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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	44
Q.2	39
Q.3	–
Q.4	–
Section-B	
Q.5	07
Q.6	18
Q.7	23
Q.8	–
Total Marks Obtained	131

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

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Keep it up.

IMPORTANT INSTRUCTIONS

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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.

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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/mm². 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]

$v_{cutting} = 200\ m/min \quad \alpha = 10° \quad b = 2mm$

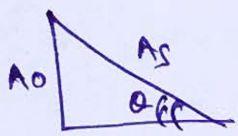
$t_1 = t_0 = 0.2\ mm$

$\mu = 0.5$

$\tau_s = 400\ \frac{N}{mm^2}$

$F_{shear} = \tau_s \times A_s$

$= \tau_s \times \frac{A_0}{\sin\theta}$



θ = shear angle.

$F_{shear} = 400\ \frac{N}{mm^2} \times \frac{b \times t_1}{\sin\theta}$

$F_{shear} = \frac{400 \times 2 \times 0.2}{\sin\theta} = \frac{160}{\sin\theta}$

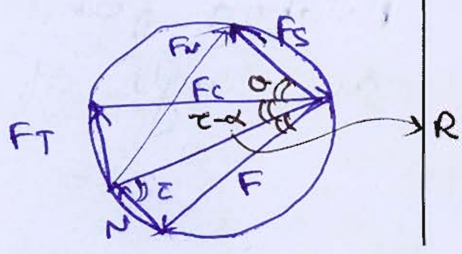
τ = frictn angle = $\tan^{-1}(\mu) = 26.565°$

$2\theta + \tau - \alpha = 90°$ [using 1st angle Merchant theory]

$2\theta + 26.565° - 10 = 90°$

$\boxed{\theta = 36.717°}$

$F_{shear} = F_s = \frac{160}{\sin 36.717} = 267.616N$



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$$R = \frac{F_s}{\cos(\theta + \tau - \alpha)} = \frac{267.616}{\cos(36.717 + 26.565 - 10)}$$

$$= 447.610 \text{ N}$$

Cutting Force = $F_c = R\cos(\tau - \alpha) = 447.610 \cos(16.565) = 429.033$ N

Thrust force = $F_T = R\sin(\tau - \alpha) = 447.610 \sin(16.565) = 127.615$ N

(ii) using Lee & Shafer

$$\theta + \tau - \frac{\alpha}{2} = 45°$$

$$\theta = 45 - 26.565 + 10 = 28.435°$$

$$F_s = \frac{160}{\sin\theta} = 336.020 \text{ N}$$

$$R = \frac{F_s}{\cos(\theta + \tau - \alpha)} = \frac{336.020}{\cos(28.435 + 26.565 - 10)} = 475.205 \text{ N}$$

$F_c = R\cos(\tau - \alpha) = 455.482$ N

$F_T = R\sin(\tau - \alpha) = 135.482$ N

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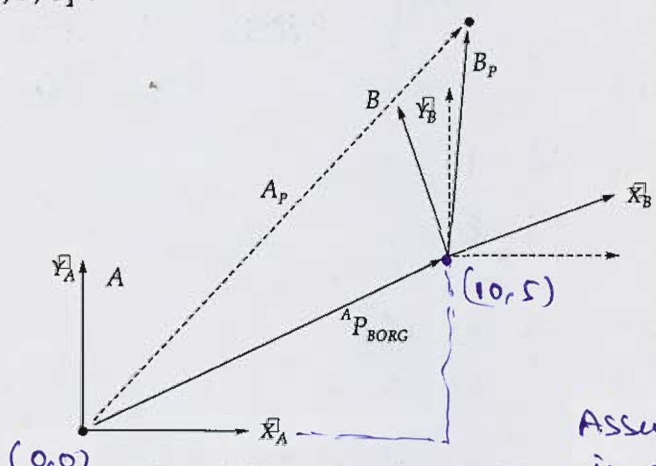
Q.1 (b) Figure shown below represents a frame {B}, which is rotated relative to frame {A} about Z-axis by 30 degrees, translated 10 units in $\hat{X}_A$ and translated 5 units in $\hat{Y}_A$. Find ^{A}P, where $^{B}P = [3, 7, 0]^T$.



Frame (B) rotated and translated

Assuming frame A is at origin (0,0)

[12 marks]

$$^{B}P = \text{Point P wrt B frame} = \begin{bmatrix} 3 \\ 7 \\ 0 \end{bmatrix}_{3\times1}$$

Rotating frame B about Z_B axis by an angle of 30° in clockwise directn

$$ {}^{B}P_{\text{after rotatn}} = \left[Rot_Z \ \theta = -30^\circ \right] \times \begin{bmatrix} 3 \\ 7 \\ 0 \end{bmatrix} $$

$$ = \begin{bmatrix} c30^\circ & +s30^\circ & 0 \\ -s30^\circ & c30^\circ & 0 \\ 0 & 0 & 1 \end{bmatrix}_{3\times 3} \times \begin{bmatrix} 3 \\ 7 \\ 0 \end{bmatrix}_{3\times 1} $$

$c30^\circ = \cos 30^\circ$

$s30 = \sin 30^\circ$

$$ = \begin{bmatrix} 6.098 \\ 4.562 \\ 0 \end{bmatrix} $$

Now translating the above ${}^{B}P_{\text{after rotatn}}$ point to origin i.e about A frame.

$$ {}^{A}P_{\text{after translatn}} = \begin{bmatrix} 6.098 + 10 \\ 4.562 + 5 \\ 0 \end{bmatrix} = \begin{bmatrix} 16.098 \\ 9.562 \\ 0 \end{bmatrix} $$

$$ {}^{A}P = \begin{bmatrix} 16.098 \\ 9.562 \\ 0 \end{bmatrix} $$

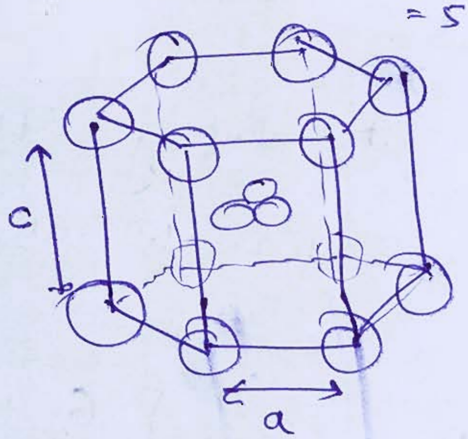
Q.1 (c) Titanium has an HCP unit cell for which the ratio of the lattice parameters (c/a) is 1.58. If the radius of the Ti atom is 0.1445 nm, then determine the unit cell volume, the density of Ti and compare it with the literature value of 4.51 g/cm^3.
[Atomic weight of *Ti* = 47.87 gm/mol]

