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ESE – 2019 MAINS
OFFLINE TEST SERIES

MECHANICAL ENGINEERING

TEST – 6
SOLUTIONS

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01(a).

Sol: If we refer to figure below, we find that atoms touch along the edge of the cube in SC structures. The corner atoms are centered on the corners of the cube, so

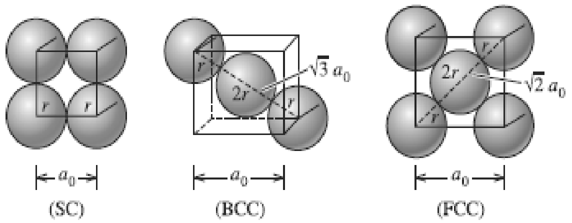
$$a_o = 2r$$

In BCC structures, atoms touch along the body diagonal, which is $\sqrt{3a_o}$ in length. There are two atomic radii from the center atom and one atomic radius from each of the corner atoms on the body diagonal, so

$$a_o = \frac{4r}{\sqrt{3}}$$

In FCC structures, atoms touch along the face diagonal of the cube, which is $\sqrt{2a_o}$ in length. There are four atomic radii along this length, two radii from the face centered atom and one radius from each corner, so

$$a_o = \frac{4r}{\sqrt{2}}$$



The relationships between the atomic radius and the lattice parameter in cubic systems

01(b).

Sol: *Table: Comparison of MIG welding with TIG welding*

MIG WELDING	TIG WELDING
1. Metal rod is used as electrode and work piece is used as another electrode.	1. Tungsten rod is used as electrode.
2. It is gas shielded metal arc welding.	2. It is gas shielded tungsten arc welding.
3. Continuous feed electrode wire is used which is fast feeding.	3. Welding rods are used which are slow feeding.
4. The welding area is flooded with a gas which will not combine with the metal.	4. Gas is used to protect the welded area form atmosphere.
5. MIG can weld materials such as mild steel, stainless steel and aluminum. A range of material thicknesses can be welded from thin gauge sheet metal right up to heavier structural plates.	5. TIG can weld things like kitchen sinks and tool boxes. Pipe welding and other heavier tasks can also be performed. You just need to have a unit that is capable of putting out the amount of power that you need.
6. MIG requires consumable metallic electrode.	6. It uses non consumable tungsten electrode
7. Electrode is fed continuously from a wire reel.	7. It does not require electrode feed.
8. DC with reverse polarity is used.	8. It can use both A.C and D.C.
9. It can weld up to 40 mm thick metal sheet.	9. Metal thickness is limited about 5 mm.
10. MIG is comparatively faster than TIG.	10. TIG is a slow welding process.

- Thorium or Zirconium is doped to improve electron emission characteristics of the electrode.

01(c).

Sol: Consolidated requirements are determined by summing the forecast and order data.

Week 1 = 40 + 15 = 55

Week 2 = 5 + 40 + 10 = 55

Required production is determined by

Production = beginning inventory – consolidated requirements

Week 1 = 60 – 55

= 5 (No new production is needed.)

Week 2 = 5 – 55

= (50) (Schedule a production run.)

Ending inventory is determined by

Ending inventory = beginning inventory + production – requirements

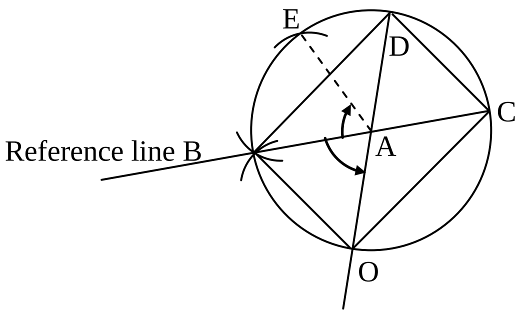
Week 2 = 5 + 90 – 55 = 40

Initial inventory = 60	Week									
Production run = 90	1	2	3	4	5	6	7	8	9	10
Requirements	55	55	65	55	60	50	50	50	55	50
Beginning inventory	60	5	40	65	10	40	80	30	70	15
Production required		90	90		90	90		90		90
Ending inventory	⑤	40	65	10	40	80	30	70	15	55

The Production required row shows the tentative master schedule amounts.

01(d).

Sol:



OA = AD = 6 μm
DB = 10 μm
OB = 5 μm
OE = 10.5 μm
AB = 6.3 μm
Imbalance position = angle BAO
= 71° CCW

Figure the geometrical construction of the present problem with lengths of various arcs. From this the net effect of the imbalance is given as

AB = 6.3 μm = 5 gm

Hence, the residual imbalance is given as

OA = AD = 6 μm = 4.762 gm

AB is the reference line. The fourth observation intersects at E, hence angle to be measured in the CW direction (i.e. ∠BAE). Hence, the unbalance position is given as ∠BAO = 259° CW

direction or (∠BAO = 71°CCW direction).

The unbalance magnitude and phase can be also obtained from equations (E) and (H), we have

$$x = \pm\sqrt{\frac{1}{2}\left(a_1^2 + a_2^2\right) - a_o^2} = 4.762 \text{ gm}$$

and $$\cos\varphi = \frac{\left(-a_1^2 + a_2^2\right)}{2a_o x} = 71^\circ$$

01(e).

Sol: Preventive Methods for Prevention of Corrosion:

1. **Cathodic Protection:**
Cathodic protection is one of the most important method to control corrosion of machine parts immersed in soil or liquid. In this method, the anodic metal is converted into cathodic metal which is not corroded.

This method is of two types:

(a) Sacrificial anodic protection.

(b) Impressed current protection.

Sacrificial Anodic Protection:

- The metallic structure which is to be protected is connected with a more anodic metal. By this, all the corrosion get concentrated at a more anodic metal and protected metal acts as cathode and can be saved from corrosion.
- The more active metal (anodic metal) used for this purpose is known as sacrificial anode.
- Commonly used metals for this purpose are Mg, Zn, Al and their alloys.
- These sacrificial metals should be replaced by fresh one at appropriate time.

This method of corrosion control is used in following areas:

(a) For protecting buried pipe lines of oil and water.

(b) Protecting marine structure, ship parts etc.

(c) Protecting domestic water boilers or tanks.

Impressed Current Protection:

- The protecting metal in connected to external DC source with its negative terminal. The positive terminal is connected to an insoluble anode like graphite, platinum or scrap iron.
- Impressed current nullifies the corrosion current as the protecting metal gets electrons and become cathode.
- The anode material should also be replaced periodically.

2. Protective Coatings:

- Metal having wide range application in field of engineering suffers with the problem of corrosion.
- The metals or alloys having good resistance to corrosion have less availability, high cost and have fabrication problem.
- The coating forms the continuous physical barriers between the coated surface and the environment.
- The coated surfaces not only have resistance to corrosion but also provides decoration, improved wear-resistance, resistance to oxidation, thermal insulation, hardness and improved electrical properties.

(i) Metallic Coating:

- The deposition of a metal on the surface of substrate (base metal) is called metallic coating.
- Depending on the position of base metal and coating metal in electrochemical series, the metallic coating is classified as anodic coating or cathodic coating. The anodic or cathodic behaviour of metal deposited on the surface of other metal depends on its electrode potential.

(a) *Anodic Coating:* When the coating on the surface of base metal is done with the metal having lower reduction potential value then the coating is called anodic coating because the coating metal gets oxidized in contact with atmosphere.

The electron released at anode moves freely in base metal. Thus, coating metal acts as sacrificial anode.

(b) *Cathodic Coating:* When the coating on the base metal is done with metal having higher electrode potential (reduction potential) value, the coating is called cathodic coating because the coating metal has higher resistance to corrosive environment than the base metal and when electrochemical cell is set up between two metals, the coating metal would behave as cathode and the base metal as anode.

- The coating metal provides better protection to base metal unless there is no discontinuity or any cracks in the coating.
- The common example is coating of tin on iron.

(ii) *Drip Coating or Hot Dipping:*

- Hot dipping process of the substrate (base metal) is literally dipped (or immersed) into a liquid bath of coating metal.
- After immersion the substrate (base metal) is withdrawn and the excess coating material is removed by suitable methods like centrifugation, rolling, etc.
- Here we discuss the coating on iron or steel sheets by zinc and tin by the process of hot dipping respectively known as Galvanization and Tinning.

(a) *Galvanization:* Hot dipping coating of zinc known as galvanizing has been used to protect iron and steel parts against corrosion of base metal.

Major applications: The major application the galvanizing is also done for smaller iron article like nuts, bolts, pipes, roofing sheets, screws, bucket tubes etc.

(b) *Tinning:* The coating of tin over iron article is known as tinning.

Applications:

Protective coating for food handling (container for food stuffs, ghee, oils, kerosene and packing material), to facilitate the soldering of a variety of components used in electronic equipment.

Tinning is widely used for coating of steel, copper and brass sheets.

(iii) *Electroplating:*

The electroplating or electro deposition or electrochemical deposition is the production of metallic coating on the solid surface by passing electric current (direct current) through an electrolytic solution containing the soluble salt of coating metal.

3. Organic Coatings (Paints)

Organic coatings are inert organic barriers like paints, varnishes, lacquers and enamels applied on metallic/non-metallic surfaces for corrosion protection as well as decoration.

The protective value of organic coating depends on:

(a) Chemical inertness to corrosive environment

(b) Surface adhesion

(c) Impermeability to salt and water, gases

(d) Its proper application method

Paint:

- Paint is a mechanical dispersion mixture formed by the dispersion of pigments, which are solids, into the drying oils.
- These two substances are essential constituents in the formation of paints.
- The pigment constitutes the body of the paints while drying oils bind together the grains of the body.
- The other ingredients known as driers and thinners are added only to develop certain qualities in the paints.

02(a).

Sol: (i) and (ii) The proposed solution is tested for optimality in table. It is found to be non-optional. To improve this solution, a closed path is drawn beginning with the cell CS.

The revised solution is given in second table. It is found to be optimal. The minimum transportation cost involved is Rs. 149. the optimal schedule is : A to Q: 12; A to R: 2; A to S: 8; B to R: 15; C to P: 7; and C to S: 1.

