ACE
Engineering Academy
(Leading institute for ESE/GATE/PSUs)

ESE – 2019 MAINS
OFFLINE TEST SERIES

MECHANICAL ENGINEERING

TEST – 10
SOLUTIONS

All Queries related to **ESE – 2019 MAINS Test Series** Solutions are to be sent to the following email address

testseries@aceenggacademy.com | **Contact Us : 040 – 48539866 / 040 – 40136222**

01(a)(i).

Sol: $Q_1 - Q_2 \propto \dfrac{dT_1}{dt}$

$$\Rightarrow Q_1 - Q_2 = C.\frac{dT_1}{dt}$$

C is room capacitance (storage factor).

So, $Q_2 = \dfrac{T_1 - T_2}{R}$

R is resistance (opposition)

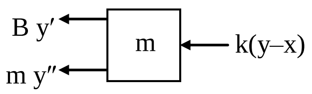
$$\Rightarrow Q_1 - \frac{(T_1 - T_2)}{R} = C.\frac{dT}{dt}$$

$$\Rightarrow RQ_1 = T_1 - T_2 + RC.\frac{dT}{dt} \text{ ....(I)}$$

is the differential equation.

01(a)(ii).

Sol: Free body diagram of mass 'm' :



Algebraic sum of the forces is equal to zero

$$my'' + By' + k(y - x) = 0$$

$$\Rightarrow my'' + By' + ky = kx$$

$$\Rightarrow m\frac{d^2y}{dt^2} + B\frac{dy}{dt} + ky = kx$$

01(b).

Sol: Let the sequence of processes be 0-1-2 where 0 is for the annealed material, 1 applies to 3 mm wire with a previous 20% area reduction on entry to the die and 2 applies to the wire at exit, following a further area reduction of $100(3^2 - 2.75^2)3^2$ = 15.9%. The natural strains associated with the 20% and 15.9% reduction are:

$$\varepsilon_{0-1} = \ln(\ell_1/\ell_0) = \ln(A_0/A_1) = \ln(1/0.80) = 0.223$$

$$\varepsilon_{1-2} = \ln(\ell_2/\ell_1) = \ln(A_1/A_2) = \ln(1/0.84) = 0.174$$

Thus, the natural strains at entry to and exit from the die are 0.223 and 0.397.

The swift law gives the corresponding stresses as 282.4 MPa and 395.5 MPa. Using a mean yield stress Y_m = 339 MPa for the draw process,

$F = A_2Y_m\, ln(A_1/A_2) = 5.94 \times 339 \times ln(7.069/5.94)$

= 350.4 N

The greatest reduction, based upon the flow stress in the drawn material, is found from

$350.4 = 395.5\, ln(A_1/A_2)$

giving $A_1/A_2 = 2.425$

and $d_2 = 1.926$ mm.

01 (c) (i)

Sol: **SPT rule**

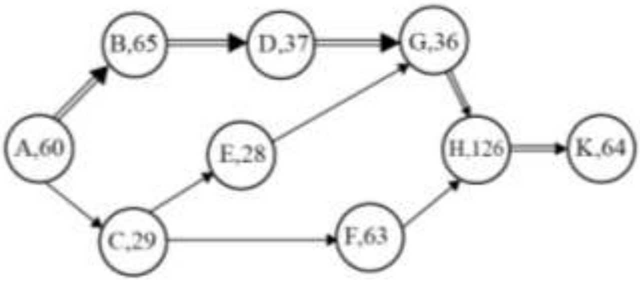
Jobs	Process time (t_i)	Completion time (c_i)	Due date
T	2	2	4
R	4	6	14
P	6	12	10
Q	8	20	12
S	12	32	18
		$\Sigma c_i = 72$	

Total flow time = 72 hours

Mean flow time = $\dfrac{\Sigma c_i}{n} = \dfrac{72}{5}$ = 14.4 hours

01 (c) (ii)

Sol:



Path	Duration
A – B – D – G – H – K	388
A – C – E – G – H – K	343
A – C – F – H – K	342

Time required to complete one product

= 388 min.

Total time required to produce 4000 units

= 4000 × 388 = 15,52,000 min

Available time = 250 × 8 × 60

= 1,20,000 min

Minimum number of work stations

$$= \frac{\text{Total time required}}{\text{Available time}}$$

1 $$= \frac{15,52,000}{1,20,000} = 12.93 \approx 13$$

01(d).

Sol: Differences between Preventive Maintenance and Predictive Maintenances:

Preventive Maintenance	Predictive Maintenances
• Reduces break down and thereby down time • Less odd-time repair and reduces over time of crews • Lower maintenance and repair costs • Less stand-by equipments and spare parts • Better product quality and fewer reworks and scraps • Greater safety of workers • Increases plant life • Increases chances to get production incentive bonus • Catastrophic failures still likely to occur and sometimes unneeded maintenance may be required • Potential for incidental damage to components in conducting unneeded maintenance.	• Increased component operational life/availability • Allows for pre-emptive corrective actions • Decrease in equipment or process downtime • Decrease in costs for parts and labor • Better product quality • Improved worker and environmental safety • Improved worker morale • Energy savings • Estimated 8% to 12% cost savings over preventive maintenance program • Increased investment in diagnostic equipment and in staff training • Savings potential not readily seen by management

01(e).

Sol: The volume of the unit cell is

$V = a_o b_o c_o = (0.45258)(0.45186)(0.76570)$

$= 0.1566 \text{ nm}^3$

$= 1.566 \times 10^{-22} \text{ cm}^3$

(i) From the density equation:

$$5.904 \text{ g/cm}^3 = \frac{(x \text{ atoms/cell})(69.72 \text{ g/mol})}{(1.566\times10^{-22})(6.02\times10^{23})}$$

x = 8 atoms/cell

(ii) From the packing factor (PF) equation:

$$PF = \frac{(8)(4\pi/3)(0.1218)}{0.1566} = 0.387$$

02(a).

Sol: EOQ at lowest price,

$$EOQ_{49.00} = \sqrt{\frac{2DC_o}{C_c}}$$

$$= \sqrt{\frac{2\times490\times64}{0.2\times49}} = 80 \text{ packages}$$

This solution is infeasible.

According to price schedule, we cannot purchase 80 packages at a price of Rs. 49 /- each.

We calculate next price of EOQ at Rs. 50.25

$$EOQ_{50.25} = \sqrt{\frac{2DC_o}{C_c}}$$

$$= \sqrt{\frac{2\times490\times64}{0.2\times50.25}} = 79 \text{ packages}$$

This EOQ is feasible.

But Rs. 50.25 per package is not the lowest price.

However, we have to determine whether total costs can be reduced by purchasing 200 units and thereby obtaining a quantity discount.

$$TC@Q_{79} = \frac{Q}{2}\times C_c + \frac{D}{Q}\times C_o + D\times C_u$$

$$= \frac{79}{2}\times(0.20\times50.25) + \frac{490}{79}\times(64.00) + 490\times50.25$$

= Rs. 25416.44 /year

$$TC@Q_{200} = \frac{Q}{2}\times C_c + \frac{D}{Q}\times C_o + D\times C_u$$

$$= \frac{200}{2}\times(0.20\times49) + \frac{490}{200}\times(64.00) + 490\times49$$

= Rs. 25146.80 /year

Hence, optional order quantity is 200 units.

