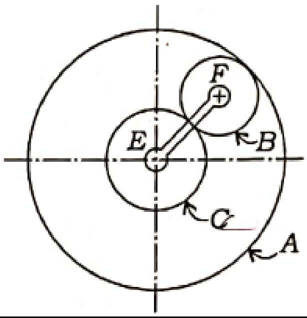
Determine the value of force P for which magnitude of tensile stress in rod 1 is equal to compressive stress in rod 2 if Q is 5 kN.

[12 marks]

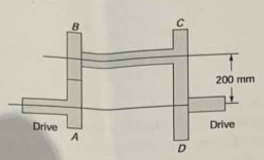
(b) A compound cylinder is made by shrinking a cylinder of outer diameter 20 cm over another cylinder of inner diameter 10 cm. If the numerical value of the maximum hoop stress developed due to shrinkage fitting in both the cylinders is the same, what will be the junction diameter?

[12 marks]

(c) A 200 kg cylinder is hang by means of two cables AB and AC that are attached to the ... A horizontal force P perpendicular to the wall holds the cylinder

Q.3 (a)	3. *(a)* A horizontal gas engine running at 200 r.p.m. has a bore of 200 mm and a stroke of 400 mm. The connecting rod is 900 mm long and the reciprocating parts weigh 20 kg. When the crank has turned through an angle of 30° from the inner dead centre, the gas pressures on the cover and the crank sides are 500 kN/m^2 and 60 kN/m^2 respectively. The diameter of the piston rod is 40 mm. Determine— *(i)* turning moment on the crankshaft; *(ii)* thrust on the bearings; *(iii)* acceleration of the flywheel which has a mass of 8 kg and radius of gyration of 600 mm while the power of the engine is 22 kW.
Source	**Q 33 page 73 similar MADE EASY MAINS WORKBOOK** **Q.33** A horizontal gas engine running at 210 rpm has a bore of 220 mm and stroke of 440 mm. The connecting rod is 924 mm long and mass of reciprocating parts is 20 kg. When the crank has turned through an angle of 30° from the inner dead centre, the gas pressures on the cover and crank end sides are 500 kN/m^2 and 60 kN/m^2 respectively. Diameter of the piston rod is 40 mm. Determine: 1. Turning moment on crank shaft 2. Thrust on the bearings 3. Acceleration of flywheel which has a mass of 8 kg and radius of gyration 600 mm while the power of the engine is 22 kW.
Q.3 (b)	*(b)* An epicyclic gear consists of three gears *A*, *B* and *C* as shown in the figure given below. The gear *A* has 72 internal teeth and gear *C* has 32 external teeth. The gear *B* meshes with both *A* and *C* and is carried on an arm *EF* which rotates about the centre of *A* at 20 r.p.m. If the gear *A* is fixed, determine the speed of gears *B* and *C* : 
Source	**Q 24 , Pg 71 , MADE EASY MAINS WORKBOOK**

Q.20 The speed ratio of the reverted gear train shown in figure is to be 12. The module pitch of gears A and B is 3.125 mm and of gears C and D is 2.5 mm. Calculate the suitable number of teeth for the gears. No gear is to have less than 24 teeth.



Q.21 A suitable reversed gear using four gear wheels in to be used for a clock, the minute hand of which is fixed to the driving spindle and the hour hand to a driven sleeve rotating freely on the same driving spindle axis. The modular pitch is to be kept same for all the wheels and each wheel should have least number of teeth but not 11 or less. Determine number of teeth on each wheel of the gear train.

Q.22 The shafts A and D are in the same line (axes on one line). They are geared together through intermediate shaft carrying wheels B and C which mesh with the wheels on A and D respectively. Wheels A and B have a module 4 mm and C and D have a module 9 mm. The number of teeth on any wheel is to be not less than 15 and speed of D is to be about, but not greater than 1/12 the speed of A and the ratio of each reduction is same. Find:

1. Number of teeth on all the wheels
2. Actual reduction
3. Centre distance

Q.23 In a Gear train shown in the figure, the sun gear S rotates at 500 rpm and the planet carrier A rotates at 100 rpm in the same direction. Determine the number of teeth on each gear and the speed of the planet gear P if the diametric pitch of all the gears is 3 teeth/cm and the diameter of the fixed gear F is to be as close to 25 cm as possible.

Q.24 In an epicyclic gear of the sun and plane type show in figure 1, the pitch circle diameter of the internally toothed ring is 252 mm and the module is 3.5 mm. The ring D is stationary. The spinder A, which carries three planet wheel P of equal size, is to make one revolution is the same sense as the sun wheel S for every five revolution on the driving spindle carrying the sun wheel S. Determine appropriate number of teeth for all the wheels.

Q.3 (c)

(c) A single-cylinder reciprocating engine has a speed of 300 r.p.m., stroke 300 mm, mass of reciprocating parts 50 kg, mass of revolving parts at 150 mm radius 37 kg. If two-thirds of the reciprocating parts and all the revolving parts are to be balanced, find—

(i) the balance mass required at a radius of 300 mm;

(ii) the residual unbalanced force when the crank has rotated 60° from top dead centre.

Source

ESE mains test series test no-11 Question 3(b)

(b) An inside cylinder uncoupled locomotive with cranks at right angles is to be balanced for revolving masses and the 2/3rd of the reciprocating masses. The revolving mass per cylinder is 225 kg and the reciprocating mass per cylinder is 270 kg. The cylinder centre lines are 60 cm apart and the wheel centres are 150 cm apart. Find:

1. The magnitude and position of the balance weights required at a radius of 75 cm.
2. The hammer blow and maximum variation of tractive efforts, when the cranks rotate at 4 rps and stroke length is 64 cm.

[20 marks]

Q 51 page 77 similar question in MADE EASY ESE MAINS Workbook

<table>
<tr><td></td><td>

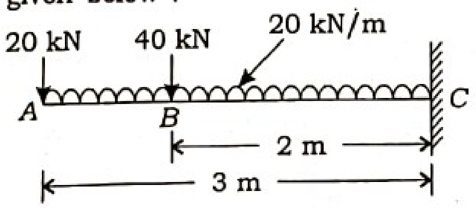
Q.51 The following data refers to a 2-2 wheels coupled wheel locomotive:
Rotation mass per cylinder = 160 kg, Reciprocating mass per cylinder = 180 kg
Crank radius = 0.3 m, Balance massesposition radius on wheels = 0.8 m
Angle between the cranks = 90°, Wheels planes gap = 1.5 m, Wheel diameter = 2 m
Mass of each coupling rod = 100 kg, Coupling rod crank radius = 0.2 m
Angle between each coupling rod crank with adjacent engine crank = 180°
Distance between coupling rods = 1.8 m
Balance: Complete Rotation + 2/3rd of Reciprocation
(i) Find the balance mass requirement along with their orientations on the driving wheels in order to have balancing.
(ii) Find the balance mass requirement along with their orientations on the Trailing wheels in order to have balancing.

</td></tr>
<tr><td></td><td></td></tr>
<tr><td>

Q.3 (d)

</td><td>

(d) Draw the shear force and bending moment diagram for the cantilever beam as shown in the figure given below :



</td></tr>
<tr><td>

Source

</td><td>

MADE EASY ESE Mains Test Series – Test 11 question 4b

(b) A beam of 20 m span is hinged at each end. It carries a UDL of $\frac{3}{4}$ kN/m on left half of beam, together with a 12 kN point load at 15 m from the left hand end. In addition to this, it is subjected to couples of 28.25 kNm in anticlockwise direction at left hand support and 41.75 kNm in the clockwise direction at right hand support. Find the reactions at the ends and draw BM and SF diagrams.

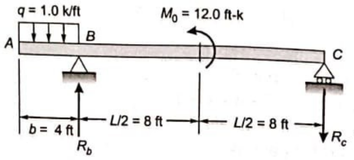
[20 marks]

MADE EASY ESE Mains workbook Unsolved question 22 and Solved Question 5 and Question 7

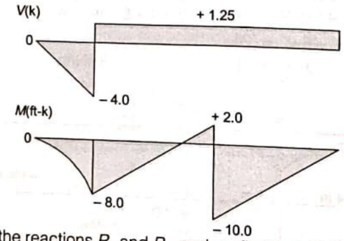
</td></tr>
</table>

Publications

Question-5 Construct shear-force and bending-moment diagrams for the beam with overhang shown in given figure (a). The beam is subjected to a uniform load of constant intensity $q = 1.0$ k/ft on the overhang and a counterclockwise couple $M_0 = 12.0$ ft-k acting midway between the supports.



Solution :



We can readily calculate the reactions R_b and R_c, and we find that R_b is upward and R_c is downward, shown in the figure. Their numerical values are as follows:

$$R_b = 5.25 \text{ k}$$
$$R_c = 1.25 \text{ k}$$

Utilizing the techniques already described, we now draw the shear-force diagram (Figure (b)). Note that shear force does not change at the point of application of the couple M_0. The bending-moment diagram the shape shown in Figure (c). At B, the moment is

$$M_b = \frac{qb^2}{2} = -\frac{1}{2}(1.0 \text{ k/ft})(4\text{ft})^2 = -8.0 \text{ ft-k}$$

which is also equal to the area of the shear-force diagram between A and B. The slope of the bendi moment diagram from B to C is 1.25 k (that is, the slope equals the shear force), but the bending mom changes abruptly due to the couple M_0. Note that this change is equal to M_0. Maximum or minimum val of the bending moment occur where the shear force changes sign and where the couple is applied.

Question-6 Calculate the reactions at A and B for the beam shown in figure, and draw t bending moment and shear force diagrams.

Solution :

Let the reactions A and B be V_a and V_b respectively. Taking moments about A.

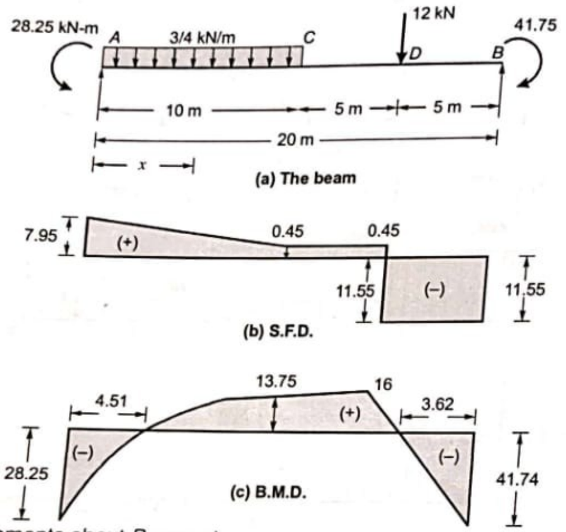
we have

$$V_b L + WL = \frac{WL}{3} + W\frac{4L}{3}$$

∴

Question-7 A beam of 20 m span is hinged at each end. It carries a udl of 3/4 kN/m on the left hand half of the beam together with a 12 kN point load at 15 m from the left hand end. In addition to this, it is subjected to couples of 28.25 kN-m is anticlockwise direction on left hand support and 41.75 kN-m in the clockwise direction at the right hand support. Find the reactions at the ends and draw the B.M. and S.F. diagrams inserting principal values.

Solution :



Reactions : Taking moments about B, we get

$$\Sigma M_B = 0 = 28.25 + \left(10 \times \frac{3}{4} \times 15\right) + 12 \times 5 - R_A.20 - 41.75$$

which gives $R_A = 7.95$ kN (↓)

∴ $R_B = 7.5 + 12 - 7.95 = 11.55$ kN (↓)

S.F.D. : For AC, $F_x = 7.95 - 0.75x$,

which is linear variation.

At $x = 0$, $F_x = 7.95$s kN

At $x = 10$ m

$F_C = 7.95 - 7.5 = 0.45$ kN

For CD, $F_x = 7.95 - 7.5 = 0.45$ kN

which is constant from C to D

For DB, $F_x = 7.95 - 7.5 - 12 = -11.55$ kN

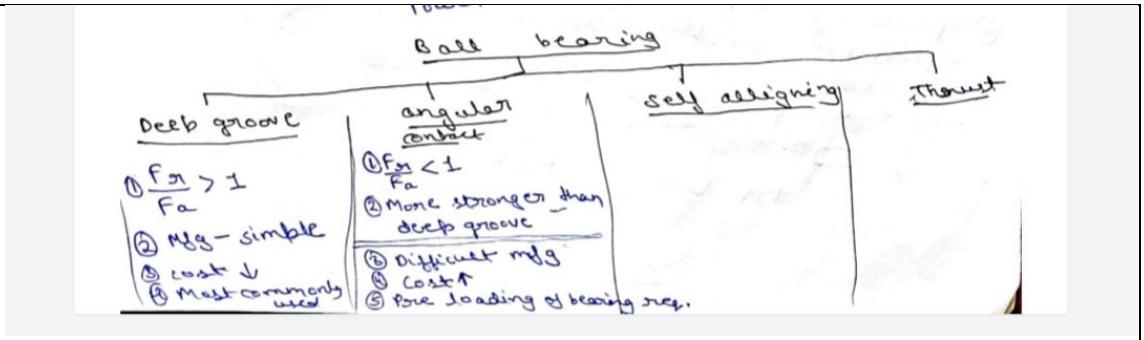
which is constant from D to B

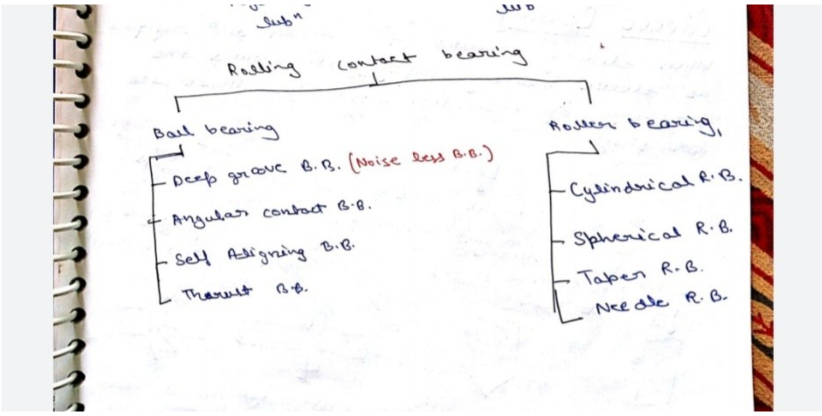
B.M.D. : For AC, $M_x = -28.25 + 7.95x - \frac{0.75x^2}{2}$

which is a parabolic variation

At $x = 0$

Q.4 (a) (i)	4. (a) (i) Describe angular contact bearings and taper roller bearings with the help of neat sketches. Also, cite at least two advantages and two disadvantages of each.
Source	Directly from MADE EASY Class Notes


Ball bearing
Deeb groove
angular contact
Self alligning
Thrust
① Fr/Fa > 1
② Mfg – simple
③ cost ↓
④ Most commonly used
① Fr/Fa < 1
② More stronger than deep groove
③ Difficult mfg
④ Cost ↑
⑤ Pre loading of bearing req.


