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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-6 : Production Engineering and Material Science

+ Mechatronics and Robotics

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	28
Q.2	30
Q.3	—
Q.4	—
Section-B	
Q.5	18
Q.6	20
Q.7	42
Q.8	—
Total Marks Obtained	138

Signature of Evaluator .... Cross Checked by ....

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IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section A : Production Engineering and Material Science + Mechatronics and Robotics

(a) Mild steel is being machined at a cutting speed of 200 m/min with a tool of rake angle 10°. The width of cut and uncut thickness are 2 mm and 0.2 mm respectively. If the average value of the coefficient of friction between the tool and chip is 0.5 and shear stress τ_s of the work material is 400 N/mm^2. Determine:

1. Shear angle
2. The cutting and the thrust component of machine force

By using

(i) Merchant's theory

(ii) Lee and Shaffer relation

[12 marks]

Q1. Given,

Cutting Speed = 200 m/min $\alpha = 10^\circ$

Chip thickness (uncut) = 0.2 mm width = 2 mm

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

$\beta = \tan^{-1}(0.5) = 26.565^\circ$

(i) Merchant's theory

$\phi = \frac{\pi}{4} - \frac{\beta}{2} + \frac{\alpha}{2} \Rightarrow \phi = 45 - \frac{26.565}{2} + \frac{10}{2}$

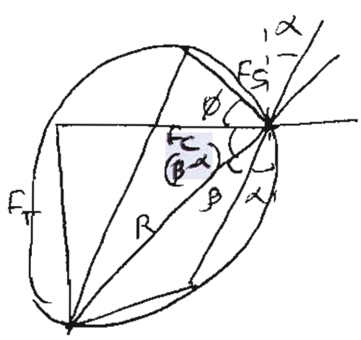
$= \boxed{36.7174^\circ}$

∴ Shear angle = 36.7174°

F_s (Shear force) = $\frac{\tau \times t \omega}{\sin\phi} = \frac{400 \times 0.2 \times 2}{\sin(36.7174)} = \boxed{267.617\ N}$

∴ R (resultant) = $\frac{F_s}{\cos(\phi+\beta-\alpha)} = \frac{267.617}{\cos(53.2824)}$

$= \boxed{450.79\ N}$



∴ $F_c = R\cos(\beta-\alpha) = \boxed{432.08\ N}$

(cutting force)

F_T (Thrust force) = $R\sin(\beta-\alpha) = \boxed{128.52\ N}$

Case II : using lee and Shaffer relation

$\phi = \frac{\pi}{4} - \beta + \alpha \Rightarrow \boxed{\phi = 28.435^0}$

$\therefore$ ~~R~~ $F_s = \frac{\tau \times 0.2 \times 2}{\sin\phi} = \boxed{336.02 N}$

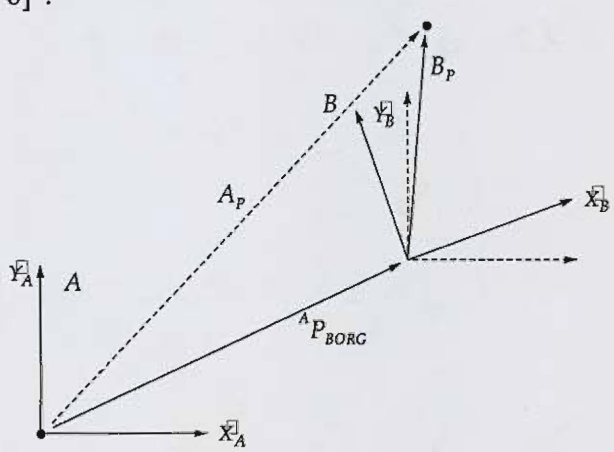
$\therefore R = \frac{F_s}{\cos(\phi + \beta - \alpha)} = \frac{F_s}{\cos(45)} = 475.204 N$

$\therefore F_c = 455.47 N$

$\boxed{F_T = 135.48 N}$

12

Q.1 (b) Figure shown below represents a frame {B}, which is rotated relative to frame {A} about Z-axis by 30 degrees, translated 10 units in $\hat{X}_A$ and translated 5 units in $\hat{Y}_A$. Find ^AP, where $^BP = [3, 7, 0]^T$.



Frame (B) rotated and translated

[12 marks]

Sol:

Rotation about Z - 30 dege. $\theta_1 = 30$

$\therefore Rot_{(z)} = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & 0 \\ s\theta_1 & c\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ $trans(x) = \begin{bmatrix} 1 & 0 & 0 & 10 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$$Trans_{(y)} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^{B}T_{A} = Trans_{(y)} \times Trans_{(x)} \times Rot_{(z)}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 10 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & 0 \\ S\theta_1 & C\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 10 \\ 0 & 1 & 0 & 5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & 0 \\ S\theta_1 & C\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^{B}T_{A} = \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & 10 \\ S\theta_1 & C\theta_1 & 0 & 5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Here. $${}^{A}T_{B} = \begin{bmatrix} R^T & -R^T D \\ 0 & 1 \end{bmatrix} \quad D = \begin{bmatrix} 10 \\ 5 \\ 0 \end{bmatrix} \quad R = \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 \\ S\theta_1 & C\theta_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\therefore R^T = \begin{bmatrix} C\theta_1 & S\theta_1 & 0 \\ -S\theta_1 & C\theta_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad -R^T D = \begin{bmatrix} -C\theta_1 & -S\theta_1 & 0 \\ S\theta_1 & -C\theta_1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} 10 \\ 5 \\ 0 \end{bmatrix}$$

$$\therefore -R^T D = \begin{bmatrix} -10C\theta_1 - 5S\theta_1 \\ 10S\theta_1 - 5C\theta_1 \\ 0 \end{bmatrix} = [$$

$$\therefore {}^{A}T_{B} = \begin{bmatrix} -0.866 & -0.5 & 0 & -11.16025 \\ +0.5 & -0.866 & 0 & 0.66087 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 3 \\ 2 \\ 0 \\ 1 \end{bmatrix}$$

