HARASHTRA STATE BOARD OF TECHNICAL EDUCATION
(Autonomous)
(ISO/IEC - 27001 - 2005 Certified)

MODEL ANSWER

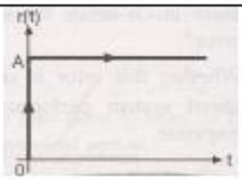
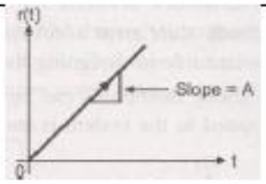
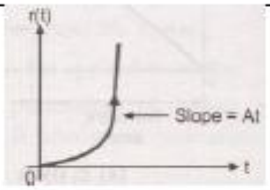
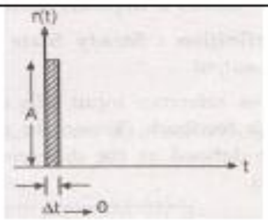
WINTER– 17 EXAMINATION

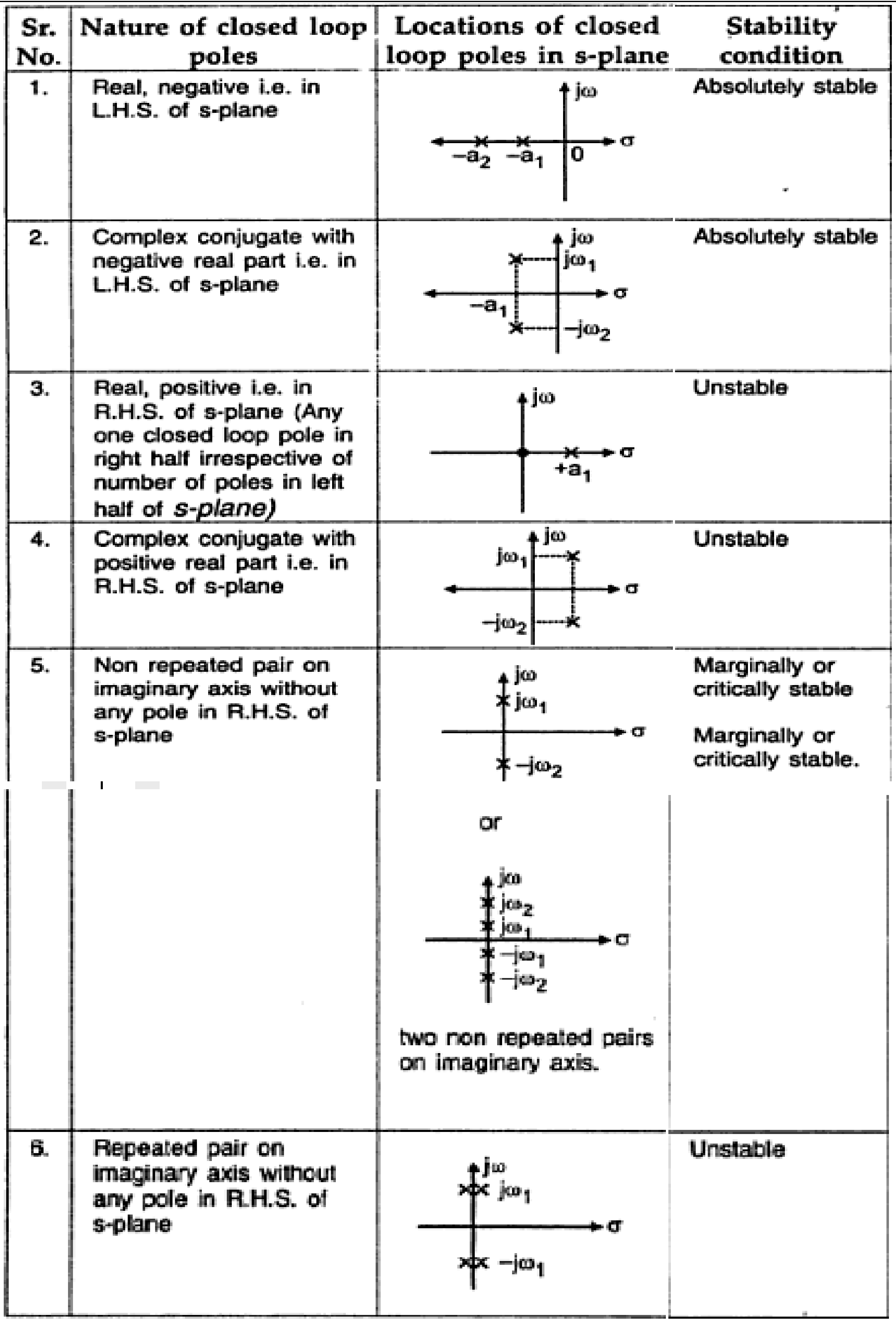
Subject Title: Control System Subject Code: 17538

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

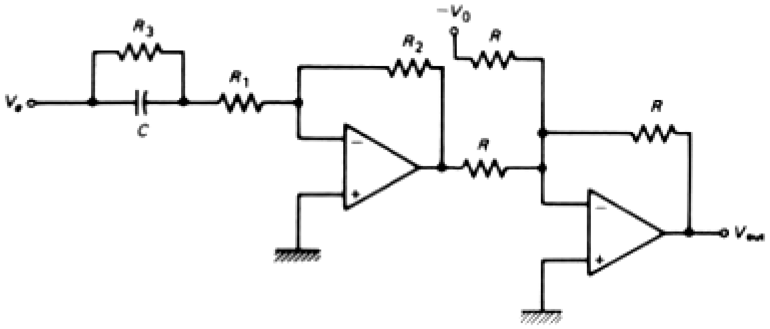
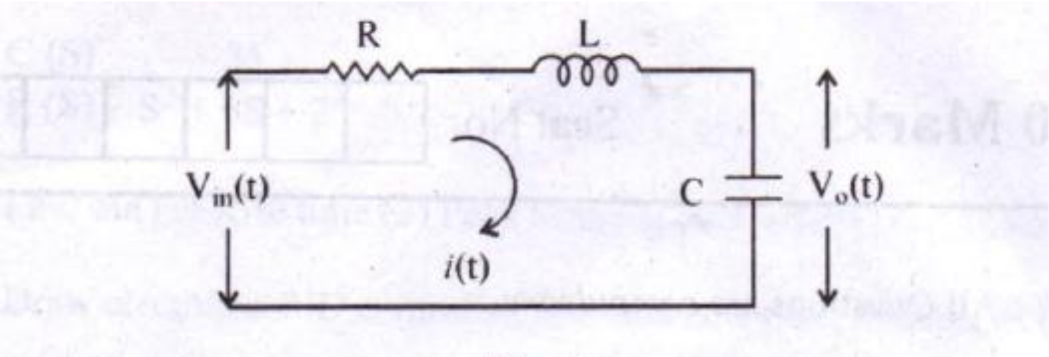
<table>
<tr><th>Q. No.</th><th>Sub Q.N.</th><th>Answer</th><th>Marking Scheme</th></tr>
<tr><td>Q.1</td><td></td><td>Attempt any THREE:</td><td>12-Total Marks</td></tr>
<tr><td></td><td>i)</td><td>Differentiate between time varying and time invarying system. (3 points)</td><td>4M</td></tr>
<tr><td></td><td>Ans:</td><td>
<table>
<tr><th>S.N.</th><th>Time varying System</th><th>Time invarying system.</th></tr>
<tr><td>1</td><td>A linear time variant or varying system is defined as a control system in which parameters of the system are varying with time that means as time passes parameters varies.
OR
A system is said to be Time variant if its input output characteristics change with time.</td><td>A linear time in-variant or varying system is defined as a control system in which parameters of the system does not vary with time.
OR
A system is said to be Time Invariant if its input output characteristics do not change with time.</td></tr>
<tr><td>2</td><td>Y(t)=t X(t)
System depends on time <i>t</i> so it is time-variant.</td><td>Y(t)=A X(t)
System does not depend explicitly on <i>t</i> so it is time-invariant.</td></tr>
<tr><td>3</td><td>Eg: rocket launching system, space shuttle/vehicle</td><td>Eg: RC ,RLC networks, different electrical network.</td></tr>
</table>
</td><td>2M Definition+1M each point (Any other relevant point shall be considered)</td></tr>
</table>