Rolling contact bearing
Ball bearing
Deep groove B.B. (Noise less B.B.)
Angular contact B.B.
Self Alligning B.B.
Thrust B.B.
Roller bearing
Cylindrical R.B.
Spherical R.B.
Taper R.B.
Needle R.B.

(v) Noise Less B.B. (out of anti friction bearing only)
(vi) " (common)

Angular bearing

(Two bearings are req to support load in two direction)

(6) Two bearings req. to bear axial load in both direction.

(7) Does not permit any misalignment b/w shaft and bearing housing

Self aligning

(1) Permit misalignment b/w shaft and bearing housing

(2) Two rows of moving ball are used.

(3) Fr ✓ Fa ✓

Thrust B. bearing

Fr ✗ Fa ✓

that's why preferred for only vertical shaft

Roller

(1) Cylindrical R.B.

Fr ✓ Fa ✗

Horizontal shaft

– maximum radial load bearing capacity

(2) Spherical R.B.

– permit misalignment b/w shaft and bearing housing

– 2 row of moving roller are used

Fr ✓ Fa ✓

Scanned by CamScanner

(3) Taper Rolling bearing

→ maximum load bearing capacity

→ Fatigue and Impact loading

$\frac{F_r}{F_a} > 1$

eg. Axle of Bus, Truck

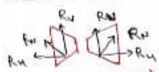
→ manufacturing is very difficult

→ cost maximum

→ Pre loading is required

→ Taper's Roller are very sensitive to assemble in races hence adjacent nut on tightening nut are require

→ Radial space required more



→ always used in pair.

→ don't permit misalignment

(4) Needle R.B.

$\frac{L}{D} > 1$

Fr ✓ Fa ✓

– needle rollers are used where radial space is constraint.

– ... bearing capacity in a given radial

Q.4 (a) (ii)

(ii) A pair of spur gears with 20° full-depth involute teeth consists of a 20 teeth pinion meshing with a 41 teeth gear. The module is 3 mm while the face width is 40 mm. The material for both the pinion and the gear is steel having an ultimate tensile strength of 660 N/mm^2. The gears are heat-treated to a surface hardness of 400 BHN. The pinion rotates at 1500 r.p.m. and the service factor is 2·0. Assume that the velocity factor accounts for the dynamic load and the factor of safety is 1·5. Determine the rated power that the gears can transmit. Assume a Lewis form factor of 0·32.

Source

Similar with some value change, from MADE EASY ESE Mains workbook

We know that pitch circle diameter of the pinion,

$$D_P = m\,.T_P = 8 \times 15 = 120 \text{ mm}$$

and pitch circle diameter of the gear,

$$D_G = m.T_G = 8 \times 45 = 360 \text{ mm}$$

Question-23 A pair of spur gears with 20° full-depth involute teeth consists of a 20 teeth pinion meshing with a 41 teeth gear. The module is 3 mm while the face width is 40 mm. The material for pinion as well as gear is steel with an ultimate tensile strength of 600 N/mm². The gears are heat-treated to a surface hardness of 400 BHN. The pinion rotates at 1450 rpm and the service factor for the application is 1.75. Assume that velocity factor accounts for the dynamic load and the factor of safety is 1.5. Lewis form factor for 20 teeth as 0.32.

Determine the rated power that the gears can transmit.

Solution :

Given : $n = 1450$ rpm, $Z_p = 20$, $Z_g = 41$, $m = 3$ mm, $b = 40$ mm, $C_s = 1.75$, FOS = 1.5, BHN = 400, $S_{ut} = 600 \text{ N/mm}^2$

For Beam strength,

...ce the same material is used for the pinion and the gear, the pinion is weaker than the gear.

$$\sigma_b = \left(\frac{1}{3}\right)S_{ut} = \left(\frac{1}{3}\right)(600) = 200 \text{ N/mm}^2$$

$$S_b = mb\sigma_b\,y = 3(40)(200)(0.32) = 7680 \text{ N}$$

Q.4 (b)

(b) What advantages do the welded joints offer in comparison to riveted joints? Neatly sketch the basic symbols used to specify the following types of weld :

(i) Fillet

(ii) Square butt

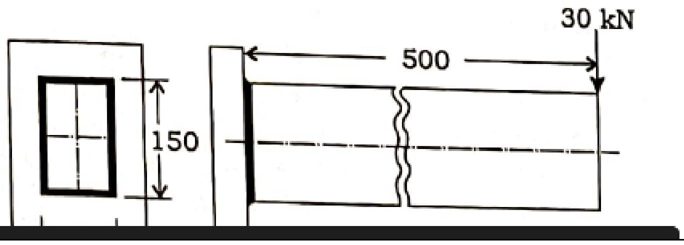
(iii) Single V-butt

(iv) Spot

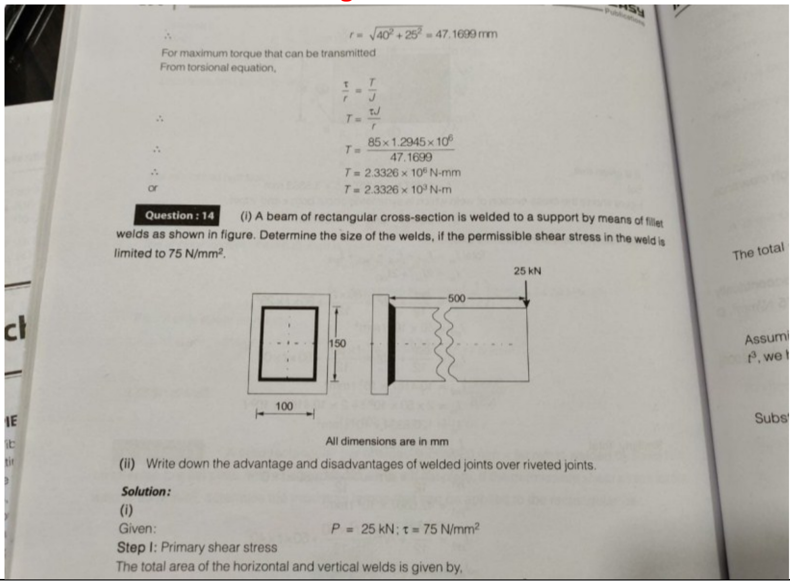
(v) Seam

(vi) Projection

A beam of rectangular cross-section is welded to a support by means of fillet welds as shown in the figure given below. Determine the size of the welds if the permissible shear stress is 80 N/mm^2 :



Source — **Same with some value change from MADE EASY ESE MAINS Workbook**



$\therefore \quad r = \sqrt{40^2 + 25^2} = 47.1699$ mm

For maximum torque that can be transmitted
From torsional equation,

$$\frac{\tau}{r} = \frac{T}{J}$$

$$\therefore \quad T = \frac{\tau J}{r}$$

$$\therefore \quad T = \frac{85 \times 1.2945 \times 10^6}{47.1699}$$

$$\therefore \quad T = 2.3326 \times 10^6 \text{ N-mm}$$

or $\quad T = 2.3326 \times 10^3$ N-m

Question : 14 (i) A beam of rectangular cross-section is welded to a support by means of fillet welds as shown in figure. Determine the size of the welds, if the permissible shear stress in the weld is limited to 75 N/mm^2.

25 kN, 500, 150, 100

All dimensions are in mm

(ii) Write down the advantage and disadvantages of welded joints over riveted joints.

Solution:

(i)

Given: $\quad P = 25$ kN; $\tau = 75$ N/mm^2

Step I: Primary shear stress

The total area of the horizontal and vertical welds is given by,

Q.4 (c)

(c) A shaft is subjected to a maximum torque of 10 kN-m and a maximum bending moment of 7·5 kN-m at a particular section. If the allowable equivalent stress in simple tension is 160 MN/m^2, find the diameter of the shaft according to *(i)* maximum shear stress theory, *(ii)* strain energy theory and *(iii)* shear strain energy theory. Take Poisson's ratio as 0·24.

Source — **MADE EASY SOM Class notes**

2) In M.S shaft of 50mm dia is subjected to BM of 1.5 KNm and a torque of T. If the yield point of steel in tension is 210 MPa, then find the max value of torque without causing yielding according to
i) Max principal stress th.
ii) Max shear stress th.

Q2 $d = 50$ mm
B.M = 1.5 KN-m.
T → torque = ?
$\sigma_y = 210$.

(i) In case of combined bending & twisting.
max^m principal stress is given by:

$$\frac{16}{\pi d^3}\left[M + \sqrt{M^2+T^2}\right] \le \sigma_y$$

∵ by max^m principle stress thr.

$$\sigma \le \sigma_y$$

$$\therefore \frac{16}{\pi (50)^3}\left[1.5 + \sqrt{1.5^2+T^2}\right] \le 210$$

$$\therefore T = 3.33 \text{ KNm}$$

(ii) By max^m shear stress th.

$$\tau_{max} \le \frac{\sigma_y}{2}$$

$$\frac{16}{\pi d^3}\sqrt{M^2+T^2} \le \frac{\sigma_y}{2}$$

$$\frac{16}{\pi (50)^3}\sqrt{(1.5)^2+T^2} \le 105$$

$$T = 2.09 \text{ KNm}$$

ESE MAINS WORKBOOK Question

<table>
<tr><td></td><td>
$x = 4$ m
Hence
$$T_E = -2 + \frac{1}{4}(4)^2 = 2 \text{ kN-m (P)}$$
Thus, the torque changes sign in the portion DE, the torque is zero at $x = \sqrt{8} = 2828$ m from D or at 1.172 m from E.
Figure (b) shows the variation of torque along the length of the shaft.

Question-27 A circular shaft, transmitting 50 kW of power at 120 r.p.m, is supported a bearings that are 4 metres apart. At 1.5 m from one bearing it carries a pulley which exerts a transverse load of 16 kN on the shaft. Determine the suitable diameter of the shaft if (a) the maximum direct stress is not to exceed 120 N/mm², (b) the maximum intensity of shear stress is not to exceed 60 N/mm¹, (c) the stress which acting alone would produce the same maximum strain, is not to exceed 120 N/mm², and (d) the direct stress which acting alone would produce the same maximum strain energy is not to exceed 120 N/mm¹. Take 1/m = 0.3.

Solution :
$$T = \frac{60P}{2\pi n} = \frac{60\times 50}{2\pi(120)} = 3.9789 \text{ kN-m} = 3.9789 \times 10^6 \text{ N-mm}$$
$$M = \frac{Wab}{L} = \frac{16\times 1.5\times 2.5}{4} = 15 \text{ kNm} = 15 \times 10^6 \text{ N-mm}$$
(i) *Maximum principle stress criterion*
$$f = \frac{16}{\pi d^3}\left[M + \sqrt{M^2 + T^2}\right]$$
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>**Q.5 (a)**</td><td>
5. *(a)* Describe the following microconstituents of iron-carbon alloys in relation to the phases present, arrangement of phases and their relative mechanical properties :
(i) Spheroidite
(ii) Pearlite
(iii) Bainite
(iv) Martensite
</td></tr>
<tr><td>Source</td><td>From MADE EASY Theory Book Material Science</td></tr>
</table>

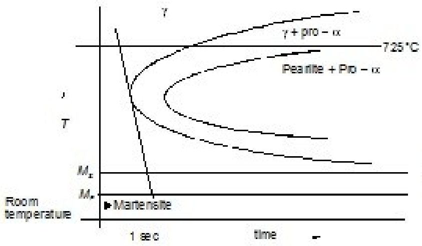
8.7 Hardening With Self Tempering

(i) Here the article is not held in the quenching medium until it is completely cooled but is withdrawn to certain a certain amount of heating the core which accounts for the self tempering.

(ii) The method is applied for chillers, surge hammers, hand hammers.

(iii) Centre punches and other tools which require a high surface hardness and tough core.

8.8 TTT Diagram for Hypoeutectoid and Hypereutectoid Steels



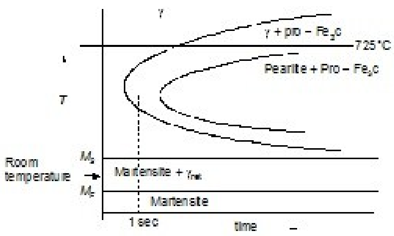


Figure 8.5 TTT diagram of Hypoeutectoid steel **Figure 8.6** TTT Diagram for Hypereutectoid steel

As it can be seen in the diagram that due to the presence of hypereutectoid phase start line shifts towards left and nose of TTT diagram appears prior to 1 sec, so hardenability of both hypo and hyper eutectoid steels are inferior to eutectoid steel. In the microstructures along with normal pearlite phase there will be pro eutectoid phase.