4×4 . 4×1

$$\therefore {}^{A}P_{B} = \begin{bmatrix} -17.25825 \\ -3.89213 \\ 0 \\ 1 \end{bmatrix}$$

$$\therefore {}^{A}P = [-17.25825 \quad -3.89213 \quad 0]^T$$

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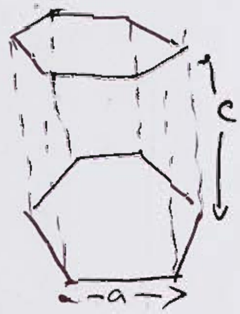
Q.1 (c) Titanium has an HCP unit cell for which the ratio of the lattice parameters (c/a) is 1.58. If the radius of the Ti atom is 0.1445 nm, then determine the unit cell volume, the density of Ti and compare it with the literature value of 4.51 g/cm^3.
[Atomic weight of Ti = 47.87 gm/mol]

[12 marks]

Sol.

HCP unit cell

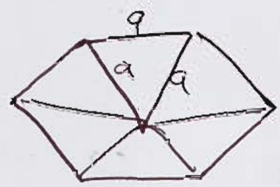


$\therefore$ Volume of unit cell $= 6\times\frac{1}{2}\times a^2\times \sin 60° c$

$= \frac{3a^2\sqrt{3}}{2} c$

$= \frac{3\sqrt{3}}{2} a^2 (1.58a)$

$= \boxed{4.104 a^3}$



for HCP we know that, $\boxed{a = 2r}$

$\therefore$ Volume $= 4.104 \times 8 \times 0.1445 \times (10^{-9})^3 m^3$

$= \boxed{~~0.1445~~ 0.099 \times 10^{-27} m^3} = 9.908 \times 10^{-29} m^3$.

~~Send~~ density $= \frac{mass}{Volume} (\rho)$

we know that for HCP no. of atoms in a crystal unit cell $n = 6\times\frac{1}{6}\times 2 + 3 + \frac{1}{2}\times 2 = 6$ atoms.

Atomic weight $=$ 47.87 gm/mol.

$\therefore$ weight of 6 atoms $= \frac{47.87 \text{ gm}}{6.023\times10^{23}} \times 6$

$\therefore \rho = \frac{6\times 47.87 \times 10^{6}}{6.023\times 10^{23} \times 9.908 \times 10^{6}} = \boxed{4.813\ g/cm^3}$

10

1 (d) State:

(i) Gibbs phase rule and lever rule

(ii) Isomorphous system

(iii) Peritectic reaction in steel

[12 marks]

(e) How are grinding operations or grinding machines classified based on the type of surface produced? Explain with neat sketch.

[12 marks]

Q.2 (a) Calculate the dimensions of a cylindrical side and top riser used for a steel casting of 30 cm × 18 cm × 12 cm dimension. The volume shrinkage can be taken as 7%. Derive all the relations used for solving the question.

[20 marks]

Sol.

Given,

Volume of Casting $= 30 \times 18 \times 12 \text{ cm}^3 = 6480 \text{ cm}^3$

Shrinkage volume $= 0.07 \times 6480 = 453.6 \text{ cm}^3$.

Case 1: For Side Riser.

Let the height of the riser $= h$ and diameter of riser be 'D'.

∴ We know that

Solidification time $(t_s) \propto \left(\frac{V}{SA}\right)^2$

∴ for having maximum solidification time to $\frac{V}{SA}$ must be maximum.

∴ let the volume of a ~~riser~~ side riser be V

$\therefore \frac{V}{SA} = \frac{V}{2\pi r^2 + 2\pi r h} = \frac{V}{2\pi r^2 + 2\pi r\left(\frac{V}{\pi r^2}\right)}$ $V = \pi r^2 h$, $h = \frac{V}{\pi r^2}$

$\therefore \frac{V}{SA} = f_n(V, r)$ for a given volume.

$\frac{df}{dr} = 0 \Rightarrow V\left[4\pi r - \frac{2V}{r^2}\right] = 0$

$\therefore 4\pi r = \frac{2V}{r^2}$ $\boxed{2\pi r \cdot r^2 = V}$

& we know that $V = 2\pi r^2 \cdot h$

$\therefore h = 2r$ or $\boxed{h = D}$ is the optimum condition.

Similarly for top riser

$\frac{V}{SA} = f(V, r) = \frac{V}{2\pi r\left(\frac{V}{\pi r^2}\right) + \pi r^2}$

$V\left[2\pi r - \frac{2V}{r^2}\right] \Rightarrow \pi r \cdot r^2 = V$

$\therefore \boxed{h = r}$ or $\boxed{h = D/2}$

6

A/q Shrinkage volume of riser = ~~3x~~ 0.02 Shrinkage vol.

$= \cancel{3}\ 0.02 \times 453.6\,cm^3$

$= \cancel{1360.8\,cm^3}$

∴ Side riser $= 453.6\,cm^3$

$V = \frac{\pi D^2}{4} \times D$ $\therefore D = \cancel{12.01cm}$ $8.32\,cm$

$H = \cancel{12.01cm}$ $8.32\,cm$

for side riser

$V = \frac{\pi D^2}{4} \times \frac{D}{2} =$ $D = 10.4923\,cm$

$H = 5.24615\,cm$

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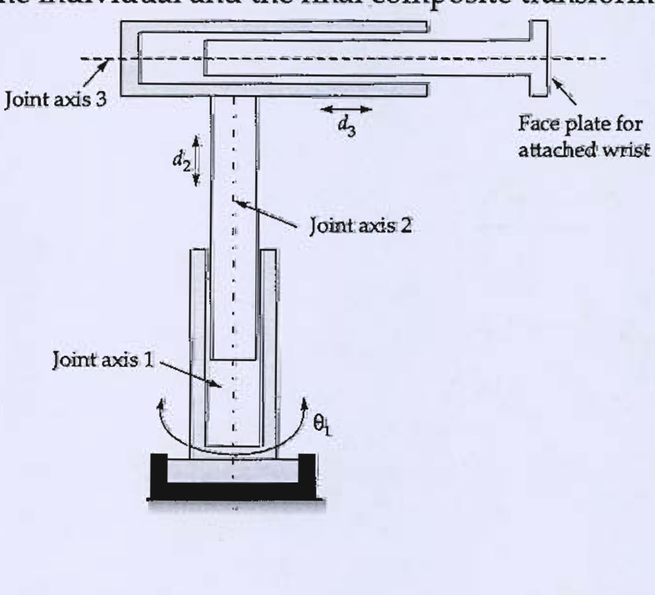
2 (b) For the given 3-link cylindrical manipulator.