[12 marks]

$\frac{c}{a} = 1.58$ $r = 0.1445$ nm

$a = 2r$
$a = 0.289$ nm
$c = 0.45662$ nm

$Z = 3 + 1 + \frac{1}{12} \times 1$
$= 5$ atoms



Volume of unit cell

$= \frac{\sqrt{3}}{4} a^2 \times 6 \times c$

$= \frac{6\sqrt{3}}{4} \times (0.289)^2 \times (0.45662)$

$= 0.099083765 \times (nm)^3$

$1\,nm = 10^{-9}\,m$
$= 10^{-7}\,cm$

$= 0.099083765 \times 10^{-21}\,cm^3$

Density

$= \frac{mass}{Volume} = \frac{(Z) \times (AMU)}{N_A \times volume} = \frac{5 \times 47.87}{6.022 \times 10^{23} \times 0.099083765 \times 10^{-21}}$

$= 5 \times 0.80226$

$= 4.0113\ g/cm^3$

Z = No. of atoms in one hcp unit cell

(8)

So, if we compare with literature value of 4.51 g/cm³ obtained value i.e. 4.0113 g/cm³ is less in magnitude because the value of 'c' parameter varies.

(d) State:
(i) Gibbs phase rule and lever rule
(ii) Isomorphous system
(iii) Peritectic reaction in steel

[12 marks]

(i) Gibbs phase rule -

It states that no. of phases when added to the number of degree of freedom of a system is equal to the number of components plus 1.

$$P+F = C+1$$

P = No. of phases exist.
F = degree of freedom
C = No. of components.

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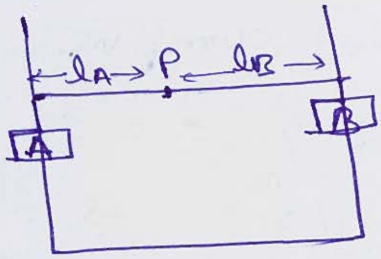
Lever Rule :-

Point P is considered as a fulcrum.



To find % of A = $\frac{l_B}{l_A + l_B} \times 100$

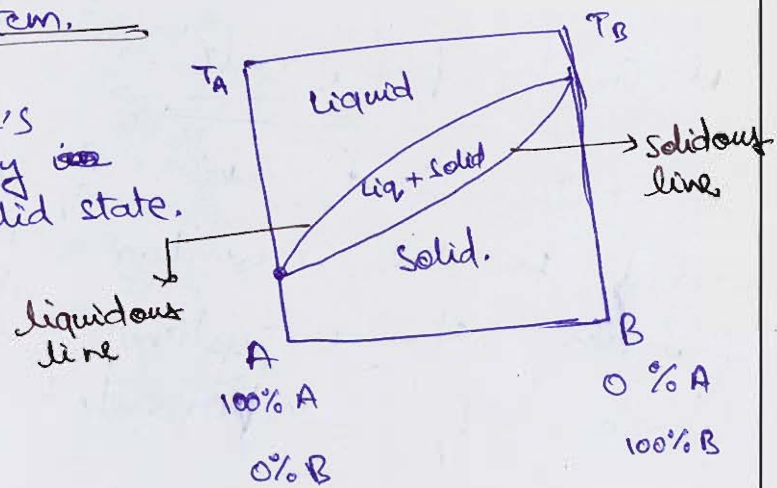
% of B = $\frac{l_A}{l_A + l_B} \times 100$

This rule is used to obtain the individual % concentration of two phases A and B ~~separately~~ of a mixture of A and B.

$l_A + l_B$ = length of tie-line.

(ii) ## Isomorphous System.

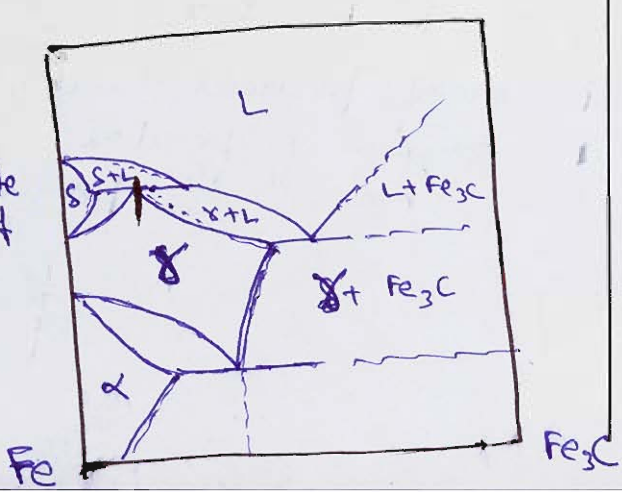
In this system there's a complete solubility of A & B in solid state.



(iii) ## Peritectic Reaction

$\delta + L \rightleftharpoons \gamma$

δ ferrite solid form + Liquid form ⇌ austenite phase of iron



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

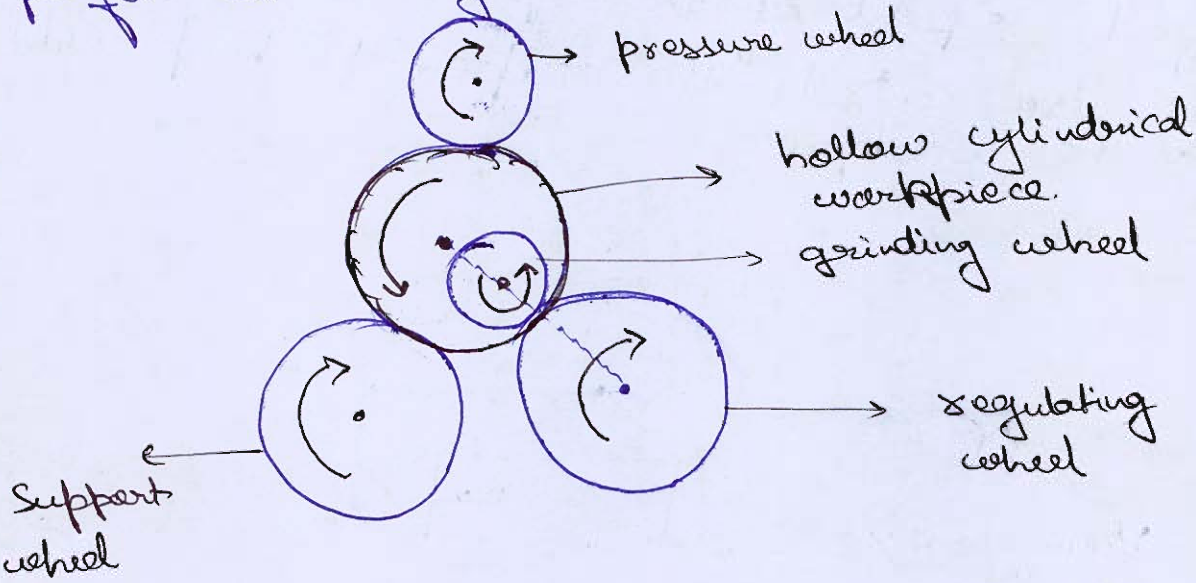
[12 marks]

There are 2 types of grinding operatn -

1.) Internal grinding.