02(b).

Sol: **Merchant's circle:**

For establishing the relationship between measurable and actual forces Merchant's circle will be used.

Assumptions made in drawing merchant's circle:

1. Shear surface is a plane extending upwards from the cutting edge.
2. The tool is perfectly sharp and there is no contact along the clearance face.
3. The cutting edge is a straight line extending perpendicular to the direction of motion and generates a plane surface as the work moves past it.
4. The chip does not flow to either side, that is chip width is constant.
5. The depth of cut remains constant.
6. Width of the tool is greater than that of the work
7. Work moves with uniform velocity relative tool tip.
8. No BUE is formed

Given data :

Chip thickness ratio (r) = 0.5

Rake angle (α) = 5^o

Main cutting force (F_c) = 1600 N

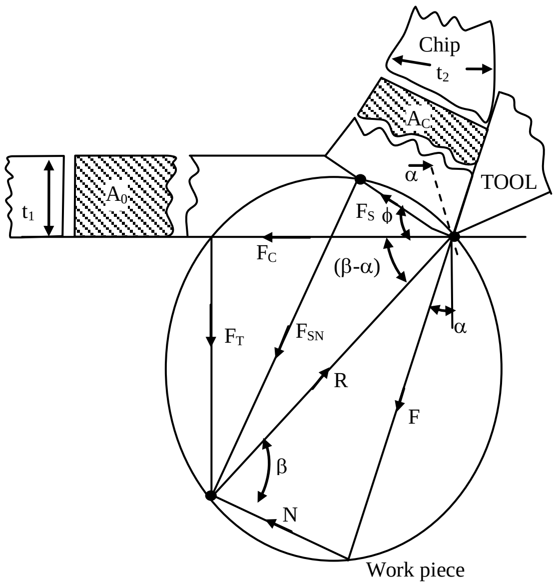
Thrust force (F_t) = 1300 N

For orthogonal cutting operation

Shear angle (ϕ) = $\tan^{-1}\left(\frac{r\cos\alpha}{1-r\sin\alpha}\right)$

$= \tan^{-1}\left(\frac{0.5\times\cos 5^o}{1-0.5\sin 5^o}\right)$

$\phi = 27.5°$



From the merchant circle:

Friction force (F) = $F_C\sin\alpha + F_T\cos\alpha$

$= 1600\sin5^o + 1300\cos5^o$

= 1434.5 N

Normal force (N) = $F_C\cos\alpha - F_T\sin\alpha$

$= 1600\cos5^o - 1300\sin5^o$

= 1480.6 N

Coefficient of friction (μ) = $\frac{F}{N}$

$= \frac{1434.5}{1480.6} = 0.969$

$\Rightarrow$ $\mu = 0.97$

02(c).

Sol: Types of imperfections or defects:

The various types of crystal imperfections are:

1. Point defects :

(a) Vacancies

(b) Displacement of atoms

(c) Impurities/ Inclusions

(d) Frankel defect

(e) Schottky defect

2. Line defects:

(a) Edge Dislocation

(b) Screw Dislocation

3. Surface or Grain boundaries defects:

(a) Grain boundaries

(b) Tilt boundaries

(c) Twin boundaries

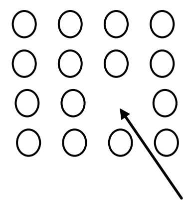
4. Volume defects: Stacking faults

1. Point defects:

- Defect is aphysical discontinuity existing among the lattice of atoms.
- If the defect is confined to a single atom in the lattice, it is called as point defect (as shown in figure below).

(a) Vacancy:

- Missing of atom from the regular lattice side as shown in figure below. Vacancies create deficiency of bonding among the lattice of atoms. Hence strength will decrease.



(b) Displacement of atoms

- Movement of atom from one lattice site to another lattice site, within the lattice.
- Displacement of atom does not change the number of bonds with surrounding atoms. Hence, strength does not change but it may change other properties of the material.

  Ex: In the pure form of silicon it is electrically bad conductor. By adding aluminum or phosphorus, free electrons will be created in the lattice. This electron will travel through the vacancies. So that current can flow and it becomes as electrically good conductor.

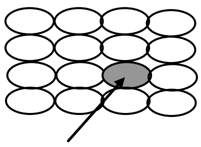
(c) Impurities/ Inclusions

- Addition of foreign atoms to the lattice of atoms is called inclusion.

  (i) Substitutional Inclusion:

- The foreign atoms will occupy the position of lattice atom by removing the lattice atom. Substitutional inclusion does not change the strength of the material but it may change other properties of the material (as shown in figure below).

Ex: Addition of chromium to steel will improve the corrosion resistance but the strength remains the same.



Substitutional impurity

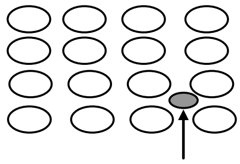
Condition for substitutional inclusion:

- Diameter of foreign atom (dx) = diameter of lattice atom (dL)
- Valency of 'x' should be equal to valency of 'L'. (Valency is nothing but capacity of the formation of bonds by an atom with surrounding atoms).

(ii) Interstitial inclusion:

- The foreign atom will occupy the empty space available within the lattice, without disturbing the position of lattice atoms.
- Interstitial inclusion will increase the no. of bonds with surrounding atoms hence strength will increases (as shown in figure below).

Ex: Addition of carbon to iron will improve the strength of iron and forms as steel.



Interstitial impurity

Condition for interstitial inclusion:

- Diameter of foreign atom < diameter of lattice atom.
- Valency of impurity (x) > valency of lattice atom (L)

(d) Frenkel Defects:

- If the lattice atom occupies the interstitial position by creating vacancy in lattice, it is called Frankel defect. Frankel defect slightly changes the strength of the material.
- Frenkel defect is observed in ionic crystals.
- Frenkel defect arises when an ion moves form a regular site to an interstitial site.

- Cations are generally the smaller ions and hence they move into the void space or interstitial position. Whereas anions do not enter into the void space because they can not be accommodated in the void space as the void space is smaller in size than the anions.

  Ex: Silver halides and CaF_2

(e) Schottkey Defect :

- Pair of vacancy existing with different charges in a lattice, so that the whole change of the material will be balanced.
- Schottky defect is also observed in ionic crystals.
- Schottky defect arises due to vacancies in crystals. A pair of vacant ion sites i.e., one cation and one anion which are missed in an ionic crystal is called a Schottky defect.

  Ex: Alkali halides.

2. Line defects :

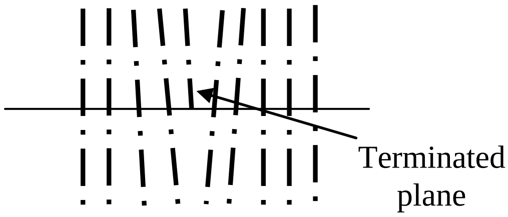
- If the defect is confined to more number of atoms in a lattice, it is known as line defect.

  Ex: Crack formation in a material, where along the line of crack, the atoms are missing. Hence, it is a line defect.

- A *dislocation* may be defined as a disturbed region between two substantially perfect parts of a crystal.