1. It can be observed from TTT diagram of hypereutectoid steel that martensite finish line appears below room temperature.
2. To produce uniform phase martensite, such sample are quenched in liquid nitrogen and the process is called cryogenic treatment of materials.

8.9 Hardenability Curves

As shown in figure, austenite sample is quenched on one side and different cooling rates will be experienced by the sample as we go away from the tip.

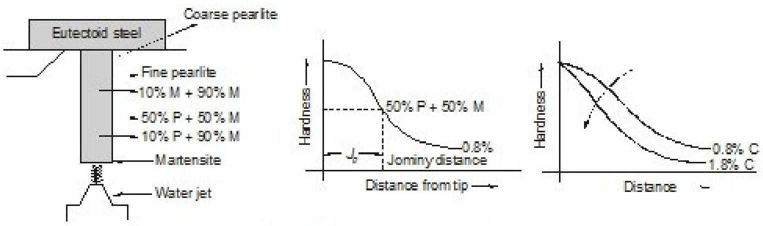


Figure 8.7 Jominy and Quench test

Q.5 (b)

(b) In an orthogonal cutting operation, the cutting speed is 2·5 m/s, rake angle is 6° and the width of cut is 10 mm. The undeformed chip thickness is 0·2 mm. 13·36 grams of steel chips with total length of 50 cm are obtained. The tool post dynamometer gives cutting and thrust forces as 1134 N and 453·6 N respectively. Find—

(i) shear plane angle;

(ii) friction energy at tool-chip interface as percentage of total energy;

(iii) specific cutting energy.

Assume density of steel = 7·8 grams/cm^3. 1

Source From S.K. Mondal Sir Class Notes

IFS-2012

An orthogonal machining operation is being carried out under the following conditions :

depth of cut = 0.1 mm,

chip thickness = 0.2 mm,

width of cut = 5 mm,

rake angle = 10°

The force components along and normal to the direction of cutting velocity are 500 N and 200 N respectively. Determine

(i) The coefficient of friction between the tool and chip.

(ii) Ultimate shear stress of the workpiece material. [10]

185

GATE-2006 Common Data Questions(2)

In an orthogonal machining operation:

Uncut thickness = 0.5 mm

Cutting speed = 20 m/min	Rake angle = 15°
Width of cut = 5 mm	Chip thickness = 0.7 mm
Thrust force = 200 N	Cutting force = 1200 N

Assume Merchant's theory.

The percentage of total energy dissipated due to friction at the tool-chip interface is

(a) 30% (b) 42%

(c) 58% (d) 70%

188

GATE-2018

An orthogonal cutting operations is being carried out in which uncut thickness is 0.010 mm, cutting speed is 130 m/min, rake angle is 15° and width of cut is 6 mm. It is observed that the chip thickness is 0.015 mm, the cutting force is 60 N and the thrust force is 25 N. The ratio of friction energy to total energy is____________(correct to two decimal places)

190

Specific Energy Consumption

$$e = \frac{Power(W)}{MRR\left(mm^3/s\right)} = \frac{F_c}{1000\,fd}$$

Sometimes it is also known as specific power consumption.

For 2020 (IES, GATE, PSUs)

223

Q.5 (c)

(c) Describe four tests of flexibility that an automated manufacturing system should satisfy to qualify as being flexible. Also list the application areas where FMS technology is successfully employed.

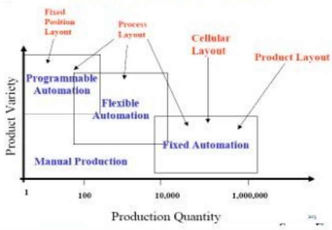
Source

From S.K. Mondal Sir Class Notes

Programmable Automation

- Can change the design of the product or even change the product by changing the program.
- Used for the low quantity production of large number of different components.
- Equipment are designed to be flexible or programmable. High investment in general purpose equipment
- Most suitable for batch production
- Lower production rates than fixed automation

Automation Application



What is an FMS?

- A *flexible manufacturing system* (FMS) is a manufacturing system in which there is some amount of flexibility that allows the system to react in the case of changes.
- Two categories of flexibility
  - **Machine flexibility**, covers the system's ability to be changed to produce new product types, and ability to change the order of operations executed on a part.
  - **Routing flexibility**, which consists of the ability to use multiple machines to perform the same operation on a part, as well as the system's ability to absorb large-scale changes, such as in volume, capacity, or capability.

FMS Components

- Most FMS systems comprise of three main systems
  - Work machines (typically automated CNC machines) that perform a series of operations;
  - An integrated material transport system and a computer that controls the flow of materials, tools, and information (e.g. machining data and machine malfunctions) throughout the system;
  - Auxiliary work stations for loading and unloading, cleaning, inspection, etc.

For ESE 2019 Main

FMS Goals

- Reduction in manufacturing cost by lowering direct labor cost and minimizing scrap, re-work, and material wastage.
- Less skilled labor required.
- Reduction in work-in-process inventory by eliminating the need for batch processing.
- Reduction in production lead time permitting manufacturers to respond more quickly to the variability of market demand.
- Better process control resulting in consistent quality.

Page 127 of 130

Advantages of FMS

- Faster, lower- cost changes from one part to another which will improve capital utilization
- Lower direct labor cost, due to the reduction in number of workers
- Reduced inventory, due to the planning and programming precision
- Consistent and better quality, due to the automated control
- Lower cost/unit of output, due to the greater productivity using the same number of workers
- Savings from the indirect labor, from reduced errors, rework, repairs and rejects

by S K Mondal

Disadvantages of FMS

- Limited ability to adapt to changes in product or product mix (e.g., machines are of limited capacity and the tooling necessary for products, even of the same family, is not always feasible in a given FMS)
- Substantial pre-planning activity
- Expensive, costing millions of dollars
- Technological problems of exact component positioning and precise timing necessary to process a component
- Sophisticated manufacturing systems

IES -2018 Main

What are the important ingredients (elements) of an FMS ? In what kind of manufacturing scenario, is it best to be employed ? For the same case, or in general, enlist its four major advantages.

[12 Marks]

IFS 2018

What do you understand by Flexible Manufacturing System (FMS) ? [3 Marks]

Which conditions are suitable for its application? [7 Marks]

Similar Theroy in MADE EASY Theory Book – Manufacturing Engg

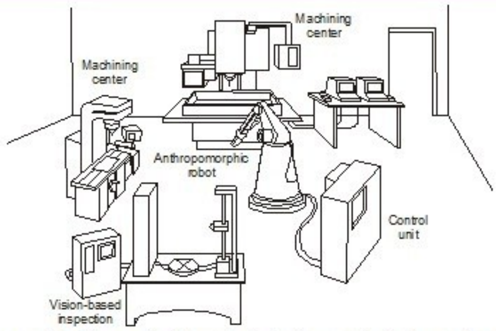


Figure 6.13 A flexible manufacturing cell, showing two machine tools, an automated part inspection system, and a central robot serving these machines

6.12 Flexible Manufacturing System (FMS)

A flexible manufacturing systems integrates all major elements of manufacturing into a highly automated system. FMS consist of manufacturing cells, each containing an industrial robot and an automated material handing systems, all interfaced with a central computer.

This system is highly automated and is capable of optimizing each step of the total manufacturing operation. These steps may involve one or more processes and operations (such as machining grinding, cutting, forming, powder manufacturing, heat treating and finishing) as well as handling of raw materials inspection and assembly.

The flexibility of FMS is such that it can handle a variety of part configuration and produce them in any order.

FMS can be regarded as a system which combine the benefit of two other system (a) the highly production but inflexible transfer line (b) job shop production which can produce large product variety on stand -alone machines but is inefficient.

6.12.1 Elements of FMS

The basic elements of a flexible manufacturing system are (a) workstations, (b) automated handling and transport of materials and parts, (c) control systems and (d) Automated storage and retrival system.

6.13 Just-In-Time (JIT) Production

The just-in-time production concept was implemented in Japan to eliminate waste of materials, machines, capital, manpower, and inventory throughout the manufacturing system. The JIT concept has the following goals:

- Receive supplies just in time to be used.
- Produce parts just in time to be made into subassemblies.
- Produce subassemblies just in time to be assembled into finished products.
- Produce and deliver finished products just in time to be sold.

Q.5 (d)

(d) Describe at least five main functions carried out by coating on electrode in electric arc welding process. Also, list the constituents of coating and their purpose.

Source

Same question in Test -7 of MADE EASY MAINS TEST SERIES

Q.5. (c) Solution:

Functions of flux coating:

1. Flux coating material may act as deoxidizers.
2. Flux coating material by forming the slag, protect liquid metal from the atmospheric gases.
3. Flux coating material increases the strength of the joint by adding alloying element.
4. Flux coating material control the viscosity of liquid metal and heat transfer rate in the weld pool.
5. Flux coating material by reducing the arc blow increases the stability of the arc.
6. Flux coating material by reducing the heat transfer losses increases the heat concentration on the workpiece.

Flux coating materials:

i. **De-oxidizing material**: Graphite, Alumina, Ferro silicon and Ferro manganese.
ii. **Slag formation compounds**: Iron oxide, Silicon dioxide, Titanium oxide, Silica flour and Calcium fluoride.
iii. **Arc stabilizer**: Sodium oxide, Calcium oxide, Potassium silicate.
iv. **Alloying elements**: Chromium, Nickel, Cobalt and Vanadium.

5.e

-

Q.5 (e)

(e) Explain the distinction between the following using block diagrams and examples : 6

(i) Measurement systems and Control systems

(ii) Open-loop systems and Closed-loop systems

Source

Similar question in MADE EASY MAINS Workbook

coefficient of sliding friction as 0.15 and cylinder bore diameter as 50 mm. Calculate the surge pressure.

3. Control Systems

Q.10 Explain in detail about the word "Control System", And State the difference between "Openloop Control System" and Closed Loop Control System" with proper examples for each.

From MADE EASY THEORY BOOK

15.6.2 Close Loop System

A closed loop control system uses a measurement of the output and feedback of this signal to compare it with the desired output. The system can be easily spotted by seeing its block relation, it does not always maintain only relation from one block head to another block tail, it also has relation from different blocks as shown in Fig. 15.4 of closed loop feedback control system. Since the increasing complexity of the system is under control and the optimum performance of feedback system has grown it in past few decades.

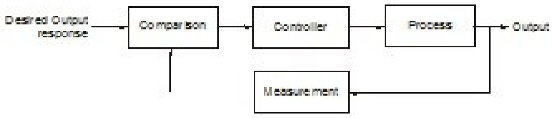


Fig. 15.4 Close loop control system (feedback system)

Advantages:

1. Close loop control is more accurate, even in the case of non-linearity.
2. Highly accurate because the error of output can be modified by feedback signal.
3. Range of Bandwidth is large.
4. Lesser sensitive to disturbance and noise.
5. Lesser sensitive to the characteristics and parameter variations.

Disadvantages:

1. The cost is high.
2. Design is complicated.
3. More maintenance required, which further increases the cost.
4. Overall gain reduces due to feedback.

15.7 CONTROLLABILITY

It can be defined as the ability of taking input from any external source to make changes in the internal state of any device from one state to another state in a given time interval. A system is at a state of vector X can be called as controllable if the state of system is changed when input is changed.

15.7.1 Controllability Matrix

For linear time-invariant system, ζ has full row rank of p.

(P is the dimension of the matrix also called order of the system)

$$\zeta = [B \cdot AB \cdot A^2B \,.....\, A^{p-1} B] \in R^{p \times pq}$$

A system can be called as controllable when a state X_1 can be transferred to the zero state $X = 0$ in a given number of steps.

A system can be called as controllable when the rank of the system matrix A is p, and the rank of the controllability matrix is,

$$\text{Rank}(\zeta) = \text{Rank}(A^{-1}\zeta) = p$$

If the second equation is not satisfied, the system can't be treated as controllable.

In MATLAB controllability matrix can be easily created with the ctrb command. For controllability matrix (ζ) simply type.

$$\zeta = \text{ctrb}(A, B)$$

The phase characteristics are necessary for compensation system, especially if the magnitude response is to remain constant. Occasionally, it is necessary to alter the phase characteristics of a given system, without altering the magnitude characteristics. To do this, we need to alter the frequency response in such a way that the phase response is altered, but the magnitude response is not altered. To do this, we implement a special variety of controllers known as phase compensators. They are called compensators because they help to improve the phase response of the system. There are two general types of compensators: Lead Compensators and Lag Compensators. If we combine the two types, we can get a special Lead-Lag Compensator system.

15.6 CONTROL SYSTEM CONFIGURATION

There are two types of control system configurations:

1. Open loop control systems or non-feedback control systems.
2. Closed loop control systems or feedback control systems.

15.6.1 Open loop Systems

An open loop control system utilizes an actuating device to control the process directly without using feedback channel. A component or process to be controlled can be represented by a block diagram as shown in Fig. 15.2. The block can be investigated one at a time, the output of one block will be input to another block and we can use cause and effect reasoning. This will become complicated when it is connected in a close loop system because of interaction between different blocks.

Fig. 15.2 Process to be controlled

Fig. 15.3 Open loop control system (Non feedback)

Example: Electronic fan switch.

Reference input: When the fan switches on, a 230 V is applied. So reference input is 230 V signal.

Controller: The electronic voltage controller when turning the knob to the desired position, the voltage will increase or decrease to an appropriate value. It can have a value like 230 V which is at maximum speed and 115 V at half speed and so on. Once we set the speed nothing need to be done, let there are three fans and you turn the knob at same amount but the speed is slightly different for every fan. This happens because of inappropriate settings, inconsistency in ball bearing performance, imperfect blade design which causes different amount of drag forces. So, an open loop system is one where we cannot correct the error of desired output and the actual output.