2.) External grinding.

Internal grinding of a workpiece is performed using centreless grinding machine



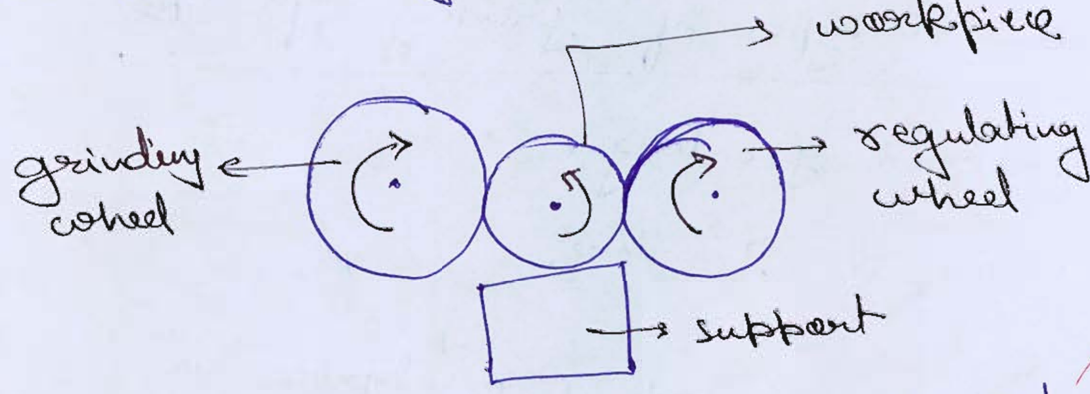
→ regulating, support, & pressure wheel rotates in same directn or sense.

→ workpiece and grinding wheel rotates in same sense.

→ Centres of workpiece, regulating wheel & grinding wheel are in one line

External grinding

In this operatn external surface of the workpiece is grinded.



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→ Regulating wheel is used to provide feed, speed of the operation.

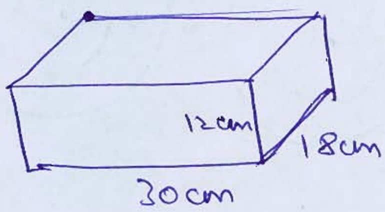
→ It also controls the taper to be provided on the workpiece.

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.

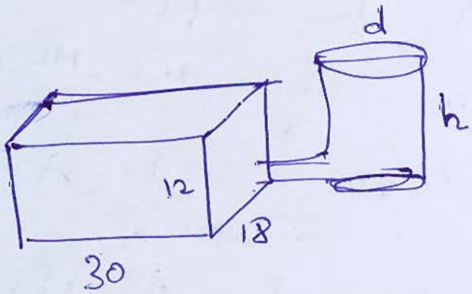
[20 marks]

Casting size.

Volume Shrinkage = 7%



(i) Side riser.



$\left(\frac{V}{A}\right)_{\text{cylinder side riser}} = \dfrac{\frac{\pi}{4} d^2 h}{\pi d h + \frac{\pi}{4} d^2 \times 2}$

using Chvorinov's principle —

$t_s \propto \left(\frac{V}{A}\right)^2$ $\quad t_s = K\left(\frac{V}{A}\right)^2$

t_s → Solidificatn time

K is a proportionality const.

For optimum cylinder side riser –

t_s should be maximum.

~~(Solid)~~

$$\frac{dA}{d(d)} = 0$$

$$\frac{d\left(\pi d h + \frac{\pi}{4} d^2 \times 2\right)}{d(d)} = 0$$

$$(h\pi) + \frac{\pi}{4} \times 2 \times 2 d = 0$$

$$\boxed{d = h}$$

→ optimum design condition for side riser

$$(t_s)_{\text{side riser}} = K\left(\frac{V}{A}\right)^2 = K\left(\frac{\frac{\pi}{4} \times d^2 \times d}{\pi d d + \frac{\pi}{4} \times d^2 \times 2}\right)^2$$

$$= K\left(\frac{d^3}{4d^2 + 2d^2}\right) = K\left(\frac{d}{6}\right)^2$$

$$(t_s)_{\text{casting}} = K\left(\frac{V}{A}\right)^2 = K\left[\frac{30 \times 18 \times 12}{2(30 \times 12 + 12 \times 18 + 30 \times 18)}\right]^2$$

$$= K(8.4287)$$

$V_{(\text{riser})} = 3 \times$ (% shrinkage volume of casting) [Assuming this equation]

$$\frac{\pi}{4} \times d^2(d) = 3 \times \frac{7}{100} \times 18 \times 12 \times 30$$

$$\boxed{d = 12.0106 \text{ cm}}$$

Now $\Rightarrow (t_s)_{\substack{riser\\ side}} > (t_s)_{casting}$

$$k\left(\frac{d}{6}\right)^2 > k(8.4287)$$

$$\left(\frac{12.0106}{6}\right)^2 > 8.4287$$

$$4.007 > 8.4287$$

which is false.