1 Assign the co-ordinate frames based on D-H representation.

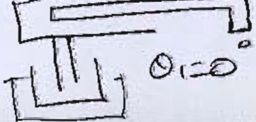
2. Make the D-H parameter table.

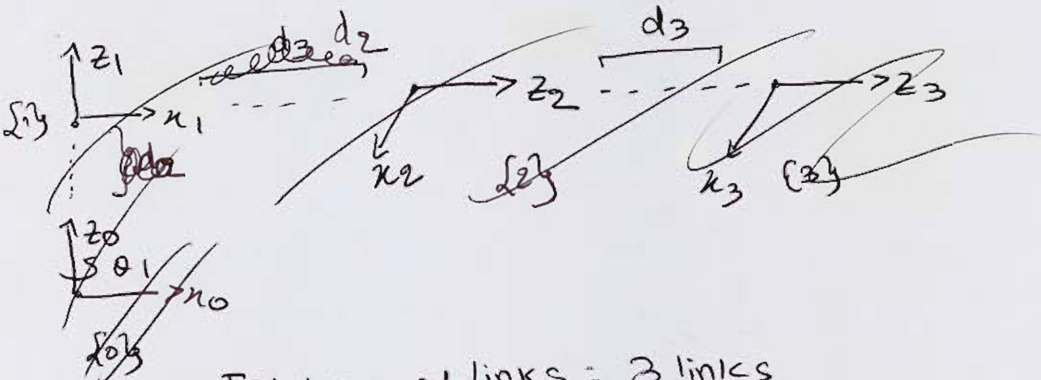
3. Prepare the individual and the final composite transformation matrix.



[20 marks]

1. Home position of manipulator $\theta_1 = 0$ $d_3 = 0$ minimum $d_2 =$ minimum





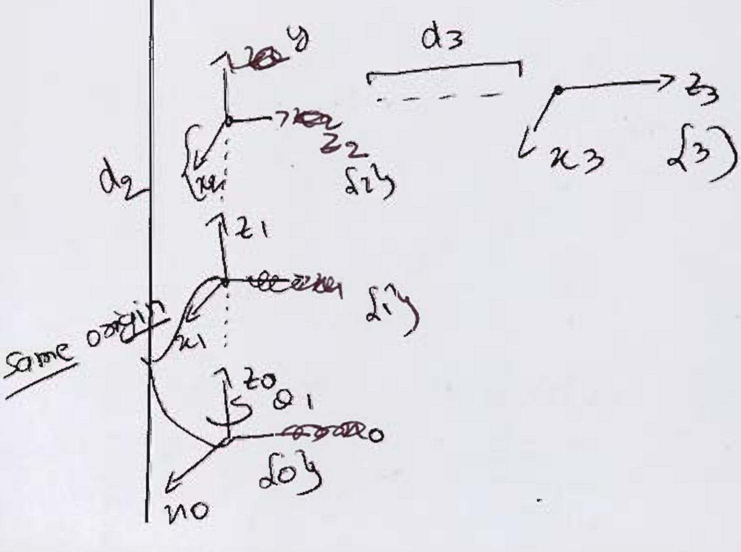
Total no. of links = 3 links
Total no. of frames = 4 ({0}, {1}, {2}, {3})

{0}: Base frame
{2}: End Effector frame.

D-H Table based on above configuration:

Plane	θ	α	a	d	Cθ	Sθ	Cα	Sα
1	θ_1	0	0		$C\theta_1$	$S\theta_1$	1	0
2	0	-90	0	d_2	1	0	0	-1
3	0	0	0	d_3	1	0	1	0

Frames



$$^{i-1}T_i = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & \sin\theta_i \sin\alpha & a_i \cos\theta_1 \\ s\theta_i & \cos\theta_i & -\cos\theta_i \sin\alpha & a_i \sin\theta_1 \\ 0 & \sin\alpha & \cos\alpha & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Generalised Transformation matrix.

$$\therefore {}^0T_1 = \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & 0 \\ S\theta_1 & C\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^1T_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^2T_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$\therefore$ overall Transformation matrix;

$$^0R_3 = {}^0T_1 \, {}^1T_2 \, {}^2T_3$$

$$= \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & 0 \\ S\theta_1 & C\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

12

$$= \begin{bmatrix} C\theta_1 & -S\theta_1 & -S\theta_1 & 0 \\ S\theta_1 & C\theta_1 & C\theta_1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} C\theta_1 & -S\theta_1 & -S\theta_1 & -d_3 S\theta_1 \\ S\theta_1 & C\theta_1 & C\theta_1 & d_3 C\theta_1 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Q.2 (c) Explain the following heat treatments processes:

1. Process annealing
2. Full annealing
3. Normalizing
4. Spheroidizing

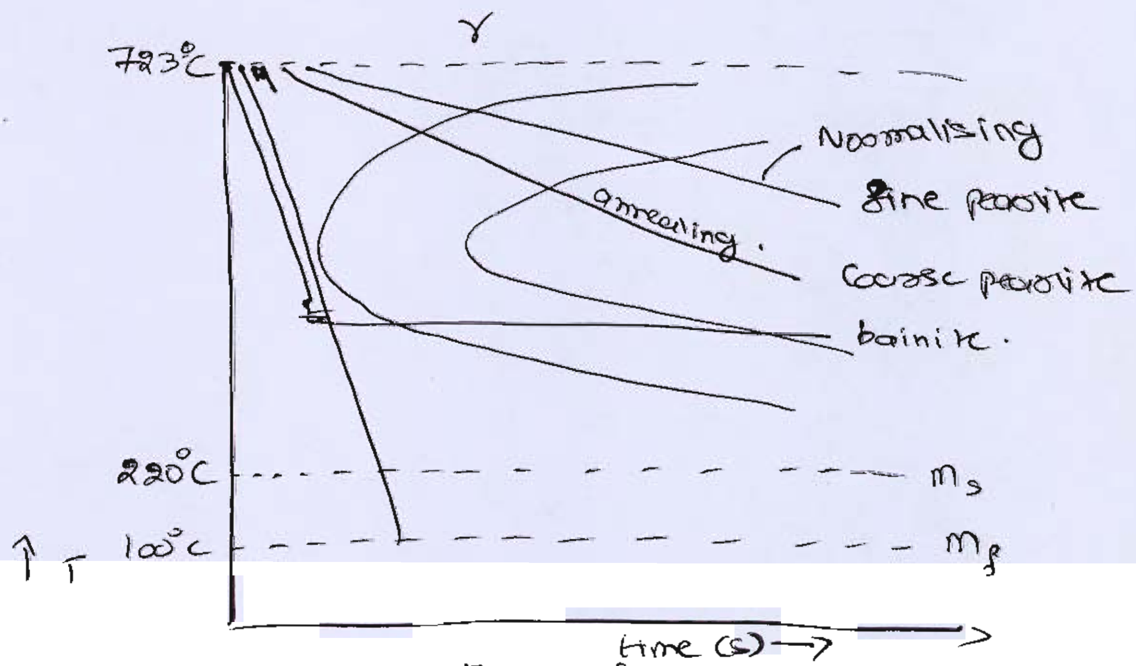
[20 marks]

Sol. 1) Full annealing: It is one of the heat treatment mechanism in which the material is heated above its eutectic temp. and allowed to cool down within the furnace itself, i.e cooling is very slow, which leads to the formation of coarse pearlitic micro-structure imparting enhanced ductility and Toughness at the cost of reduced hardness.

2) Normalizing: It is also a heat treatment mechanism, the starting phase and condition of the material is same as that of the material undergoing a full annealing process, but here the cooling rate is faster than in annealing. The hot material is allowed to cool in a water or salt-bath. The degree of hardness is more in normalised material as compared to annealed material. The final micro-structure is fine pearlitic, thus Toughness

and ductility is less than coarse pearlitic structure.

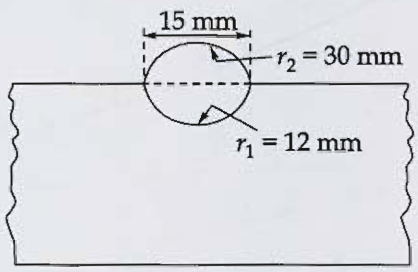
3) Spheroidizing : The process of formation of nodules or spheroidal form of one of the constituent of alloy or solid-solution during the process of recrystallisation, grain-growth or recovery is known as spheroidizing. for Example - Grey cast iron has free graphite flakes present in its micro-structure which imparts good lubricating properties and grey texture to fractured surface. Due to the addition of magnesium and Cerium, these graphite flakes takes the shape of sphere, thus imparting enhanced ductility due to reduction in local stress concentration factors.



TTT - diagram

12

Q.3 (a) The cross-section of weld bead is shown in figure. The profile of the bead and the fusion zone are taken circular for convenience. Bead width and radii of curvature of circular profiles are shown in figure. What is percentage dilution?



[20 marks]

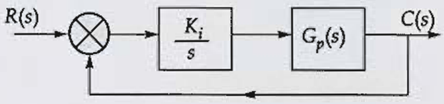
Q.3 (b) What is corrosion, explain with the help of electrochemcial reactions?

[20 marks]

Q.3 (c) A closed-loop system has the process transfer function:

$$G_p(s) = \frac{1}{s(s+4)}$$

and is used in conjunction with an integral controller as shown below:



Obtain the following

1. The system type
2. The steady-state errors when used with a step input and with a ramp input.
3. Evaluate the stability of the system in relation to a system with proportional control.
4. Evaluate the stability with integral control

[20 marks]

(a) A continuous and aligned fibre-reinforced composite is to be produced consisting of 30 vol% aramid fibre and 70 vol% of a polycarbonate matrix: Mechanical characteristics of these material are as follows:

	Modulus of elasticity	Tensile strength
Aramid fibre	131 GPa	3600 MPa
Polycarbonate	2.4 GPa	65 MPa

Assume that the composite as described above has the cross sectional area of 320 mm^2 and subjected to a longitudinal load of 44.5 kN. Calculate

1. The fibre matrix load ratio.
2. The actual loads carried by both fibre and matrix phases.
3. The magnitude of the stress on each of the fibre and matrix phases.
4. What strain is experienced by the composite?

[4 × 5 = 20 marks]

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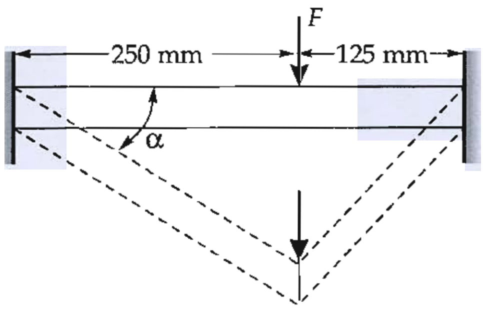
(b) A 375 mm long sheet with a cross-sectional area of 5×10^{-4} m^2 is stretched with a force, F, until $\alpha = 20°$. The material has a true stress-true strain relationship as, $\sigma = (700 \text{ MPa})\epsilon^{0.3}$. Calculate:



(i) The total workdone, ignoring end effects and bending.