Proposed Solution: Non-optimal

Ware house	Market				supply	u_i
	P	Q	R	S		
A	(–4) 6	3 $\boxed{12}$	+ 5 $\boxed{1}$	4 $\boxed{9}$ –	22	0
B	(–6) 5	(–9) 9	2 $\boxed{15}$	(–6) 7	15	–3
C	5 $\boxed{7}$	(–1) 7	8 $\boxed{1}$ –	(1) 6 +	8	3
Req.	7	12	17	9	45	
v_j	2	3	5	4		

Total cost = 3×12+5×1+4×9+2×15+5×7+8×1

= Rs.150

Improved Solution: Optimal

Ware house	Market				supply	u_i
	P	Q	R	S		
A	(–3) 6	3 $\boxed{12}$	5 $\boxed{2}$	4 $\boxed{8}$	22	0
B	(–5) 5	(–9) 9	2 $\boxed{15}$	(–6) 7	15	–3
C	5 $\boxed{7}$	(–2) 7	(–1) 8	6 $\boxed{1}$	8	2
Req.	7	12	17	9	45	
v_j	3	3	5	4		

Total cost

= 3×12 + 5×2 + 4×8 + 2×15 + 5×7 + 6×1

= Rs. 149

02(b)(i).

Sol: The Taylor’s tool life equation is:

$$V.T^n = C = \text{constant}$$

where,

V = cutting velocity in m/min

T = tool life in min

n = Taylors exponent which depends on the cutting tool material.

C = Taylors constant or cutting velocity for one minute tool life

Given that when the cutting velocity is increased by 50%, the tool life reduces by 40%,

i.e., when $V_2 = 1.5V_1$, $T_2 = 0.6T_1$

From the given data

$$(V_1).(T_1)^n = (V_2).(T_2)^n$$

$$(T_1/T_2)^n = V_2/V_1$$

Applying log on both sides

$n = [\ln(V_2/V_1) / \ln(T_1/T_2)]$

$= [\ln(1.5V_1/V_1) / \ln(T_1/0.6T_1)]$

$n = \ln(1.5) / \ln(1/0.6) = 0.794$

02(b)(ii).

Sol: Given that:

$V = 200$ m/min, $\alpha = 10°$, $b = 2$ mm

$t = 0.2$ mm, $\mu = 0.5$, $\tau_s = 400$ N/mm^2

By Merchant theory:

(i) $$\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2}$$

where

$\beta = \tan^{-1}\mu = \tan^{-1}(0.5) = 26.56°$

$$\phi = 45^o + \frac{10^o}{2} - \frac{26.56}{2} = 36.71°$$

$$F_s = \tau_s \times \frac{bt}{\sin\phi} = \frac{400 \times 0.2 \times 2}{\sin 36.71^o} = 267.62 \text{ N}$$

(ii) $$F_c = \frac{F_s}{\text{Cos}(\phi + \beta - \alpha)} \times \cos(\beta - \alpha)$$

$$= \frac{267.62}{\cos(36.71^o + 26.56^o - 10^o)} \times \cos(26.56^o - 10^o)$$

$= 428.925$ N

$F_t = F_c \times \tan(\beta - \alpha) = 428.925 \times \tan(26.56° - 10°)$

$= 127.54$ N

02(c).

Sol:

Force (N)	**Gage Length (cm)**	**Diameter (mm)**	**True stress (MPa)**	**True strain (cm/cm)**
16,240	3.6642	12.028	143	0.200
19,066	4.4754	10.884	205	0.400
19,273	5.4663	9.848	253	0.600

$$\text{True stress} = \frac{F}{\frac{\pi}{4}(d)^2}$$

True strain = $\ln(1 + e)$

$$\text{Eng. strain } (e) = \frac{\Delta L}{L}$$

where, σ_t = true stress

ε_t = true strain

n = strain hardening coefficient

$\sigma_t = K\varepsilon_t^n$ $\ln 143 = \ln K + n \ln 0.2$

$\ln 253 = \ln K + n \ln 0.6$

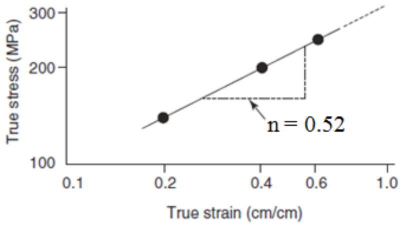
on simplification:

$(4.962 - 5.517) = n(-1.609 + 0.511)$

$\Rightarrow \ln 143 = \ln K + n \ln 0.2$

$n = 0.52$

A strain hardening coefficient of 0.51 is typical of FCC metals.



03(a).

Sol: **Shell moulding** is an expendable mold casting process that uses a resin covered sand to form the mold. As compared to sand casting, this process has better dimensional accuracy, a higher productivity rate, and lower labor requirements. It is used for small to medium parts that require high precision. Shell mold casting is a metal casting process similar to sand casting, in that molten metal is poured into an expendable mold. However, in shell mold casting, the mold is a thin-walled shell created from applying a sand-resin mixture around a pattern. The pattern, a metal piece in the shape of the desired part, is reused to form multiple shell molds. A reusable pattern allows for higher production rates, while the disposable molds enable complex geometries to be cast. Shell mold casting requires the use of a metal pattern, oven, sand-resin mixture, dump box, and molten metal.

Shell mold casting allows the use of both ferrous and non-ferrous metals, most commonly using cast iron, carbon steel, alloy steel, stainless steel, aluminum alloys, and copper alloys. Typical parts are small-to-medium in size and require high accuracy, such as gear housings, cylinder heads, connecting rods, and lever arms.

The shell mold casting process consists of the following steps:

Pattern creation: A two-piece metal pattern is created in the shape of the desired part, typically from iron or steel. Other materials are sometimes used, such as aluminum for low volume production or graphite for casting reactive materials.

Mold creation: First, each pattern half is heated to 175-370 °C and coated with a lubricant to facilitate removal. Next, the heated pattern is clamped to a dump box, which contains a mixture of sand and a resin binder (Fig: Step - I). The dump box is inverted, allowing this sand-resin mixture to coat the pattern (Fig: Step - II). The heated pattern partially cures the mixture, which now forms a shell around the pattern (Fig: Step - III). Each pattern half and surrounding shell is cured to completion in an oven and then the shell is ejected from the pattern (Fig: Step - IV).

Mold assembly: The two shell halves are joined together and securely clamped to form the complete shell mold. If any cores are required, they are inserted prior to closing the mold. The shell mold is then placed into a flask and supported by a backing material (Fig: Step - V).

Pouring: The mold is securely clamped together while the molten metal is poured from a ladle into the gating system and fills the mold cavity.

Cooling: After the mold has been filled, the molten metal is allowed to cool and solidify into the shape of the final casting.

Casting removal: After the molten metal has cooled, the mold can be broken and the casting removed. Trimming and cleaning processes are required to remove any excess metal from the feed system and any sand from the mold.

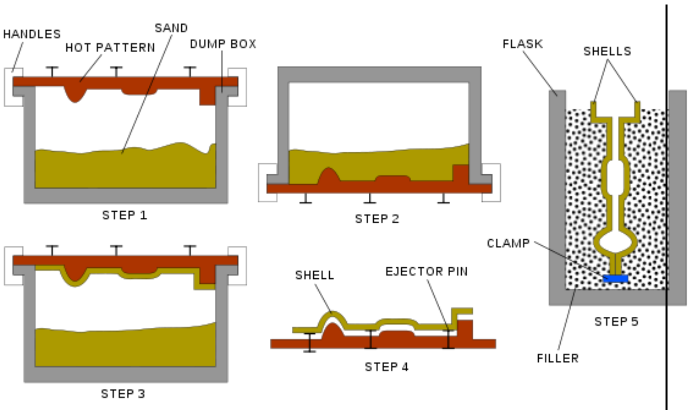


Fig: Shell molding casting process.

Applications:

- Cylinder heads, connecting rods, Engine blocks and manifolds, machine bases

Advantages

- Shell molding can be completely automated for mass production.
- The high productivity, low labour costs, good surface finishes.
- Complex shapes and fine details can be formed with very good surface finish, high production rate.
- Low tooling cost, little scrap generated.
- Very large parts and complex shapes can be produced.
- Many material options.
- Low tooling and equipment cost.
- Short lead time possible.

Disadvantages

- The gating system must be part of the pattern because the entire mold is formed from the pattern, which can be expensive.
- The resin for the sand is expensive, although not much is required because only a shell is being formed.
- High equipment cost.
- Poor material strength.
- Secondary machining often required.
- High labour cost if done manually.

03(b).

Sol:

	A	**B**	**capacity**
Casting	7	5	35
Machining	8	4	32
Inspection	4	6	24
Profit/Unit	30	40	
	x	**y**	

$Z_{max} = 30x + 40y$

Subject to

$7x + 5y \leq 35$

$8x + 4y \leq 32$

$4x + 6y \leq 24$

$x \geq 0, \quad y \geq 0$

$Z_{max} = 30x + 40y$

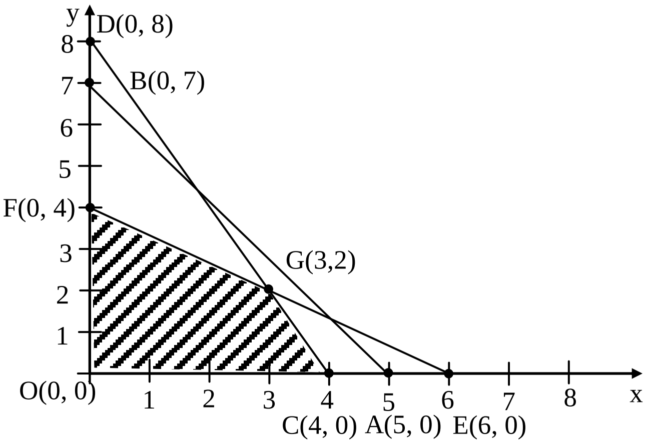
Subject to

$$\frac{x}{5} + \frac{y}{7} \leq 1 \quad \ldots\ldots\ldots\ (1)$$

$$\frac{x}{4} + \frac{y}{8} \leq 1 \quad \ldots\ldots\ldots..(2)$$

$$\frac{x}{6} + \frac{y}{4} \leq 1 \quad \ldots\ldots\ldots..(3)$$

$x \geq 0, \ y \geq 0$



"G" is the intersection of (2) and (3) equations

$$\begin{array}{r} 8x + 4y = 32 \\ 4x + 6y = 24 \\ \hline 8x + 4y \quad = 32 \\ -8x \pm 12y = -48 \\ \hline -8y = -16 \\ y = 2 \end{array}$$

$4x + 6y = 24$

$4x + 6 \times 2 = 24$

$4x = 12$

$x = 3$

$Z_{max} = 30x + 40y$

Corner points of solution space are

O(0,0); C(4,0); G(3,2); F(0,4)

$Z_0 = 0$

$Z_C = 30 \times 4 + 40 \times 0 = 120$

$Z_G = 30 \times 3 + 40 \times 2 = 170$

$Z_F = 30 \times 0 + 40 \times 4 = 160$

$Z_{max} = 170$; $x = 3$; $y = 2$

03(c).