Hence redesigning riser –

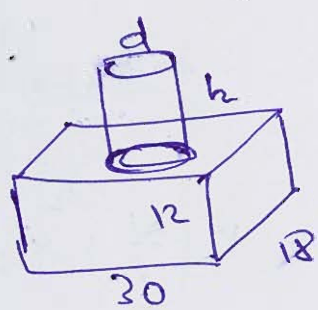
$$k\left(\frac{d}{6}\right)^2 = k\,8.4287$$

$$d = 17.4193 \text{ cm}$$
$$h = 17.4193 \text{ cm}$$

$\Rightarrow$ final dimension of cylindrical side riser

(ii) Top riser.

$$\left(\frac{V}{A}\right)_{riser} = \left(\frac{\frac{\pi}{4}d^2h}{\pi dh + \frac{\pi}{4}d^2}\right)$$



For optimum design –

$$\frac{dA}{d(d)} = 0 = \pi h + \frac{\pi}{4}\times 2d$$

$$h = \frac{d}{2} \Rightarrow \text{optimum condition.}$$

$$(t_s)_{\substack{riser\\ Top}} = k\left(\frac{V}{A}\right)^2_{\substack{riser\\ Top}} = k\left[\frac{\frac{\pi}{4}d^2h}{\pi dh + \frac{\pi}{4}d^2}\right]^2$$

$$= k\left(\frac{d}{6}\right)^2$$

~~Now, ⇒ $(t_s)_{Top\ riser} > (t_s)_{casting}$.~~

~~$K\left(\frac{d}{6}\right)^2 > K(8.4287)$~~

$V_{Top\ riser} = 3 \times \%$ shrinkage Volume of casting (assuming this equation)

$$\frac{\pi}{4} \times d^2 \times \frac{d}{2} = 3 \times \frac{7}{100} \times 18 \times 12 \times 30$$

$$d = 15.1325\ cm$$

Now, ⇒ $(t_s)_{Top\ riser} > (t_s)_{casting}$.

$$K\left(\frac{d}{6}\right)^2 > K(8.4287)$$

$$6.3609 > 8.4287$$

which is false –

Hence redesigning the top riser –

$$K\left(\frac{d}{6}\right)^2 = K(8.4287)$$

$d = 17.4193$ cm
$h = 8.7096$ cm ⇒ final dimension of top riser

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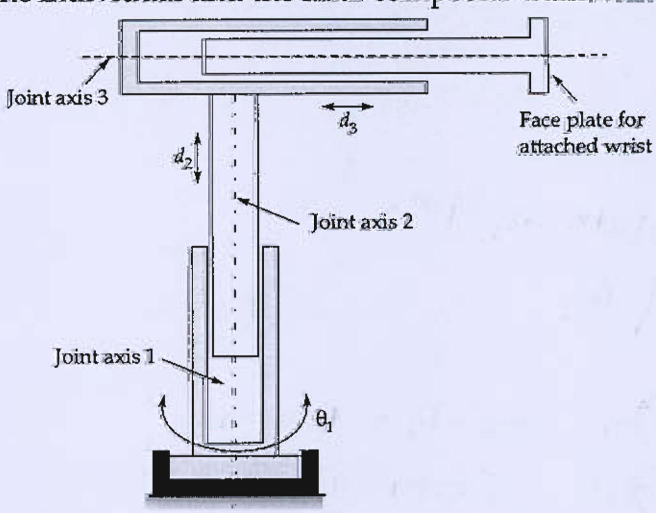
2 (b) For the given 3-link cylindrical manipulator.

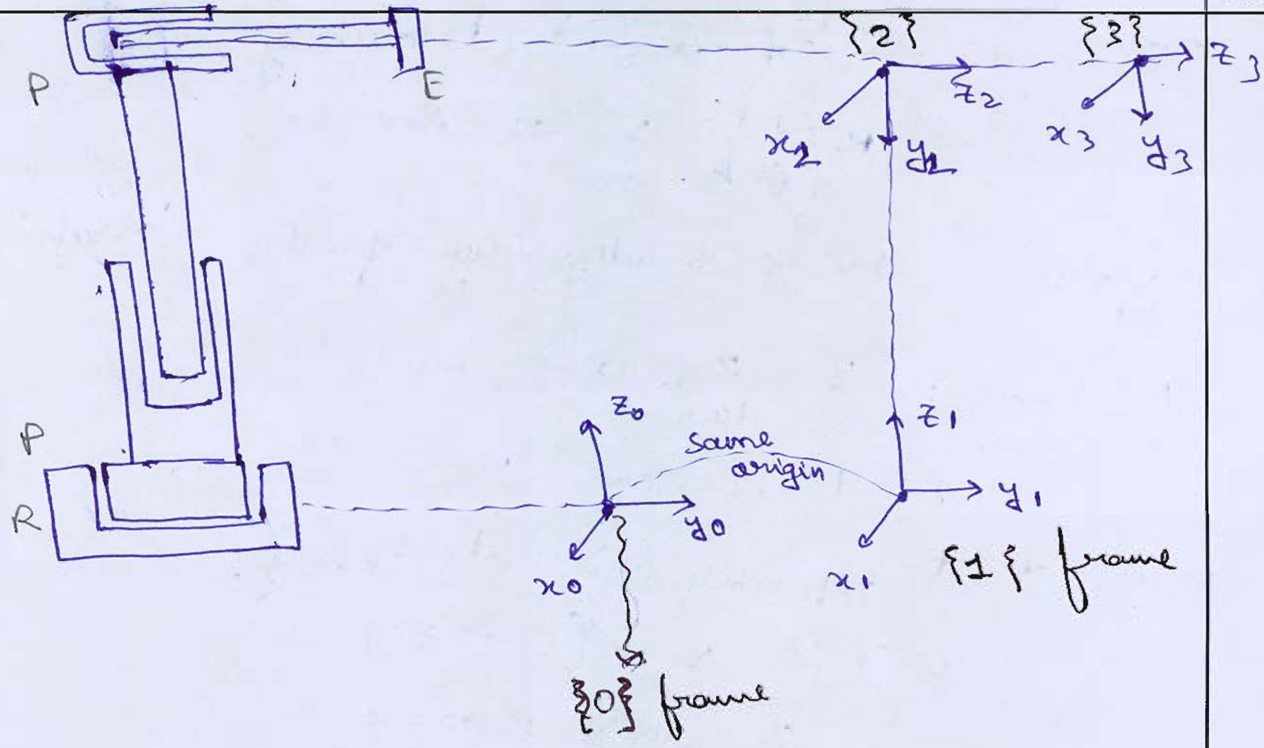
1 Assign the co-ordinate frames based on D-H representation.

2. Make the D-H parameter table.

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



[20 marks]



	$^{i-1}T_i$	θ_i	d_i	a_i	α_i
R → P	$^0T_1$	θ_1	0	0	0
P → P	$^1T_2$	0	d_2	0	90°
P → E	$^2T_3$	0	d_3	0	0

$$^0T_1 = \begin{bmatrix} \text{Rotation about } z \text{ axis of } \theta_1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^{1}T_2 = \begin{bmatrix} \text{Translation of } d_2 \text{ along} \\ z\text{-axis} \end{bmatrix} \begin{bmatrix} \text{Rotation of} \\ 90^\circ \text{ about } x \\ \text{axis} \end{bmatrix}$$

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

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

$${}^{2}T_3 = \begin{bmatrix} \text{Translation of } d_3 \text{ along} \\ z \text{ axis.} \end{bmatrix}$$

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

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

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

[20 marks]

1.) Process annealing

It is a multistage heat treatment process in which specimen is heated and then air cooled in multiple stages..