(ii) What is α_{max} before necking begins?

[20 marks]

.4 (c) An annealed low carbon steel strip (K = 350 MPa and n = 0.26) 200 mm wide and 10 mm thick, rolled to a thickness of 6 mm. The roll radius and coefficient of friction are 150 mm and 0.1 respectively.

1. Calculate the roll pressure at the entrance to the rolls, at the neutral point and at the exit of rolls.
2. Find the magnitude of back tension required to make the rolls begin to slip.

   Use Von Mises criterion.

[20 marks]

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Section B : Production Engineering and Material Science + Mechatronics and Robotics

Q.5 (a) Composition of a nickel superalloy is as follows : Ni = 70.0%, Cr = 20.0%, Fe = 5.0% and rest titanium. Calculate rate of dissolution (in mm/min) if the area of the tool is 1600 mm^2 and a current of 1500 A is being passed through the cell. Assume dissolution to take place at lowest valency of elements.

$$A_{Ni} = 58.71 \text{ gm/mol}, \rho_{Ni} = 8.9 \text{ gm/cc}, Z_{Ni} = 2/3$$
$$A_{Cr} = 51.99 \text{ gm/mol}, \rho_{Cr} = 7.19 \text{ gm/cc}, Z_{Cr} = 2/3/6$$
$$A_{Fe} = 55.85 \text{ gm/mol}, \rho_{Fe} = 7.86 \text{ gm/cc}, Z_{Fe} = 2/3$$
$$A_{Ti} = 47.9 \text{ gm/mol}, \rho_{Ti} = 4.51 \text{ gm/cc}, Z_{Ti} = 3/4$$

where symbol A, ρ and Z are atomic mass, density and valency of elements respectively.

[12 marks]

80 l.

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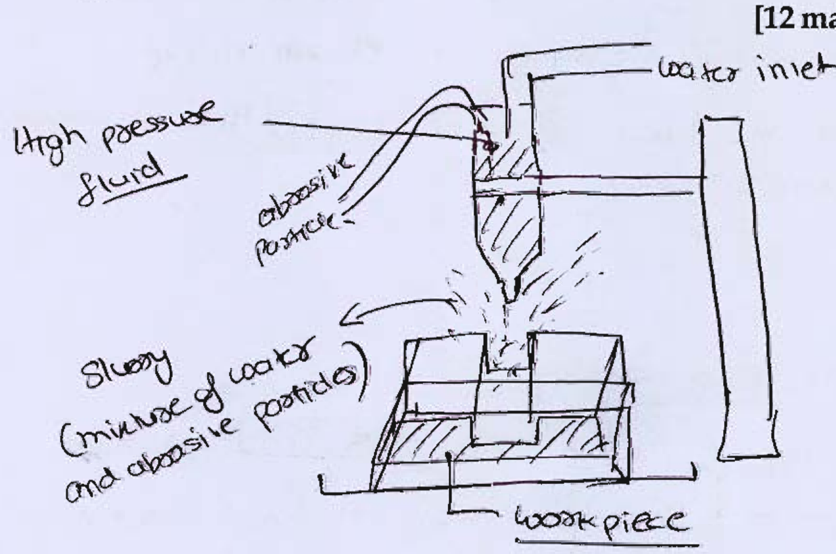
Q.5 (b) Explain the principle of abrasive water-jet machining using suitable schematic diagram. Write the advantages and applications of AWJM.

[12 marks]

Sol.



Principle of abrasive water-jet machining

1) A slurry is prepared with the mixture of hard abrasive particle such as alumina, carbides, etc and water.

High pressure fluid is channeled through a nozzle over the workpiece, due to nozzle action, a very high velocity discharge of slurry is obtained.

~~These high velocity~~ The abrasive particles also attained very high velocity along with the water particle, these particle collides over the workpiece surface and a very high contact stress is generated which results in erosion of the workpiece material. These erosions are microscopic in nature and thus the abrasive particles being hard cause a pitting removal of workpiece surface. Thus controlled movement of the jet produces the ~~desige~~ desired geometry over the workpiece.

Advantage of ~~AJW~~ AWJM

1) These are non-conventional machining process mean to work on a very brittle material ~~irrespective of~~ which otherwise would be very difficult with conventional machining.

2) Complex geometry can be ~~obtain~~ made

3) Negligible heat affected zone, thus negligible residual thermal stresses.

(9)

Application

1) Cutting of rocks, marbles and granite

2) ~~Diamond~~ ~~In~~ Application in sheet metal industry.

3) Cutting of very hard materials

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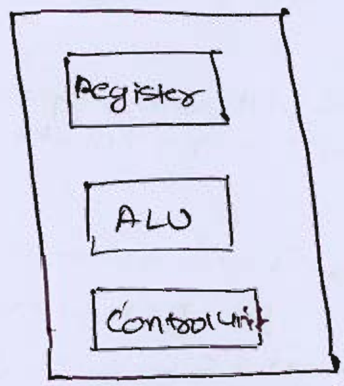
Q.5 (c) Draw the block diagram of a microcomputer and explain briefly the three segments (ALU, register and control unit) of a microprocessor. What are the application areas of microprocessor?

[12 marks]

Sol.



Microprocessor

The three segment of microprocessor are

1> Register - These are the components which is used to store the data, or the intermediate result which is being required by the micro-processor during its logic calculation through its ALU (Arithmetic and Logic unit) component.

2> ALU - It stands for Arithmetic and Logic unit. All the mathematical and logical calculation is performed through ALU component of micro-processor. It fetches the data from register carries out the calculations on these data and can either give command to other devices through control unit or stores the result in register or both.

3> Control unit → It forms a bridge through which the microprocessor controls and commands the other peripheral devices / component of the system. It passes on the commands to the other component of system such as external memory, output devices, etc.