<table>
<tr><td></td><td>ii)</td><td>Name the standard test inputs. Draw them and give their Laplace transform.</td><td>4M</td></tr>
<tr><td></td><td>Ans:</td><td>The different standard test inputs are-
a) Step input b) Impulse input c) Ramp input d) Parabolic input
<table>
<tr><th>Test Signal</th><th>Graphical representation</th><th>Laplace representation</th></tr>
<tr><td>Unit Step Input</td><td> </td><td>$\frac{1}{s}$</td></tr>
<tr><td>Unit Ramp Input</td><td> </td><td>$\frac{1}{s^2}$</td></tr>
<tr><td>Unit Parabolic Input</td><td> </td><td>$\frac{1}{s^3}$</td></tr>
<tr><td>Unit Impulse</td><td> </td><td>1</td></tr>
</table>
</td><td>List of std. i/p-1M, Sketches& L.T-3M</td></tr>
<tr><td></td><td>iii)</td><td>Define stability. Draw the location of poles for stable, unstable and marginally stable systems.</td><td>4M</td></tr>
<tr><td></td><td>Ans:</td><td>When the system is excited by a bounded input, the output is also bounded and controllable. In the absence of the input, output must tend to zero irrespective of the initial condition.
<u>OR</u>
If the poles of the system are located on the left half of the s-plane system is said to be stable.</td><td>Definition 1M</td></tr>
</table>



Sr. No.	Nature of closed loop poles	Locations of closed loop poles in s-plane	Stability condition
1.	Real, negative i.e. in L.H.S. of s-plane	jω σ $-a_2$ $-a_1$ 0	Absolutely stable
2.	Complex conjugate with negative real part i.e. in L.H.S. of s-plane	jω $j\omega_1$ σ $-a_1$ $-j\omega_2$	Absolutely stable
3.	Real, positive i.e. in R.H.S. of s-plane (Any one closed loop pole in right half irrespective of number of poles in left half of *s-plane)*	jω σ $+a_1$	Unstable
4.	Complex conjugate with positive real part i.e. in R.H.S. of s-plane	jω $j\omega_1$ σ $-j\omega_2$	Unstable
5.	Non repeated pair on imaginary axis without any pole in R.H.S. of s-plane	jω $j\omega_1$ σ $-j\omega_2$ or jω $j\omega_2$ $j\omega_1$ σ $-j\omega_1$ $-j\omega_2$ two non repeated pairs on imaginary axis.	Marginally or critically stable Marginally or critically stable.
6.	Repeated pair on imaginary axis without any pole in R.H.S. of s-plane	jω $j\omega_1$ σ $-j\omega_1$	Unstable

S plane for stable, unstable & marginally stable-1M each

	iv)	**Draw electronic PD controller and write its output equation. State why derivative controller is not used alone.**	**4M**
	Ans:	**Diagram -**  **Equation:** $V_{Out} = \frac{R_2}{R_1 + R_3} V_e + \left(\frac{R_2}{R_1 + R_3}\right) R_3 C \frac{dV_e}{dt} + V_O$ Derivative control action responds to the rate at which the error is changing. Derivative action is not used alone because it provides no output when error is constant. **OR** The equation for D controller is: $P_o = K_D \frac{dE_p}{dt}$ It shows that the controller output will be zero if i) error Ep is zero ii) if error is constant. Therefore D controller is not used alone.	**2M** **Output Equation-1M** **State-1M**
	B)	**Attempt any ONE:**	**6M**
	i)	**Find the transfer function of the RLC circuit in figure 1.**  **Fig. 1**	**6M**

Ans:

Vin(t) = i(t)R + L[di(t) / dt] + [1 / C] ∫[i(t)] dt.

Take Laplace transform,

Vi(s) = I (s) [R + SL + 1/ SC] -------(1)

Vo(t) = [1 / C] ∫[i(t)] dt.

Hence, Vo (s) = 1 / SC I(s) -------(2)

Divide equation (2) by (1)

Vo(s)/ Vi(s) = 1/ [R + SL + 1/ SC]

Vo(s) / Vi(s) = (1 / SC)/(R + SL + 1 /SC)

Vo(s) / Vi(s) = 1 / (SRC+S^2 LC +1)

Input equ-1.5M
Output equ-1.5M
Transfer Function -3M

ii) **Draw Bode plot for the open loop transfer functions.**

$$G(S)\,H(S) = \frac{20}{S\,(1 + 0.25)}$$

6M

NOTE: The question is $G(S)H(S) = \frac{20}{S(1+0.2S)}$

Ans: **Step 1**: Convert the given open loop transfer function to time constant form:
Given equation is already in time constant form

$$G(S)H(S) = \frac{20}{S(1+0.2S)}$$

Step 1-1M

Step 2: Identify the factors;

1. Open loop gain K=20, Magnitude in dB= 20 log K= 20 log 20=26.02dB

2. Pole at origin (1/S) which has a magnitude plot with slope of -20dB/decade.
   For ω=1, Magnitude in dB for (1/S) = -20 log 1=0 dB

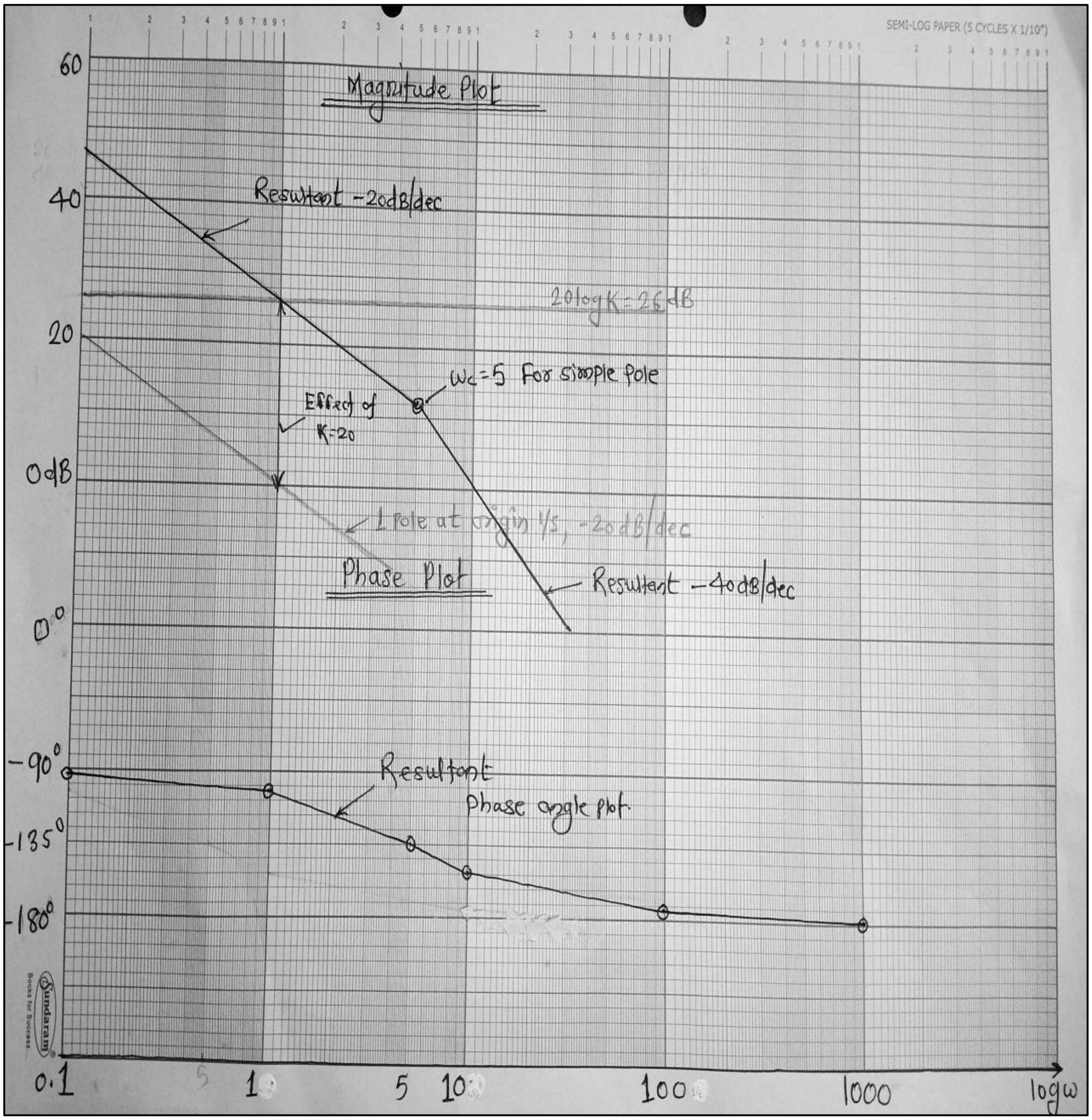
3. First order poles (1+0.2S). The corner frequency is ωc =1/0.2=5rad/sec. Till the corner frequency the magnitude plot's slope will be -20 dB/decade and from the corner frequency it changes to -40dB /decade.