2.) Full annealing.

It is a conventional annealing process in which the specimen is heated and dead cooled in the furnace. So, that rate of cooling is very less.

3.) Normalising

It is also a heat treatment process in which the specimen is heated at higher temperature than in annealing and the cooled in air.

In Normalising process strength as well as ductility is increased.
But in annealing only ductility is increased.

4.) Spheroidizing.

It is ~~an~~ an ~~annealing~~ annealing process in which needle like grain struct-ure is converted into round shape structure, to increase the strength and ductility.

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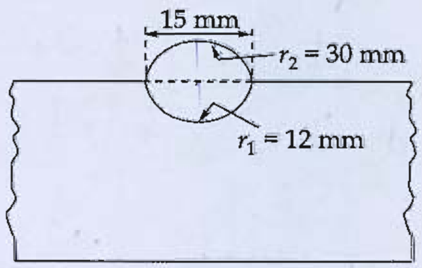
Refer to Solution

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]

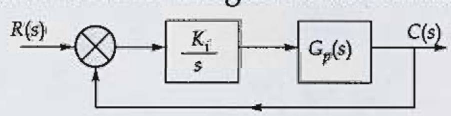
Q.3 (b) What is corrosion, explain with the help of electrochemcial reactions?

[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]

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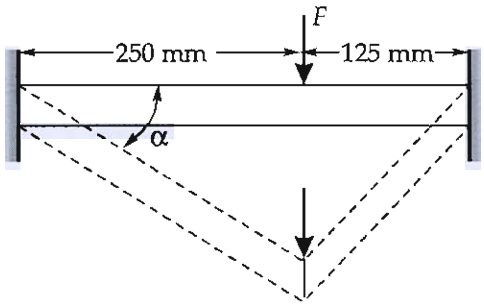
4 (b) A 375 mm long sheet with a cross-sectional area of 5×10^{-4} m^2 is stretched with a force, F, until $\alpha = 20°$. The material has a true stress-true strain relationship as, $\sigma = (700\ \text{MPa})\epsilon^{0.3}$. Calculate:



(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.

$A_{Ni} = 58.71$ gm/mol, $\rho_{Ni} = 8.9$ gm/cc, $Z_{Ni} = 2/3$

$A_{Cr} = 51.99$ gm/mol, $\rho_{Cr} = 7.19$ gm/cc, $Z_{Cr} = 2/3/6$

$A_{Fe} = 55.85$ gm/mol, $\rho_{Fe} = 7.86$ gm/cc, $Z_{Fe} = 2/3$

$A_{Ti} = 47.9$ gm/mol, $\rho_{Ti} = 4.51$ gm/cc, $Z_{Ti} = 3/4$

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

[12 marks]

$m = ZIt.$ (Faraday' law)

$\frac{m}{t} = \frac{eI}{F}$

MRR. $= \frac{V}{t} = \frac{eI}{F\rho}$

$= \frac{e_{equiv} I.}{F \rho_{equivalent.}}$

$\frac{1}{e_{equiv}} = \frac{x\%}{e_1} + \frac{y\%}{e_2} + \frac{z\%}{e_3} + \frac{a\%}{e_4}$

$\frac{100}{e_{equiv}} = \frac{70}{\left(\frac{58.71}{2}\right)} + \frac{20}{\left(\frac{51.99}{3}\right)} + \frac{5}{\left(\frac{55.85}{2}\right)} + \frac{5}{\left(\frac{47.9}{3}\right)}$

$e_{equivalent} = 24.808$

$\frac{100}{\rho_{equiv}} = \frac{70}{8.9} + \frac{20}{7.19} + \frac{5}{7.86} + \frac{5}{4.51}$

$\rho_{equival} = 8.0699$ kg/m^3

$\frac{2}{3} \div \frac{1}{6}$

$\frac{2}{3} \div \frac{1}{63} = \frac{1}{9}$

1m – 10^{-1}

Rate of dissolution = $\frac{MRR}{A}$

$$= \frac{24.808 \times 1500}{96500 \times 8.0699 \times 1600 \times \frac{10^3}{10^6} \times 10^{-2}}$$

$= 2.9865 \frac{cm}{s}$

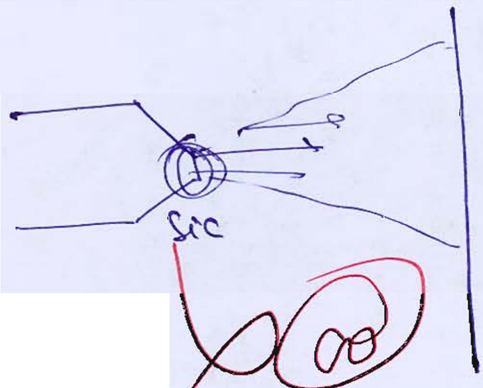
$= 2.9865 \times 10 \frac{mm}{min} \times 60$

$= 1791.9208 \frac{mm}{min}$

6

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

[12 marks]



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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]

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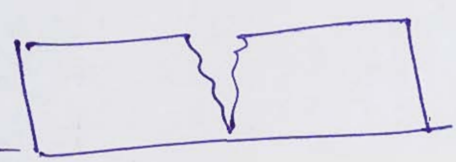
Q.5 (d) Explain hot spots and hot tears in metal casting, their formation mechanisms and causes. Suggest preventive measures and illustrate with a neat schematic diagram.

[12 marks]

Hot tears is a metallurgical defect



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Q.5 (e) A robot arm having one DOF (revolute joint) is stationary at $\theta = 0°$. It is required to move it to $\theta = 60°$ 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]

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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]

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:

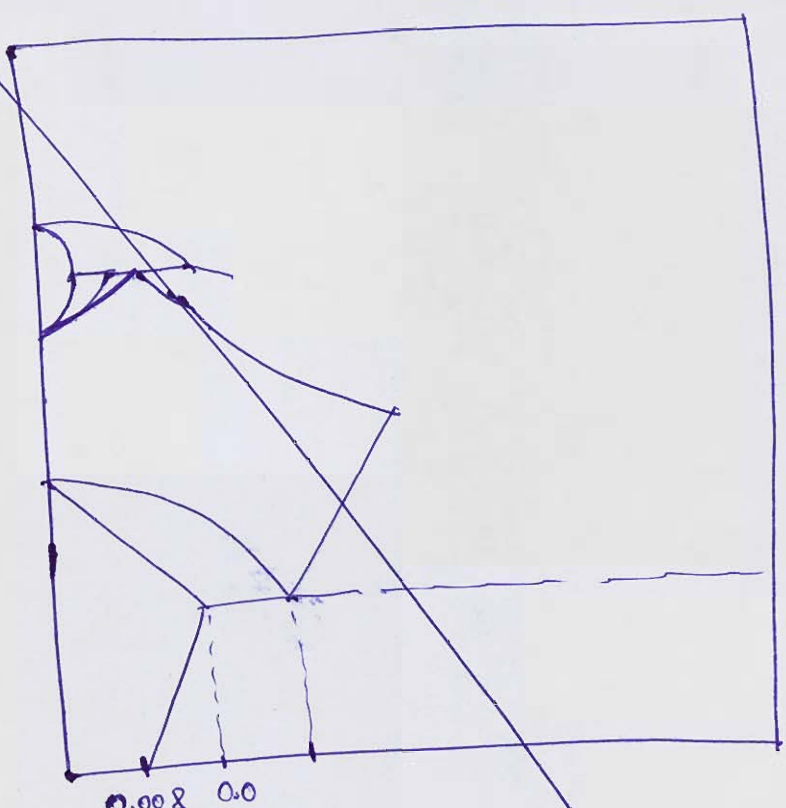
(i) What is the proeutectoid phase?

(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]

$D_1 = 50$ mm $D_2 = 80$ mm

$D = \sqrt{D_1 D_2} = \sqrt{50 \times 80} = \sqrt{40 \times 100} = 63.245$

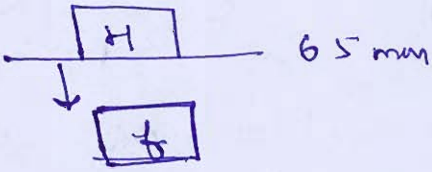
~~$i = 0.45 + 0.001 D^{1/3}$~~

$i = 0.45 D^{1/3} + 10^{-3} D$

$= 0.45 (63.245)^{1/3} + 10^{-3} (63.245)$

$= 1.8561$ μm

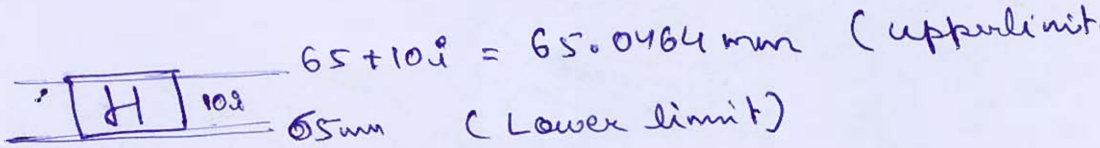
Basic size = 65 mm



For Hole H —

fundamental deviation = 0

Tolerance grade = IT8 | Tolerance = 25 i
= 25 × 1.8561 × 10^-3
= 46.403 × 10^-3 mm

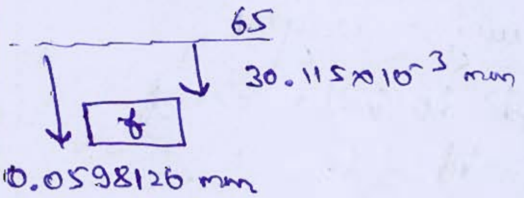


$65^{+46.403 \times 10^{-3}}_{+0}$

For shaft f. —

upper deviatn = fundamental deviatn = $-5.5\ D^{0.41}$
$= -5.5\,(63.245)^{0.41}$
$= -30.115\ \mu m$

Tolerance grade = IT7 | Tolerance = 16 i
= 16 × 1.8561 × 10^-3
= 0.02969 mm



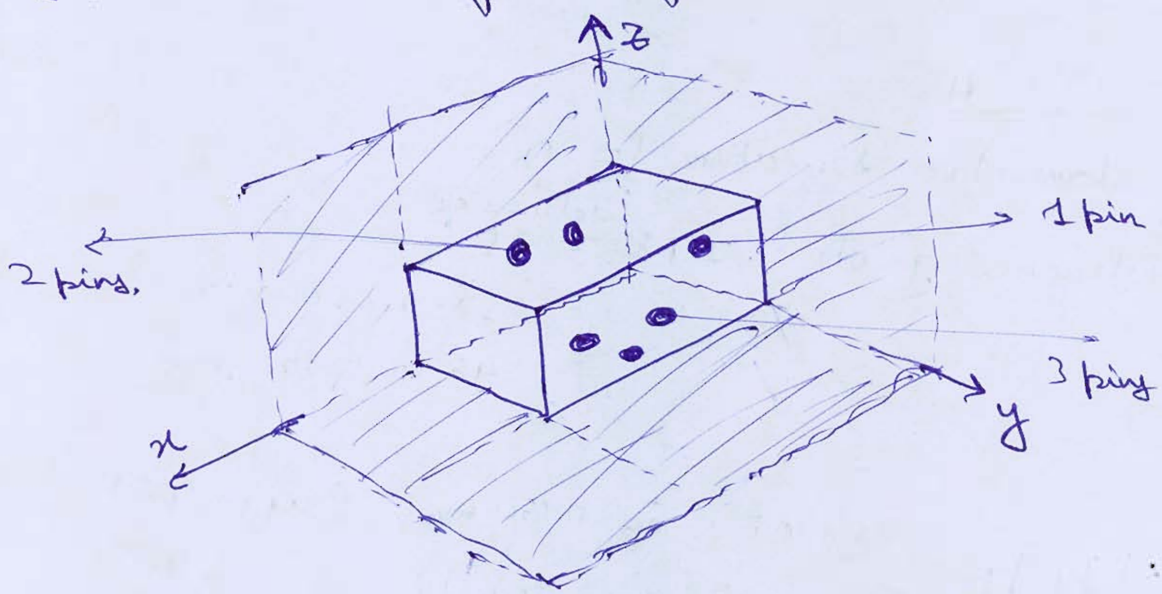
10

$65^{-30.115 \times 10^{-3}}_{-0.0598126}$

upper limit of shaft = 64.969885 mm

Lower limit of shaft = 64.94018 mm

(iii) 3-2-1 principal of Location is a method of locating using 3 pins at the bottom & 2 pins, 1 pins from the 2 side surface of a cuboid.



→ In this principal only 3 degree of freedom is provided to the cuboid ~~[illegible]~~ i.e x, y, z axis translation only rest 9 degree of freedoms are restricted.

→ Total for a body there are 12 degree of freedom 6 translation & 6 rotations about x, y, z axis.