Application area of micro-processor

1> ~~The The Air-conditioners used in our uses micro-pro~~

1> Various electro-mechanical devices such as vehicle, Air conditioners, Elevators uses micro-processor to give desired output.

2> ~~Personal computers~~ All forms of Computer uses micro-processor for giving out the result based on the users input.

3> Televisions, video-games, CCTV's controller, Traffic signal controller, in aviation traffic management, Rail networks, Kavach integrated system, etc are ~~couple~~ some of the areas where micro-processor plays a crucial role.

9

Q.5 (d) Explain hot spots and hot tears in metal casting, their formation mechanisms and causes. Suggest preventive measures and illustrate with a neat schematic diagram.

[12 marks]

Q.5 (e) A robot arm having one DOF (revolute joint) is stationary at θ = 0°. It is required to move it to θ = 60° in 5 seconds. Find the coefficients of a cubic equation that accomplishes this motion and brings the manipulator to rest at the goal point.

[12 marks]

Sol.

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Q.6 (a) An accelerometer is designed with a seismic mass of 50 gram, a spring constant of 5000 N/m, and a damping constant of 30 N.s/m. If the accelerometer is mounted to an object experiencing displacement $x_{in}(t) = 5\sin(100t)$ mm, find each of the following:

(i) The actual acceleration amplitude of the object.

(ii) The amplitude of the steady state relative displacement between the seismic mass and the housing of the accelerometer.

(iii) The acceleration amplitude, as measured by the accelerometer.

(iv) An expression for the steady state relative displacement of the seismic mass relative to the housing as a function of time $[x_r(t)]$

[20 marks]

Sol.

$m = 50gm \quad K = 5000\ N/m \quad C = 30\ Ns/m$

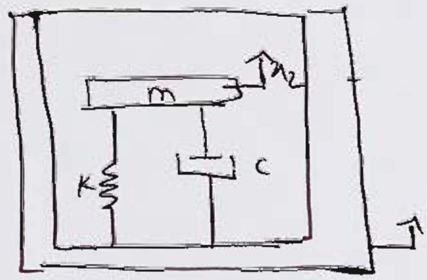
$x_{in}(t) = 5\sin(100t)$

$\therefore \omega_n(\text{natural frequency}) = \sqrt{\frac{K}{m}} = 316.227\ rad\,s^{-1}$

$\xi(\text{damping factor}) = C/(2m\omega_n) = \boxed{0.9486}$

$\therefore$

∴ Due to the vibratory motion of the base,



$x_2 = K\sin(\omega t - \phi)$

$\omega = 100\ rad s^{-1}$.

We know that, from equilibrium condition,

$m\ddot{x}_2 + K(x_2 - x_1) + C(\dot{x}_2 - \dot{x}_1) = 0$

$\therefore m\ddot{x}_2 + C\dot{x}_2 + Kx_2 = C\dot{x}_1 + Kx$

$= \sqrt{(CA\omega)^2 + (KA)^2}\sin(\omega t - \alpha)$

∴ ~~Amplitude of~~

We can observe that vibratory motion of the base is equivalent to harmonic force of amplitude

$F_0 = A\sqrt{(C\omega)^2 + (K)^2}$

$\therefore F_0 = 0.005\sqrt{(30\times 100)^2 + (5000)^2} = \boxed{29.154\ N}$

(i) ∴ Actual acceleration amplitude of object of mass 50gm $= \frac{F_0}{m} = \boxed{583.095}\ m/s^2$

(ii) Steady state relative displacement of object w.r.t to housing be x.

We know that

$$X = \frac{A\left(\frac{\omega}{\omega_n}\right)^2}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}}$$

$$= \frac{0.005\left(\frac{100}{316.227}\right)^2}{\sqrt{\left(1-\left(\frac{100}{316.227}\right)^2\right)^2 + \left(2\times 0.9486\times\frac{100}{316.227}\right)^2}}$$

$$= \frac{5\times10^{-4}}{\sqrt{0.81 + 0.35993}}$$

$$= 4.6226\times10^{-4}\,m = \boxed{0.46226\,mm}$$

(iii) Acceleration amplitude as measured by accelerometer

$\Rightarrow X_{relative} \times \omega^2$

$= 0.46226\times(100)^2 = \boxed{4622.6\ ms^{-2}}$

(iv) Relative displacement function

$X_{rel} = A\sin(\omega t - \phi)$

$= 0.46226\sin(100t - \phi)$

$\phi = \tan^{-1}\left(\frac{c\omega}{k - m\omega^2}\right) = \tan^{-1}\left(\frac{30\times100}{5000 - 0.050\times100^2}\right)$

$= 33.69^\circ = 0.588$ radians

$\therefore Y_{rel} = 0.46226\sin(100t - 0.588)$

20

Q.6 (b) By drawing the iron-carbon diagram observe the following for 1.0 kg of austenite containing 1.15 wt% C cooled to just below 727°C:

(i) What is the proeutectoid phase?

(ii) How many kilogram each of total ferrite and cementite is formed?

(iii) How many kilogram each of pearlite and the proeutectoid phase is formed?

(iv) Schematically sketch and label the resulting microstructure.

[20 marks]

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Q.6 (c) **(i)** Calculate the fundamental deviation and tolerance and hence the limits of size for shaft and hole for the following fit 65 $H_8 f_7$ mm. The diameter steps are 50 mm and 80 mm. For the shaft designation f, upper deviation is assumed as $-5.5D^{0.41}$.

(ii) What is 3-2-1 principal of Location? What are the various degrees of freedom for body in space? Distinguish between a jig and a fixture.

[10 + 10 marks]

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7 (a) (i) Derive the relation for maximum uncut thickness in upmilling operation.