(a) Edge Dislocation

- By applying force on the lattice along the line of defect the lattice can break or crack easily which is known as edge dislocation (as shown in figure below).
- At the edge of a material, if any defect is created, then it acts as a line defect in the material.
- Edge dislocations are caused by the termination of a plane of atoms in the middle of a crystal.



- In such a case, the adjacent planes are not straight, but instead bend around the edge of the terminating plane so that the crystal structure is perfectly ordered on either side.

(b) Screw Dislocation

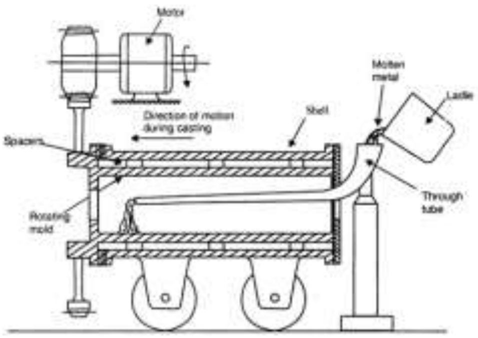
- If the movement of atom planes is following a translation motion followed by rotational motion, it is known as screw dislocation.
- In this phenomenon the arrangement of atoms in the lattice will be in the form of circular fashion at different planes.
- Therefore, screw dislocation defects will change the surface properties of the material significantly.

  Ex: During casting process of different alloying elements, if the densities of alloying elements are different then the movement of atoms on the top surface is different compared with bottom surface. Hence, these defects change the surface properties of the component.

03(a).

Sol:

- Centrifugal casting is a casting technique that is typically used to cast thin-walled cylinders. It is typically used to cast materials such as metals, glass, and concrete. A high quality is attainable by control of metallurgy and crystal structure. Unlike most other casting techniques, centrifugal casting is chiefly used to manufacture rotationally symmetric stock materials in standard sizes for further machining, rather than shaped parts tailored to a particular end-use.
- Typical materials that can be cast are iron, steel, stainless steels, glass and alloys of aluminum, copper and nickel.
- Two materials can be combined by introducing a second material during the process.
- Typical parts made by this process are pipes, flywheels, cylinder liners, and other parts that are axi-symmetric. It is notably used to cast cylinder liners and sleeve valves for piston engines, parts which could not be reliably manufactured otherwise.
- Cylinders and shapes with rotational symmetry are most commonly cast by this technique. Long castings are often produced with the long axis parallel to the ground rather than standing up in order to distribute the effect of gravity evenly.
- Thin-walled cylinders are difficult to cast by other means. Centrifugal casting is particularly suited as they behave in the manner of shallow flat castings relative to the direction of the centrifugal force.
- Centrifugal casting is also used to manufacture disk and cylinder shaped objects such as railway carriage wheels or machine fittings where grain, flow, and balance are important to the durability and utility of the finished product.
- Noncircular shapes may also be cast providing the shape is relatively constant in radius.

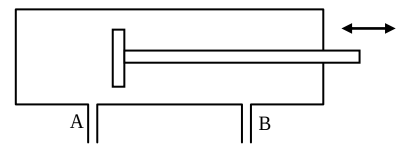


- In centrifugal casting, a permanent mold is rotated continuously at high speeds (300 to 3000 rpm) as the molten metal is poured. The molten metal spreads along the inside mold wall, where it solidifies after cooling. The casting is usually a fine-grained casting with an especially fine-grained outer diameter, due to the rapid cooling at the surface of the mold. Lighter impurities and inclusions move towards the inside diameter and can be machined away following the casting.

- Casting machines may be either horizontal or vertical-axis. Horizontal axis machines are preferred for long, thin cylinders, vertical machines for rings and bearings.
- Castings usually solidify from the outside in. This directional solidification improves some metallurgical properties. Often the inner and outermost layers are removed and only the intermediary columnar zone is used.

03(b).

Sol:



A (1^{st} port), B (2^{nd} port)

(i) Force (F) = Pressure (P) × Area (A)

so,

$$P_{extension} = \frac{Force(F)}{Area(A_c)}$$

$$= \frac{10,000}{\frac{\pi}{4}(0.04)^2} = 7.957 \text{ MPa}$$

$$P_{retraction} = \frac{Force(F)}{A_c - A_{rod}} = \frac{10,000}{\frac{\pi}{4}[0.04^2 - 0.02^2]}$$

= 10.61 MPa

(ii) Piston velocities

$$V_{extension} = \frac{Q_{in}}{A_c} = \frac{3.2\times10^{-3}}{\frac{\pi}{4}(0.04)^2} = 2.52 \text{ m/sec}$$

$$V_{retraction} = \frac{Q_{in}}{A_c - A_r} = \frac{3.2\times10^{-3}}{\frac{\pi}{4}[0.04^2 - 0.02^2]}$$

= 3.395 m/sec

(iii) Length of piston rod expansion (extension)

l = velocity of extension × time of opening 1^{st} port (A)

$$= V_{extension}\times 0.1 = 0.252 \text{ m.}$$

(iv) length of piston rod retracted = velocity of retraction × time of opening 2^{nd} port (B)

$$= V_{retraction}\times 0.2 = 0.679 \text{ m.}$$

03(c).

Sol: Common NDT methods used for metals are :

1. Magnetic Particle Crack Detection
2. Radiography testing
3. Dye Penetrant Testing
4. Ultrasonic Testing
5. Eddy Current and Electro-magnetic Testing
6. Acoustic Emission Testing (AET)
7. Leak Testing
8. Visual and Optical Testing (VT)

Radiography testing

Advantages

- Information is presented pictorially.
- A permanent record is provided which may be viewed at a time and place distant from the test.
- Useful for thin sections.
- Sensitivity declared on each film.
- Suitable for any material.

Disadvantages

- Generally unable to cope with thick sections.
- Possible health hazard.
- Need to direct the beam accurately for two-dimensional defects.
- Film processing and viewing facilities are necessary, as is an exposure compound.
- Not suitable for automation, unless the system incorporates fluoroscopy with an image intensifier or other electronic aids.
- Not suitable for surface defects
- No indication of depth of a defect below the surface.

03(d).

Sol:

(A) Nickel Improves strength, toughness, corrosion resistance, and hardenability.

(B) Chromium Improves toughness, hardenability, wear and corrosion resistance, and high-temperature strength; promotes carburization and depth of hardening in heat treatment.

(C) Manganese Deoxidizes steel; improves hardenability, strength, abrasion resistance, and machinability; reduces hot shortness; decreases weldability

(D) Tungsten Improves hardness, especially at elevated temperature

(E) Vanadium Improves strength, toughness, abrasion resistance, and hardness at elevated temperatures; inhibits grain growth during heat treatment

04(a).

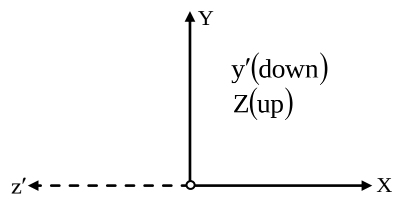
Sol: $F_1 = \begin{bmatrix} ? & 0 & -1 \\ ? & 0 & 0 \\ ? & -1 & 0 \end{bmatrix}$ is the orientation matrix between fixed base frame and movable frame.