8

→

Jigs	Fixture
(a) Light weight	(a) Heavy weight.
(b) used to hold the workpiece	(b) used to hold the workpiece.
(c) Jigs used in radial drilling machine	(c) Chuck of a lathe machine is an example of fixture

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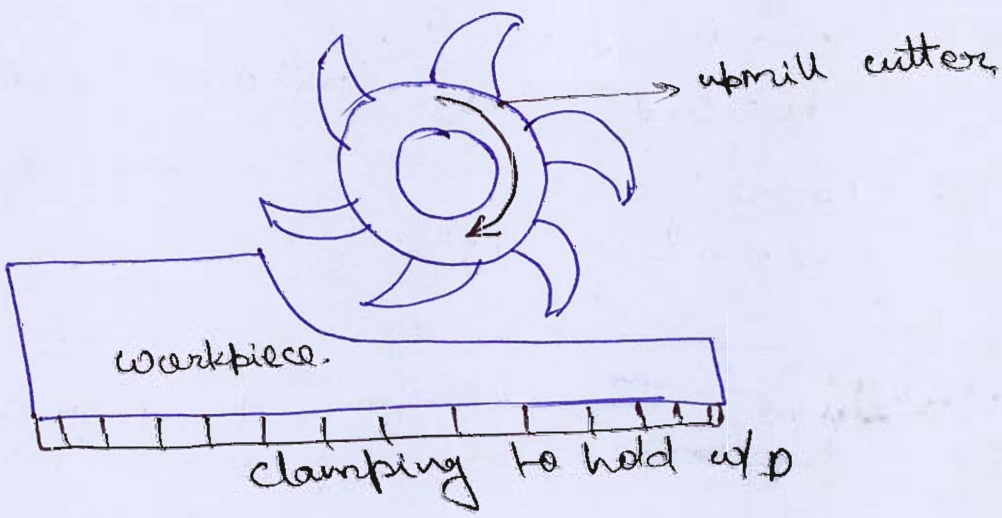
Q.7 (a) (i) Derive the relation for maximum uncut thickness in upmilling operation.

(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]

(i)

$$t_{max} = \frac{2 f_m}{Z N}\sqrt{\frac{d}{D}\left(1-\frac{d}{D}\right)}$$



f_m = feed per minute (mm/min)

Z = No. of teeths on cutter.

N = rotation of cutter in rpm

d = depth of cut

D = diameter of Rotor.

(iii) Slab milling → is a horizontal milling

$Z = 15$ $\alpha = 10°$

$N = 200$ rpm

$D = 80$ mm

$f_m = 75$ mm/min

$d = 5$ mm

$w = 50$ mm

$\tau_s = 420$ MPa

$\mu = 0.7$ ⇒ $\tau = \tan^{-1} 0.7 = 34.992°$

Torque vs θ_0

Lee-Shafer:

$\theta + \tau - \frac{\alpha}{2} = 45°$

t_{max} = uncut chip thickness $= \frac{2 \times f_m}{Z N} \sqrt{\frac{d}{D}\left(1 - \frac{d}{D}\right)}$

$= \frac{2 \times 75}{15 \times 200} \sqrt{\frac{5}{80}\left(1 - \frac{5}{80}\right)}$

$t_2 = 0.0121$ mm

7

$\theta + \tan^{-1}(0.7) - \frac{10}{2} = 45°$

$\theta = 50 - 34.992 = 15.0079°$

$F_s = \frac{\tau_s \times A_0}{\sin\theta} = \frac{420 \times 50 \times t}{\sin 15.0079}$

t = depth of cut = $\sqrt{d(D-d)} = \sqrt{375} = 19.3649$ mm

$$F_s = \frac{420 \times 50 \times 19.365}{\sin(15.0079)}$$

$$= 1570.418 \text{ KN}$$

$$F_c = R\cos(\tau - \alpha)$$

$$= \frac{F_s \cos(\tau - \alpha)}{\cos(\theta + \tau - \alpha)}$$

$$= \frac{1570.418 \times \cos(24.992)}{\cos(24.992 + 15.0079)}$$

$$= 1858.081 \text{ KN}$$

Power = $F_c \cdot V_{cutting}$

$$= F_c \cdot \left(\frac{\pi D N}{1000}\right) \times \frac{1}{60}$$

$$= 1858.081 \times \frac{\pi \times 80 \times 200}{60 \times 1000}$$

$$= 1556.622 \text{ KW}$$

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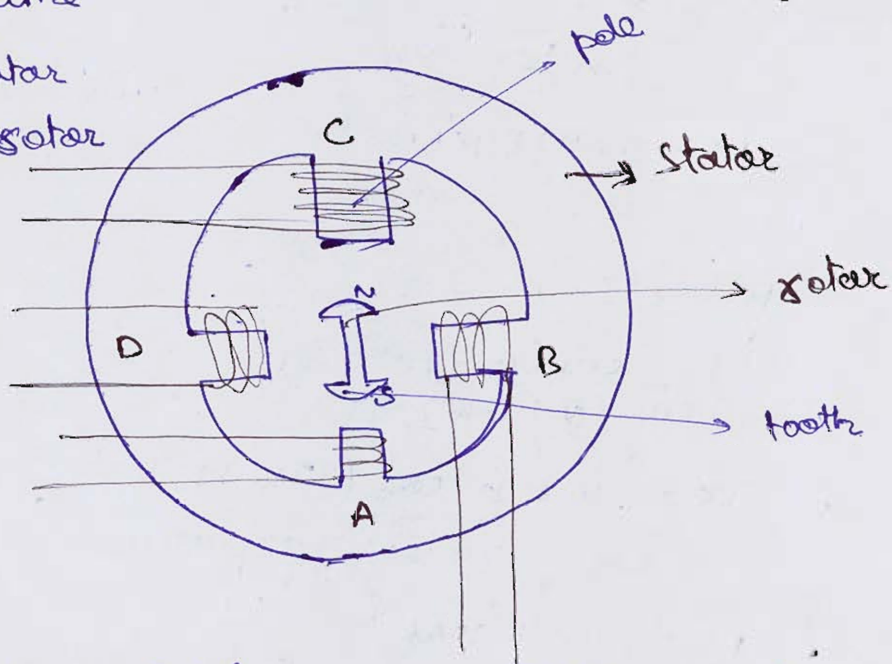
Q.7 (b) Explain stepper motor. Briefly discuss the working of the permanent magnet stepper motor with schematic diagram. Also write advantages and disadvantages of stepper motor.

[20 marks]

Let us assume there are –
4 pole of stator
2 tooths of rotor



Stator Pitch = $\frac{360^\circ}{\text{No. of poles}} = \frac{360^\circ}{4} = 90^\circ$

Rotor Pitch = $\frac{360^\circ}{\text{No. of tooths on rotor}} = \frac{360^\circ}{2} = 180^\circ$

Full step angle = Rotor pitch − Stator pitch
= $180^\circ - 90^\circ$
= 90°

→ ~~Prin~~ The stepper motor works on the principle of ~~Exicity~~ exciting the poles by passing current through windings ~~on the poles~~ using drive circuits.