Sol: The unbalance in rotors will not only cause rotor vibrations, but also transmit rotating forces to bearings and to the foundation structure. The force thus transmitted may cause damage to the machine parts and its foundation. If the transmitted force is large enough, it might affect even the neighbouring machines and structures. Thus, it is necessary to remove the unbalance of a rotor, to as large an extend as possible, for its smooth running. The residual unbalance estimation in rotor-bearing system is an age-old problem. From the state of the art of the unbalance estimation, the unbalance can be obtained with fairly good accuracy

1. *Two plane balancing:* For rigid rotors only ($\omega < \omega_{cr}$) this method can be used.
2. *N-plane balancing:* For flexible rotors ($\omega > \omega_{cr}$) this method is used. If the shaft deflects, and the deflection and the centrifugal force change with speed, as it does in the vicinity of critical speeds ($\omega > \omega_{cr}$).

2-plane cradle balancing machine:

The rotor is placed in the bearings of a cradle as shown in Figure.

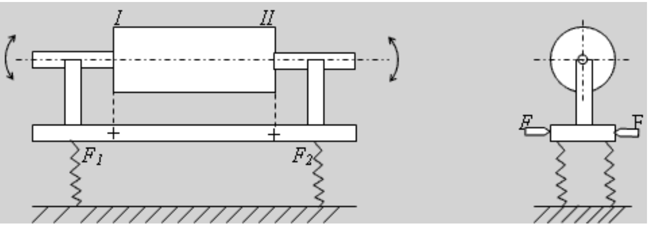


Figure: 2-plane cradle balancing machine

The cradle is placed on two springs and can be fulcrumed about F_1 or F_2 to form a simple vibrating system. Two fulcrum can be located at two chosen balance planes (i.e. I and II), where the correction mass to be added. The rotor can be driven by a motor through a belt pulley arrangement. If the spring system is such that the natural frequency of the system is in the range of motor speed, the phase angle or the location of the mass in either plane can be determined as follows. Fulcrum the cradle in plane *I* by fixing F_1 and releasing F_2. Run the rotor to resonance, observing the amplitude of vibration to the right of fulcrum F_2. This vibration is due to all the unbalance in plane *II*, since the unbalance in plane *I* has no moment about F_1. Use a trial mass at a chosen location and determine the amplitude of vibration.

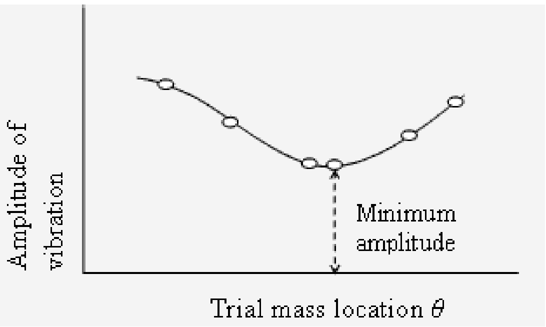


Fig: Plot of vibration amplitudes versus trial mass locations

Make a plot of this amplitude for different location of the same trial mass (see Fig.). The trial mass for correction is added at the location where the amplitude of vibration is minimum. Increase or decrease the trial mass at the same locations, until the desired level of balance is achieved. Similar procedure can be repeated by Fixing F_2 and releasing F_1. This procedure is tedious and sometimes may be time consuming.

Systematic Balancing: A procedure to determine the correction mass and location can be laid down as follows, based on four observations of amplitude :

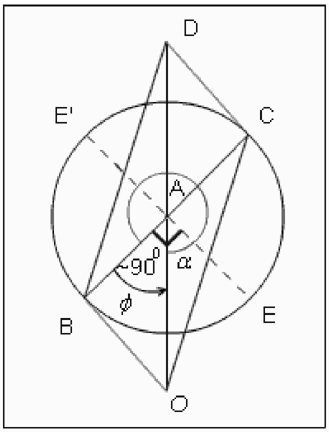
(i) without any mass addition to the rotor

(ii) with a trial mass at $\theta = 0°$

(iii) with a trial mass at 180° and

(iv) with same trial mass at $\theta = \pm 90°$, where θ measured from a conveniently chosen location. This procedure has to be repeated for two cases (e.g. when first fulcrum at F_1 and then second fulcrum at for F_2).

Let OA be the amplitude measured with trial run (1), OB is the amplitude measured in trial run (2) by addition of a trial mass W_t at 0° (arbitrary chosen location on rotor). Hence the vector AB will represent the effect of trial mass W_t. OC is the vibration measured in trial run (3), with the trial mass at 180°. So we will have AB = AC with 180° phase difference between them (Hence AC vector is also the effect of trial mass W_t so the magnitudes AB = AC and phase will be 180°). However we know only OA, OB & OC from test run (1), (2) & (3) respectively & conditions AB = AC with 180° phase. From this information, construct or locate points O, A, B & C on a plane.



Erect a line OAD equal to 2OA. With O a center and OB & OC as radii and D as center and OC & OB as radii draw arcs to intersect at B & C. Draw a circle with BC as diameter and A as center. Construct the parallelogram OBDC (point B and C we will be obtained by above construction). Now AB represents 0° position (i.e. the reference line) and AC 180° position on the rotor (AO is actual unbalance). The angular measurement may be clockwise (CW) or counter CW (CCW) and is determined from the fourth observation (see figure). The observation could be either OE or OE' (+90° or –90°). If the value observed is in the vicinity of OE, then the angle to be measured CCW. However it will be CW if OE' is the reading observed in test (the fourth run also checks the validity of the linearity used in the balancing procedure). The magnitude of trial mass W_t is proportional to AB. The unbalance OA can be obtained accordingly in mass term. The location of unbalance is ∠OAB and the direction from figure (i.e. CW or CCW). The test is repeated by making the cradle pivoted at F_2 and measurements made in plane I. This procedure is very time consuming and also restricts the mass and size of the rotor. Modern balancing machines use amplitude and phase measurement in two planes for balancing a rotor. The machines are either soft support or hard support machines.

03(d).

Sol: This is a binary system (C = 2). The two components are Cu and Ni. Assume constant pressure. Therefore, the following equation can be used:

$$1 + C = F + P$$

C is the number of chemically independent components, usually elements or compounds, in the system; *F* is the number of degrees of freedom, or the number of variables (such as temperature, pressure, or composition), that are allowed to change independently without changing the number of phases in equilibrium and *P* is the number of phases present

(a) At 1300°C, P = 1, since only one phase (liquid) is present; C = 2, since both copper and nickel atoms are present. Thus,

$$1 + C = F + P$$

$$\therefore \quad 1 + 2 = F + 1 \quad \text{or} \quad F = 2$$

We must fix both the temperature and the composition of the liquid phase to completely describe the state of the copper-nickel alloy in the liquid region.

(b) At 1250°C, P = 2, since both liquid and solid are present; C = 2, since copper and nickel atoms are present. Now,

$$1 + C = F + P$$

$$\therefore \quad 1 + 2 = F + 2 \quad \text{or} \quad F = 1$$

If we fix the temperature in the two-phase region, the compositions of the two phases are also fixed. Alternately, if the composition of one phase is fixed, the temperature and composition of the second phase are automatically fixed.

(c) At 1200°C, P = 1, since only one phase (solid) is present; C = 2, since both copper and nickel atoms are present. Again,

$$1 + C = F + P$$

$$\therefore \quad 1 + 2 = F + 1 \quad \text{or} \quad F = 2$$

and we must fix both temperature and composition to completely describe the state of the solid.

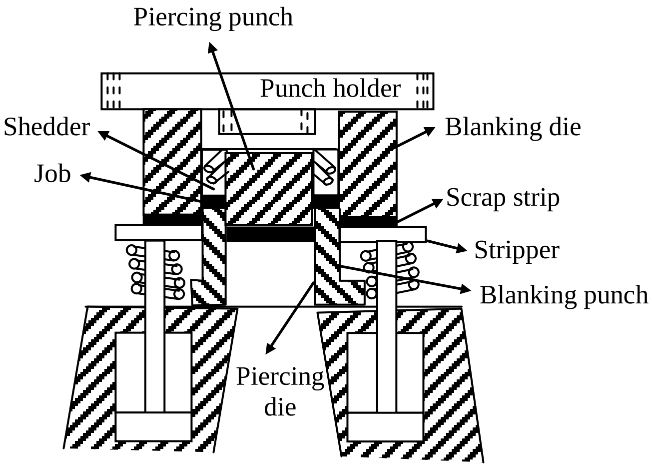
04(a)(i).

Sol: Types of dies:

1. Simple dies:

If operation is performed in only one stroke at one stage it is called as a simple die.

Compound dies: In these dies, two or more cutting operations may be performed at one station and at one stroke. The example is washer provided by blanking and piercing operations simultaneously. These are accurate and economical in mass production



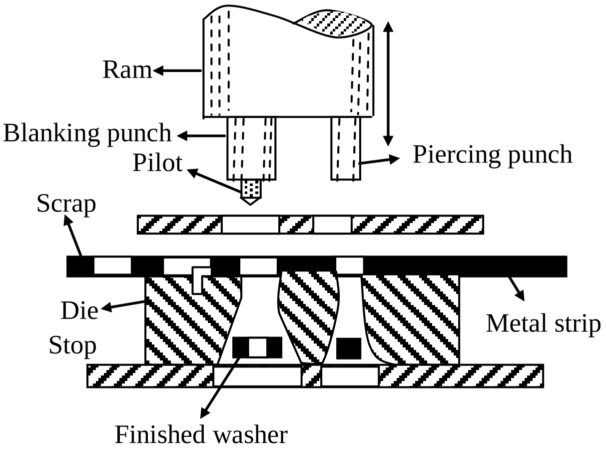
Compound die assembly

Limitations:

- Both the methods of reducing the punch cannot be used. Hence, the force required is higher.
- It is difficult to design and manufacture the punch and die combination for producing more than 3 operations.