Step 2-1M

Step 3: Phase angle plot

Step 3-2M

Frequency ω(rad/sec)	**Factor 1 K=20, Φ1=**	**Factor 2 1/S Φ2=**	**Factor 3 1/(1+0.2S) Φ3= $-\tan^{-1} 0.2\omega$**	**Φ=Φ1+Φ2+Φ3**
0.1	0^0	-90^0	-1.14^0	-91.14^0
1	0^0	-90^0	-11.31^0	-101.31^0
5	0^0	-90^0	-45^0	-135^0
10	0^0	-90^0	-63.43^0	-153.43^0
100	0^0	-90^0	-87.14^0	-177.14^0
1000	0^0	-90^0	-89.71^0	-179.71^0

		Step 4: Draw the magnitude plot and phase angle plot on semilog paper. 	**Step 4-2M**
Q 2		**Attempt any two:**	**16M**
	a)	**By Routh's Array, find out the stability of the system with characteristic equation.** $S^5 + S^4 + 2S^3 + 2S^2 + 2S + 2 = 0$	**8M**
	Ans:	The Characteristic equation is**S^5+S^4+2S^3+2S^2+2S+2=0** So, Apply Routh's Array	**First Routh's Array-2M** **Auxiliary equ-1M**

$$\begin{array}{c|ccc} S^5 & 1 & 2 & 2 \\ S^4 & 1 & 2 & 2 \\ S^3 & 0 & 0 & 0 \text{ special case} \\ S^2 & & \text{Routh ‘array failed} & \\ S^1 & & & \\ S^0 & & & \end{array}$$

Final Routh’s array-3M

Auxiliary equation: $A(S)= S^4+2S^2+2=0$
Taking derivative, $dA(S)/dS= 4S^3+4S=0$
By replacing the row of zeros with coefficient of derivative of auxiliary equation, the new Routh’s array will be:

$$\begin{array}{c|ccc} S^5 & 1 & 2 & 2 \\ S^4 & 1 & 2 & 2 \\ S^3 & 4 & 4 & 0 \\ S^2 & 1 & 2 & 0 \\ S^1 & -4 & 0 & 0 \\ S^0 & 2 & 0 & 0 \end{array}$$

Conclusion-
The first column has 2 sign changes which indicate that there are two poles on right side of S-plane. So the system is unstable

Conclusion 2M.

b) **(i) State how AC servomotor is different from two phase induction motor.**

(ii) Define servo system. Draw its block diagram and explain each block.

8M

Ans: **(i)**

Sr.No	AC servo motor	2 phase induction motor
1	Low inertia	High inertia
2	Linear Torque-speed characteristic	Nonlinear Torque-speed characteristic
3	Less susceptible to low frequency noise	Susceptible to low frequency noise
4	Low power applications	Low and high power applications
5	Diameter of rotor is small	Diameter of rotor is large
6	X/R ratio is less	X/R ratio is more

Any 4 relevant point 1M each
Definiton-1M

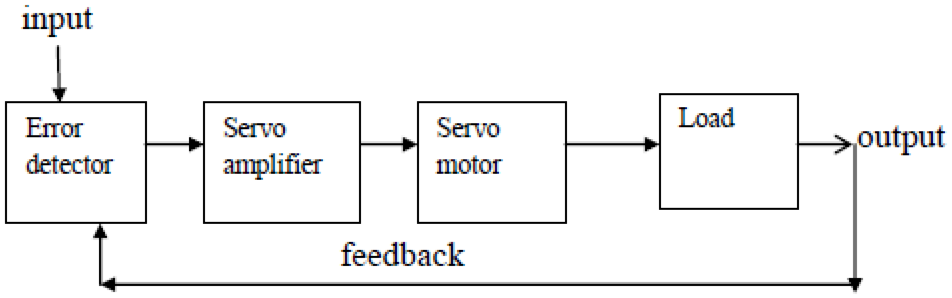
OR

Two Phase Induction Motor	**AC Servomotor**
In these motor the current flows through rotor due to principle of induction	In these motors, signal error is converted in to angular velocity to correct the error.
Two phase induction motor are type of AC motor where power is supplied to the rotor by means of electromagnetic induction, rather than a Commutator or slip rings.	A servomotor is a rotary actuator that allows for precise control of angular position.
These motor are widely used in high power industrial drives.	Servomotors are used in applications such as robotics, CNC machinery or automated manufacturing.
Speed of the induction motor is controlled by the number of poles pairs and the frequency of the supply voltage.	Servomotors are controlled by microcontrollers.
Torque producing capacity is high	Torque speed characteristic is linear.

(ii) Servo System: Servo systems are automatic feedback control system which work on error signals with output is the form of mechanical position, velocity or accelerations.

Block diagram:

Block Diagram-2M



The components of servo systems are:

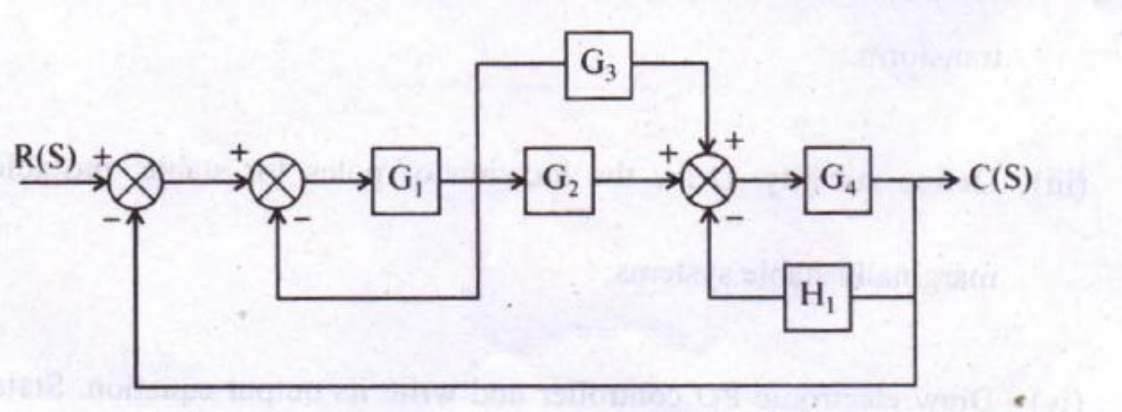
1) Error detector-All feedback control systems operate from the error signal which is generated by a comparison of the reference and the output. Error detectors perform the crucial task of comparing the reference and output signals. In a purely electrical system where the reference and output are voltages, the error detector is a simple comparator.

2) Servo amplifier-The error signals are amplified to drive the motor.

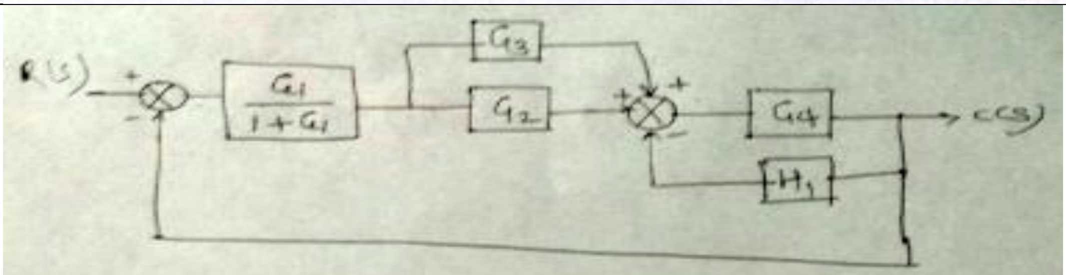
3) Servo motor-Motor are used to convert electrical signal applied, into the angular velocity or movement of shaft.