→ so cosine values between frames.

	x′	y′	z′
x	?	90	180
y	?	90	90
z	?	180	90

$= \begin{bmatrix} ? & 0 & -1 \\ ? & 0 & 0 \\ ? & -1 & 0 \end{bmatrix}$

→ Co-ordinate frames x y z & x′y′ z′



As per right hand rule x′ is same like y co-ordinate. So angles between x′ with x y z coordinates as follows.

	x′
x	90
y	0
z	90

So cosine values applied, then

$$\begin{bmatrix} 0 & 0 & -1 \\ 1 & 0 & 0 \\ 0 & -1 & 0 \end{bmatrix}$$

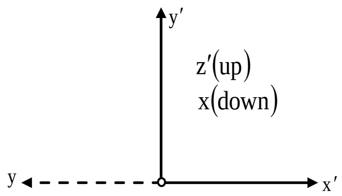
$[0\ 1\ 0]^T$ is missing elements

(ii) $F_2 = \begin{bmatrix} 0 & 0 & -1 \\ -1 & 0 & 0 \\ ? & ? & ? \end{bmatrix}$, cosine values between frames are

	x′	y′	z′
x	90	90	180
y	180	90	90
z	?	?	?

$$= \begin{bmatrix} 0 & 0 & -1 \\ -1 & 0 & 0 \\ ? & ? & ? \end{bmatrix}$$

Co-ordinate frames x y z and x′ y′ z ′ of F_2



As per right hand rule z is same as y′

so

	x′	y′	z′
z	90	0	90

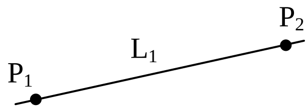
⇒ cosine values (0 1 0) is missing elements

$$\begin{bmatrix} 0 & 0 & -1 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

04(b)(i).

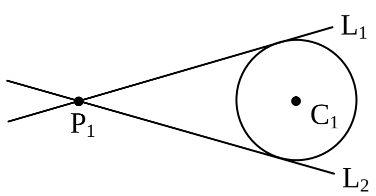
Sol:

1.



$L_1 = \text{LINE}/P_1, P_2$ Line passing through 2 points.

2.

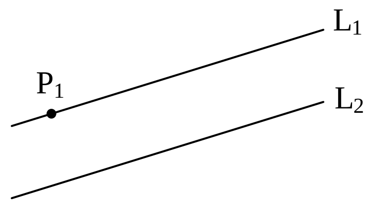


L_1 = LINE/P_1, LEFT, TANTO, C_1

Line passing through point P_1 and tangent to circle C_1.

3. L_2 = LINE/P_1, RIGHT, TANTO, C_1

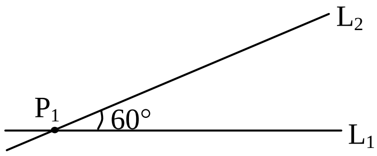
4.



L_1 = LINE/P_1, PARLEL, L_2

Line L_1 passing through point P_1 & parallel to line L_2.

5.



$L_2 = \text{LINE}/P_1, \text{ATANGL}, 60, L_1,$

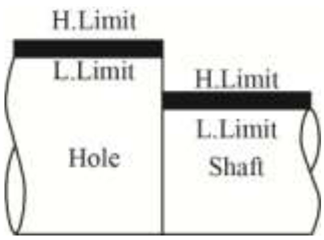
Line L_2 passing through point P_1 and making and angle of 60° to line L_1.

04(b)(ii).

Sol:

(i) Clearance fit: In this type of files, the largest permitted shaft diameter is smaller than the diameter of the smallest hole so that any shaft can freely rotate or slide through any hole. i.e., when limit of hole is greater than H. limit of shaft.

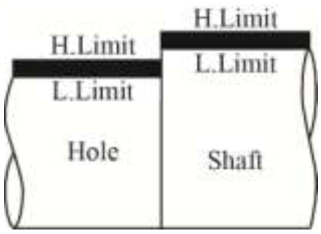
There will always be a clearance Fit between mating parts Ex. Piston cylinders



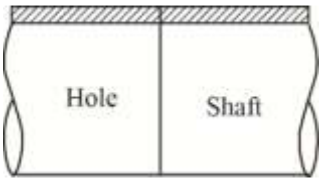
(ii) Interference Fit: In this type of fits, the minimum permitted diameter of the shaft is larger than the maximum allowable diameter of hole. i.e., when H. limit of hole is less than L.limit of shaft.

There are always the non mating parts that will be assembled only with application force, called interference fits.

Ex: Bearing Bushes fitted into housings.



(iii) <u>Transition fits:</u> In this type of fits, the diameter of the largest allowable hole is greater than that of the smallest shaft, but the smallest hole is smaller than the largest shaft or smallest shaft.



When the L.Limit of hole is smaller than the H.Limit of shaft and the allowance is less than the sum of the tolerances on the holes and shaft, we will have clearance fits.

04(c).

Sol:

(i) Spheroidization annealing:

- Spheroidised annealing transforms lamellar pearlite into globular type (matrix of ferrite with carbon in the form of spheroidal carbides).
- The Spheroidised structure has lowest hardness and strength but possess good machinability, toughness and ductility.
- The process of Spheroidisation annealing consists of heating the steel just above the lower critical temperature (730^o–770^oC), and prolonged holding at this temperature followed by slow cooling to 600^oC within the furnace.
- The subsequent cooling may be conducted in still air; the process is applied to high carbon steels to improve machinability.

(ii). Diffusion Annealing:

- Applicable to hardened steels and H.C.S.
- During casting process of high carbon steels, carbon distributes non-uniformly in iron lattice because density of iron is greater than density of carbon $\Rightarrow$ produces non uniform composition $\Rightarrow$exhibits inferior properties.
- By heating the component to 550°C temperature, carbon particles will achieve velocity and travel from high concentration zones to low concentration zones (diffusion) $\Rightarrow$Carbon is distributed uniformly in the component $\Rightarrow$ composition is uniform $\Rightarrow$ exhibits superior properties.

Note: Diffusion annealing is also called as material modification process.

05(a).

Sol: Reliability Centered Maintenance (RCM): RCM methodology deals with some key issues not dealt with by other maintenance programs. RCM is a systematic approach to evaluate a facility's equipment and resources to best of the two and results in a high degree of facility reliability and cost-effectiveness. "It is a process used to determine the maintenance requirements of any physical asset in its operating context to maximize the level of reliability and safety." RCM leads to a maintenance program that focuses preventive maintenance (PM) on specific failure modes likely to occur.

Advantages

- Can be the most efficient maintenance program
- Lower costs by eliminating unnecessary maintenance or overhauls
- Minimize frequency of overhauls
- Reduced probability of sudden equipment failures
- Able to focus maintenance activities on critical components
- Increased component reliability
- Incorporates root cause analysis

Disadvantages

- Can have significant start-up cost, training, equipment, etc.
- Savings potential not readily seen by management.

05(b).

Sol:

(i) Perforating:

The method of producing many no. of smaller size of holes in the sheet is called perforating as shown in the figure below.

(ii) Notching:

The method of removing a piece of material from the edge of the sheet is called notching as shown in the figure below.