Advantages:

1. Simple construction
2. Low cost
3. Maintenance is easy
4. Stability is good

Disadvantages

1. Less Accuracy
2. Reliability is less
3. The change in output cannot be modified

Other Examples: Electric hand dryer, Automatic washing machine, Bread toaster, Automatic tea or coffee maker, Light switches etc.

Q.6 (a)

6. *(a)* *(i)* In an open die forging, a strip 150 mm wide, 400 mm long and 10 mm thick is compressed in plane strain such that the dimension 400 remains same. The yield strength of material in uniaxial compression is equal to 200 N/mm^2. Find the minimum, average and maximum die pressures at the beginning of plastic deformation if the coefficient of friction on the interface between the die and the material is equal to 0·1.

Source **Similar from S.K. Mondal Sir Class Notes of Mains Batch**

condition will occur.

IES – 2005 Conventional

A strip of lead with initial dimensions 24 mm x 24 mm x 150 mm is forged between two flat dies to a final size of 6 mm x 96 mm x 150 mm. If the coefficient of friction is 0.25, determine the maximum forging force. The average yield stress of lead in tension is 7 N/mm²

Solution: $h = 6$ mm, $2L = 96$ mm, $\mu = 0.25$

$$x_s = L - \frac{h}{2\mu}\ln\left(\frac{1}{2\mu}\right) = 48 - \frac{6}{2\times0.25}\ln\left(\frac{1}{2\times0.25}\right) = 39.68\,mm$$

$$F_{total} = 2\times\int_0^{x_s}\left\{P_s + \frac{2K}{h}(x_s - x)\right\}B.\,dx + 2\times\int_{x_s}^{L} 2K\,e^{\frac{2\mu}{h}(L-x)}\,B.\,dx$$

Applying Von-Mises theory $K = \frac{\sigma_0}{\sqrt{3}} = 4.04\,N/mm^2$

$$P_s = \frac{K}{\mu} = 16.16\,N/mm^2$$

or

or $$F = 2\times\int_0^{39.68}\left\{16.16 + \frac{2\times0.25}{6}(39.68 - x)\right\}\cdot150.\,dx + 2\times\int_{39.68}^{48}(2\times4.04)\,e^{\frac{2\times0.25}{6}(48-x)}\cdot150.\,dx$$

$$= 510\text{ kN} + 29.10\,kN = 539\text{kN}\,(Von-Mises)$$

Applying Tresca's Theory, $K = \frac{\sigma_s}{2} = 3.5\,N/mm^2$; $P_s = \frac{K}{\mu} = \frac{3.5}{0.25} = 14\,N/mm^2$

$$F = 2\times\int_0^{39.68}\left\{14 + \frac{2\times3.5}{6}(39.68 - x)\right\}\cdot150\cdot dx + 2\int_{39.68}^{48}(2\times3.5)\,e^{\frac{2\times0.25}{6}(48-x)}\cdot150\cdot dx$$

$$442\,kN + 25\,kN = 467\,kN\,(Tresca's)$$

Practice Problem-1

A strip of metal with initial dimensions 24 mm x 24 mm x 150 mm is forged between two flat dies to a final size of 6 mm x 96 mm x 150 mm. If the coefficient of friction is 0.05, determine the maximum forging force. Take the average yield strength in tension is 7 N/mm²

Given: 2L = 96 mm; L = 48 mm; h = 6 mm; B = 150 mm; $\mu = 0.05$

$$x_s = L - \frac{h}{2\mu}\ln\left(\frac{1}{2\mu}\right) \qquad K = 4.04\text{ N/mm}^2$$

$$x_s = -90.155\,mm$$

Since x_s came negative so there will be no sticking only sliding will take place.

Q.6 (a) (ii)

(ii) For a product, the purchase prices are given below :

Sl. No.	*Order Quantity* (Q_i)	*Unit Prices* (₹)
1	$Q_1 < 500$	10·00
2	$500 \le Q_2 < 750$	9·25
3	$Q_3 \ge 750$	8·75

Determine the optimum purchase quantity if the annual demand of the product is 2400 units. The cost of ordering is ₹ 100 and the inventory carrying charge is 24% of the purchase price per year.

Source | **Question asked in TEST SERIES – Test No. 15**

<table>
<tr><td></td><td>

Q.5 (c) Solution:
If, $C = ₹250,\ C_0 = 10\%$ of C
$$EOQ = \sqrt{\frac{2DC_0}{C_h}} = \sqrt{\frac{2\times 15000\times 2500}{250\times 0.1}} = 1732.051 \text{ units}$$
This calculated EOQ do not fall under offered lot size of 1-1499, so we have to go to next unit price.
If $C = ₹235,\ C_h = 0.1\times 235 = ₹23.5$
$$EOQ = \sqrt{\frac{2DC_0}{C_h}} = \sqrt{\frac{2\times 15000\times 2500}{23.5}} = 1786.474 \text{ units}$$
$$TIC(EOQ) = \sqrt{2DC_0C_h} = \sqrt{2\times 15000\times 2500\times 23.5} = ₹41982.14$$
$$\text{Total cost, (TC)} = TIC + D\times C = 41982.14 + 15000\times 235$$
$$= ₹3566982.14$$
$$\text{Total cost, } C(Q=2500) = D\times C + \frac{Q}{2}\times C_h + \frac{D}{Q}\times C_0$$
$$= (15000\times 225) + \left(\frac{2500}{2}\times 225\times 0.1\right) + \left(\frac{15000}{2500}\times 2500\right)$$
$$= 3375000 + 28125 + 15000$$
$$TC = ₹3418125$$
$$\text{Total cost, } C(Q = 5000) = D\times C + \frac{Q}{2}\times C_h + \frac{D}{Q}\times C_0$$
$$= (15000\times 220) + \frac{15000}{5000}\times 2500 + \frac{5000}{2}\times 22$$
$$= 3300000 + 7500 + 55000 = ₹3362500$$
As evident from total inventory cost which is minimum for Q = 5000, best lot size for ordering is 5000 and above.
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Q.6 (b)</td><td>(b) What is a eutectoid reaction? Explain the development of microstructure in iron-carbon alloys of hypoeutectoid, eutectoid and hypereutectoid compositions when they are cooled from high temperature with the help of neatly labelled diagrams indicating the phases present.</td></tr>
<tr><td>Source</td><td>From MADE EASY Theory Book</td></tr>
</table>

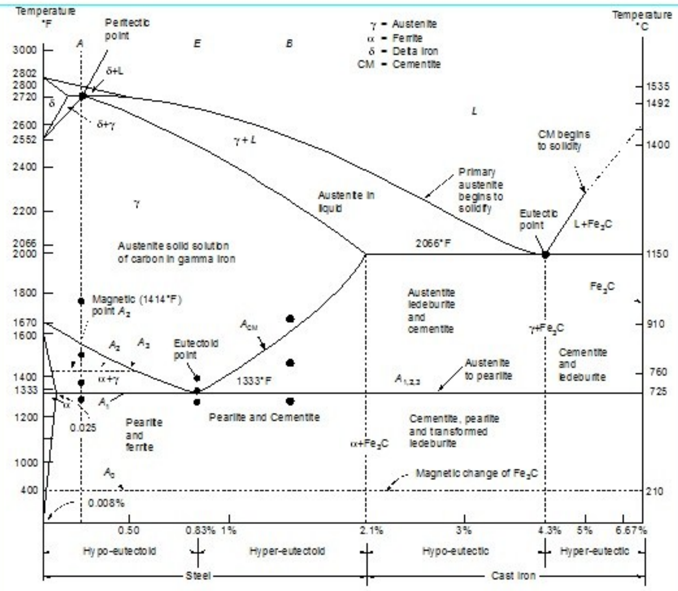


Figure 5.7 Fe-Fe_3C phase diagram

5.8.1 Eutectic Reaction

On such phase diagram, there appears a point at which there is no mushy zone and liquid directly converts into two different solids. At Eutectic point 3 phases exist in equilibrium simultaneously.

$$L \xrightarrow[4.3\%C]{1150^\circ C} \gamma + Fe_3C$$

5.8.2 Eutectoid Reaction (phase mixture of iron)

$$\gamma \xrightarrow[0.83\%C]{725^\circ C} \alpha + Fe_3C \quad \text{(pearlite)}$$

- When one solid upon cooling converts into two different solids, these reaction is called Eutectoid reaction.

- Austenite is not stable below 725°C so carbon diffuses from one interstitial side to another and forms alternate plate like structure of α and Fe_3C called **Pearlite** (result of diffusion process)
- Similarly eutectic decomposition produces alternate layers of austenite and cementite and these microstructures are called **Ledeburite**.
- There are 5 types of iron:
  α - Ferrite
  γ - Austenite
  δ - Iron
  Fe_3C - cementite

5.8.3 Peritectic Reaction

$$\delta + L \xrightleftharpoons[0.18\%]{1493} \gamma$$

When there is a large difference in the melting point of two materials, solid and liquid phases changes to come to solid phase or cooling and vice-versa of heating, the state of the system is peritectic point.

5.8.4 Definition of Important Phases

α - Ferrite. It is define as an interstitial. Solid solution of carbon in α iron which is of bcc structure having N_{avg} = 2 and magnetic in character only upto 768°C during heating.

(i) **γ - Austenite :** It is define as an interstitial solid solution of carbon in γ-iron which is of FCC structure with N_{avg} atom = 4 and non magnetic in characteristic.

(ii) **δ - Ferrite :** is define as an interstitial; solid solution of carbon in iron which is of BCC structure with N_{avg} = 2 and non magnetic in character.

Name	Type	Temperature	Structure	C-content
Ferrite	α	below 725	bcc	0.05%
δ-Iron	δ	1410 - 1539°C	bcc	0.1%
Austenite	γ	910° – 1410°C	fcc	2%
Cementite	Fe_3C	below 1175°C	Orthorhombic	6.67%

5.9 Peritectoid Reaction

When two solids combine together to form a single solid

$$S_1 + S_2 \xrightleftharpoons[\text{heating}]{\text{Cooling}} S_3$$

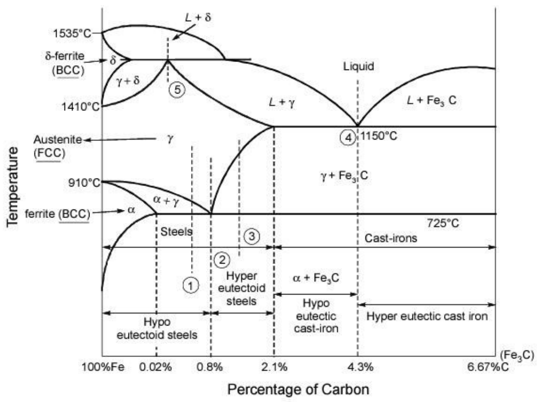
NOTE : This reaction appears in alloys when there is large difference in the melting point.

The phase diagram on which this reaction appears are caled peritectic phase diagrams. There is another fourth invariant reaction which doesn't appear on Fe - C diagram is called peritectoid reaction.

Similar question asked in ESE MAINS Test Series Test No 15 , Question 6c(ii)

Q.6 (c) Solution:

(ii)



Q.6 (c) Solution:

Annealing: Annealing is the heating of steel to austenizing temperature and then cooling slowly in the furnace.

The purpose of annealing is :

1. To reduce hardness
2. To improve machinability
3. To increase or to restore ductility
4. To relieve internal stresses
5. To reduce or eliminate structural inhomogeneity
6. To refine grain size
7. To prepare steel for subsequent heat treatment.

Slow cooling results in the formation of spheroidal carbide and (coarse) lamellar pearlite. These products are very soft. The cooling rate during annealing varies depending upon the alloying elements in the steel and lower rate of cooling is used for alloy steels as compared to plain C-steels. Annealing results in the formation of ferrite, spheroidal element and coarse pearlite. All these phases and micro - constituents are relatively soft and therefore this is known as softening treatment and produces relatively lower hardness values will ductility increases. There are 4 types of annealing process.

1. **Full Annealing :** Primary objective of this process is to reduce hardness and increase ductility.

   The process involves :

   (a) heating the steel to about 50° to 75°C above the upper critical temperature for hypoeutectoid steels and about 50° to 75°C above the lower critical temperature for hyper eutectoid steel.

   (b) Holding at this temperature for a sufficient time depending upon the thickness of object the holding time is 3 - 4 min/mm of thickness of the largest sections.

   (c) Followed by slow cooling in the furnace. The rate of cooling varies from 30°C - 200°C per hour depending upon the composition and stability of austenite.

2. **Process Annealing :** It is usually carried out to remove the effects of cold working and to soften it to make it suitable for further plastic deformation as in the case of sheet and mill industries. It is the recrystallization of cold worked steel by heating below the lower critical temperature. The exact temperature depends upon the extent of cold working, grain size, composition and holding time.

3. **Spheroidize Annealing :** This process is applied to medium and high carbon steels which are difficult to machine. These steels are heat treated (annealed) to develop spheroidite structure of Fe_3C embedded in a matrix of α-phase of iron

29

These steels are heated below lower critical temperature at about 600°C, soaked at this temperature for about 18-24 hours and then slowly cooled.

4. **Diffusion Annealing :** Diffusion annealing or homogenizing is applied to allow steel ingots and heavy complex casting for eliminating the chemical inhomogeneity is applied to alloy within the separate crystals by di... Homogenizing is carried out at temperature 1000 - 1200°C.