Explaination-2M

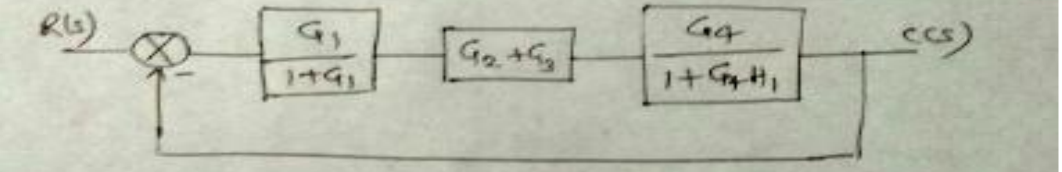
c) **Find the transfer functions of the given block diagram, (fig. 2)** **8M**

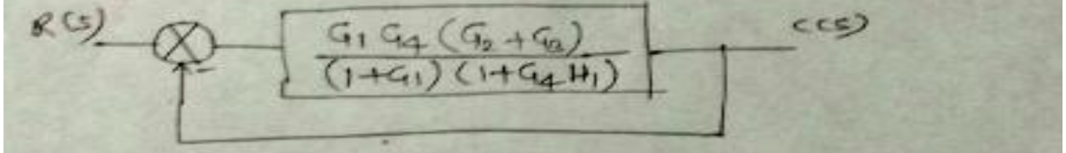


Ans:



2M

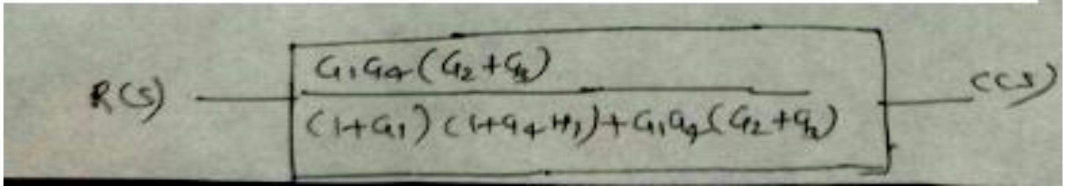


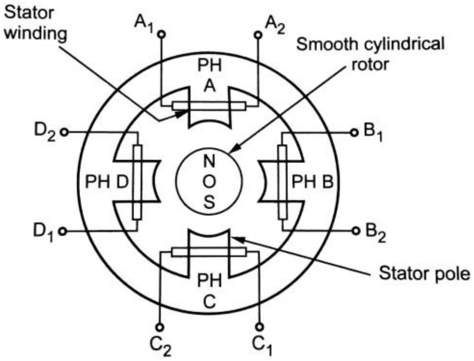
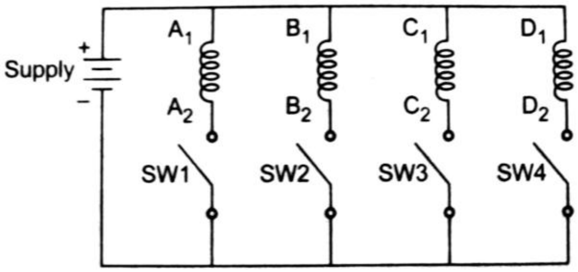


4M

$$= \frac{\frac{G_1 G_4 (G_2 + G_3)}{(1+G_1)(1+G_4 H_1)}}{1 + \frac{G_1 G_4 (G_2 + G_3)}{(1+G_1)(1+G_4 H_1)}}$$

$$= \frac{G_1 G_4 (G_2 + G_2)}{(1+G_1)(1+G_4 H_1) + G_1 G_4 (G_2 + G_3)}$$



		$T.F. = \dfrac{G_1G_4(G_2+G_3)}{(1+G_1)(1+G_4H_1)+G_1G_4(G_2+G_3)}$	**2M**
Q. 3		**Attempt any FOUR:**	**16M**
	a)	**Draw and explain the construction and working of anyone type of stepper motor.**	**4M**
	Ans:	(**Marks may be given to any one type of Stepper motor**) **Permanent magnet stepper motor:** **Construction :** **Diagram :**  **Four phase permanen tmagnet stepper motor**  **Drive circuit** **Explanation:** • The stator of this type of motor has four poles. Around the poles exciting coils are wounded (A, B, C, D) • Rotor may be salient or smooth cylindrical type. It is made up of ferrite material and permanently magnetized. **Working**: • When voltage pulses are applied to various phases with the help of driving	**2M** **2M**

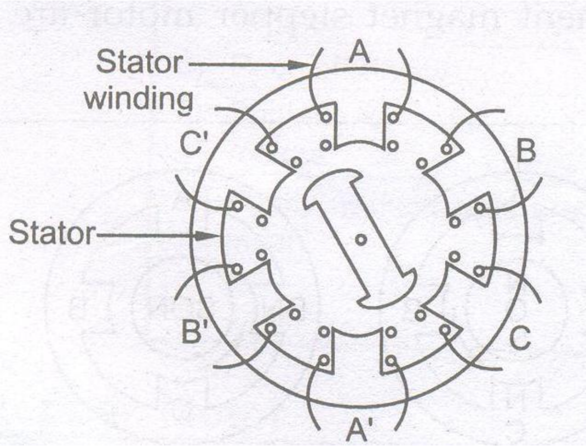
circuit, the rotor makes 90^o revolution called step for each input voltage pulse

- It can be explained as under :

1) When switch SW1 is closed exciting the phase A, we have a North pole in phase A due to this excitation. An electromechanical torque is developed and rotor rotates to adjust its magnetic axis with the magnetic axis of the stator.
2) Next phase B is excited with switch SW2 after disconnecting phase A. Due to this, rotor further rotates to adjust its magnetic axis with north pole of phase B. Hence it rotates through 90^o called step.
3) Similarly when phase C and phase D are sequentially excited, the rotor tends to rotate through 90^o in clockwise direction, every time when such sequence is repeated.

OR

Variable Reluctance Stepper Motor:



Construction :

The figure above represents a variable reluctance stepper motor with single stack whose stator is wound for 3 phases. The stator has six salient poles or teeth with concentrated exciting windings around each one of them. The rotor is made up of slotted steel laminations. It has 2 salient poles without any exciting windings. The coils of the driving circuit are wound around opposite poles such that they are connected in series. The three phases are energized from a DC source with the help of switches.

Working:

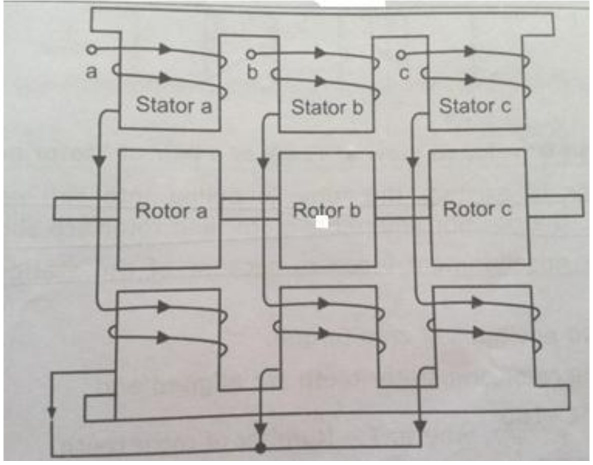
When any one phase is excited by the closing of the switch in series, the corresponding poles act as north and south poles. The rotor between them adjusts itself in minimum reluctance position between stator and rotor. When the next phase is excited by the closing of the second switch keeping the previous phase excited, the magnetic axis of the stator shifts by 30 degrees. So the rotor will also rotate through 30 degree step to attain the new minimum reluctance position. By successively exciting the three phases in specific sequence, the motor is made to complete one revolution.