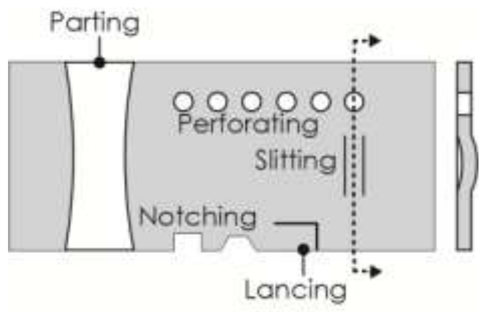


Fig: *Sheet metal shearing operations*

(iii) Slitting:

The method of producing an incomplete hole or blank at the centre of sheet is called slitting as shown in the figure above.

(iv) Lancing:

The method of producing an incomplete blank or hole at the edge of sheet is called lancing as shown in the figure above.

(v) Trimming:

The method of removing a small amount of material from complete circumference of sheet is called trimming operation or edge trimming operation.

05(c)(i).

Sol:

(i) The rotation angle of Stepper Motor (SM) is proportional to input pulse.

(ii) stepper motor has full torque at stand still

(iii) precise positioning and repeatability

(iv) excellent response to starting , stopping, reversing

(v) simple and cheapest, used in open loop applications

(vi) rugged and can work in any environment

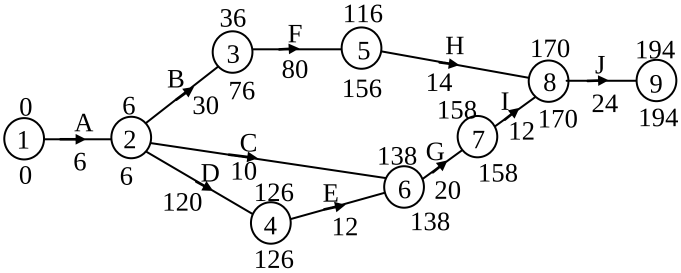
05(c)(ii).

Sol:

Micro processor	Micro controller
All the peripherals (Memory/I/O) are interfaced.	All the peripherals and processor are integrated and inbuilt
More hardware	Less hardware
Size, cost, more	Size and cost are less
Power consumption more	Power consumption is less
Von Neumann Architecture	Hardwared Architecture
More Access time for peripherals (memory/I/O)	Less Access time
More OP codes	Less OP codes
Perform multiple tasks	Single or few tasks
Real-time tasks not possible	Real-time tasks possible
Used in general purpose applications	Specific applications used in embedded systems

05(d).

Sol:



Events	ACT MM	Duration (d)	EST	LST	EFT	LFT	TF
1 – 2	A	6	0	0	6	6	0
2 – 3	B	30	6	46	36	76	40
2 – 6	C	10	6	128	16	138	122
2 – 4	D	120	6	6	126	126	0
4 – 6	E	12	126	126	138	138	0
3 – 5	F	80	36	120	116	156	40
6 – 7	G	20	138	138	158	158	0
5 – 8	H	14	116	156	130	170	40
7 – 8	I	12	158	158	170	170	0
8 – 9	J	24	170	170	194	194	0

EFT → Earliest Finish Time

EST → Earliest Start Time

LFT → Latest Finish Time

LST → Latest Start Time

LST = LFT – Duration LFT – d

EFT = EST + Duration EST+ d

Total float = TF = LST – EST = LFT – EFT

For which ever activity total float is zero that activity is on critical path

1 – 2 – 4 – 6 – 7 – 8 – 9

A – D – E – G – I – J is the critical path

05(e).

Sol:

(a) 795°C

(b) Primary α-ferrite

(c) At 726°C,

α:0.0218% C

$$\%\alpha = \frac{0.77-0.35}{0.77-0.0218}\times 100 = 56.1\ \%$$

γ: 0.77% C %γ = 43.9%

(d) α:0.0218% C

$$\%\alpha = \frac{6.67-0.35}{6.67-0.0218}\times 100 = 95.1\ \%$$

Fe_3C: 6.67% C %Fe_3C = 4.9%

(e) Primary α: 0.0218% C

% Primary α = 56.1 %

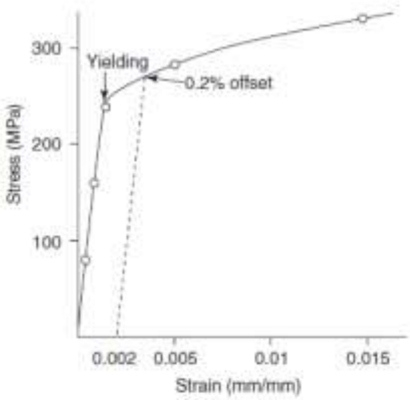
Pearlite: 0.77% C

% Pearlite = 43.9 %

06(a).

Sol: $\sigma = \frac{F}{\left(\frac{\pi}{4}\times 20\right)} = \frac{F}{314.2}$

$$\varepsilon = \frac{(\ell - 40)}{40}$$



(a) 0.2% offset yield strength = 274 MPa

(b) tensile strength = 417 MPa

(c) $E = \frac{(238.7-0)}{(0.001388-0)}$ = 172,000 MPa

= 172 GPa

(d) % elongation = $\frac{(47.42-40)}{40}\times 100 = 18.55\%$

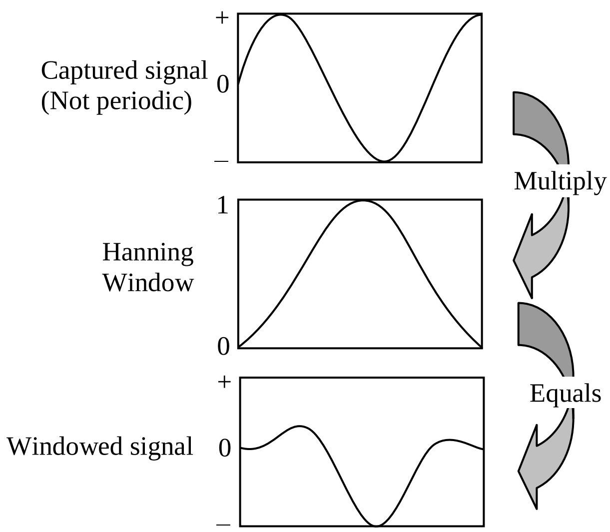
(e) % reduction in area

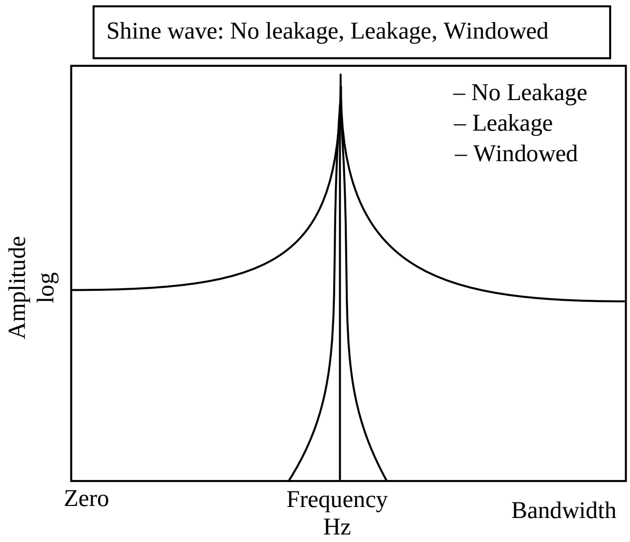
$$= \frac{(\pi/4)(20)^2 - (\pi/4)(18.35)^2}{(\pi/4)(20)^2}\times 100 = 15.8\%$$

06(b)(i).