PROGRESSIVE DIE:

- In progressive die also more than one cutting operation is performed in one stroke but at different stages and blanking will be the last operation.
- In progressive die, because the operations are performed at different stages, either the provision of shear or staggering of punches method will be used for reducing the punch force.



- Manufacturing is easy.

Disadvantage: Balancing of force on punch head is difficult.

Transfer die:

- In transfer die more than one cutting operation is performed in one stroke at different stages.
- But here the blanking operation will be the first operation and blank produced in first stage is travelling from one to another stage for completing the remaining punching operation.
- Out of two, progressive dies are preferable because sheet need to be set for every stage at every time.

Combination dies:

- If more than one cutting and forming operations are performed in one stroke at one stage it is called as combination die.

  For ex: blanking combined with deep drawing operation, blanking combined with bending and punching combined with drawing etc

Multiple Die:

To produce more than one component per stroke, more than one die is kept in parallel and is called as multiple die.

Ex: To produce 10 washers per stroke, then 10 compound die or 10 progressive dies are kept in parallel.

04(a)(ii).

Sol: Let the ram force F = YA_r, move through an incremental distance $\delta\ell$ to give the work increment

$$\delta W = YA_r\delta\ell = \frac{YV}{\ell}\delta\ell \text{ -------------------(1)}$$

where *V* is the volume displaced in a length ℓ. With a homogenous deformation of rigid plastic material, occuring between an initial length ℓ_r and a final length ℓ_e, the work/unit volume becomes

$$\frac{W}{V} = Y\int_{\ell_r}^{\ell_e}\frac{d\ell}{\ell} = Y\ln\left(\frac{\ell_e}{\ell_r}\right) = Y\ln\left(\frac{A_r}{A_e}\right) \text{ ------(2)}$$

where $A_r\ell_r = A_e\ell_e$ provides the reduction in area ratio. On the ram side, the specific work is

$$\frac{W}{V} = \frac{F\ell_r}{A_r\ell_r} = \frac{F}{A_r} \text{ ----------------------(3)}$$

Equating (2) and (3) gives the ram force:

$$F = YA_r\ln\left(\frac{A_r}{A_e}\right) \text{ ------------------------(4)}$$

In the first stage, the area reduction is

$$\frac{A_0 - A_1}{A_1} = 0.1 \Rightarrow \frac{A_o}{A_1} = 1.11$$

and from this, the true strain is

$$\varepsilon = \ln\left(\frac{\ell_1}{\ell_0}\right) = \ln\left(\frac{A_o}{A_1}\right) = \ln(1.11) = 0.105$$

From the Hollomon law, the corresponding flow stress is $\sigma = 980\times0.105^{0.19} = 638.6$ MPa.

In the second stage the strain increment is similarly found:

$$\Delta\varepsilon = \ln\left(\frac{\ell_e}{\ell_r}\right) = \ln\left(\frac{A_r}{A_e}\right) = \ln\left(\frac{20}{18}\right)^2 = 0.211$$

The total strain after stage 2 is

$\varepsilon = 0.105 + 0.211 = 0.316$,

for which the stress is

$\sigma = 980\times0.316^{0.19} = 787.3$ MPa.

The average stress for stage 2 is

$$\sigma_m = \frac{638.6+787.3}{2} = 712.97 \text{ MPa}$$

and from this, the extrusion force in equation (4) may be modified to account for work hardening:

$$F = \sigma_m A_r \ln\left(\frac{A_r}{A_e}\right)$$

$$= 712.97\times\frac{\pi}{4}(20)^2 \ln\left(\frac{20}{18}\right)^2 = 47.2\,\text{kN}$$

04(b).

Sol:

(i) Hypoeutectic

(ii) 14% Sn

(iii) α: 19% Sn L: 61.9% Sn

$$\%\alpha = \frac{61.9-35}{61.9-19}\times100\% = 63\%$$

% L = 37%

(iv) **α:** 19% Sn, β: 97.5% Sn

$$\%\alpha = \frac{97.5-35}{97.5-19}\times100\% = 80\%$$

% β = 20%

(v) Primary α: 19% Sn

% primary α = 63%

Eutectic: 61.9% Sn

% eutectic = 37%

(vi) α: 2% Sn β: 100% Sn

$$\%\alpha = \frac{100-35}{100-2}\times100\% = 66\%$$

% β = 34%

04(c).

Sol: Given:

D = 5,000 units,

A = Rs. 250/order,

h = 30% of Rs. 100 = Rs. 30/unit/year

and b = Rs. 10/unit/year.

We have

When back-ordering is permitted:

(i) $$\text{EOQ} = \sqrt{\frac{2DA}{h}}\sqrt{\frac{b+h}{b}}$$

$$= \sqrt{\frac{2\times5000\times250}{30}}\sqrt{\frac{10+30}{10}}$$

= 577.35 units

(ii) Maximum shortage level,

$$S = \sqrt{\frac{2DAh}{hb+b^2}}$$

$$= \sqrt{\frac{2\times5000\times250\times30}{30\times10+10\times10}} = 433.01 \text{ units}$$

Total variable cost

$$= \sqrt{2DAh\left(\frac{b}{b+h}\right)}$$

$$= \sqrt{2\times5000\times250\times30\times\left(\frac{10}{10+30}\right)}$$

= Rs. 4330.13

When back-ordering is not permitted:

Total variable cost = $\sqrt{2DAh}$

$$= \sqrt{2 \times 5000 \times 250 \times 30}$$

$$= \text{Rs. } 8660.25$$

(iii) Additional cost when back-ordering is not permitted.

$$= \text{Rs. } 8660.25 - \text{Rs. } 4330.13$$

$$= \text{Rs. } 4330.12$$

05(a)(i).

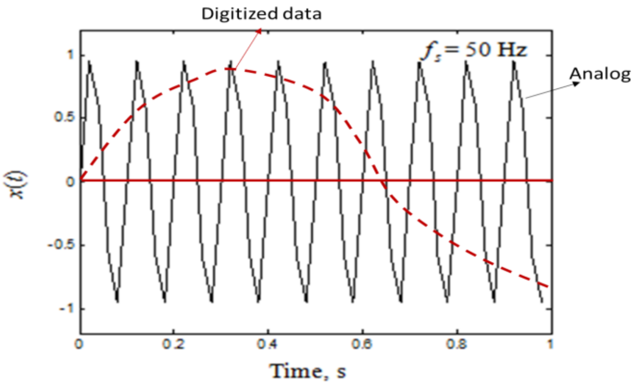
Sol: There are three main parameters are measured to evaluate the vibration characteristics of any dynamic system as displacement, velocity and acceleration.

The peak-to-peak distance is measured from the upper limit to the lower limit, measured in mm to micron level. The velocity of a vibrating object is continually changing. At the upper and lower limits, the object stops and reverses its direction of travel, thus its velocity at these two points is zero. While passing through the neutral or position of rest, the velocity is at its maximum. Since, the velocity is continually changing with respect to time, the peak or maximum velocity is always measured and commonly expressed in mm-per-second peak. When expressing the vibration characteristic in terms of velocity, both the displacement and frequency are considered. Since, the vibrating object must reverse course at the peak displacements this is where the maximum acceleration is occurs. Like velocity, acceleration is constantly changing, and the peak acceleration is usually measured.

05(a)(ii).

Sol:

(a) **Aliasing problem:** When an Analog signal $x(t)$ is changed into a sequence of digital data $\{x_n\}$ (n = 0, 1, 2, …, N) a virtual (or imaginary) wave is obtained if a fast signal is sampled slowly. For example, when a signal illustrated by the full line is sampled as shown in Figure, a virtual signal wave illustrated by the dashed line appears, although it is not contained in the original signal. The digitized signal is a representative to acquired Analog signal however it does not contain the original signal form, this phenomenon is called aliasing. This problem generally observed with a smaller sampling interval as the signal frequency increases.

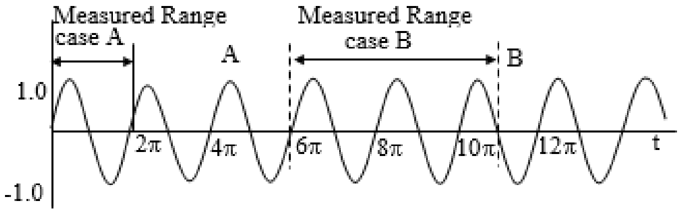


(b) **Nyquist Frequency:** To overcome the aliasing problem, the sampling frequency should be greater than two times to the critical frequency component**.** When a signal is composed of the components whose frequencies are all smaller than f_c we must sample it with a frequency higher than $2f_c$ or the sake of not losing the original signal's information. The frequency $2f_c$ is called Nyquist frequency.

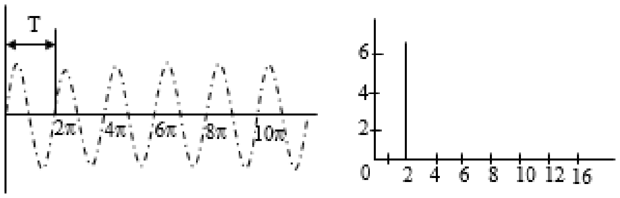
For example, if sample the signal having components of 1, 2 and 6 kHz with a sampling frequency of 10 kHz, we have an imaginary spectrum of 4 kHz, which does not exist practically. But, if sample it with a frequency of more than 12 kHz (2×6 kHz), such an aliasing problem does not occur.

(c) Leakage errors: In FFT or DFT, computations are based on the assumption that the data sampled over a time period are repeated before and after data measurement. For example, there two waves A and B measured with sampling internal and converted to digitized data as explained herebelow,

The wave A measured with sampling interval is $\Delta t = \dfrac{2\pi}{16} = 0.3926$ and the range measured is exactly twice the fundamental period. The computation of FFT or DFT is performed for the wave as shown by the dotted line in figure (a). It means, the measured the assumed wave is same as the original signal and therefore we get a correct signal spectrum.