OR

Multistack variable reluctance stepper motor:

In this type, the windings are arranged in different stacks. The figure represents a three stack stepper motor. The three stacks of the stator have a common frame. The rotors have a common shaft. The stator stacks and rotors have toothed structure with same teeth size. The stators are pulse excited and rotors are unexcited. When the stator is excited, the rotor gets pulled to the nearest minimum reluctance position where the stator and rotor teeth are aligned. The stator teeth of various stacks are arranged to have a progressive angular displacement of :

$\alpha = 360/(\alpha T)$ where q = number of stacks, T = number of teeth .



b) **Explain on-off controller. Give example.** **4M**

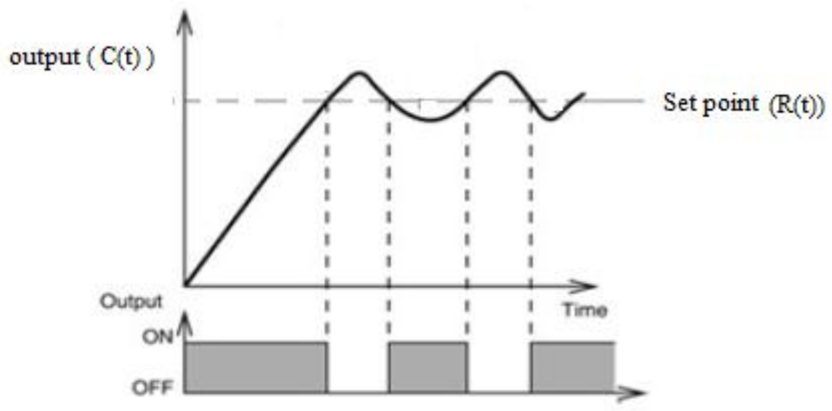
Ans: ON-OFF controller (or) two position controller **2M**

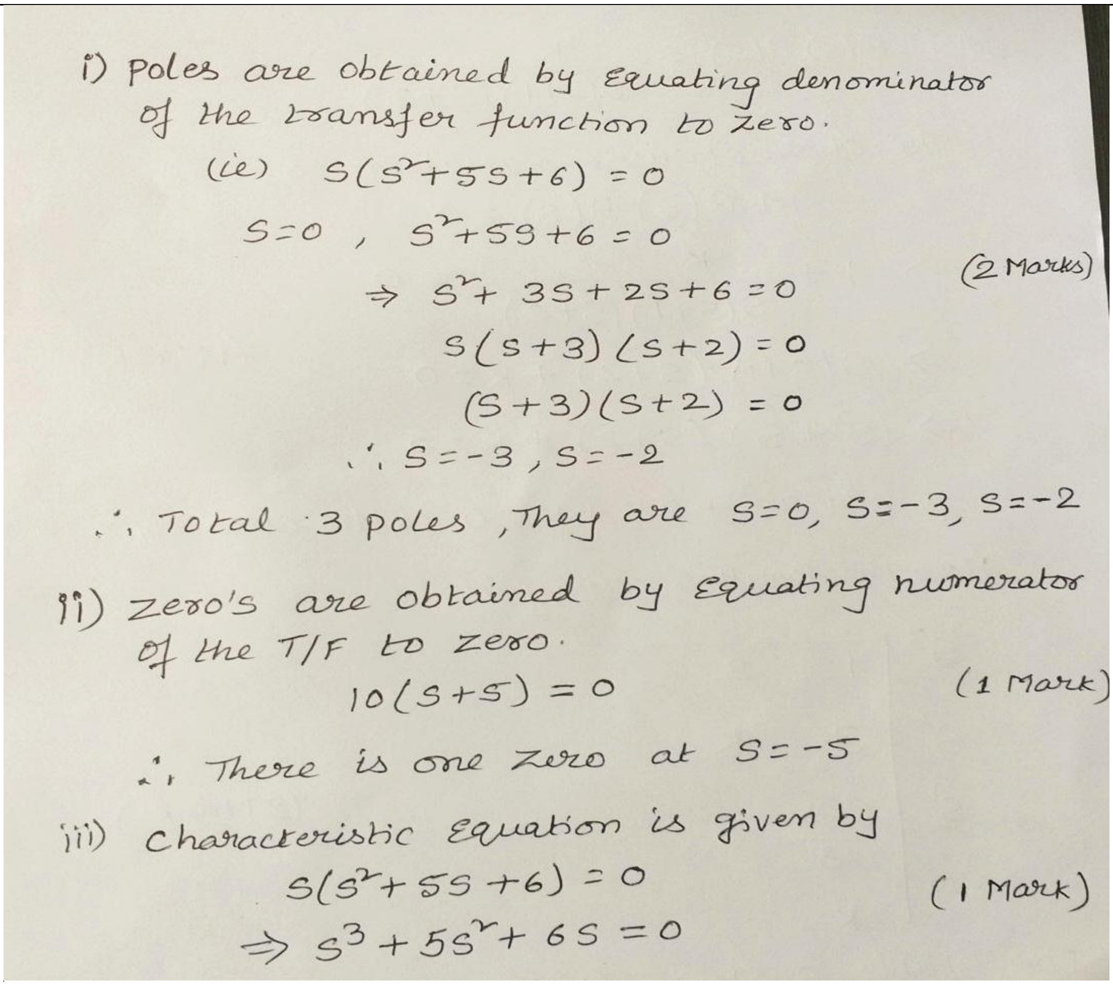
1) The ON-OFF controller is a type of controller in which the controller output changes to maximum or minimum value depending upon whether the measured value is greater or less than the set point.
2) It is the simplest and cheapest mode of action, hence commonly used in industrial and domestic control systems.
3) The controller output is given by

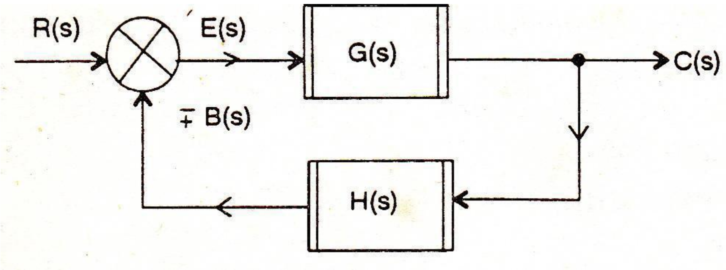
   $p = 0\ \%, \quad e_p < 0$

   $p = 100\ \%, \quad e_p > 0$

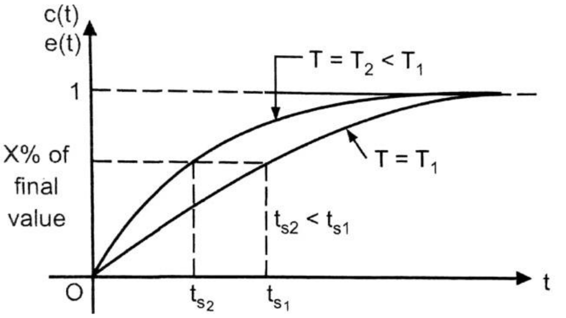
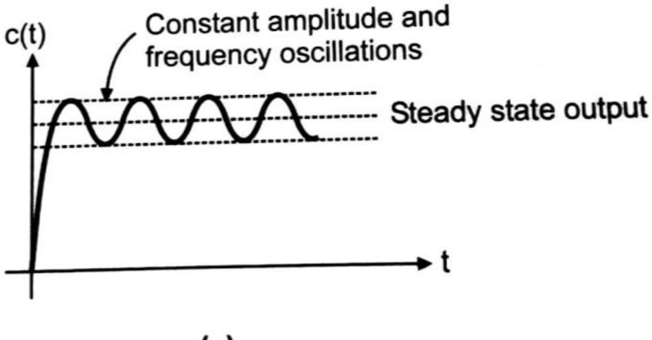
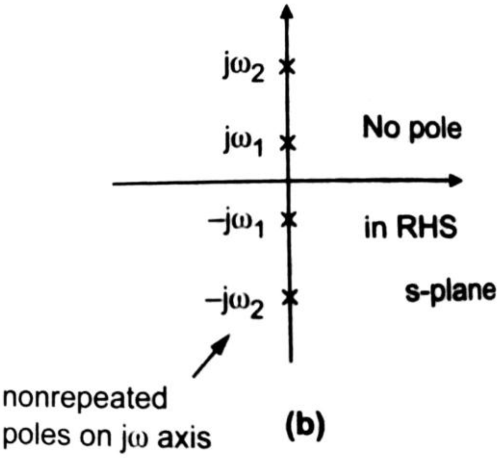
   where e_p is input error and p is controller output.
4) From the above relation, it is seen that when the measured variable is below the set point, controller is ON and output is maximum. When the measured variable is above the set point the controller is OFF and output is minimum.