Q.7.(a) Solution:

Side riser:

For side riser, volume, $V = \pi r^2 h$

Surface area, $A = 2\pi r^2 + 2\pi rh$

Q.6 (c)(i)

(c) *(i)* Describe, with neat sketches, the working principle of—

(1) linear variable differential transformer (LVDT);

(2) Hall effect sensor. 5+

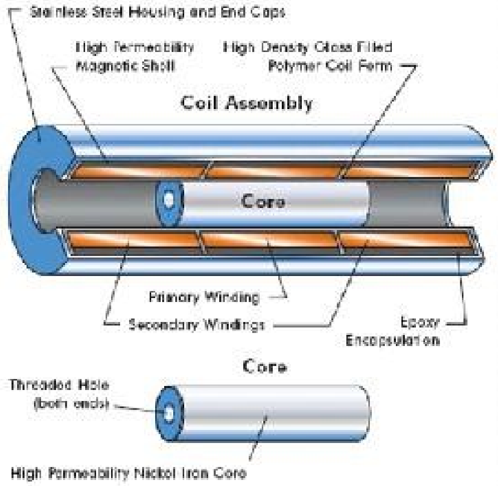
Source Direct from S.K. Mondal Class Notes

LVDT

- Acronym for Linear Variable Differential Transformer, a common type of electromechanical transducer that can convert the rectilinear motion of an object to which it is coupled mechanically into a corresponding electrical signal.
- LVDT linear position sensors are readily available that can measure movements as small as a few millionths of an inch up to several inches, but are also capable of measuring positions up to ±20 inches (±0.5 m).
- A **rotary variable differential transformer** (**RVDT**) is a type of electrical transformer used for measuring angular displacement.

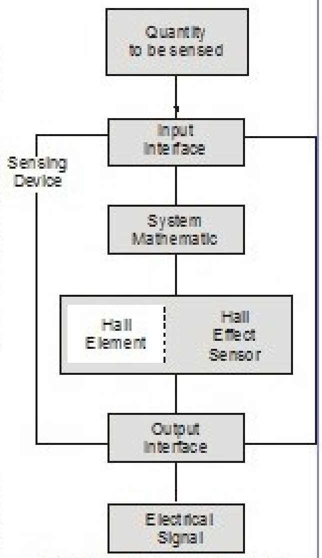
by S K Mondal 18

LVDT



13

Source	**MADE EASY Theory Book – Mechatronics Pg 327**

	14.2 HALL EFFECT SENSOR Hall Effect is an ideal sensing technology. A hall element is made by using a thin conducting sheet where its output terminals are kept perpendicular to the direction of current. The block diagram of a Hall Effect sensing device is shown in Figure 14.14. A Hall Effect based sensing element is often called a Hall device. A Hall Effect sensor senses the magnetic field and measures the physical quantity (like current, temperature, position and pressure, etc.) through the change in the magnetic field around the medium in which the physical quantity is to be measured through the input interface. The electrical signal from the Hall Effect sensor is converted into a desired signal according to the application requirements of the output interface.  Fig: 14.14 General Sensor based on Hall Effect **14.2.1 Theory of Hall Effect** The Hall Effect was discovered by the physicist Edwin H. Hall in the year 1879. The Hall Effect was named after him. The theory of Hall Effect states that a voltage potential is developed across a conductor when a magnetic field is applied at right angles to the direction of an electric current in the conductor.
Q.6 (c)(ii)	*(ii)* A measurement system consists of a cylindrical load cell of diameter 2·5 mm. The material of the cell is steel with modulus of elasticity, $E = 210$ GPa and Poisson's ratio, $\gamma = 0{\cdot}3$. This carries four strain gauges each with gauge factor 2·1. Two of them are mounted longitudinal and other two are transverse. The resistances of the gauges are 120 Ω. This load cell is required to yield a voltage through the bridge of strain gauges with bias 10 V. If the maximum load sustained by the cell is –2500 N, what is the corresponding voltage across the bridge?
Source	**Similar question in ESE MAINS Test Series – test 15**

Q.7 (b) Solution:

(i)

Load cells are elastic devices that can be used for measurement of force through indirect methods i.e., through use of secondary transducers.

Load cells utilize an elastic member as the primary transducer and strain gauges as secondary transducer. When the combination of the strain gauge-elastic member is used for weighing, it is called a "load cell".

While designing load cells using strain gauges the following factors should be considered:

i. Stiffness of the elastic element.

ii. Optimum positioning of gauges on the element.

iii. Provision for compensation of the temperature.

When large loads are to be measured, the direct tensile -compressive member may be used, whereas, in case of small loads, strain amplification provided by bending may be used with advantage.

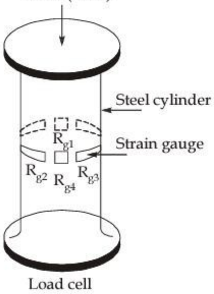
Strain-gauge load cells: These cells convert weight or force into electrical outputs which are provided by the strain gauges; these outputs can be connected to various measuring instruments for indicating, recording and controlling the weight or force.

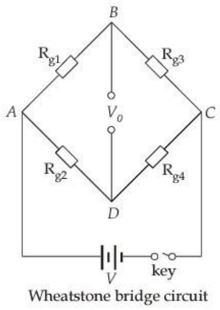
Usually the strain gauges are directly applied to the force developing device and the device is calibrated against strain-gauge output.

- These are excellent force measuring devices, particularly for transient and non-steady forces.
- These are used in conjuction with CRO (for display purposes) for measurement of rapidly changing loads.

Construction and working of the load cell:

It consists of a steel cylinder, on which four identical strain gauges are mounted. The gauges R_{g1} and R_{g4} are along the direction of applied load and the gauges R_{g2} and R_{g3} are attached circumferentially to gauges R_{g1} and R_{g4}. All the four gauges are connected electrically to the four limbs of a Wheatstone bridge circuit.





When there is no load on the cell, all the four gauges have the same resistance (i.e. $R_{g1} = R_{g2} = R_{g3} = R_{g4}$). Obviously the terminals B and D are at the same potential, the bridge is balanced and the output voltage is zero.

i.e.,
$$V_{AB} = V_{AD} = \frac{V}{2}$$

and,
$$V_{AB} - V_{AD} = V_o = 0$$

On the application of a compressive load to the unit, the vertical gauges (R_{g1} and R_{g4}) undergo compression (i.e., negative strain) and, therefore, there is decrease in resistance. The circumferential gauges R_{g2} and R_{g3}, simultaneously, undergo tension (i.e., positive strain) leading to increase in resistance. The two strains are not equal; these are related to each other by a factor, μ, the Poisson's ratio.

Voltage due to applied load will be given as:

$$V_o = (1+\mu)\left(\frac{dR}{R}\times\frac{V}{2}\right)$$

Obviously, this voltage is a measure of the applied load.

The use of four identical strain gauges in each arm of the bridge provides full temperature compensation and also increases the sensitivity of the bridge $2(1 + \mu)$times.

Uses: The strain gauge load cells find extensive use in the following:

i. Road vehicle weighing devices.

ii. Draw bar and tool force dynamometers.

iii. Crane load monitoring etc.

(ii)

We know that, output voltage is:

$$V_o = (1+\mu)(G.F)\times\epsilon\times\frac{V_i}{2}$$

G.F = Gauge factor

μ = Poission's ratio

ϵ = Strain

V_i = Supply voltage

We know that $\epsilon = \frac{\sigma}{E} = \frac{1\times10^6}{200\times10^9} = 5\times10^{-6}$

So, output voltage,

$$V_o = (1+0.3)\times2\times5\times10^{-6}\times\frac{6}{2} = 3.9\times10^{-5}$$

$$V_o = 39\,\mu V$$

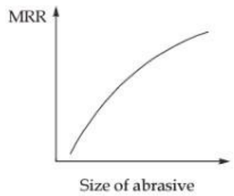
Sensitivity of load cell wheat stone bridge,

$$S = \frac{V_o}{P} = \frac{39\times10^{-6}}{3\times10^3} = 13\times10^{-9}\ V/N$$

Q.7 (c) Solution:

(i)

1. **Size of abrasive**: By increasing size of abrasive MRR increases because impact will be on more area, so MRR increases. Because standoff distance is large so MRR will never decrease.

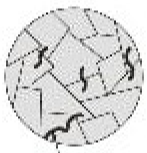


Q.7 (a)(i)	7. *(a)* *(i)* On the basis of microstructure, briefly explain why gray iron is brittle and weak in tension. Compare gray and malleable cast irons with respect to (1) composition and heat treatment, (2) microstructure and (3) mechanical properties.
Source	Question asked in Test Series – test No. 15

Q.5 (d) Solution:

Cast Iron: Cast iron are defined as the iron-carbon alloys that contain carbon between 2.1% and 6.67%. However commercial cast irons normally contain less than 4.5% of carbon. They can be easily melted because of the high percent of carbon and can be castable to required shape because of their fluidity.

Gray cast iron microstructure consists of graphite flakes dispersed throughout the metal matrix. The tips of the graphite flakes are sharp and pointed, and may act as the sites for crack initiation, when an external tensile stress is applied.

	Gray cast iron	Malleable cast iron
(i) Composition and heat treatment	C - 2.5 - 4% Si - 1.5% Mn - 0.7 - 0.8% No special heat treatment required	C - 2.0 - 2.7% Si - 1-1.7% Mn - <0.5% Requires initial rapid cooling for formation of white cast iron, later, white cast iron is held at 800-900°C for more graphite formation, which leads to formation of malleable cast iron.
(ii)	 Graphite flakes	 Graphite clusters
(iii) Mechanical characteristics	→ Weak in tension, but excellent compressive strength. → Good machinability as graphite flakes offer lubrication and chip breaking. → Very good damping characteristics as graphite flakes absorb energy → Good resistance to adhesive wear.	→ Increased ductility → Higher corrosion resistance → Excellent impact strength → Higher tensile strength
(iv) Application	As damper machine base materials, engine blocks of automobiles	General engineering equipments and others including connecting rods, transmission gears and other heavy duty services

Q.7 (a)(ii)

(ii) Cite three sources of internal residual stresses in metal components. What are two possible adverse consequences of these stresses? Describe the following heat treatment procedures for steels and for each, the intended final microstructure :

Full annealing, Normalizing, Tempering and Quenching

Source Theory in MADE EASY Theory Book – Material Science
Also in Class Notes

Slow cooling results in the formation of spheroidal carbide and (coarse) lamellar pearlite. These products are very soft. The cooling rate during annealing varies from depending upon the alloying element in the steel and lower rate of cooling is used for alloy steels as compared to plain C-steels. Annealing results in the formation of ferrite, spheroidal element and coarse pearlite. All these phases and micro - constituents are relatively soft and therefore this is known as softening treatment and produces relatively lower hardness values will ductility increases. There are 4 types of annealing process.

1. **Full Annealing :** Primary objective of this process is to reduce hardness and increase ductility.

   The process involves :
   (a) heating the steel to about 50 to 75°C above the upper critical temperature for hypoeutectoid steels and above the lower critical temperature for hyper eutectoid steel.
   (b) Holding at this temperature for a sufficient time depending upon the thickness of object the holding time is 3 - 4 min/mm of thickness of the largest sections.
   (c) Followed by slow cooling in the furnace. The rate of cooling varies from 30°C - 200°C per hour depending upon the composition and stability of austenite.
2. **Process Annealing :** It is usually carried out to remove the effects of cold working and to soften it to make it suitable for further plastic deformation as in the case of sheet and mill industries. It is the recrystallization of cold worked steel by heating below the lower critical temperature. The exact temperature depends upon the extent of cold working grain size, composition and holding time.
3. **Spheroidize Annealing :** This process is applied to medium and high carbon steels which are difficult to machine. These steels are heat treated (annealed) to develop spheroidite structure of Fe_3C embedded in a matrix of α-phase of iron. These steels are heated below lower critical temperature (A_1) at about 600°C, soaked at this temperature for about 18–24 hours and then slowly cooled.
4. **Diffusion Annealing :** Diffusion annealing or homogenizing is applied to allow steel ingots and heavy complex casting for eliminating the chemical in homogeneously is applied to alloy within the separate crystals by diffusion. Homogenizing is carried out at temperature 1000 - 1200°C.

8.1.2 Normalizing

It is the heat treatment process which is given to a product, which are subjected to relatively high stresses, the process consist of heating steel to a temperature 40 - 50°C above the line where austenite is stable, holding at that temperature for a short period and subsequently cooling in air at room temperature. This is known as air quenching , normalizing produces microstructure consisting of ferrite and pearlite for hypo-eutectic steel and pearlite and cementite for hypereutectoid steel. Normalizing increase impact strength in steels. Normalized steel are harder and stronger but less ductile than annealed steels with the same composition.

Comparison between Normalizing and Annealing :

1. Normalizing require a heating range which is about 40° C above that of annealing.
2. Mechanical properties of steels are better than those produced by annealing.
3. Heat treatment process is of short duration due to increased rate of cooling of the metal in air.
4. If mechanical properties is not the main concern of the heat treatment, better machinability and removal of internal stresses is possible in annealing than obtained by normalizing.

8.1.3 Hardening

1. Hardening is a process in which steel heated to austenite temperature held at this temperature and then quenched in water oil or molten salt bath.

2. Hypoeutectoid steel are heated from 30 - 50°C above the upper critical temperature, while hypereutectoid steels are heated above the lower critical temperature.
3. Cooling at a rate higher then the critical value enables the austenite to be supercooled to martensite point. Due to rapid cooling carbon freezes at its locations and the micro structure appears like colloidal solution of cementite in ferrite.

NOTE

- After hardening, steel must be tempered to reduce brittleness, relieve the internal, stress caused by hardening and to obtain the desire mechanical properties of steels.
- Hardening followed by tempering is to increase the mechanical properties of steel.