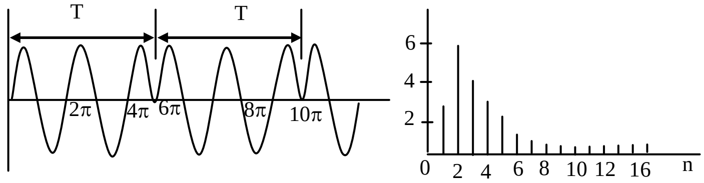


(a) Original signal and measured range



(b) Assumed signal and its spectrum (case A)

In case B, the sampling interval is $\Delta t = \dfrac{5\pi}{16} = 0.236$ and the range measured is about 2.5 times the period of the original signal. In this case, the assumed wave shown in is not smooth at the junction and differs from the original signal in time domain. As a result, the magnitude of the correct spectrum decreases and spectra that do not exist in the original signal appear. The magnitude of the correct spectrum decreases and spectra that do not exist in the original signal appear on both sides of the correct spectrum, this phenomenon is called the leakage errors.



(c) Assumed signal and its spectrum (case B)

05(b).

Sol: Given, $\lambda = 10$ per hour

$$\mu = \frac{1}{5}\times 60 = 12 \text{ per hour}$$

$$\rho = \frac{\lambda}{\mu} = \frac{10}{12}$$

(i) The probability that an arriving customer can drive directly to the space in front of the window,

$$P_o + P_1 + P_2 = P_o + \frac{\lambda}{\mu}P_o + \left(\frac{\lambda}{\mu}\right)^2 P_o$$

$$= P_o\left(1+\frac{\lambda}{\mu}+\left(\frac{\lambda}{\mu}\right)^2\right)$$

$$= \left(1-\frac{\lambda}{\mu}\right)\left(1+\frac{\lambda}{\mu}+\left(\frac{\lambda}{\mu}\right)^2\right) \quad [\because P_o = 1-\frac{\lambda}{\mu}]$$

$$= \left(1-\frac{10}{12}\right)\left(1+\frac{10}{12}+\frac{100}{144}\right) = 0.42$$

(ii) Probability that an arriving customer will have to wait outside the indicated space,

$$S = 1 - 0.42 = 0.58$$

(iii) Average waiting time of a customer in a queue,

$$= \frac{\lambda}{\mu}\frac{1}{\mu-\lambda} = \frac{10}{12}\left(\frac{1}{12-10}\right) = \frac{5}{12} = 0.417\text{hours}$$

05(c)(i).

Sol: The Brinell hardness test is widely used for testing metals and non-metals of low to medium hardness. In the test, a hardened steel (or cemented carbide) ball of 10 mm diameter is pressed into the surface of a specimen using a load of 500, 1500, or 3000 kg. The load is then divided into the indentation area to obtain the Brinell Hardness Number (BHN). In equation form,

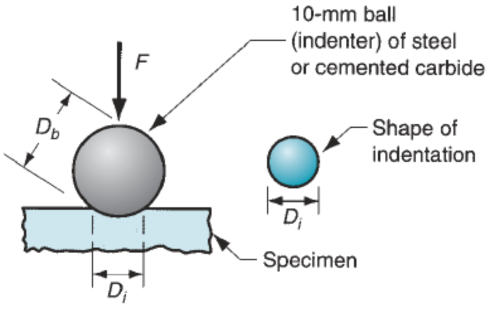
$$HB = \frac{2F}{\pi D_b\left(D_b - \sqrt{D_b^2 - D_i^2}\right)}$$

where, HB is Brinell Hardness Number (BHN);

'F' is indentation load, kg;

'D_b' diameter of the ball, mm;

'D_i' is diameter of the indentation on the surface mm as shown in figure (a).



(a) Brinell

The resulting BHN has units of kg/mm^2, but the units are usually omitted in expressing the number. For harder materials (above 500 BHN), the cemented carbide ball is used because the steel ball experiences elastic deformation that compromises the accuracy of the reading. Also, higher loads (1500 and 3000 kg) are typically used for harder materials. Because of differences in results under different loads, it is considered good practice to indicate the load used in the test when reporting HB readings.

Given,

Brinell hardness measurement:

Diameter of indenter (D_b) = 10 mm

Load (F) = 500 kg,

Indentation (D_i) = 4.5 mm

Brinell hardness number

$$(HB) = \frac{2F}{\pi D_b\left(D_b - \sqrt{D_b^2 - D_i^2}\right)}$$

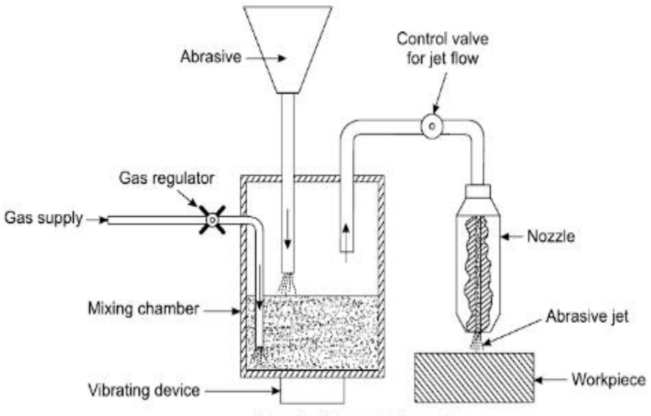
$$HB = \frac{500}{(\pi/2)(10)\left[10 - \sqrt{10^2 - 4.5^2}\right]} = 29.8$$

05(c)(ii).

Sol: FCC metals do not normally display a transition temperature; instead the impact energies decrease slowly with decreasing temperature and in at least some cases (such as some aluminium alloys), the energies even increase at low temperatures. The FCC metals can obtain large ductilities, giving large areas beneath the true stress-strain curve.

05(d).

Sol: In AJM, a focused jet or stream of abrasive particles carried by high pressure gas (carrier) is made to impinge on the work surface through a nozzle (as shown in below fig). The metal cutting occurs due to erosion caused by the abrasive particles impacting the work surface at a high speed. As a result of repeated impact, small bits of material get loosened and separated from the workpiece surface, exposing a fresh surface to the jet. AJM is different from sand blasting as the latter is a surface cleaning process and AJM is a metal cutting process.



Abrasive jet machining set-up.

Characteristics:

Abrasive particles of aluminium oxide, silicon carbide, or glass power with particle size 10 to 50 microns are used in this process, larger size particles used for rough machining and smaller size for finish work. Abrasives are contained in a hopper and fed into the mixing chamber. Compressed air or high pressure gas is supplied to the mixing chamber at a pressure 2 to 8 kgf/cm^2 and the chamber is vibrated. The amplitude of these vibrations controls the flow of abrasive. These abrasives mixed in the gas stream travel through the hose and finally pass through the nozzle at a very high speed (150 to 300 m/min). Since nozzles are subjected to very high abrasion wear, they are made of hard materials such as tungsten carbide or ceramic (synthetic sapphire).

Metal removal rate in AJM depends on the nozzle diameter, composition of abrasive gas mixture, hardness of abrasives, velocity of jet, distance of workpiece from jet and the workpiece material. A typical example may be cutting of glass with a rate of

16 mm^3/min. A tolerance of ± 0.05 mm in diameter can be attained.

Application:

AJM finds use in fine drilling, cutting thin section of glass and refractory, machining intricate profiles on hard and fragile materials, contouring, aperture drilling for electronic microscope, machining of semi-conductors, frosting and abrading of glass article, cleaning and polishing of plastics, etc.

Advantages:

The process is capable of cutting intricate holes and shapes in materials of any hardness and brittleness; it has the ability to cut fragile and heat-sensitive materials; it has low capital cost, etc.

Limitations:

Material removal rate is slow, machining accuracy is poor, nozzle wear rate is high, abrasives may stick on to the surface of soft material and hence additional work of cleaning the surface is involved. AJM is therefore not suitable for machining ductile materials. Also, the abrasive used cannot be reclaimed.

05(e).

Sol: Nickel and Cobalt Alloys :

- *Nickel and cobalt alloys are used for* corrosion protection and for high-temperature resistance, taking advantage of their high melting points and high strengths. Nickel is FCC and has good formability; cobalt is an allotropic metal, with an FCC structure above 417°C and an HCP structure at lower temperatures. Special cobalt alloys are used for exceptional wear resistance and, because of resistance to human body fluids, for prosthetic devices.
- Powders of nickel- and cobalt-based super alloys can be formed using spray atomization followed by hot isostatic pressing. These materials are used to make the rings that retain turbine blades, as well as for turbine blades for aircraft engines.
- Iron, nickel, and cobalt are ferromagnetic. Certain Fe-Ni- and Fe-Co-based alloys form very good magnetic materials. A Ni-36% Fe alloy (Invar) displays practically no expansion during heating; this effect is exploited in producing bimetallic composite materials. Cobalt is used in WC-Co cutting tools.

Nickel and Monel :

- Nickel and its alloys have excellent corrosion resistance and forming characteristics. When copper is added to nickel, the maximum strength is obtained near 60% Ni. A number of alloys, called Monels, with approximately this composition are used for their strength and corrosion resistance in salt water and at elevated temperatures. Some of the Monels contain small amounts of Aluminum and titanium.