(ii) In a slab milling operation with a straight teeth cutter, the cutter has 15 teeth with 10° rake angle and rotates at 200 rpm. The diameter of the cutter is 80 mm and the table feed is 75 mm/min, the depth of cut being 5 mm. The width of the mild steel job is 50 mm and ultimate shear stress of work material is 420 N/mm^2. Assuming the coefficient of friction between the chip and cutter to be 0.7 and using the Lee and Shaffer relation, plot the variation of the resultant torque with cutter rotation and estimate the average power consumption.

[8+12 marks]

Upmilling operation

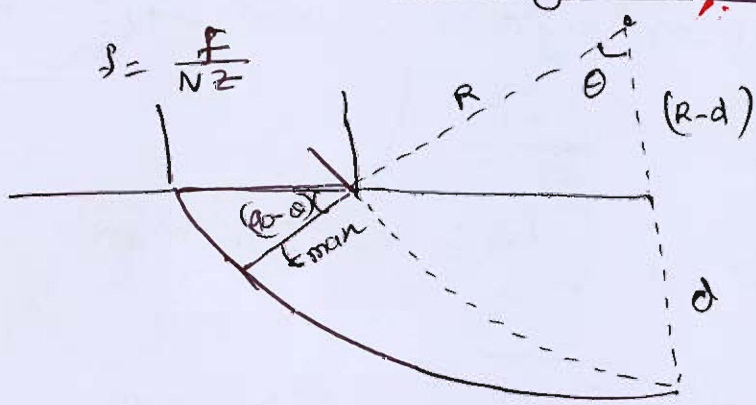


Fig.

f = feed given/revolution $= \frac{F}{NZ}$ d = depth of cut.

N = Speed of the cutter

Z = no. of teeth on the milling tool

$\cos\theta = \frac{R-d}{R} = 1 - \frac{d}{R}$.

$\sin\theta = \sqrt{1-\cos^2\theta} = \sqrt{1-\left(1-\frac{d}{R}\right)^2}$

$= \sqrt{1 - 1 - \frac{d^2}{R^2} + \frac{2d}{R}}$

(ignoring $\frac{d^2}{R^2}$ term)

$\therefore \sin\theta = \sqrt{\frac{2d}{R}}$.

from geometry t_{max} = maximum uncut thickness of chip.

$\therefore t_{max} = \frac{f}{NZ}\cos(90-\theta) = \frac{f}{NZ}\sin\theta$

$t_{max} = \frac{f}{NZ}\sqrt{\frac{2d}{R}} = \boxed{\frac{2f}{NZ}\sqrt{\frac{d}{D}}}$

D = Diameter of the cutter

8

(ii) Given, $\alpha = 10^\circ$ $z = 15$ teeth $N = 200$ rpm

$D = 80$ mm $F = 75$ mm/min $d = 5$ mm $w = 50$ mm

$\tau = 420$ MPa $\mu = 0.7$

According to lee and Shaffer relation

$$\frac{\pi}{4} = \phi - \beta + \alpha$$

$\Rightarrow \therefore \phi =$ shear plane angle $\beta = \tan^{-1}(0.7) = 34.992^\circ \approx 35^\circ$

3

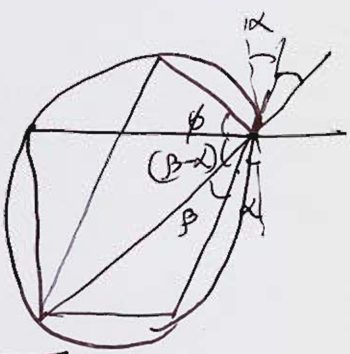
$$\therefore \left[\phi = \frac{\pi}{4} + 35 - 10 = 70^\circ\right]$$

$$\therefore F_s = \tau \times \frac{t}{\sin\phi} \times w$$ $t =$ average uncut chip thickness

$$t = \frac{f}{NZ}\sqrt{\frac{d}{D}} \Rightarrow \frac{75}{200 \times 15}\sqrt{\frac{5}{80}} = 6.25 \times 10^{-3}\text{ mm}$$

$$\therefore F_s = 420 \times \frac{6.25 \times 10^{-3}}{\sin 70} \times 50 = \boxed{139.673\text{N}}$$

$\therefore$ R = resultant force.



A/q $R\cos(\beta - \alpha + \phi) = F_s$

$$\therefore R = \frac{139.673}{\cos(95)} = \boxed{-1602.56\text{ N}}$$

–ve shows the direction only.

$$\therefore F_c = |R|\cos(\beta - \alpha) = \boxed{1452.412\text{N}}$$

$$\therefore \text{Torque} = F_c \times R = 1452.412 \times \frac{40}{1000} = \boxed{58.096\text{Nm}}$$

Power $= F_c \times V_c = 1452.412 \times 0.837775$

$= \boxed{1216.769\text{ W}}$

$= \boxed{1.216\text{ kW}}$

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Q.7 (b) Explain stepper motor. Briefly discuss the working of the permanent magnet stepper motor with schematic diagram. Also write advantages and disadvantages of stepper motor.

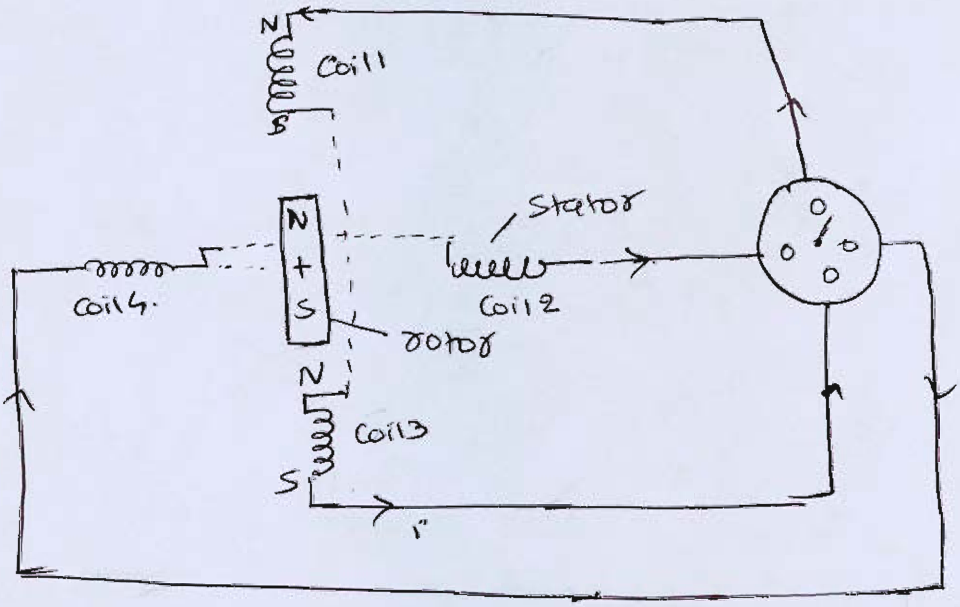
[20 marks]