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	A	B	C	D	θ (angle of rotatn)
			0	0	0°
(a.)	1	0	0	0	90°
(b)	0	1	0	0	180°
(c.)	0	0	1	0	270°
(d.)	0	0	0	1	360°
(e.)	1	0	0	0	

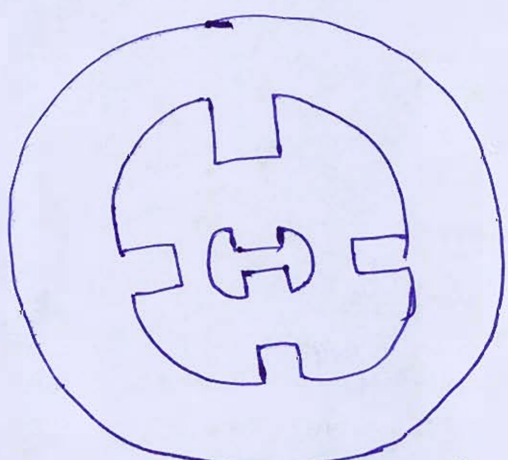
1 ⇒ denotes current

0 ⇒ denotes no current.

→ From the above table in the row (a) we have excited the pole A and all the poles are not excited i.e. with 0 current.

→ Now in the row (b.) we have excited the pole B and passed 0 current in other poles, thus this will allow the tooth to rotate by one full step angle i.e. 90°.

And the tooth will be in new position as shown below.



→ Similarly in each row each pole is excited as per the above table and tooth rotates.

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DisAdvantage	Advantage
1.) Stepper motor rotor is not fixed in one position when all the poles carries 0 current.	1.) Number of poles can be increased to increase the resolution of the stepper motor.
2.) Torque generated is less i.e no detent torque.	

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]

.8 (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]

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]

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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

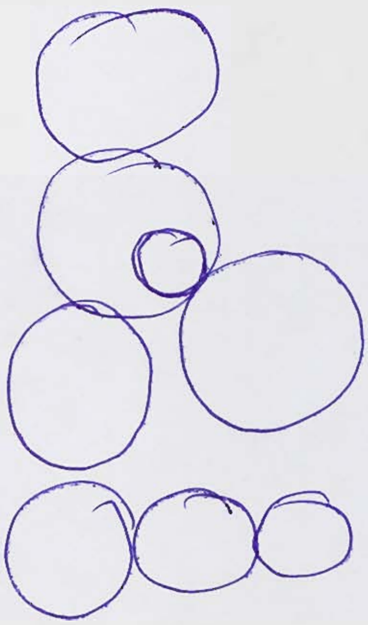
[20 marks]

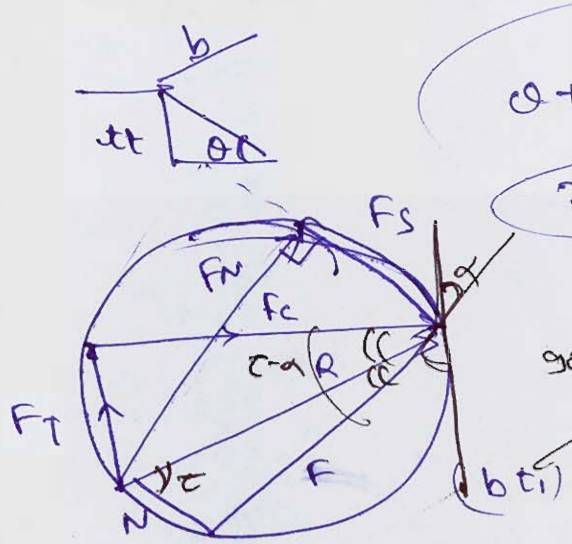
OOOO

Space for Rough Work

Space for Rough Work

Space for Rough Work



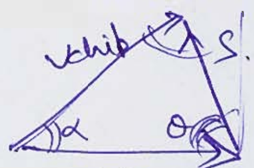


$\theta + \frac{\tau}{2} - \frac{\alpha}{2} = 45°$

$2\theta + \tau - \alpha = 90°$

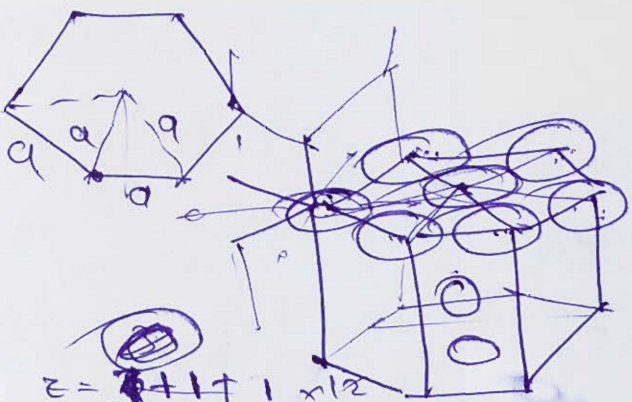
$90 - \alpha - (90 - \tau)$

~~$90 - \alpha - 90$~~ $+ \tau$



$\gamma = \frac{t_1}{t_2} = \frac{l_2}{l_1} = \frac{V_{chip}}{V_{cut}}$

$t_1 = s(\sin\phi)$.



P, V.

$P + F = C + 2$

IT 6 → 10 i

7 — 16 i

8 25 i

hcp = $Z = 3 + 1 + \frac{1}{12} \times 12$

fcc $Z = 4$

bcc $Z = 2$

scc $Z = 1$

$4 + \frac{1}{12} \times 12$ 1 +

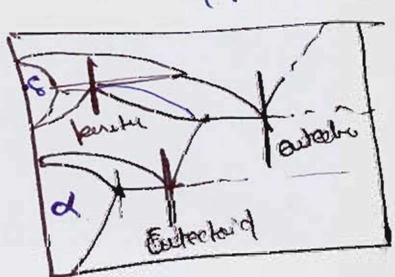
5

4 +

$\theta + \beta - \frac{\alpha}{2} = 45°$

$\theta + \frac{\beta}{2} - \frac{\alpha}{2} = 45$

α, δ, γ



$i = 0.045 \times 10^{-3} D$

$i = 0.45 + 10^{-3}(D)^{1/3}$

$i = 0.45 D^{1/3} + 0.001 D$

$= 0.45 D^{1/3} + 0.001 D.$