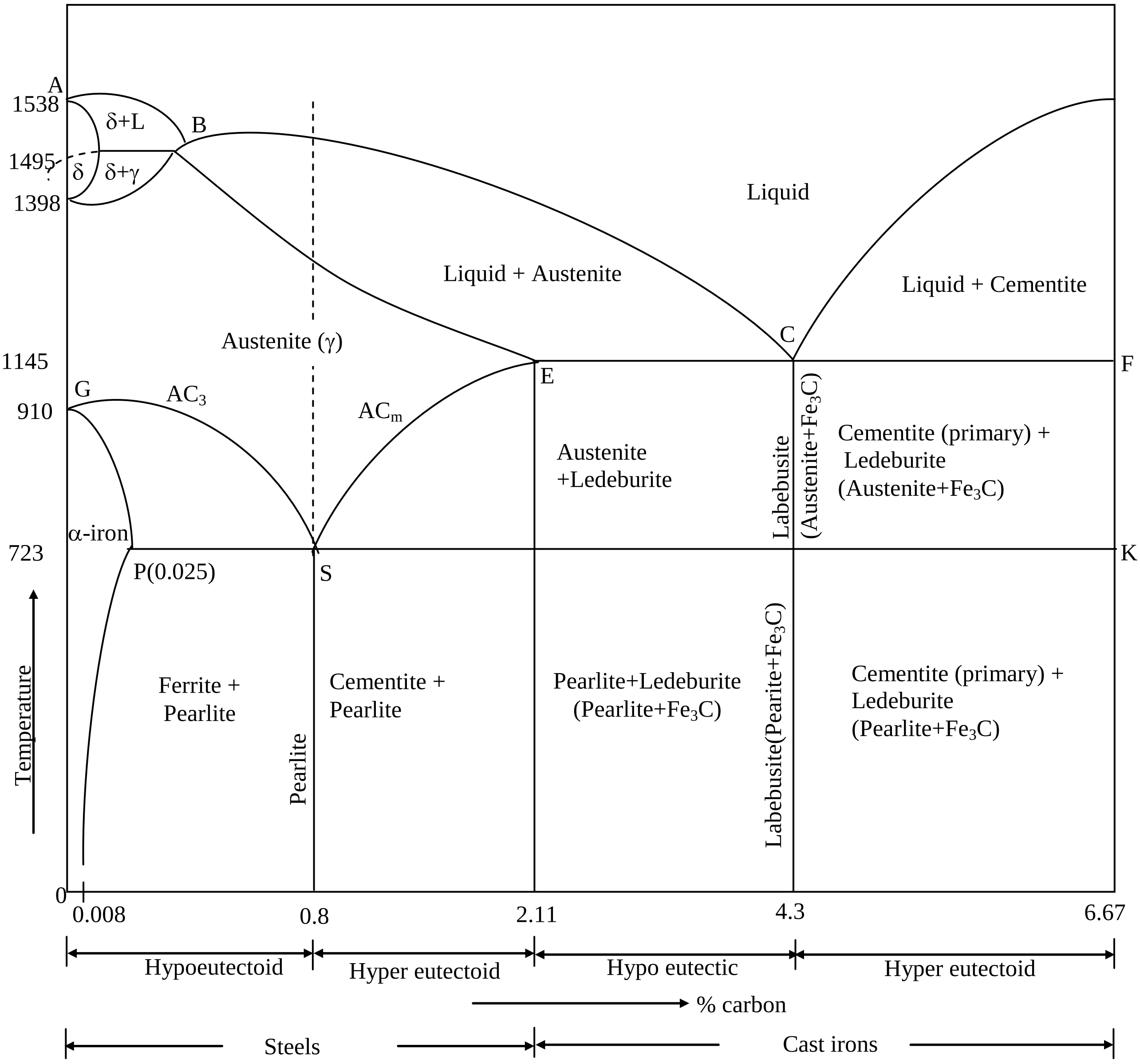
- Super alloys are nickel, iron-nickel, and cobalt alloys that contain large amounts of alloying elements intended to produce a combination of high strength at elevated temperatures, resistance to creep at temperatures up to 1000°C, and resistance to corrosion. These excellent high-temperature properties are obtained even though the melting temperatures of the alloys are about the same as that for steels. Typical applications include vanes and blades for turbine and jet engines, heat exchangers, chemical reaction vessel components, and heat-treating equipment.
- To obtain high strength and creep resistance, the alloying elements must produce a strong, stable microstructure at high temperatures. Solid-solution strengthening, dispersion strengthening, and precipitation hardening are generally employed.

06(a).

Sol: Iron-Iron carbide equilibrium diagram:

From the figure shown below:

- The iron-iron carbide equilibrium diagram concerns transformations that occur in alloys having compositions from pure iron to cementite (6.67 % of carbon). Besides it establishes a correlation between the micro structure and properties of steel and cast irons and provides a basis to understand the principles of heat treatment.
- Carbon is added to iron, to improve the strength of iron as interstitial inclusion. So that the strength of iron can be improved. The maximum solubility of carbon in iron is 6.67 %, called as critical concentration.
- If Carbon is added to iron, it forms iron carbide (Fe_3C) phase, also known as cementite, which is more hard and brittle phase.
- If % of carbon = 0 to 2.11 % → Steel
- If % of carbon = 2.11 to 6.67 → cast iron
- Brittleness & Hardness of cast iron will be more compared to steel.



Iron – Iron carbide equilibrium diagram

In any phase, if carbon content is high ⇒ Iron carbide (free iron volume is less) ⇒ It exhibits more hardness.

∴ $H_{Fe} < H_{steel} < H_{cast\ iron}$

Also

$(H)_{iron} < (H)_{LCS} < (H)_{MCS} < (H)_{HCS} < (H)_{CI}$

About δ–Fe:

- The max solubility of carbon in iron is 0.008% at 1495°C.
- δ Fe contains very small carbon content ⇒highly ductile phase.
- δ Fe is difficult to produce because addition of very small carbon content in iron lattice at high temperature with uniform distribution is very difficult⇒most unstable phase and difficult to exist.
- Structure is B.C.C

About γ–Fe (Austenite):

- Max solubility of carbon is 2.11% at 1145°C.
- The min temperature above which γ iron can form is 723°C at .77% carbon.
- By varying carbon content form 0 to 2.11%, variety of steels can be produced in Austenite phase either by heating or cooling process, the grain size of γ Fe can be modified ⇒ Strength can be changed.
- Structure is FCC
- γ Fe is non magnetic in nature.

About α–Fe (ferrite):

- The maximum solubility of carbon is 0.025% at 723°C.
- The min solubility of carbon is 0.0025 % at room Temperature.
- As it contains very less % of carbon, its properties are similar to pure iron.
- Structure is B.C.C
- Magnetic in nature.
- Easily producible.

The iron-iron carbide equilibrium diagram has three invariant reactions as follows:

(i) **The peritetic (point B) reaction:**

The peritectic reaction occurs at a temperature of about 1492°C and its equation may be written as:

$$\delta + \text{Liquid} \xrightleftharpoons[\text{Heating}]{\text{Cooling}} \text{Austenite}$$

The peritectic point is at 0.18 percent carbon.

(ii) **The eutectic (point C) reaction:**

The eutectic reaction occurs at a temperature of about 1130°C and its equation may be written as:

$$\text{Austenite (Solid)} \xrightleftharpoons[\text{Heating}]{\text{Cooling}} \frac{\text{Austenite + Cementite}}{\text{Eutectic mixture (Ledeburite)}}$$

The eutectic point is at 4.3 percent carbon.

(iii) **The eutectoid (point S) reaction:**

The eutectoid reaction occurs at a temperature of about 723°C.

$$\text{Austenite (Solid)}\ \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}}\ \frac{\text{Ferrite + Cementite}}{\text{Eutectic mixture (pearlite)}}$$

Note:

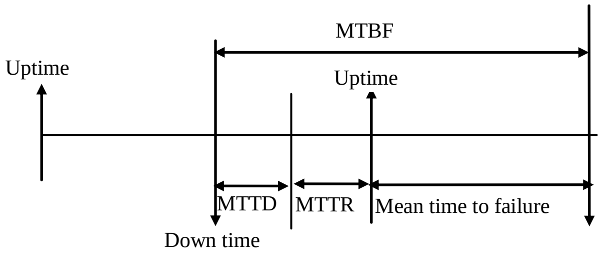
Iron – carbon phase diagram will explain the phase transformations that are happening with respect to the carbon content in iron like formation of steel or cast iron, but does not explain about the production aspects of steel and cast iron.

06(b).

Sol: Mean time between failures (MTBF) is the critical characteristic for repairable system and is mean or average time between two successive failures of the system. MTBF is obtained by running an item or equipment for a predetermined length of time under specified conditions. The average length of a time between failures can be determined as

$$\text{MTBF} = \frac{\text{Total operating hours for all items}}{\text{Total number of failures}}$$

$$= \frac{\text{No. of cycles}}{\text{Total no. of failures}}$$



MTBF representation of a system during its working period

MTBF can be expressed as inverse of failure rate ‘λ’. However, exponential distribution is a distribution which is fully defined by a single parameter that governs the scale of the distribution function

$$f(x) = \lambda e^{-\lambda t}, t \geq 0, \lambda > 0$$

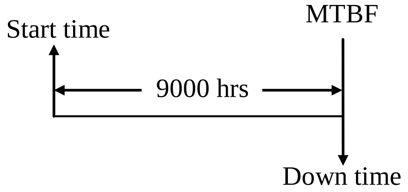
where, t = time, λ = failure rate

Case (i):

The machine mean time between failures is 9000 hrs.

The company given warranty is 1 year.

Since the MTBF is 9000 hrs and company warranty is exactly one year which is equal to MTBF.



According to statistical theory behind the statistics of confidence intervals, the statistical average becomes two as the no of samples increase.

The MTBF of 9000 hrs for one module for one year. No. of expected failure will be 1 at the end of period.

$$MTBF = \frac{T}{R} = \frac{9000}{1}$$

Chances for getting break down within warranty period is one.

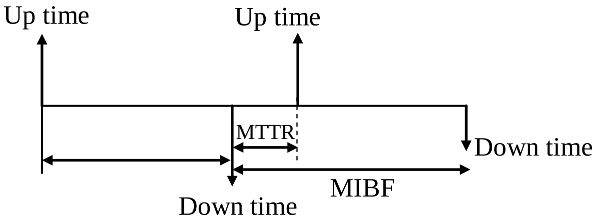
Reliability of machine :

$$R(t) = e^{-t/\text{MTBF}} = e^{-1} = 0.3677 \approx 36.8\%$$

Chances for failures over a period one year is 63.2%

For t = 9000 hr, MTBF = 9000 hrs.

Case (ii):



Total time T = 9000

Expected failure in one year = 2

$$\text{MTBF} = \frac{9000}{2} = 4500\,\text{hrs}$$

Failure rate $\lambda = \dfrac{1}{\text{MTBF}}$

$$R(t) = e^{-t/\text{MTBF}} = e^{-2} = 0.718 = 71.8\%$$

The survival of component i.e. reliability is only 71.8%

Further chances for breakdown

$$= 1 - R(t) = 1 - 0.718 = 28.2\%$$

06(c)(i).

Sol:

- Centerless grinding is an alternative process for grinding external and internal cylindrical surfaces. As its name suggests, the workpiece is not held between centers. This results in a reduction in work handling time. Hence, centerless grinding is often used for high-production work.
- The setup for external centerless grinding (Figure a), consists of two wheels: the grinding wheel and a regulating wheel. The workparts, which may be many individual short pieces or long rods (e.g.,3 to 4 m long), are supported by a rest blade and fed through between the two wheels. The grinding wheel does the cutting, rotating at surface speeds of 1200 to 1800 m/min.