		 **Graphical representation** **Example:** This controller is suitable for large scale systems with relatively slow process rates like: i. Air conditioning system ii. room heating system iii. liquid bath temperature control iv. level control in large volume tanks	**2M**
	c)	**For the transfer function** $Tf = \frac{10\,(S+5)}{S\,(S^2+5S+6)}$ find **Poles, zeros and characteristic equation.**	**4M**

	Ans:	 i) Poles are obtained by Equating denominator of the transfer function to zero. (ie) $s(s^2+5s+6)=0$ $s=0$, $s^2+5s+6=0$ $\Rightarrow s^2+3s+2s+6=0$ (2 Marks) $s(s+3)(s+2)=0$ $(s+3)(s+2)=0$ $\therefore s=-3 , s=-2$ $\therefore$ Total 3 poles, They are $s=0$, $s=-3$, $s=-2$ ii) zero's are obtained by Equating numerator of the T/F to zero. $10(s+5)=0$ (1 Mark) $\therefore$ There is one zero at $s=-5$ iii) Characteristic Equation is given by $s(s^2+5s+6)=0$ (1 Mark) $\Rightarrow s^3+5s^2+6s=0$	**2 Marks** **1 Mark** **1 Mark**
	d)	**Define: (i) Gain Margin (ii) Phase Margin (iii) Band width (iv) Cut off frequency.**	**4M**
	Ans:	**(i) Gain Margin:** The margin in gain allowable by which gain can be increased till system reaches on the verge of instability is called as Gain Margin **(ii) Phase Margin:** The amount of additional phase lag which can be introduced in the system till the system reaches on the verge of instability is called as Phase Margin. **(iii) Bandwidth:** It is defined as the range of the frequencies over which the system will respond satisfactorily. It is also defined as range of the frequency over magnitude of closed loop response does not drop by more than 3db from its zero frequency value. **(iv) Cut off frequency:** Frequency at which the magnitude of closed loop response in 3db down from its zero frequency value is called as cut off frequency.	**Each definition 1M**
	e)	**A system has G(S) H(S) = K / S (S + 1) (S + 2) find the range of K for the system to be stable.**	**4M**
	Ans:		

		Sol $G(s)H(s) = \dfrac{K}{s(s+1)(s+2)}$ The char. Equation is $1+G(s)H(s)=0$ $\Rightarrow \; 1+\dfrac{K}{s(s+1)(s+2)}=0$ $\Rightarrow \; s(s+1)(s+2)+K=0$ $\Rightarrow \; s^2+3s^2+2s+K=0$ is the char. eq^n Now the Routh's array is $\begin{array}{c\|cc} s^3 & 1 & 2 \\ s^2 & 3 & K \\ s^1 & \frac{6-K}{3} & 0 \\ s^0 & K & \end{array}$ For stable system all the Elements of First column of Routh's array should be +ve. (greater than zero) Hence for s^0 element $K>0$ and for s^1 element $\therefore \; \dfrac{6-K}{3} > 0$ $\therefore \; 6-K>0$ $\therefore \; 6>K$ Hence to make system stable range of K is $0<K<6$	1 Mark 2 Marks 1 Mark
Q. 4	**A)**	**Attempt any THREE:**	**12M**
	(i)	**Derive the transfer function of closed loop transfer function.**	**4M**
	Ans:	Transfer Function is defined as the ratio of Laplace transform of Output to that of Laplace transform of input under the assumption that all initial conditions are zero. **<u>Block diagram:</u>** (for negative feedback system) 	**1M** **1M**

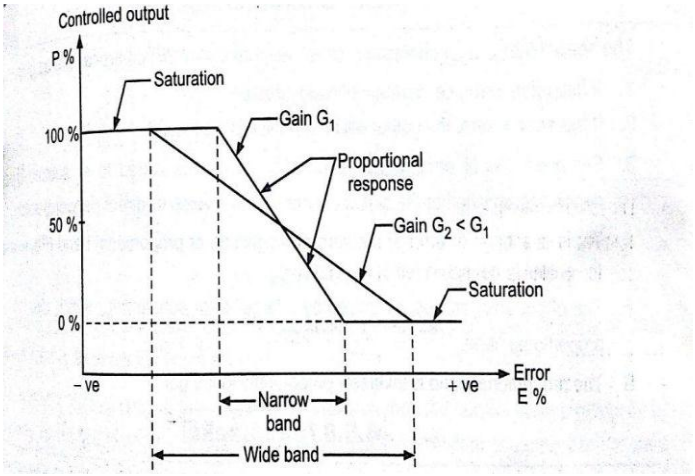
		Derivation: $G(s) = \frac{C(s)}{E(s)}$ $E(s) = \frac{C(s)}{G(s)}$ $C(s) = E(s) \text{ x } G(s)$ $B(s) = C(s) \text{ x } H(s)$ $E(s) = R(s) - B(s)$ (for negative feedback) ……. [.I.] Substitute for E(s) & B(s) in [.I.] $\frac{C(s)}{G(s)} = R(s) - C(s)\,H(s)$ $C(s) \; \{\frac{1}{G(s)+H(s)}\} = R(s)$ $C(s)\,\frac{[1+G(s)H(s)]}{G(s)} = R(s)$ Transfer Function: $\boxed{\frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)*H(s)}}$	**2M**
	(ii)	**Define Time constant. State its significance on system response.**	**4M**
	Ans:	**Definition:** Time Constant of a system is defined as the time required by the system output to reach 63.2% of its final value during the first attempt. **Significance of time constant**: The time constant gives an indication as to how fast a system tends to reach the final value. A large time constant corresponds to slow and sluggish system . A small time constant corresponds to fast response.	**2M** **2M**

		 **Effect of time constant on system response**	
	(iii)	**Define Marginal stability. Show the response of a marginally stable system w.r. to the location of poles.**	**4M**
	Ans:	**<u>Marginal Stability:</u>** A linear time invariant system is said to be critically or marginally stable if for a bounded input its output oscillates with constant frequency and amplitude For such systems, one or more pair of non-repeated roots is located on the j axis. The location of roots of Marginally stable system is shown in fig b and response shown in fig a  **(a)**  **(b)**	**2M** **2M**

<table>
<tr><td></td><td>(iv)</td><td>Compare stepper motor and DC servo motor (any 6 points).</td><td>4M</td></tr>
<tr><td></td><td>Ans:</td><td>
<table>
<tr><th>Stepper Motor</th><th>DC Servo Motor</th></tr>
<tr><td>Control winding is absent</td><td>Control winding is present</td></tr>
<tr><td>Brushes are absent</td><td>Brushes are present</td></tr>
<tr><td>Maintenance is low</td><td>Maintenance is high</td></tr>
<tr><td>Stepper motor is electromechanical device which activates a train of pulses of step angular or linear moments</td><td>Servomotor is a device which gives angular moment</td></tr>
<tr><td>Load and no load conditions do not affect the running current of stepper motor.</td><td>These conditions affect the running current.</td></tr>
<tr><td>Speed (Stepping rate) is governed by frequency of switching</td><td>Speed is controlled by supply voltage</td></tr>
<tr><td>Number of steps can be precisely controlled</td><td>It gives continuous rotation depending upon control voltage.</td></tr>
</table>
</td><td>4M
(any other relevant points)</td></tr>
<tr><td></td><td>B)</td><td>Attempt any ONE:</td><td>6M</td></tr>
<tr><td></td><td>(i)</td><td>A unity feedback system has
$$G(S) = \frac{10\,(S+1)}{S(S+2)\,(S+10)}$$
Find (1) Type of the system (2) Error coefficients $K_{p2}K_{V2}$, K_a and steady state errors</td><td>6M</td></tr>
</table>

	Ans:	Sol (i) For unity feed back system ∴ H(s) = 1 to determine type of system it is required to bring G(s) H(s) into its time constant form. $G(s)\,H(s) = \frac{10(s+1)}{s(s+2)(s+10)}$ $= \frac{10(1+s)}{s\;2(1+0.5s)\;10(1+0.1s)}$ $= \frac{0.5(1+s)}{s(1+0.5s)(1+0.1s)}$ comparing with standard form the type of system is 1 ii) Error coefficients Kp, Kv, Ka and steady state errors $K_p = \lim_{s\to 0} G(s)\,H(s)$ $= \lim_{s\to 0} \frac{10(s+1)}{s(s+2)(s+10)} = \infty$ $K_v = \lim_{s\to 0} s\,G(s)\,H(s)$ $= \lim_{s\to 0} \frac{s\;10(s+1)}{s(s+2)(s+10)} = 1/2 = 0.5$ $K_a = \lim_{s\to 0} s^2\,G(s)\,H(s)$ $= \lim_{s\to 0} \frac{s^2\;10(s+1)}{s(s+2)(s+10)} = 0$ Therefore e_{ss} for unit step input =0 e_{ss} for unit ramp input =1 e_{ss} for unit parabolic input =∞	**1M** **(note: Marks can be given even if equation is not in the time constant form)** **3M** **2M**
	(ii)	**Explain proportional controller action with equation and response. Define Proportional Band and offset. State the methods to eliminate offset.**	**6M**
	Ans:	**1. <u>Proportional Controller action :</u>** In this mode the output of controller is proportional to the input error signal. A linear relationship exists between controller output and error. Therefore over some range errors about a set point, each value of error has a unique value of controller output. i.e. one to one correspondence. **2. <u>Equation of P control action :</u>** The P control action can be represented as $P = K_p e_p + P_o$ Where K_p=proportional gain P=Controller output e_p = error signal P_o= controller output without error	**1M each**

3. Response :



4. Proportional Band: It is defined as the range of error to cover zero to 100 % of controller output.

PB = 100/K_p where K_p is proportional gain

5. Offset : The proportional controller produces a permanent residual error in the controlled variable, when a change in load occurs. This is referred to as offset.