Sol: Spectral leakage is a problem that arises in the digital processing of signals. Leakage causes the signal levels to be reduced and redistributed over a broad frequency range, which must be addressed in order to analyze digital signals properly. To reduce leakage, a mathematical function called a window is applied to the data. Windows are designed to reduce the sharp transient in the re-created signal as much as possible.

Windows are typically shaped as functions that start at a value of zero, move to a value of one, and then return to a value of zero over one frame. The captured signal is multiplied by the window as shown in *Figure below*



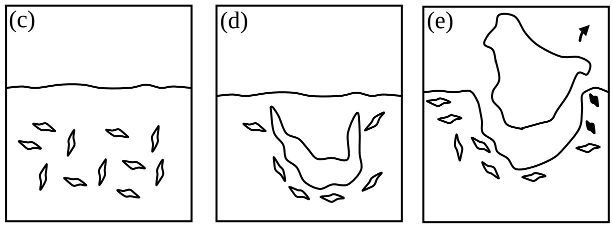


There are many different windows, each optimized for a particular situations. Some windows include:

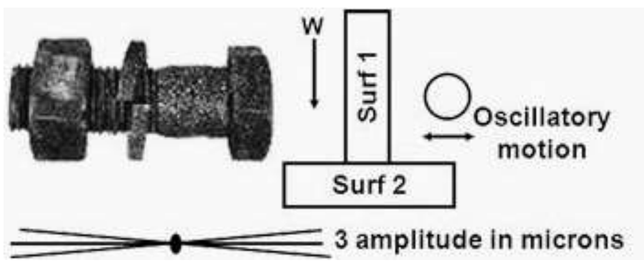
- Hanning – Used for general data analysis, good tradeoff between frequency and amplitude accuracy
- Flattop – Excellent accuracy for amplitude, often used in calibration
- Tukey – Used for transient events
- Exponential – Used in impact hammer modal testing, be careful of adding artifical damping to measurement
- Uniform – Another way of saying "no window".

06(b)(ii).

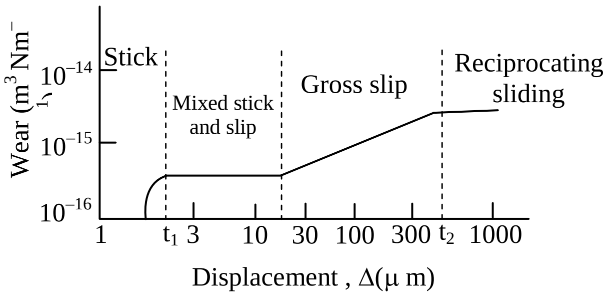
Ans: **Pitting** is a surface fatigue failure which occurs due to repeated loading of tooth surface and the contact stress exceeding the surface fatigue strength of the material. The pit itself will cause stress concentration and soon the pitting spreads to adjacent region till the whole surface is covered with pits. Subsequently, higher impact load resulting from pitting may cause fracture of already weakened tooth. Sometimes impurities in materials provide nucleus for crack generation as shown in Fig. (c). Fig. (d) shows merger of generated cracks, which finally detaches from the surface as shown in Fig.(e). Such formation of pits (removal of material) comes under measurable wear.



Fretting wear refers to small amplitude (1 to 300 μm), with high frequency oscillatory movement mainly originated by vibration. This generally occurs in mechanical assemblies (press fit parts, rivet / bolt joints, strands of wire ropes, rolling element bearings), in which relative sliding on micron level is allowed. It is very difficult to eliminate such movements and the result is fretting. Fretting wear and fretting fatigue are present in almost all machinery and are the cause of total failure of some otherwise robust components.



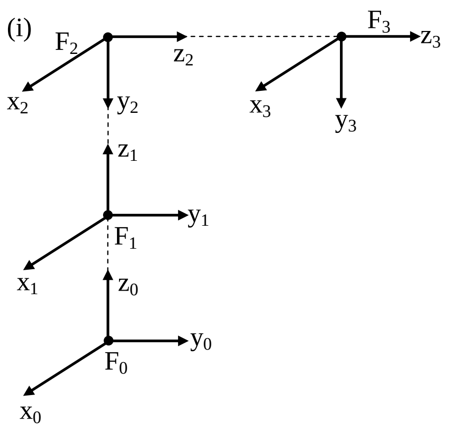
The accumulating wear debris gradually separates both surfaces and, in some cases, may contribute to the acceleration of the wear process by abrasion. The process of fretting wear can be further accelerated by temperature and reciprocating movements as short as 0.1 micron in amplitude can cause failure of the component when the sliding is maintained for one million cycles or more. The below graphs explains the fretting wear phenomenon over different conditions.



06(c).

Sol: The given RPP manipulator is cylindrical arm with T L O notation.

(i)



The four frames F_0 (x_0 y_0 z_0), F_1 (x_1 y_1 z_1), F_2(x_2 y_2 z_2) and F_3 (x_3 y_3 z_3) are as shown.

F_0, F_1 both have same origin

F_1, F_2 are vertically displaced with d_2

F_2, F_3 are horizontally displaced with d_3

(ii) D–H parameters are a, α, d, θ

	a	α	d	θ
1	0	0	0	θ
2	0	$-\pi/2$	d_2	0
3	0	0	d_3	0

(iii) Individual matrices:

$\rightarrow {}_0T_1(\theta_1) \Rightarrow$ Rotation around z(θ_1)

${}_1T_2(d_2) \Rightarrow$ translation along z (d_2) with link twist ($-\pi/2$)

${}_2T_3(d_3) \Rightarrow$ translation along z(d_3)

$$ {}_0T_1 = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \Rightarrow \text{Pure rotation only} $$

R(z, θ_1)

$$ {}_1T_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \Rightarrow \text{rotation and} $$

translation both R(x, $-\pi/2$) & T(z, d_2)

$$ {}_2T_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \Rightarrow \text{Pure traslation only } T(z, d_3) $$

Above matrices based on

${}_{(i-1)}T_{(i)} \Rightarrow 4\times4$ matrices with DH parameters

(or) based on rotation / translation / both

(iv) overall transformation matrix

$$ {}_0T_3 = [{}_0T_1][{}_1T_2][{}_2T_3] $$

$$= \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} c_1 & 0 & -s_1 & 0 \\ s_1 & 0 & c_1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} c_1 & 0 & -s_1 & -d_3 s_1 \\ s_1 & 0 & c_1 & d_3 c_1 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

07 (a)

Sol: (i)

Month (x)	**No. of oil changes (y)**	**xy**	**x^2**
1	41	41	1
2	46	92	4
3	57	171	9
4	52	208	16
5	59	295	25
6	51	306	36
7	60	420	49
8	62	496	64
$\Sigma x = 36$	$\Sigma y = 428$	$\Sigma xy = 2029$	$\Sigma x^2 = 204$

$y = a + b\,x$

$\Sigma y = na + b\,\Sigma x$

$428 = 8a + b(36)$ ---------(1)

$\Sigma xy = a\Sigma x + b\,\Sigma x^2$

$2029 = a(36) + b(204)$ -------- (2)

By solving (1) & (2)

$a = 42.46; \quad b = 2.45$

Trend line: $y = 42.46 + 2.45\,x$

Forecast for September: $x = 9$

Forecast $_{(sept)} = 42.46 + 2.45\,(9) = 64.51$

Forecast for October: $x = 10$

Forecast $_{(Oct)} = 42.46 + 2.45\,(10) = 66.96$

Forecast for November: $x = 11$

Forecast $_{(Nov)} = 42.46 + 2.45\,(11) = 69.41$

(ii) "MAD" calculation.