4. In case of tool steels, it increases the hardness and wear retaining the toughness at the same time.
5. In case of structure steel, it improves strength, activity and toughness.

   The process is carried out in three stages :
   (i) Heating the object to a temperature above the critical point.
   (ii) Holding the object at this temperature for a definite period.
   (ii) Quenching in a suitable medium.

We have discussed only one method so far. However, several methods used in hardening can be listed as follows:

1. Quenching in single medium
2. Quenching in double medium
3. Hardening with self-tempering
4. Martempering
5. Austempering

8.1.4 Tempering

The martensite which is formed during quenching is too brittle and hence cannot be used in many cases, the residual stresses are also developed during martensite formation hence hardening should be followed by tempering. Tempering consists of heating the hardened steel to a temperature below the lower critical temperature holding it for sometime and then cooling slowly. It is the final operation of heat treatment.

Some advantages :

1. Residual Stresses are relieved.
2. Ductility is improve
3. Toughness is increased
   (a) The higher the tempering temperature, the more will be the residual stresses in which hardness is reduced and toughness is increased at high temperature. The work is cooled slowly after tempering . The cooling rate considerably affect the residual stress.
   (b) The slower the cooling the lesser will be the stresses. Rapid cooling in water develops new thermal stress.

Tempering can be classified into :

1. **High Temperature Tempering (Sorbite) :** It is employed at 500 - 650°C. The resulting structure consist of solubility which gives good strength and toughness.
2. **Medium Temperature Tempering (Troostite) :** This type of tempering is employed at 350 - 500°C the resulting steel structure consists of tempered troostite.

   After tempering the work is cooled in water. This increases the endurance limit in case of spring.

Q.7 (b) (i)

(b) (i) Why is unilateral tolerance preferred over bilateral tolerance? Find the limits of tolerance and allowance for a 25 mm H_8d_9 shaft and hole pair. The 25 mm shaft lies in the 18–30 diameter step. The fundamental tolerance can be computed using $i = 0{\cdot}45\sqrt[3]{D} + 0{\cdot}001D$ µm. For H_8 hole, the fundamental tolerance is $25i$ and for d_9 shaft, the fundamental tolerance is $40i$. The fundamental deviation for the shaft can be computed using $-16D^{0{\cdot}44}$ µm. What type of fit is given by H_8d_9?

List the causes of getting primary texture and secondary texture in machined components. Further, list the three main methods of assessment of surface texture.

Source From S.K.Mondal Sir Class Notes

IES-2015 Conventional

Determine the fundamental deviation and tolerances and the limits of size for hole and shaft pair in the fit: 25 mm H8d9. The diameter steps are 18 mm and 30 mm. The fundamental deviation for d shaft is given as $-16D^{0.44}$. The tolerance unit is,

$$i = 0.45\sqrt[3]{D} + 0.001D$$

56

The tolerance grade for number 8 quality is 25i and for 9 quality is 40i.

[10 Marks]

69

Similar Numerical as in MADE EASY MAINS TEST SERIES – Test – 5

Q.1 (c) Solution:

We know that,

Fundamental tolerance, $i = 0.45(D)^{1/3} + 0.001D$ ...(1)

Now, $D = \sqrt{18 \times 30} = 23.238$ mm

Putting value of 'D' in equation (1).

$$i = 0.45 \times (23.238)^{1/3} + 0.001 \times 23.238$$
$$= 1.3074\ \mu m$$

For IT8 grade tolerance $= 25i = 25 \times 1.3074 = 32.685\ \mu m$

For IT9 grade tolerance $= 40i = 40 \times 1.3074 = 52.296\ \mu m$

Fundamental deviation of 'f' type of shaft $= -5.5D^{0.41}$

$$= -5.5 \times (23.238)^{0.41} = -19.976\ \mu m \simeq -20\ \mu m$$

Tolerance of hole $= 25i = 32.685\ \mu m = 0.032685$ mm

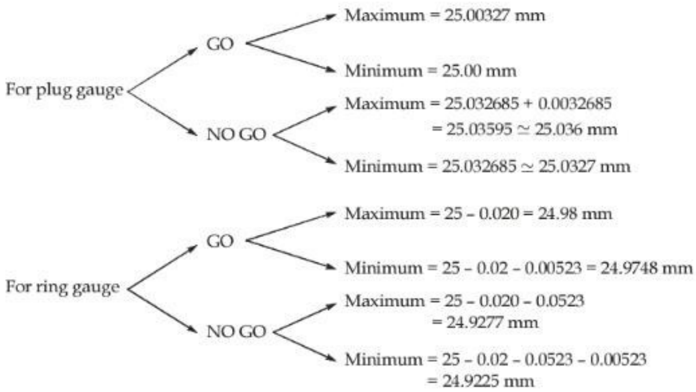
Tolerance of plug gauge $= 10\%$ of $32.685\ \mu m = 3.2685\ \mu m$

$= 0.0032685$ mm $\simeq 0.00327$ mm

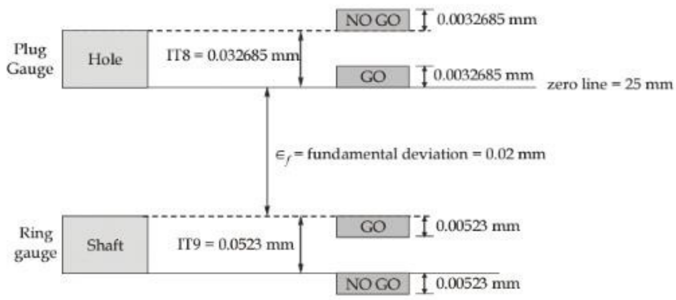
Tolerance of shaft $= 40i = 52.296\ \mu m = 0.052296$ mm $\simeq 0.0523$ mm

Tolerance on ring gauges $= 10\%$ of $52.296\ \mu m = 5.2296\ \mu m$

$= 0.0052296$ mm $\simeq 0.00523$ mm



General purpose gauge:



Q.7 (b)(ii)

assessment of surface texture.

(ii) Five jobs are to be processed on three machines. The processing time (in hours) is given in the following table. Find the optimal schedule so that the total elapsed time is minimized. Also, find the idle time on each machine :

		Jobs				
		J_1	J_2	J_3	J_4	J_5
Machines	M_1	8	10	6	7	11
	M_2	5	6	2	3	4
	M_3	4	9	8	6	5

Source

Similar question asked in Test No. 7

$$\frac{C-20}{2.427} = 1.00 \text{ or } C = 22.427 \text{ weeks}$$

The project will be completed in 22.427 weeks (approximately 23 weeks) if the probability of completing the project is 0.84.

Q.6 (c) Solution:

This is the case of n-jobs on 3-machines. So to apply Johnson's rule, it must be converted into n-jobs on 2-machine problem by creating two artificial machines X and Y. For equivalent two-machine conversion, any of the following cases must be satisfied.

Minimum processing time on $M_3 \geq$ Maximum processing time on M_1

Minimum processing time on $M_2 \geq$ Maximum processing time on M_1

Minimum processing time on $M_3 = 2$

Maximum processing time on $M_1 = 7$

Minimum processing time on $M_2 = 7$

$\therefore$ 2nd condition is satisfied. Hence, Johnson's rule can be applied.

Jobs	$X = M_3 + M_1$	$X = M_1 + M_2$
A	9	12
B	12	16
C	9	14
D	7	12
E	9	16
F	12	11
G	21	15
H	13	15

Optimum sequence:

D	A	C	E	B	H	G	F

Jobs	M_3		M_1		M_2	
	In	Out	In	Out	In	Out
D	0	3	3	7	7	15
A	3	8	8	12	15	23
C	8	10	12	19	23	30
E	10	14	19	24	30	41
B	14	20	24	30	41	51
H	20	31	31	33	51	64
G	31	46	46	52	64	73
F	46	55	55	58	73	81

Make span time = 81 hours.

Idle time = $MST - PT$ (where, PT is processing time.)

Idle time for $M_1 = 81 - 37 = 44$ hours.

Idle time for $M_2 = 81 - 74 = 7$ hours.

Idle time for $M_3 = 81 - 55 = 26$ hours.

28

$$\% \text{ utilization for } M_1 = \frac{37}{81} \times 100 = 45.68\%$$

$$\% \text{ utilization for } M_2 = \frac{74}{81} \times 100 = 91.36\%$$

$$\% \text{ utilization for } M_3 = \frac{55}{81} \times 100 = 67.90\%$$

Q.7 (a) Solution:

(i) When a solar P–V system is deployed for practical application characteristics keeps on changing with insolation and temperature. In receive maximum power, the load must adjust itself accordingly to track the maximum power point. The I-V characteristics of P–V system along with some

Q.7 (c) (ii)	*(ii)* A vector $25i + 10j + 20k$ is translated by 8 units in X and 5 units in Y directions. Subsequent to this the vector is rotated by 60° about Z-axis and 30° about X-axis. Determine the final form of the vector.
Source	**From S.K.Mondal Sir Class Notes** **Example-5** In this case, assume the same point $p(7, 3, 1)^T$, attached to F_{noa} is subjected to the same transformations, but the transformations are performed in a different order. Find the coordinates of the point relative to the reference frame at the conclusion of transformations. 1. A rotation of 90° about the z-axis, 2. Followed by a translation of [4, -3, 7], 3. Followed by a rotation of 90° about the y-axis. **Similar question asked in MADE EASY ESE MAINS test series – test 8 and test 9**

$C = 4075.18$ N

Q.1 (e) Solution:

(i)

^2P is the point with respect to moving frame {2}, ^1P is the point with respect to fixed frame and $^1R_2$ is rotation of frame with respect to fixed frame {1}.

So, $\quad ^1P = {}^1R_2 {}^2P \quad$ ...(1)

$$^1R_2 = R_z(\theta) = \begin{bmatrix} C\theta & -S\theta & 0 \\ S\theta & C\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

at $\theta = 90°$ $\quad R_z(\theta) = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

equation (1)

$$^1P = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 2 \\ 3 \\ 5 \end{bmatrix} \qquad \text{given } ^1P = [2\ 3\ 5]$$

$$^1P = \begin{bmatrix} -3 \\ 2 \\ 5 \end{bmatrix} \text{ or } [-3\ 2\ 5]^T$$

or $\quad ^1P = [-3\ 2\ 5\ 1]^T$

(ii)

As, each rotation is done about an axis of fixed reference frame {$x\ y\ z$}. So this is called fixed angle rotations.

So, the final frame orientation is obtained by composition of rotations with respect to fixed frame and the overall rotation matrix $^1R_2$ is computed by pre multiplication of matrices of elementary rotations.

$$R_{zyx}(\theta_1, \theta_2, \theta_3) = {}^1R_2 = R_x(\theta_3)R_y(\theta_2)R_z(\theta_1)$$

where, $\theta_1 = 60°$

$\theta_2 = 120°$

$\theta_3 = 90°$

$$^1R_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & C_3 & -S_3 \\ 0 & S_3 & C_3 \end{bmatrix} \times \begin{bmatrix} C_2 & 0 & S_2 \\ 0 & 1 & 0 \\ -S_2 & 0 & C_2 \end{bmatrix} \times \begin{bmatrix} C_1 & -S_1 & 0 \\ S_1 & C_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$^1R_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} -0.5 & 0 & 0.866 \\ 0 & 1 & 0 \\ -0.866 & 0 & -0.5 \end{bmatrix} \times \begin{bmatrix} 0.5 & -0.866 & 0 \\ 0.866 & 0.5 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$^1R_2 = \begin{bmatrix} -0.25 & 0.433 & 0.866 \\ 0.433 & -0.75 & 0.5 \\ 0.866 & 0.5 & 0 \end{bmatrix}$$

$$= 69.0538\ \text{N/mm}^2$$

$$\frac{S_u}{f(s)} = \sigma_u = \frac{(P_b)_u}{A}$$

$$\frac{69.0535}{f(s)} = \frac{1.67\times10^3}{36.6}$$

$$f(s) = 1.522$$

Q.1 (e) Solution:

In this case, motions alternate relative to the reference frame and current frame. Pre multiplication will be done for transformation relative to fixed frame i.e., for those which are done with respect to fixed frame (reference frame) (*xyz*). Post multiplication will be done for transformation relative to rotating frame.

$${}^0T_1 = Rot(z, 90)\ Rot(x, 90)\ \text{Trans}(0, 0, 3)\ \text{Trans}(0, 5, 0)$$

$${}^1P = \begin{bmatrix}1\\5\\4\end{bmatrix}$$

So, $${}^0P = {}^0T_1 \times {}^1P$$

$$= \begin{bmatrix}0 & -1 & 0 & 0\\1 & 0 & 0 & 0\\0 & 0 & 1 & 0\\0 & 0 & 0 & 1\end{bmatrix} \times \begin{bmatrix}1 & 0 & 0 & 0\\0 & 0 & -1 & 0\\0 & 1 & 0 & 0\\0 & 0 & 0 & 1\end{bmatrix} \times \begin{bmatrix}1 & 0 & 0 & 0\\0 & 1 & 0 & 0\\0 & 0 & 1 & 3\\0 & 0 & 0 & 1\end{bmatrix} \times \begin{bmatrix}1 & 0 & 0 & 0\\0 & 1 & 0 & 5\\0 & 0 & 1 & 0\\0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}1\\5\\4\\1\end{bmatrix}$$

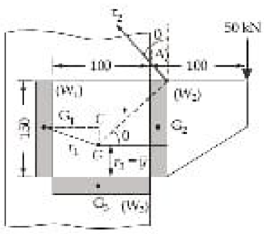
$$= \begin{bmatrix}7\\1\\10\\1\end{bmatrix}$$

Q.2 (a) Solution:

Given: $P = 50$ kN; $S_{ys} = 50\ \text{N/mm}^2$

There are two vertical welds (W_1 and W_2) and one horizontal weld (W_3).