6. Methods of eliminating offset: It can be minimized by the large proportional gain K_p, by doing manual resetting and by using integral controller

Q.5 **Attempt any TWO:** **16M**

a) **The transfer function of a system is** **8M**

$$\frac{C(S)}{R(S)} = \frac{25}{S^2 + 6S + 25}$$

Find out (1) Rise time (2) Peak time (3) Peak overshoot (4) Settling time

Ans: Comparing the above equation with the standard form below,

1M for each correct answer of w_n, ζ, w_d, Tr, θ, Tp, %M_p, T_s

$$\frac{C(s)}{R(s)} = \frac{\omega_n{}^2}{\omega_n{}^2 + 2\xi\omega_n s + s^2}$$

wn² =25 ,

hence, $w_n = \sqrt{25} = 5$ rad/sec. **w_n = 5 rad/sec**

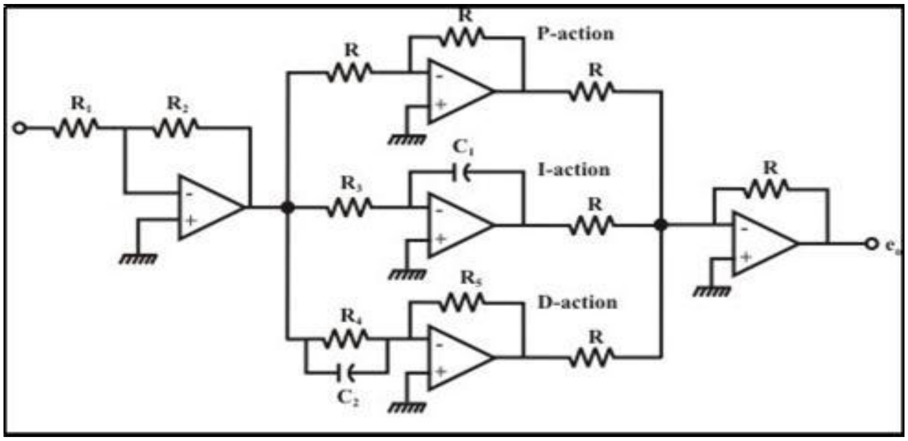
2ζwn=6

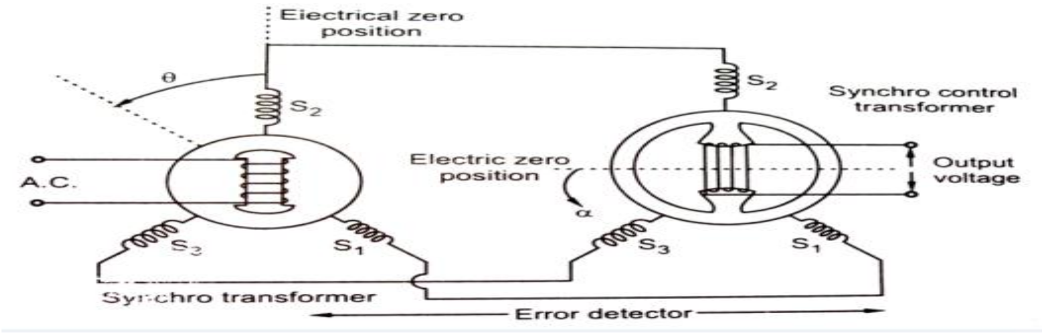
ζ = 0.6

$w_d = w_n\sqrt{(1-\xi^2)}$ **w_d = 4 rad/s .**

1) **Rise Time**: **Tr =** π –θ/ ωd

$$\theta = \tan^{-1}\left(\frac{\sqrt{(1-\xi^2)}}{\xi}\right)$$

		θ = 0.92 **Tr** = (π-0.92)/4=**0.55 sec** 2) **Peak Time** : Tp= π/wd= π/4=**0.785 sec** 3) **% Peak overshoot:** **%Mp= e**$^{-\pi \xi/\sqrt{(1-\xi2)}}$x100=**9.47%** 4) **Settling time:** $Ts = \frac{4}{\xi wn}$ T_s=**1.33sec**	
	b)	**Draw electronic PID controller. State its equation. Explain its control action in brief. State its advantages and disadvantages. (2 each)**	**8M**
	Ans:	**Diagram:**  Out put equation: $P_O = K_P E_P + K_P K_I \int E_P\,dt + K_P K_d \frac{dE_P}{dt} + P_I(0)$ **OR** $V_{Out} = \frac{R_2}{R_1} V_e + \left(\frac{R_2}{R_1}\right)\frac{1}{R_1 C_1}\int V_e\,dt + \left(\frac{R_2}{R_1}\right) R_D C_D \frac{dV_e}{dt} + V_{out}(0)$ $V_e\ is\ the\ error\ voltage$ $V_{out}(0)$ is the output when time *t* is zero **Explanation:** PID is combination of 3 control action- proportional + integral + derivative. The proportional corrects instances of error, the integral corrects accumulation of error, and the derivative takes the corrective action in anticipation. The effect of the derivative is to counteract the overshoot caused by P and I. When the error is large, the P and the I will push the controller output. This controller response makes error change quickly, which in turn causes the derivative to more aggressively counteract the P and the I.	**2M** **2M for Equation** **2M**

		Advantages: 1.Process independent - The best controller where the specifics of the process cannot be modeled 2.Leads to a "reasonable" solution when tuned for most situations. 3.Inexpensive: Most of the modern controllers are PID. **Disadvantages:** 1.Not optimal 2.Tuning can be difficult 3.Can be unstable unless tuned properly. 4.Not dependent on the process 5.Hunting(Oscillation about an operating point) 6.Derivative noise amplification	**1M(any relevant point)** **1M(any relevant point)**
c)	**(i) Draw and explain synchro error detector.** **(ii) Compare AC servo motor and DC.servo motor. (any 6 points)**		**8M**
Ans:	**(i) Diagram-**  **Fig. 1 synchro error detector** **Explanation:** Synchro transmitter along with synchro control transformer is used as error detector. The control transformer is similar in construction to that of synchro transmitter except that its rotor is cylindrical in shape. Therefore, the flux is uniformly distributed in the air gap. The output of the Synchro transmitter is given to the stator windings of the control transformer as shown. The voltage induced in the stator coils and corresponding currents of the transmitter are given to the control transformer stator coils circulating currents of same phase but different magnitude will flow through both set of stator coils. This establishes an identical flux pattern in the air gap of control transformer. The flux pattern in the air gap of control transformer will have the same orientation as that of transmitter rotor. The voltage induced in the transformer rotor will be proportional to the cosine of angle between the two rotors. The output equation is given by : $e_0(t) = V_r .\ \sin\omega t + \cos\phi$ where Vr sinwt = input voltage to the transmitter rotor and ϕ is the angular difference between both rotors. When ϕ=90 both rotors are perpendicular to each other and the output voltage is zero. This position is called electrical zero and is used as reference		**2M** **2M**

position.

(ii) Compare AC servo motor and DC servo motor.