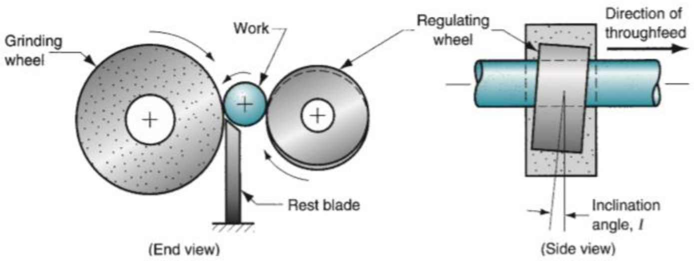


Fig (a): External centerless grinding.

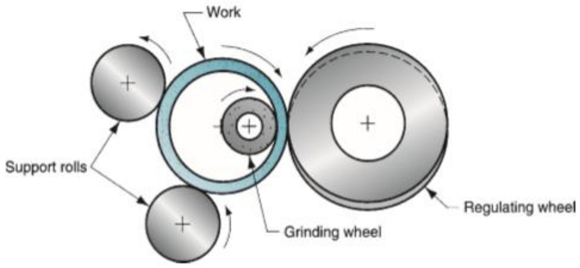


Fig (b): Internal centerless grinding.

- The regulating wheel rotates at much lower speeds and is inclined at a slight angle *I* to control through feed of the work. The following equation can be used to predict through feed rate, based on inclination angle and other parameters of the process:

$$f_r = \pi D_r N_r \sin I$$

where, f_r = through feed rate in mm/min,

D_r = diameter of the regulating wheel in mm,

N_r = rotational speed of the regulating wheel in rev/min; and

I = inclination angle of the regulating wheel.

- The typical setup in internal centerless grinding is shown in Figure (b). In place of the rest blade, two support rolls are used to maintain the position of the work. *The* *regulating wheel is tilted at a small inclination angle to control the feed of the work past the grinding wheel*. Because of the need to support the grinding wheel, through feed of the work as in external centerless grinding is not possible. Therefore, this grinding operation cannot achieve the same high-production rate as in the external centerless process.

- Its advantage is that it is capable of providing very close concentricity between internal and external diameters on a tubular part such as a roller bearing race.

06 (c)(ii).

Sol:

(i) *Angularity:* The extent to which parts feature such as a surface or axis is at a specified angle relative to a reference surface.

If the angle = 90°, then the attribute is called perpendicularity or squareness.

(ii) *Circularity:* For a surface of revolution such as a cylinder, circular hole, or cone, circularity is the degree to which all points on the intersection of the surface and a plane perpendicular to the axis of revolution are equidistant from the axis.

For a sphere, circularity is the degree to which all points on the intersection of the surface and a plane passing through the center are equidistant from the center.

(iii) *Concentricity*: The degree to which any two (or more) part features such as a cylindrical surface and a circular hole have a common axis.

(iv) *Cylindricity:* The degree to which all points on a surface of revolution such as a cylinder are equidistant from the axis of revolution.

(v) *Flatness*: The extent to which all points on a surface lie in a single plane.

07(a).

Sol: Time available for production

$$T = 60 \times 60 \text{ seconds}$$

No. of ovens to be manufactured = N = 40

Cycle time ,

$$C = \frac{T}{N} = \frac{360}{40} = 90 \text{ seconds}$$

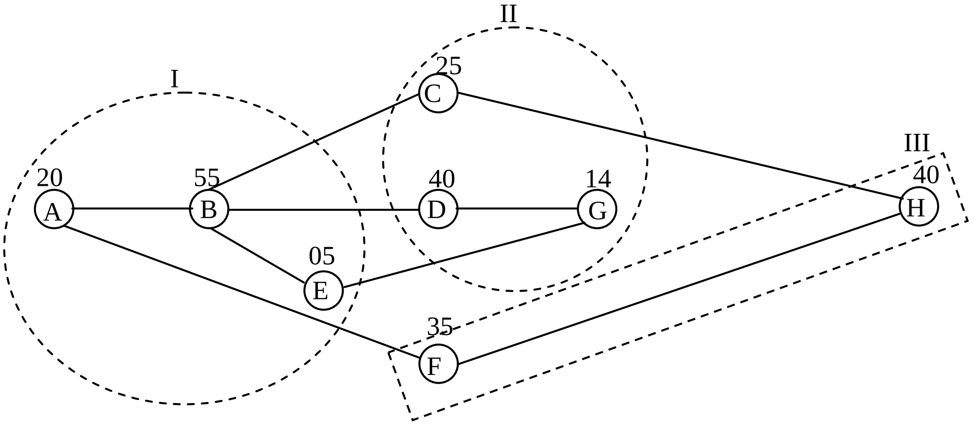
Time to assemble one unit

$$\Sigma Ti = 234 \text{ seconds}$$

Theoretical number of work stations

$$\frac{\Sigma ti}{C} = \frac{234}{90} \approx 3$$

Technological precedence diagram



Work station	Elements	Time
I	A, B, E	80
II	C, D, G	79
III	F, H	75

Actual number of work stations = n = 3

Idle time = (90 – 80) + (90 – 79) + (90 – 75) = 10 + 11 + 15 = 36 seconds

$$\eta_{line} = \frac{\Sigma t_i}{nc}\times 100 = \frac{234}{3\times 90}\times 100 = 86.67\%$$

Balance delay = 100 – η_{line} = 100 – 86.67 = 13.33%

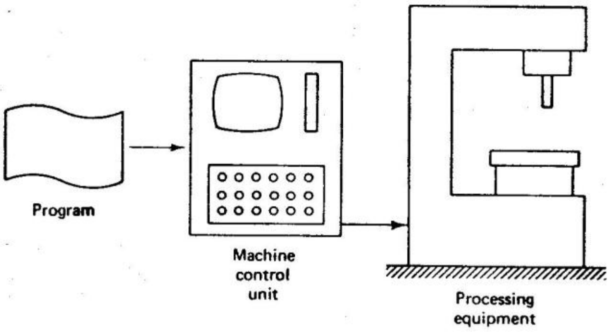
The highest allotment is 80 seconds to work station (1)

Technically 1 unit rolls out of the line every 80 seconds.

07(b).

Sol: **Major Parts in NC Machine are:**

1. MCU or CPU
2. Drive unit
3. Feed back device
4. Tape reader system
5. Manual controls



- *Machine control unit* (MCU) consists of the electronics and control hardware that read and interpret the program of instructions and convert it into mechanical action of the machine tool.
- The instruction undergo electric processing and the control unit sends command signals to the *drive units* of machine tool and also to the electrical cabinet called *magnetic box*.
- Command signals sent to the drive units of the machine tool, control the lengths of travel and the feed rates, while the command signals sent to the magnetic box control other functions such as spindle motor starting and stopping, selecting spindle speeds, actuation of tool change, coolant supply etc.
- *Feed back transducer* is provided to check whether the required lengths of tool travel has obtained. The feed back transducer sends the information of the actual position achieved to the control unit. If there is any diff between the input command and the actual position achieved, the drive unit is actuated by suitable amplifier from the error signal.
- *Feed back device* gives the feed back to the MCU for exact control of the axis of NC machines. This will help in obtaining the component dimensions within the limits specified.
- *Program* is coded into punched tape and is fed into control unit, which directs the processing equipment accordingly; NC is also called the tape control or *tape reader system.*
- Even though the above four parts are present in the NC machine still the manual intervention is required for switching on & off the machine, loading & unloading of tape, loading & unloading of work piece etc called as *manual controls.*

07(c).

Sol: **Preventive Maintenance:** All actions carried out on a planned, periodic, and specific schedule to keep an item/equipment in stated working condition through the process of checking and reconditioning. These actions are precautionary steps undertaken to forestall or lower the probability of failures or an unacceptable level of degradation in later service, rather than correcting them after they occur.

Predictive Maintenances: The use of modern measurement and signal processing methods to accurately diagnose item/equipment condition during operation. This action will help to understand the condition of the system before major failure.

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

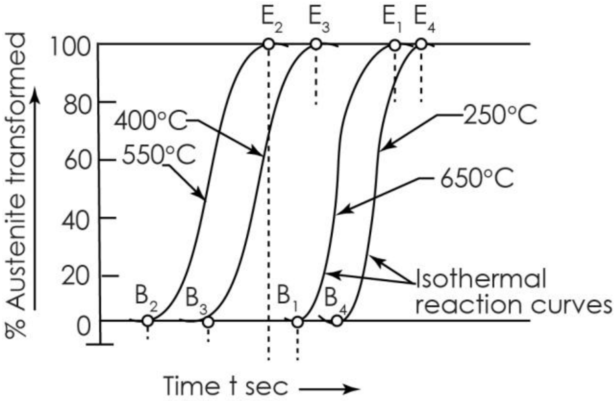
07(d).

Sol: T-T-T Diagram:

- A T-T-T (Time-Temperature-transformation) diagram is also called as *S*-curve, *C*-curve isothermal (decomposition of austenite) diagram and Bain's curve. T-T-T diagrams are extensively used in the assessment of the decomposition of austenite in heat-treatable steels. As the iron-carbon phase diagram does not show time as a variable, the effects of different cooling rates on the structures of steels are not revealed. Secondly, equilibrium conditions are not maintained in heat treatment. The iron-carbon equilibrium diagram reveals on the phases and corresponding microstructures under equilibrium conditions but many useful properties of the steels are obtained under non-equilibrium conditions such as variable rates of cooling as produced during quenching and better transformation of austenite into pearlite and martensite.
- To construct a T-T-T diagram, a number of small specimens of steel are heated to a temperature at which austenite is stable and then rapidly cooled to a number of temperatures like 650°C, 600°C, 500°C, 250°C, etc. The specimens are held at these temperatures for different periods of time (isothermally) until the austenite is completely decomposed. It will be observed experimentally that, at the start of the cooling

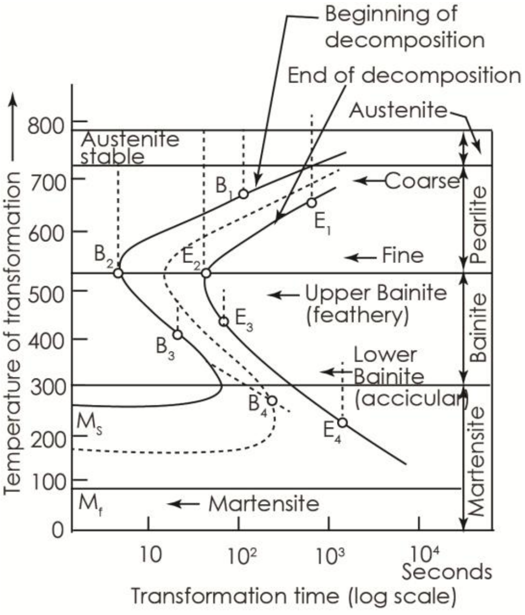
as marked by points B_1, B_2, B_3 and B_4, there is no decomposition of austenite. This time period is called the incubation period. After this, austenite begins to decompose into the ferrite-cementite mixtures. After a certain period of time, the process of decomposition of austenite is stopped, as designated by points E_1, E_2, E_3 and E_4 . It will also be observed that the rate of decomposition of austenite is not constant but is rapid initially and gradually slows down.