Centre of Gravity (G) of the weld:



$$\bar{x} = 50\ \text{mm}$$

Take moment about W_3 weld and treating weld as a line,

$$(150+150+100)\bar{y} = 150 \times 75 + 150 \times 75 + 100 \times 0$$

$$\bar{y} = 56.25\ \text{mm (from } W_3 \text{ weld)}$$

$$A_1 = 150t\ \text{mm}^2$$

$$A_2 = 150t\ \text{mm}^2$$

$$A_3 = 100t\ \text{mm}^2$$

Q.8 (a) (i)	8. *(a)* *(i)* Explain briefly the following : (1) Four configurations of Robot (2) Work volume (3) Spatial resolution (4) Accuracy (5) Repeatability
Source	From S.K.Mondal Sir Class Notes

form

ical Joint

rismatic Joint

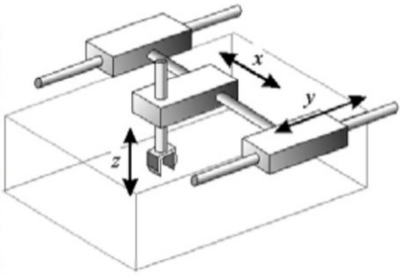
U Joint

rm

Types of Robot (Based on Coordinate axis)

- **Cartesian or Gantry robot(3P):**
- It's a robot whose arm has three prismatic joints, whose axes are coincident with a Cartesian coordinator.
- Used for pick and place work, application of sealant, assembly operations, handling machine tools and arc welding.

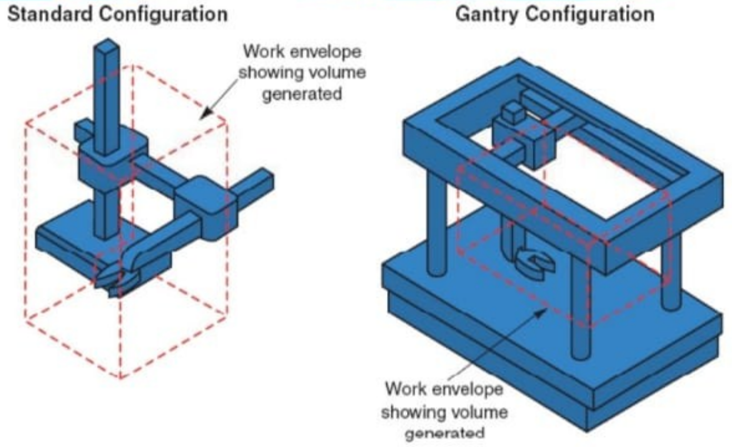
Cartesian Robot



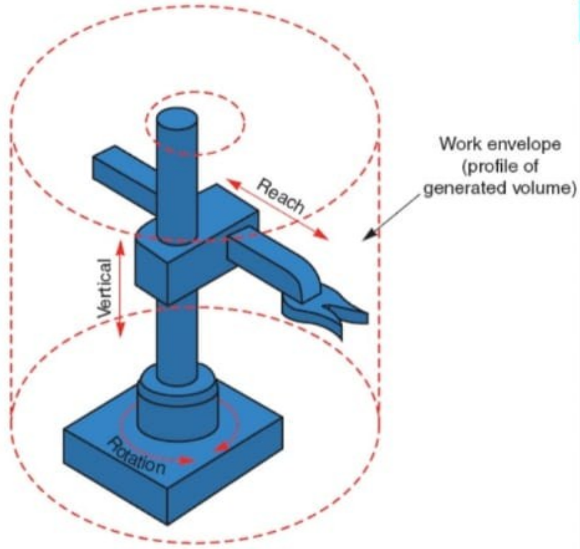
end-effector

PUM

[redacted]



- Despi
  precis
  prefer
  manip
- Gantr
  must l
- The (
  volum



- Despi
  precis
  prefer
  manip
- Gantr
  must l
- The (
  volum

- Its mechanical stiffness is lower than Cartesian and Cylindrical configurations

Articula

- It's a ro
  has a

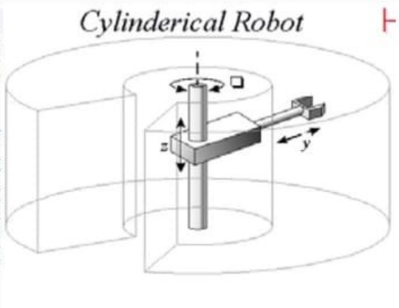
[redacted]

sealant, assembly operations, handling machine tools and arc welding.

[redacted]

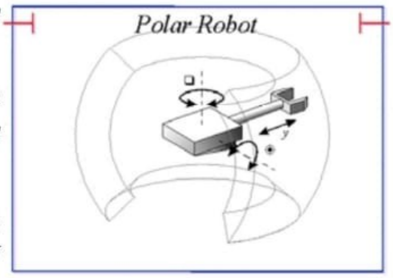
Types of Robot

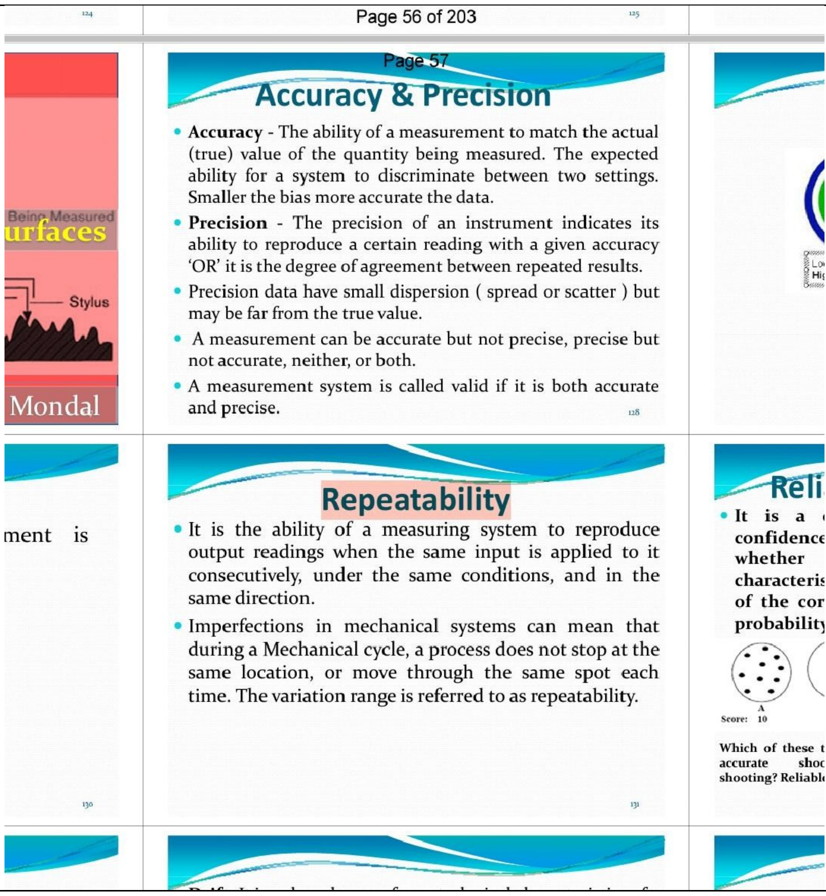
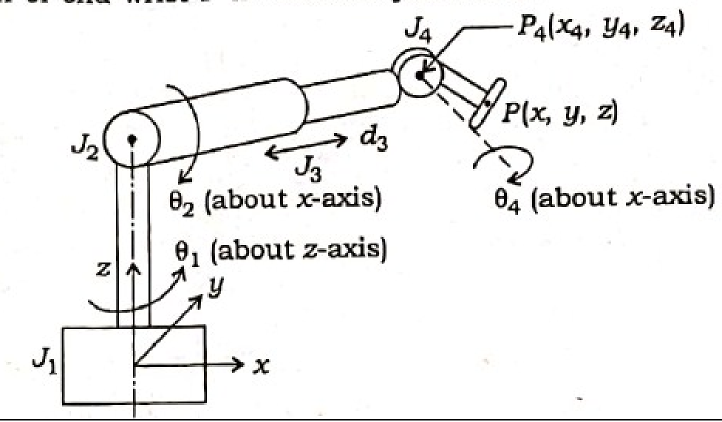
- **Cylindrical robot(R2P):**
- It's a robot whose axes form a cylindrical coordinate system.
- Used for assembly operations, handling at machine tools, spot welding, and handling at die casting machines.

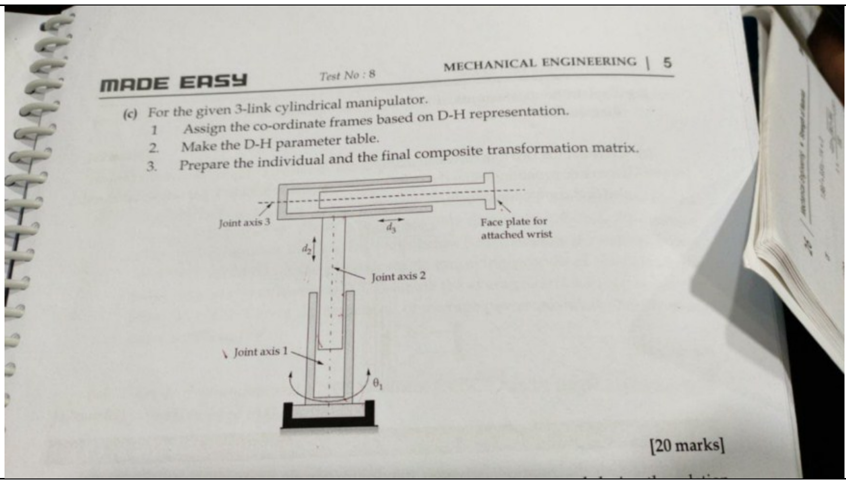
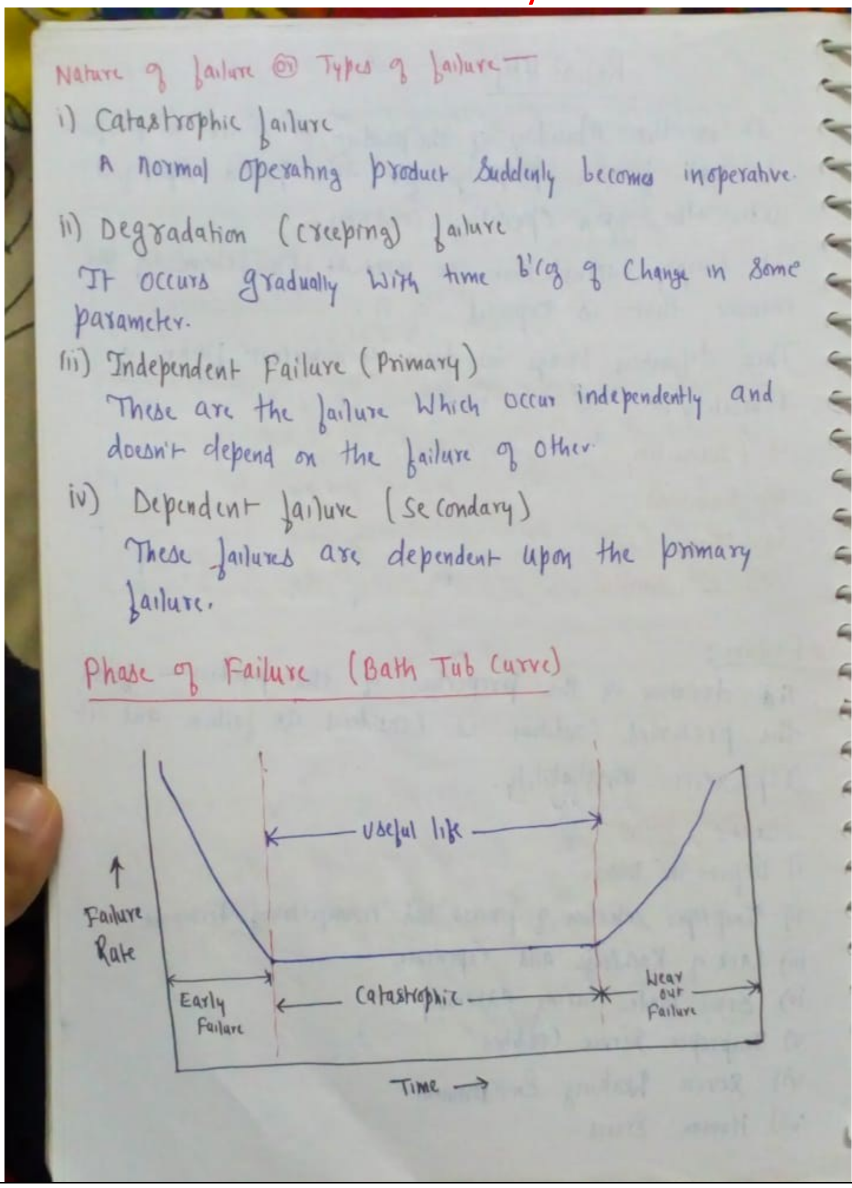


Types of Robot

- **Spherical or Polar robot(2RP):**
- It's a robot whose axes form a polar coordinate system.
- Used for machining, welding, spray painting etc.