Sr. No.	**AC servo motor**	**DC servomotor**
1	Low power output	High power o/p
2	Maintenance is less	Maintenance is more maintenance
3	No Brushes / commutators absent	Brushes / problem, commutators present
4	Stable and smooth operation	Noisy operation
5	Less problem of stability	More problem of stability
6	No RF noise because of absence of brushes	Brushes produce RF noise.
7	Non – linear characteristics	Linear characteristics
8	No voltage supply to rotor, Rotor current is supplied inductively by rotating magnetic field of stator.	Voltage is given through power supply to rotor.
9	Applications:- low power(computer peripherals, recorders etc.)	Application: high power (machine tools, robotics)

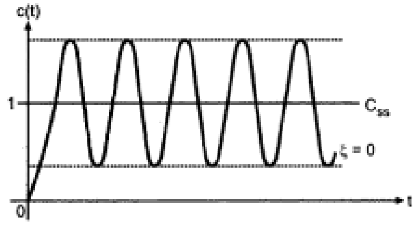
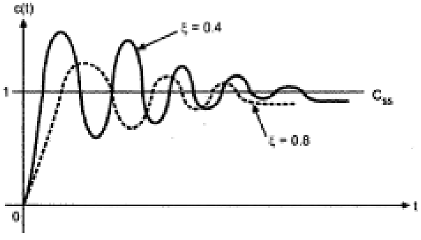
4M
(any 6 points)

Q.6 **Attempt any FOUR:** **16M**

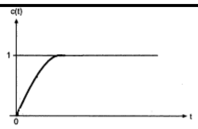
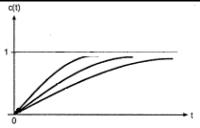
a) **Draw the effect of damping on a system response with the help of location of poles and output response. (for all 4 cases of damping factor)** **4M**

Ans:

Effect of damping on system:

No.	**Range of ζ**	**Range of ζ**	**Nature of response**	**System Classification**
1	$\zeta = 0$	Purely imaginary	Oscillations with constant amplitude & frequency	 **Undamped**
2	$0 < \zeta < 1$	Complex Conjugates with negative real parts	Damped Oscillations	 **Underdamped**

1M each

3	**$\zeta = 1$**	Real,Equal and Negative	Critical & Pure exponential	 **Critically damped**
4	**$1 < \zeta < \infty$**	Real,unequal & Negative	Purely exponential slow and sluggish	 Over damped

b) **Derive the unit step response of a l st order system.** **4M**

Ans: The T.F. of First order system is ,

$$\frac{Vo(s)}{Vi(s)} = \frac{1}{1 + sRC}$$ **1M**

For Unit Step Input

$$V_i(s) = \frac{1}{s}$$ **1M**

So,

$$Vo(s) = \frac{1}{s(1+sRC)} = \frac{A}{s} + \frac{B}{1+sRC}$$

Where A“ = 1 & B“ = –RC

So,

$$Vo(s) = \frac{1}{s} - \frac{RC}{1+sRC}$$ **1M**

Taking Laplace inverse, we get

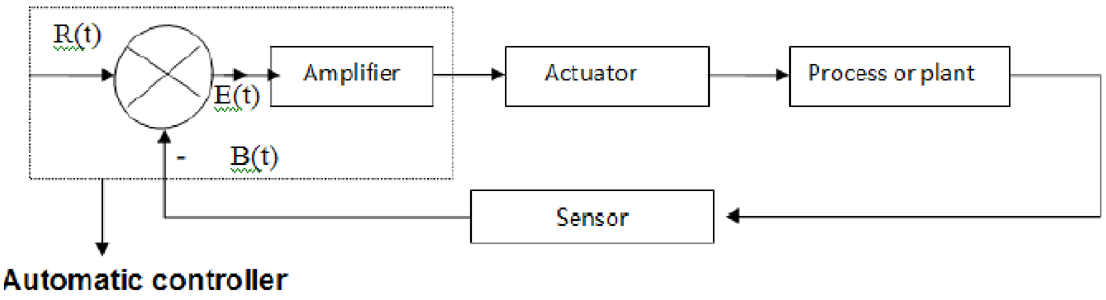
$$Vo(t) = 1 - e^{-\frac{t}{RC}} = C_{ss} + C_t(t)$$ **1M**

$$C_{ss} = 1 \text{ and } C_t(t) = - e^{-\frac{t}{RC}}$$

c) **State two advantages and disadvantages of frequency response analysis.** **4M**

Ans: **Advantages:** **Advantages -1 M each for 2 points**

1. The absolute and relative stabilities of the closed loop system can be found out from the open loop frequency response characteristics by using the methods such as Nyquist stability criteria
2. The transfer function of complicated systems can be found out practically by frequency response test when it is difficult to find
3. Frequency response test are simple and can be done practically by the readily available laboratory equipment.
4. Due to the close relation between frequency response of a system and its step response, idea about step response can be obtained from the frequency response.

		5. Without the knowledge of transfer function, the frequency response for stable open loop system can be obtained experimentally.	
		Disadvantages: 1. Time consuming 2. Out dated methods compared to digital computation , simulation and modeling. 3. Methods can be applied mainly to linear systems. 4. Not recommended for systems with larger time constant transfer function by writing differential equations.	**Disadvantages -1 M each for 2 points**
	d)	**Find out the stability of the following system with characteristic equation.** $S^4 + 2S^3 + 8S^2 + 4S + 3 = 0$	**4M**
	Ans:	$\begin{array}{c\|ccc} s^4 & 1 & 8 & 3 \\ s^3 & 2 & 4 & \\ s^2 & 6 & 3 & \\ s^1 & 3 & & \\ s^0 & 3 & & \end{array}$ As there is no sign change in 1st column of Routh's array, system is stable.	**3M** **1M**
	e)	**Draw the block diagram of process control system and explain each block.**	**4M**
	Ans:	**Diagram-**  **Explanation -** Process control system consists of process or plant, sensor, error detector, automatic Controller, actuator or control element. **1) Process or plant-** process means some manufacturing sequence. It has one variable or multivariable output. Plant or process is an important element of process control	**2M (any relevant answer)** **2M (any relevant answer)**

system in which variable of process is to be controlled.

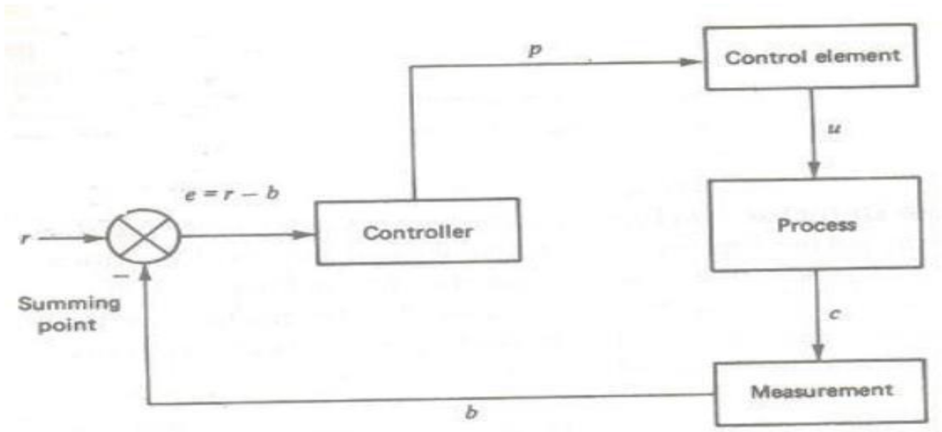
2) Sensor/measuring elements – It is the device that converts the output variable into another suitable variable which can acceptable by error detector Sensor is present in f/b path of close loop system.

3) Error detector – Error detector is summing point whose output is an error signal i.e. e(t) = r(t) - b(t) to controller for comparison & for the corrective action. Error detector compares between actual signal & reference i/p i.e. set point.

4) Automatic controller- Controller detects the actuating error signal, which is usually at a very low power level, and amplifies it to a sufficiently high level .i.e. means automatic controller comprises an error detector and amplifier.

5) Actuator or control element – Actuator is nothing but pneumatic motor or valve, a hydraulic motor or an electric motor, which produces an input to the plant according to the control signal getting from controller.

OR



Explanation :

The block diagram of process control system consists of the following blocks:-

1) Measuring element: It measures or senses the actual value of controlled variable “c” and converts it into proportional feedback variable b.

2) Error detector: It receives two inputs: set point “r” and controlled variable “p”. The output of the error detector is given by e= r-b. “e” is applied to the controller.

3) Controller: It generates the correct signal which is then applied to the final control element. Controller output is denoted by “p”.

4) Final control element: It accepts the input from the controller which is then transformed into some proportional action performed by the process. Output of control element is denoted by “u”.

5) Process: Output of control element is given to the process which changes the process variable. Output of this block is denoted by “u”.