Month (t)	**Demand (D_t)**	**Forecast (F_t)**	**$\lvert D_t - F_t \rvert$**
1	41	44.91	3.91
2	46	47.36	1.36
3	57	49.81	7.19
4	52	52.26	0.26
5	59	54.71	4.29
6	51	57.16	6.16
7	60	59.61	0.39
8	62	62.06	0.06
$\Sigma\lvert D_t - F_t\rvert$			23.62

$$\text{MAD} = \frac{\Sigma\lvert D_t - F_t\rvert}{n} = \frac{23.62}{8} = 2.95$$

07(b).

Sol:

(i) No. There is an increase in the porosity as cooling time is reduced.

(ii) Yes. In AC welding the polarity changes and the net magnetic force due to induced field counter balances that due to applied field.

(iii) Yes. In carburizing flame more incomplete combustion products, so they travel longer distances before combustion is completed.

(iv) No. Aluminum alloys have very high oxidation tendency.

(v) Yes. DC arc welding machines are used for GMAW with electrode positive (DCEP). The DCEP increases the metal deposition rate and also provides for stable arc and smooth metal transfer with DCEN the arc becomes highly unstable and also results large spatter.

07(c).

Sol: *There are in general five type of reliability models. Each model is explained below.*

Series Reliability Model: The components are arranged in series and the success of the system depends on the success of all components. Figure shows a system components connected in series and reliabilities are R_1, R_2, R_3,……., R_n.

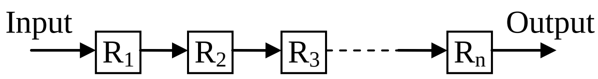


Fig: *Series Reliability Model*

The reliability of completed system is

$$R_S = R_1 x R_2 x R_3 x.......x R_n$$

$$= \prod_{i=1}^{n} R_i$$

In this system, failure of any component puts the system down.

Parallel Reliability Model: In parallel reliability model, the system can be operative even if some of the components are in the failed state. Figure shows a system components connected in series and reliabilities of '*n*' systems used are R_1, R_2, R_3,……., R_n.

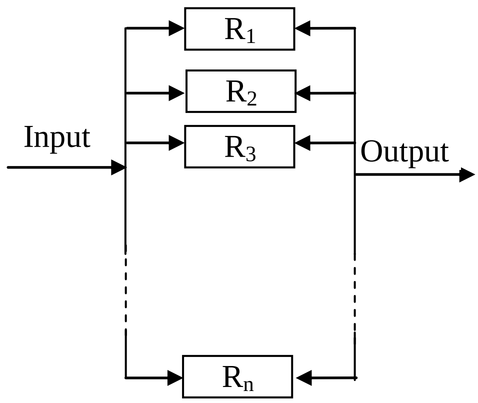


Fig: *Parallel Reliability Model*

$$R_S = 1 - \prod_{i=1}^{n} (1 - R_i)$$

$$= 1 - \prod_{i=1}^{n} \left(1 - e^{-\lambda_i t}\right)$$

Series-Parallel Reliability Model: It is more complex configuration where components are arranged in series and parallel. The technique starts with the selection of a key component, which appears to bind together the overall probability structure, and the reliability may be expressed in terms of the key components. Figure shows the series parallel reliability model.

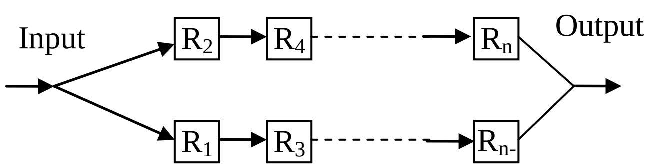
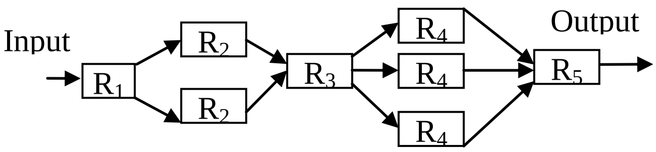


Fig: *Series parallel reliability model*

The reliability of completed system is

$$R_S = 1-(1-R_2R_4.....R_n)(1-R_1R_3.....R_{n-1})$$

Redundant Reliability Model: A system consists of some identical components connected in parallel to provide the higher reliability. Figure shows the redundant reliability model.



The reliability of whole system is

$$R_S = R_1\left(1-(1-R_2)^2\right)R_3\left(1-(1-R_4)^3\right)R_5$$

Reliability Model Based on Failure Rate: The most important consideration in reliability evaluation is the development of a reliability model based on the failure and/or repair behavior of the functional units of the system under evaluation. Usually, the functional units are put together in a block diagram to constitute a series or parallel.

The basic reliability equation for a single unit operating in the useful life period where failure rate is constant, is given by

$$R(t) = e^{-\lambda t}$$

where, λ= Failure Rate

R(t) = The probability that the unit will continuously perform its intended function in the time interval 0 to t

In case of series, the Reliability of system is

$$R_s(t) = \prod_{i=1}^{n} R_i = e^{-\sum_{i=1}^{n}\lambda_i t}$$

$$\text{MTTF} = \int_0^{\alpha} R_s(t) = \int_0^{\alpha} e^{-\sum_{i=1}^{n}\lambda_i t}\,dt$$

$$\text{MTTF} = \frac{1}{\sum_{i=1}^{n}\lambda_i}$$

In case of Parallel, the Reliability of system is

$$R_p(t) = 1-\prod_{i=1}^{n}(1-R_i) = 1-\prod_{i=1}^{n}\left(1-e^{-\lambda_i t}\right)$$

$$\text{MTTF} = \int_0^{\alpha} R_p(t) = \int_0^{\alpha}\left(1-\prod_{i=1}^{n}\left(1-e^{-\lambda_i t}\right)\right)dt$$

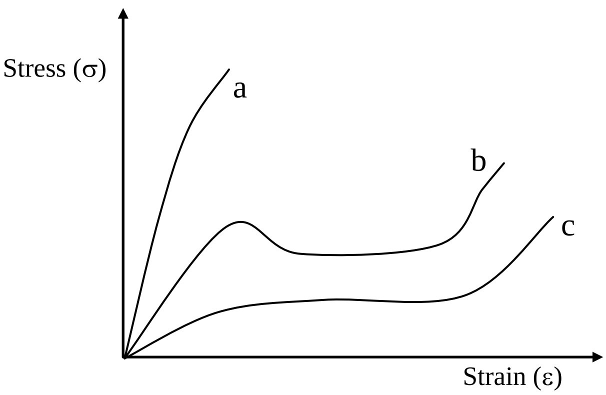
07(d).