<table>
<tr><td></td><td>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Q.8 (a)(ii)</td><td>(ii) A 4 d-o-f manipulator of Maker Robot type is shown in the figure given below. Prepare a D-H parameter table for this configuration. Define the position of end wrist P in terms of joint lengths and angles : 10

</td></tr>
<tr><td>Source</td><td>Similar question asked in ESE Mains test Series Test 8 similar to(8 ii)</td></tr>
</table>

	 MADE EASY Test No : 8 MECHANICAL ENGINEERING | 5 (c) For the given 3-link cylindrical manipulator. 1 Assign the co-ordinate frames based on D-H representation. 2 Make the D-H parameter table. 3. Prepare the individual and the final composite transformation matrix. [20 marks]
Q.8 (b) (i)	*(b)* *(i)* Draw the 'bathtub curve' and indicate various failure regions. List the major causes of failure in mechanical components/system. Draw the flowchart for failure modes and effects analysis (FMEA).
Source	**MADE EASY CLASS NOTES – Saurabh Pandey Sir**  Nature of failure or Types of failure— i) Catastrophic failure A normal operating product suddenly becomes inoperative. ii) Degradation (creeping) failure It occurs gradually with time b'cz of change in some parameter. iii) Independent Failure (Primary) These are the failure which occur independently and doesn't depend on the failure of other. iv) Dependent failure (Secondary) These failures are dependent upon the primary failure. Phase of Failure (Bath Tub Curve)

	Early failure :- These failure occur at the beginning due to defective design, manufacturing (or) assembly. Warranty is based on the concept of early failure. Catastrophic : These failures are during actual working life of product and they occur randomly and unexpectedly. The failure rate is almost constant and ~~these~~ this phase is called useful life of product Wear out :- The product is more likely to fail due to wear and tear and no. of failures is high. It is a typical ~~easy~~ p edging problem & proper care & maintanence will reduce the failure at this stage.
Q.8 (b)(ii)	*(ii)* Explain the mechanism of metal removal in die-sinking EDM. State the three main advantages of electron-beam machining (EBM).
Source	**MADE EASY Theory Book – Manufacturing engineering Chapter 7**

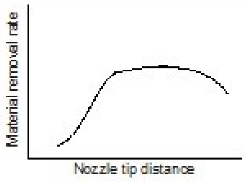


Figure 7.6 (a) Variation of MRR with respect to stand off distance

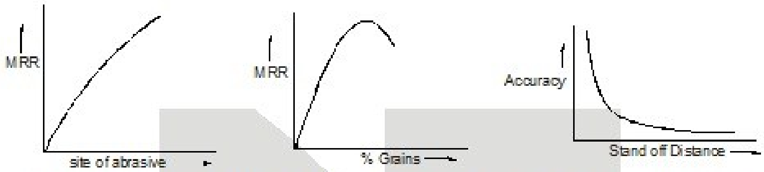


Figure 7.6 (b) Variation of MRR with respect to grain size, % of grains and stand off distance

7.5 Electric Discharge Machining (EDM)

The principle of electrical discharge machining (EDM) also called electro discharge spark erosion machining, is based on the erosion of metals by sparks discharges. We know that when two current conducting wires are allowed to touch each other, an arc is produced. If we look closely at the point of contact between two wires, we note that a small portion of the metal has been eroded away, leaving a small crater.

Although this phenomenon has been known since the discovery of electricity it was until the 1940's that a machining process based on this principle was developed. This EDM process has become one of the most important and widely accepted production technologies in manufacturing.

Principle of Operation

The basic EDM system consists of a shaped tool (electrode) and workpiece (as shown in Figure 1.98 (a)), connected to a *dc* power supply and placed in a dielectric (electrically non conducting) fluid. When the potential difference between the tool and the workpiece is sufficiently high, a transient spark discharges through the fluid, removing a very small amount of metal from the workpiece surface the capacitor discharge is repeated at rate of between 50 kHz and 500 kHz with voltage usually ranging between 50V and 380V and current from 0.1 A to 500 A.

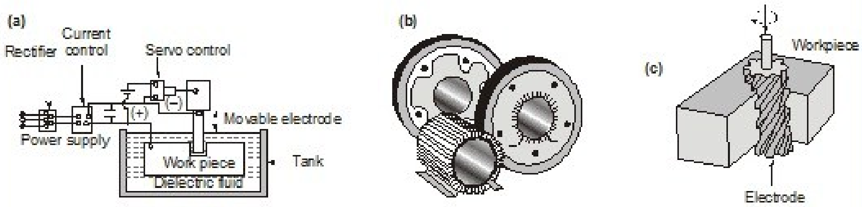


Figure 7.7 (a) The electrical-discharge machining process **(b)** Examples of cavities produced by the electrical-discharge machining process, using shaped electrodes **(c)** A spiral cavity produced by EDM using a slowly rotating electrode, similar to a screw thread

The workpiece is fixtured within the tank containing the dielectric fluid, and its movements are controlled by numerically control system. The gap between the tool and the workpiece is critical; thus the downward feed of the tool is controlled by a **servomechanism**, which automatically maintains a constant gap.

The most common dielectric fluids are minerals oils, although kerosene and distilled and deionized water are also used in specialized applications.

Recent trends involve the use of clear low viscosity fluids ; although more expansive, these fluids make cleaning easier. The machine are equipped with a pump and filtering system for the dielectric fluid.

The EDM process doesn't involve mechanical energy, the hardness, strength and toughness of the workpiece material don't necessarily influence the removed rate. The frequency of discharge or the energy per discharge is usually varied to control the removal rates as are the voltage rate and surface roughness increases with increasing current density and decreasing frequency of sparks.

The EDM process can be used on any material that is an electrical conductor. The melting point and the latent heat of melting are important physical properties that determine the volume of metal removed per discharge. As these quantities increase, the rate of material removal decreases. The volume of material removed per discharge is typically in the range of 10^{-6} to 10^{-14} mm^3.

Tool wear is an important factor because it affects dimensional accuracy and the shape produced. Tool wear is related to the melting points of the materials involved ; the lower the melting point the higher the wear rate.

Consequently, graphite electrode have the highest wear resistance. Tool wear can be minimized by reversing the polarity and using copper tools, a process called No - wear

7.6 Process Capabilities

Electrical discharge machining has numerous applications, such as the production of die cavities for large automotive body components (diesinking machining centres) deep small diameter holes with tungsten wire as the electrode, narrow slots in parts, turbine blades and various intricate shapes.

7.6.1 Uses of Dielectric Fluid

- It acts as a vehicle to drive away the clips and thus preventing them from sticking to the surface of tool.
- It helps in increasing the MRR by promoting spark between tool and work.
- It also act as a coolant medium.
- EDM process is also called **spark erosion machining** where the material is removed by erosion or repeated sparks.
- It is high voltage and low current process.

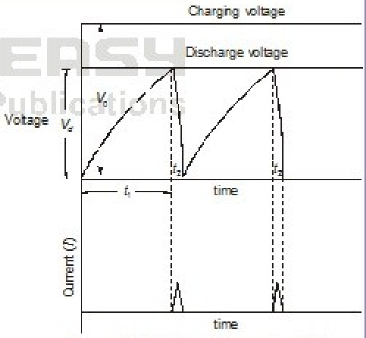


Figure 7.8 Variation of Current and Voltage

7.6.2 Tool Material

- In EDM tool also erodes due to spark hence the selection of tool depends upon wear ratio, ease of tool fabrication and cost of material.
- The most commonly used electrode material are : Cu, Tungsten alloys, Cast iron, Steel etc.

7.12 Electron Beam Machining

The source of energy in electron beam machining (EBM) is high-velocity electrons, which strike the surface of the workpiece utilize voltage in the range of 50 kV-220 kV to accelerate the electrons to speed of 50% to 80% of the speed of light. Its application are similar to those of laser beam machining except that EBM requires a vaccum. Consequently, it is used much less than laser beam machining

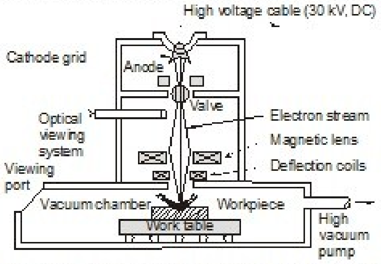


Figure 7.13 The electron-beam machining process. Unlike LBM, this process requires a vacuum, so workpiece size is limited to the size of the vacuum chamber

Electron beam machining can be used for very accurate cutting of a wide variety of metals. Surface finish is better and Kerf width is narrower than that for other thermal cutting process the interaction of the electron beam with the workpiece surface produces hazardous X-rays ; equipment should therefore, be used only by highly trained personnel.

NOTE

Electron beam machining is the process of machining material with the use of very high velocity beam of electrons. The work piece is held in vacuum chamber and the electron beam focused on it. When it strikes the surface of material it result into generation of very high temperature. Leading to metal removal due to melting and evaporation. Used for drilling very fine holes, cutting, contours and very narrow slots. It is also used for producing metering hole in injector nozzle of diesel engines.

MRR : ECM > EDM > USM
Tool Wear : USM > EDM > ECM

Q.8 (c)

(c) A manufacturer of patient medicines is proposed to prepare a production plan for medicines A and B. There are sufficient ingredients available to make 20000 bottles of medicine A and 40000 bottles of medicine B. However, there are only 45000 bottles into which either of the medicines can be filled. Further, it takes three hours to prepare enough material to fill 1000 bottles of medicine A and one hour to prepare enough material to fill 1000 bottles of medicine B, and there are 66 hours available for this operation. The profit is ₹ 8 per bottle for medicine A and ₹ 7 per bottle for medicine B.

(i) Formulate this problem as linear programming problem.

(ii) How does the manufacturer schedule his production in order to maximize profit? Use graphical method.

Source Similar question asked in ESE MAINS Test Series – test 7 , question 5e

Q.5 (e) Solution:

$$z = -3x_1 + 4x_2$$

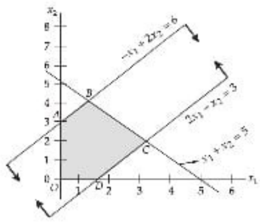
The feasible region is OABCD,

O(0, 0), A(0, 3)

$$-x_1 + 2x_2 = 6$$
$$x_1 + x_2 = 5$$

On adding we get, $x_2 = \frac{11}{3}$

$$x_1 = \frac{4}{3}$$



$B\left(\frac{4}{3}, \frac{11}{3}\right)$

$$2x_1 - x_2 = 3$$
$$x_1 + x_2 = 5$$

on solving $x_1 = \frac{8}{3}$

$$x_2 = \frac{7}{3}$$

$C\left(\frac{8}{3}, \frac{7}{3}\right)$

Now, the co-ordinates of vertices are:

O(0, 0), A(0, 3), $B\left(\frac{4}{3}, \frac{11}{3}\right)$, $C\left(\frac{8}{3}, \frac{7}{3}\right)$, $D\left(\frac{3}{2}, 0\right)$

Value of objective function at these vertices,

$$z_O = -3 \times 0 + 4 \times 0 = 0$$
$$z_A = -3 \times 0 + 4 \times 3 = 12$$
$$z_B = -3 \times \frac{4}{3} + 4 \times \frac{11}{3} = \frac{32}{3}$$

23

$$z_C = -3 \times \frac{8}{3} + 4 \times \frac{7}{3} = \frac{4}{3}$$
$$z_D = -3 \times \frac{3}{2} + 4 \times 0 = \frac{-9}{2}$$

Hence minimum value of objective function = $\frac{-9}{2}$

Maximum value of objective function = 12

Difference between maximum and minimum value of objective function.

$$= 12 + \frac{9}{2} = \frac{33}{2}$$

Q.6 (a) Solution:

The unintentional deterioration of a material by an electrochemical process is known

Similar Problem in NEXT IAS Theory Book

Example 6.5 A manufacturing company produces two products P_1 and P_2. Each product undergoes two operations on machine M_1 and M_2. The time required to perform these operation on a given machine in a given quarter is given in table. The market survey has predicted that not more than 400 pieces of product P_1 and atleast 100 pieces of P_2 and not more than 300 pieces of product P_2 can be sold in the given quarter. The per unit profit for product P_1 and P_2 are ₹30 and ₹40 respectively.

Machine	Product Time required per unit		Available capacity (hrs.)
	P_1	P_2	
M_1	1.6	1.2	720
M_2	1.2	3.0	900
Profit	₹30	₹40	

What will be the value of Maximum profit?

Solution:

Objective function, $Z = 30x + 40y$

Constraints, $1.6x + 1.2y \le 720$

$1.2x + 3y \le 900,$

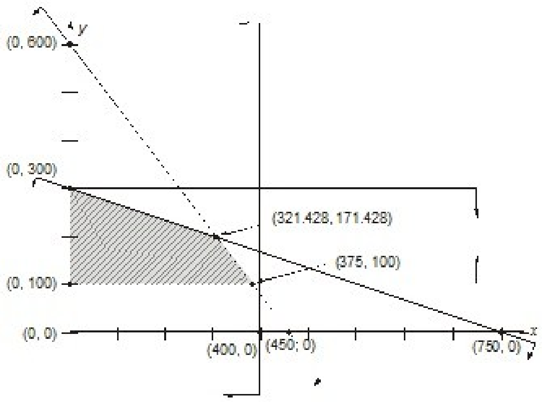
$x \le 400$

$100 \le y \le 300$

$$1.6x + 1.2y \le 720 \Rightarrow \frac{x}{450} + \frac{y}{600} = 1$$

$$1.2x + 3y \le 900 \Rightarrow \frac{x}{750} + \frac{y}{300} = 1$$

$\Rightarrow$ On solving, $x = 321.428,\ y = 171.428$



$$P(0, 300) = 30 \times 0 + 40 \times 300 = ₹12000$$
$$P(375, 100) = 375 \times 30 + 40 \times 100 = ₹15250$$
$$P(321.428, 171.428) = 30 \times 321.428 + 40 \times 171.428 = ₹16500$$
$$P(0, 100) = 30 \times 0 + 40 \times 100 = ₹4000$$

Hence, Maximum profit = ₹16500