- Figure below shows the isothermal transformation of the austenite in steel containing 0.8 % carbon. In such diagrams, for the sake of convenience, the time scale is logarithmic as the decomposition of austenite takes from a fraction of a second to hours. By plotting the starting and end points of the decomposition of austenite, two different curves are obtained. Austenite transformation takes place in the area between these two curves. The important products of austenite decomposition are labelled at the respective positions on the T-T-T diagram.
- The austenite is stable above 723°C and its stability first rapidly decreases with increase in cooling rate. It is least stable at about 500-550°C and then starts to increase below this temperature range. At temperatures between 250 and 50°C, we observe a diffusionless transformation of austenite into a hardened steel structure called Martensite. This is the super saturated solid solution of carbon in α-iron.



(a) Isothermal reaction curves

- At temperatures near 700 °C a ferrite-cementite mixture with coarse pearlite is obtained. From 700°C to 550°C, the product of austenite decomposition (a mixture of ferrite-cementite), lamellar in structure, and finer pearlite is obtained. This structure is known as sorbite. When the temperature is lowered to between 550°C to 500°C, an evenly dispersed mixture of ferrite-cementite called troostite is obtained. With further fall in temperature from 500°C to 300°C, a needle-like structure known as accicular troostite or bannite is obtained.



(b) Construction of T T T diagram

Note:

With fall in temperature, the ferrite-cementite mixture will be harder due to the increased rate of dispersion.

(a) **Martempering:**

- Applicable to steel with %C = 0 to 0.4%.
- The process consists of heating the steel to the hardening temperature and then cooled suddenly (at above the critical rate of cooling) down to a temperature just above 'Ms' point (temperature at which martensite formation begins and is nearly equal to 240°C).
- It is held there for sufficient time to equalize the temperature throughout the section i.e., whole volume converts to martensite.
- The martensitic transformation takes place under lower cooling rate and therefore the internal stresses are reduced to greater extent.
- This method can be used for heavy sections and the pieces of irregular shape.

(b) **Austempering:**

- Applicable to steel with %C = 0.8.
- Austempering is also a kind of interrupted quenching in a tempering process. But in austempering instead of martensite structure formation during quenching, Bainite structure is produced.
- Austempering of steel is carried out by heating the steel above the upper critical range to make it all austenite form.
- It is then quenched at a critical cooling rate in a oil bath maintaining a temperature range of 723°C.
- The whole austenite steel is converted to bainite. Then the second stage of gradual cooling to room temperature is done.
- The steel produced by this process has greater ductility and toughness.
- Residual stresses will be minimized.
- No cracks in the austempering component.

08(a)(i).

Sol: Bottom-up Approach:

- Bottom up approach refers to the build up of a material from the bottom; atom by atom, molecule by molecule or cluster by cluster.
- The colloidal dispersion is a good example of bottom up approach in the synthesis of nano particles.
- This method is not a new concept. All the living beings in nature observe growth by this approach only and also it has been in industrial use for over a century.

  Eg: The production of salt and nitrate in chemical industry.
- Bottom up approach gives a better chance to obtain nano structures with less defects, more homogeneous chemical composition.
- Bottom up methods can be divided into gas-phase and liquid-phase methods.

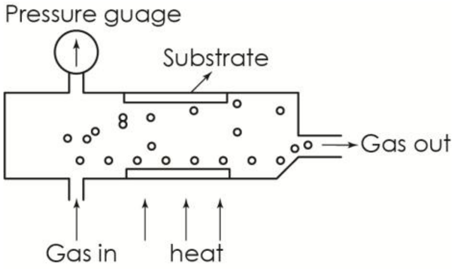
Gas-phase methods:

Plasma arcing and chemical vapour deposition

Liquid phase methods:

Sol-gel synthesis, molecular self-assembly

Chemical vapour deposition:



The material to be deposited is first heated to its gas form and then allowed to deposit as a solid on a surface.

- The method is normally performed under vacuum.
- The deposition can be direct or through a chemical reaction so that the material deposited is different from the one volatilized.
- This process is routinely used to make nanopowders of oxides and carbides of metals if carbon or oxygen are present with the metal.
- The method can also be used to generate nanopowders of pure metals, although not so easily.
- Chemical vapour deposition is often used to deposit a material on a flat surface.
- When a surface is exposed to a chemical vapour, the first layer of atoms or molecules that deposits on the surface can act as a template on which material can grow.

Properties:

- Nanomaterials have the structural features in between atoms and the bulk materials.
- While most micro structured materials have similar properties to the corresponding bulk materials, the properties of materials with nanometer dimensions are significantly different from those of atoms and bulk materials.
- This is mainly due to the nanometer size of the materials which render them:
  (1) Large ratio of surface to volume
  (2) High surface energy
  (3) Less number of imperfections
  Which do not exist in the corresponding bulk materials.
- Due to their small dimensions, nanomaterials have extremely large surface area to volume ratio, resulting in more “surface” dependent material properties.
- This in turn may enhance or modify the properties of the bulk materials.
- For example, metallic nano particles can be used as very active catalysts.
- Chemical sensors from nanoparticles and nanowires enhance the sensitivity of equipments.

08(a)(ii).

Sol: The two planes are drawn in figure. On the (010) plane, the atoms are centered at each corner of the cube face, with 1/4 of each atom actually in the face of the unit cell.

Thus, the total atoms on each face is one. The planar density is

$$\text{Planar density}\,(010) = \frac{\text{atoms per face}}{\text{area of face}}$$

$$= \frac{1\,\text{atom per face}}{(0.334)^2}$$

$$= 8.96\ \text{atoms/nm}^2 = 8.96\times10^{14}\ \text{atoms/cm}^2$$

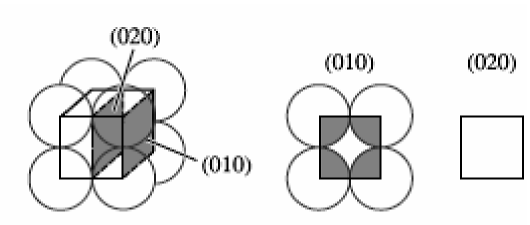


Fig: The planar densities of the (010) and (020) planes in SC unit cells are not identical

The planar packing fraction is given by,

Packing fraction (010)

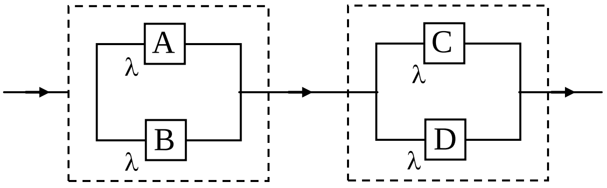
$$= \frac{\text{area of atoms per face}}{\text{area of face}}$$

$$= \frac{(1\ \text{atom})(\pi r^2)}{(a_o)^2} = \frac{\pi r^2}{(2r)^2} = 0.79$$

No atoms are centered on the (020) planes. Therefore, the planar density and the planar packing fraction are both zero. The (010) and (020) planes are not equivalent.

08(b).

Sol: Reliability diagram:



Let failure rates of A, B, C, D be λ.

$R_A = R_B = R_C = R_D = e^{-\lambda t}$

$R_{AB} = R_A + R_B - R_AR_B$

$R_{AB} = e^{-\lambda t} + e^{-\lambda t} - e^{-2\lambda t} = 2.e^{-\lambda t} - e^{-2\lambda t}$

Similarly,

$R_{CD} = 2.e^{-\lambda t} - e^{-2\lambda t}$

$R_S = R_{AB}.R_{CD} = (R_{AB})^2 = (2.e^{-\lambda t} - e^{-2\lambda t})^2$

$R_s = 4e^{-2\lambda t} + e^{-4\lambda t} - 4e^{-3\lambda t}$

$$\text{MTTF} = \int_0^\infty R_s dt = \int_0^\infty \left(4.e^{-2\lambda t} + e^{-4\lambda t} - 4e^{-3\lambda t}\right)dt$$

$$= \frac{4}{2\lambda} + \frac{1}{4\lambda} - \frac{4}{3\lambda} = \frac{24+3-16}{12\lambda} = \frac{11}{12\lambda}$$

$$\text{Failure rate} = \frac{12\lambda}{11}$$

08(c).

Sol:

Month	Forecast (Fi)	Demand (Di)	Deviation Di-Fi	|Di-Fi|
March	400	350	–50	50
April	390	440	+50	50
May	400	450	+50	50
June	410	460	+50	50
July	420	495	+75	75
August	435	510	+75	75
			$\Sigma D_i – F_i$ =250	$\Sigma\|D_i-F_i\|$ =350

$F_t = F_{t-1} + 2\,(D_{t-1} - F_{t-1})$

$\alpha = 0.2$

$F_{Apr} = 400 + 0.2\,(350–400) = 390$

$F_{May} = 390 + 0.2\,(440–390) = 400$

$F_{Jun} = 400 + 0.2\,(450–400) = 410$

$F_{July} = 410 + 0.2\,(460 - 410) = 420$

$F_{Aug} = 420 + 0.2\,(495 - 420) = 435$

$$\text{Mean absolute deviation} = \frac{\Sigma|D_i - F_i|}{n} = \frac{350}{6}$$

Cumulative deviation = $\Sigma(D_i–F_i) = 250$

Tracking signal

$$= \frac{\text{Cumulative deviation}}{\text{MAD}} = \frac{250}{\frac{350}{6}} = 4.28$$

The demand exhibits substantial variation but tracking signal is > 4

Hence an action is required to be taken and suitable correction to be made by increasing the value of (α) Smoothing constant