Stepper motor

Sol.

Stepper motor is a intermittent motion type actuator with moves by a certain angle of rotation for each unit step input. The output torque of the stepper motor is very high but due to step-wise motion of the rotor, vibration and stability is a major concern.

Working of a permanent magnet stepper motor



Permanent magnet Stepper motor contains a permanent magnet as rotor and ~~4a coils as the~~ a stator containing coils. As the coils are energised, they create a ~~b~~ their own magnetic field lines ~~in~~ and the coils are arranged and energised in such a way that South pole of the ~~coils~~ ~~Electro~~ magnetic field lines ~~energing are~~ is formed near the North pole of the permanent magnet. ~~opposite poles are~~ Due to formation of opposite magnetic poles a force of attraction is felt by the rotor and it tries to aling itself in a more stable position. Alternate switching off and energisation of coil creates a step wise rotation motion.

Advantage of stepper motor

1) They are mechanically robust in design.
2) ~~Ear~~ Capable of managing high starting Torque required equiments, as the ~~starting~~ torque's output is high.
3)

Disadvantage of stepper motor

1) Vibration is very high, thus stepper motors are noisy during their operation.
2) Energy consumption is high compared to servo-motors.
3) Speed of operation is slow.

16

Q.7 (c) Atomic radii; crystal structure, electronegativity, and the most common valency are tabulated in the following table for several elements; for those that are non-metals, only atomic radii are indicated.

Element	Atomic Radius (*nm*)	Crystal Structure	Electro-negativity	Valency
Cu	0.1278	FCC	1.9	+2
C	0.071			
H	0.046			
O	0.060			
Ag	0.1445	FCC	1.9	+1
Al	0.1431	FCC	1.5	+3
Co	0.1253	HCP	1.8	+2
Cr	0.1249	BCC	1.6	+3
Fe	0.1241	BCC	1.8	+2
Ni	0.1246	FCC	1.8	+2
Pd	0.1376	FCC	2.2	+2
Pt	0.1387	FCC	2.2	+2
Zn	0.1332	HCP	1.6	+2

Which of these elements would you expect to form the following with copper?

1. A substitutional solid solution having complete solubility.
2. A substitutional solid solution of incomplete solubility.
3. An interstinial solid solution.

[20 mark]

Copper has FCC Crystal Structure.

As per hume Rothery Rule,

For substitutional solid solution to form following conditions favours:-

i) The difference in atomic radius must be less than 15%.

ii) The substitutional solid must have same crystal structure as that of parent metal.

iii) Electronegativity difference must be less otherwise it will form ionic bond.

In view of the above conditions, following outcomes may be possible.

1) A substitutional solid solution having complete solubility -

~~All FCC Cry~~

All the elements having FCC crystal structure and atomic radius within 15% of Cu. are

Ag, Al, Ni, Pd, Pt ~~and Zn~~

but out of these choice, Pd, Pt and Al are having vast difference in their electronegativity thus are not ideal for substitutional solid solution.

∴ The Eligible elements are Ni and Ag.

(ii) A substitutional solid solution having incomplete solubility

~~All the elements having same crystal structure~~ as ~~that of copper but large atomic radius difference~~.

∴ ~~Eligible Elements are - C, H, O, Co, Cr~~

(ii) All the Elements having Either different Crystal Structure ~~or large~~ or very large atomic radius difference.

Such as - Co, Cr, Fe, Zn.

(iii) An interstitial solid solution

All the element having ~~size~~ atomic size as of the order of tetrahedral or octahedral voids. Thus eligible ~~no~~ Elements are - C, H and O.

15

3 (a) (i) What is vulcanization process? What are its effect on the properties of rubber? Draw stress strain diagram for vulcanized and unvulcanized natural rubber.

(ii) Classify Nanomaterials and elaborate on one method of manufacturing carbon nano tubes (CNT).

[10 + 10 marks]

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Q.8 (b) (i) Describe 'Degeneracy' and 'Dexterity' with respect to robots.

(ii) Calculate the inverse of following transformation matrix.

$$T = \begin{bmatrix} 0.527 & -0.574 & 0.628 & 2 \\ 0.369 & 0.819 & 0.439 & 5 \\ -0.766 & 0 & 0.643 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

[10 + 10 marks]

Q.8 (c) The following Taylor tool life equation for carbide tool, steel work piece pair is obtained experimentally: $VT^{0.25} = 650$ where V is in m/min and T is in min. A batch of 1000 steel parts, each 100 mm in diameter and 250 mm in length, is to be rough turned using a feed of 0.2 mm/rev. If the cost per edge of the throwaway carbide insert is ₹50, time required to reset the cutting edge is 1 min and the total machining cost (including operator cost) is ₹300/hr, calculate

1. optimum cutting speed for minimum cost
2. the corresponding tool life
3. total production cost if time taken to load and unload the component is 2 min, and the initial setup time is 2 hours, and
4. total production time for the given batch

[20 marks]

OOOO

Space for Rough Work

Space for Rough Work

Space for Rough Work