Sol: The Stress/Strain behavior of solid polymers can be categorized into following classes :

- **Brittle Fracture**: Characterized by no yield point, a region of Hookean behavior at low strains and failure characterized by chonchoidal lines such as seen in inorganic glasses.
- **Yield Behavior:** Characterized by a maximum in the stress/strain curve followed by yielding deformation which is usually associated with crazing or shear banding and usually ductile failure. Ductile failure exhibits a high extent of deformation on the failure surface. Yield behavior can result in necking which exhibits a close to constant load regime and a terminal increase in the stress.

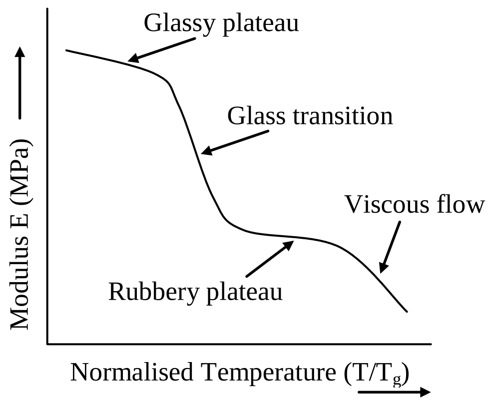
- **Rubber-Like Behavior:** Characterized by the absence of a yield point maximum but exhibiting a plateau in an engineering stress/strain curve. Often rubber-like behavior exhibits a terminal increase in the stress followed by failure which results in a tear with little permanent deformation exhibited in the failure surface, e.g. Jell-O.

Generally, a single polymer sample displays one of the characteristic failure mechanisms under normal conditions, i.e. polystyrene exhibits brittle failure, polyethylene displays necking, crosslinked polydimethylsiloxane displays rubbery behavior, high impact polystyrene displays yielding behavior. The type of behavior can also change with the type of deformation, i.e. polystyrene displays crazing or brittle failure in tension but displays shear banding and yield behavior in compression.



Glass transition temperature for polymers:

The glass–liquid transition or glass transition in short is the reversible transition in amorphous materials from a hard and relatively brittle "glassy" state into a viscous or rubbery state as the temperature is increased. An amorphous solid that exhibits a glass transition is called a glass. The reverse transition, achieved by supercooling a viscous liquid into the glass state, is called vitrification.



08(a)(i).

Sol:

(a) $Q_i - Q_o \propto \dfrac{dT}{dt}$

$\Rightarrow Q_i - Q_o = C.\dfrac{dT}{dt}$

'C' is room capacitance (storage factor)

$Q_o = \dfrac{T - T_o}{R}$

R is room resistance (opposition)

After Q_o substitution

$Q_i - \dfrac{(T - T_0)}{R} = C.\dfrac{dT}{dt}$

$Q_iR = T - T_0 + RC\dfrac{dT}{dt}$ is the required differential equation----------(i)

(b) Transfer function when $T_o = 0$

$Q_i R = T + RC\, dT/dt$

Laplace transformation is applied

$\Rightarrow Q_i(S).R = T(S) + RCST(S)$

$\Rightarrow Q_i(S).R = T(S)[1+SRC]$

$$T.F\left[\frac{T(s)}{Q_i(s)}\right] = \frac{R}{1+SRC}$$

$$= \frac{R}{1+ST}$$

(T = RC, is time constant of thermal system)

08(a)(ii).

Sol: In screw transformation moving frame is translated and rotated about same z-axis. So overall transformation matrix.

(a) T = T(z, 180°).T(0, 0, 3)

(Pre multiplication)

$$T = \begin{bmatrix} \cos\pi & -\sin\pi & 0 & 0 \\ \sin\pi & \cos\pi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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

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

(b) $P_{xyz} = [T].P_{uvw}$

So, $P_{uvw} = (4, 3, 2)$

$$P_{xyz} = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 4 \\ 3 \\ 2 \\ 1 \end{bmatrix} = \begin{bmatrix} -4 \\ -3 \\ 5 \\ 1 \end{bmatrix}$$

So point with fixed frame = (–4, –3, 5)ss

08(b).

Sol: ***Two-body Abrasion:*** This wear mechanism happens between two interacting asperities in physical contact, when one of it is harder than other. Normal load causes penetration of harder asperities into softer surface thus producing plastic deformation.

The material is displaced /removed from the softer surface by combined action of micro ploughing and micro cutting.

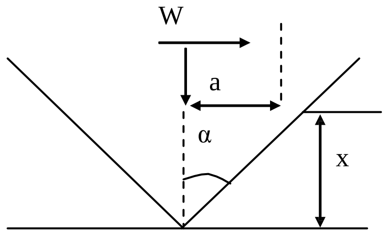


Fig : *The two-body abrasion mechanism between softer and hard materials*

Assuming conical asperities indenting soft surface during traverse motion and all material displaced by the cone is lost as wear debris.

Rabinowiz's Quantitative, law for 2-Body abusive wear

- All asperities can be represented by equal dimensions cones
- All the material displaced by conical asperity in a single pass in removed as wear particular

Load carried by i^n asperity

$$W_i = H\,[0.5 \times \pi a^2]$$

Volume swept by penetrated asperity

$$\Delta V = \frac{W_i L}{0.5 H\pi \tan\alpha}$$

Total wear is sum of the wear caused by individual asperity.

$$V = \frac{L\sum_{i-1}^{n} W_i}{0.5H\pi \tan\alpha}$$

$$Q = \frac{V}{L} = \frac{2W}{\pi \tan\alpha H} = K\frac{W}{H}$$

08(c).

Sol:

Total Variable Costs:

Book cases	1,980 × 40	= 79,200	
Beds	200 × 180	= 36,000	
Chairs	540 × 110	= 59,000	1,74,600
		Contribution Margin	95,400
		Less Fixed Cost	75,000
		Profit	20,400

The second alternative is preferable as it entails greater amount of profit.

First alternative: Total sales : Rs. 2,50,000

Product	**Sales (Rs.)**	**Quantity Sold**
Book cases	30% of 2,50,000 = 75,000	75,000/60 = 1,250
Tables	20% of 2,50,000 = 50,000	50,000/100 = 500
Chairs	50% of 2,50,000 = 1,25,000	1,25,000/200 = 625

The profit is determined as follows:

Total sales = Rs. 2,50,000

Total variable costs:

Book cases	1250 × 40	= 30,000	
Tables	500 × 60	= 30,000	
Chairs	625 × 120	= 75,000	1,55,000
		Contribution Margin	95,000
		Less Fixed Cost	75,000
		Profit	20,000

Second alternative: Total Sales = 2,70,000

Product	**Sales (Rs.)**	**Quantity Sold**
Book cases	44% of 2,70,000 = 1,18,800	1,18,800/60 = 1,980
Beds	16% of 2,70,000 = 43,200	43,200/216 = 200
Chairs	40% of 2,70,000 = 1,08,000	1,08,000/200 = 540

The profit is determined as follows:

Total Sales Rs. 2,70,000