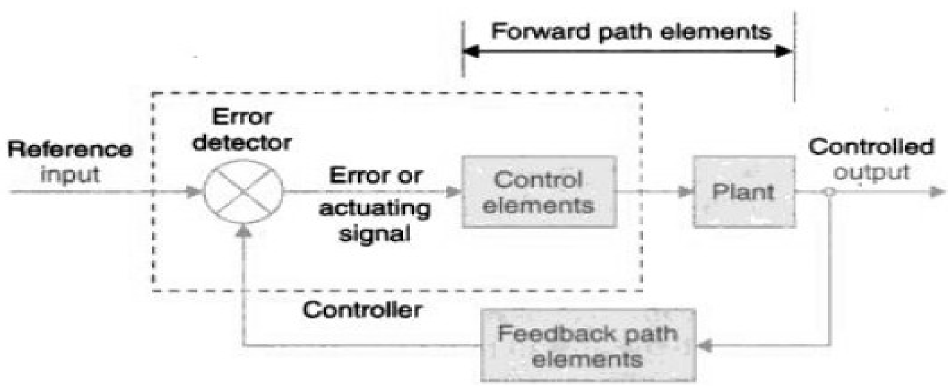
Solution	Marks
Q.2 a. Give the comparison between the open loop and closed loop systems. **Answer:**	04

OPEN LOOP	CLOSED LOOP
Utilize a controller or control actuator to obtain the desired response.	Utilizes feedback to compare the actual output to the desired output response.
System stability is not a major problem, therefore easier to build	The use of feedback makes the system response relatively insensitive to external disturbances and internal variations in system parameters
Use open loop only when the inputs are known ahead of time and there is no disturbances	System stability is a major problem because the system tends to overcorrect errors that can cause oscillations or changing amplitude.

b. With neat block diagram explain an automatic control system. 04

Answer:



The general block diagram of an automatic control system is characterized by a feedback loop as shown in figure. An error detector compares a signal obtained through feedback elements, which is a function of output response, with the reference input. any difference between these two signals constitute an error or actuating signal. The control elements in turn alter the plant in such a manner as to reduce the original error.

c. Consider the circuit (electrical) of Figure 1

(i) Identify a set of state variables (physical variables).

(ii) Draw the signal flow graph of the circuit in terms of the state variables identified in part (i).

(iii) From the signal flow graph, write the state variable equations of the circuit.

(iv) From the signal flow graph, determine the transfer function $E_C(s)/E(s)$.

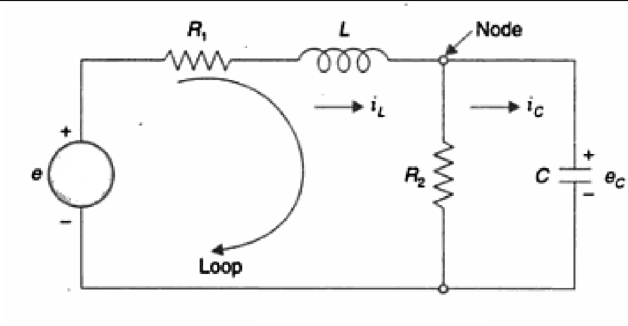


Fig.1

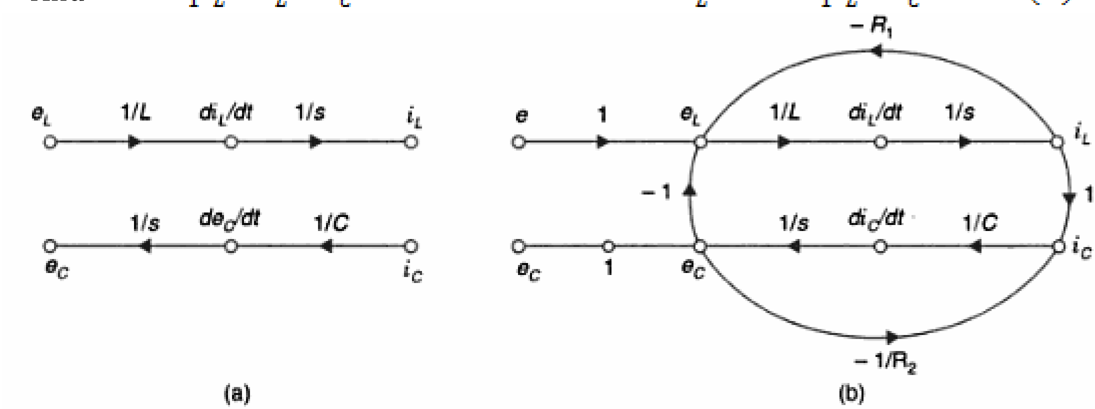
Answer:

(i) This circuit has two storage elements, so these shall be two state variables. We shall identify these as the inductor current i_L and capacitor voltage e_c; both these are associated with energy storage. 2

From the elemental laws of inductor and capacitor the signal flow graph as in Fig. The complete signal flow graph is then constructed by the KCL equation at the node and the KVL equation round the loop. These equations are

$$i_L = \frac{e_C}{R_2} + i_C \qquad or \qquad i_C = i_L - \frac{e_C}{R_2} \qquad \ldots (i)$$ 2

And $e = R_1 i_L + e_L + e_C \qquad or \qquad e_L = e - R_1 i_L - e_C \qquad \ldots (ii)$



(ii) The complete signal flow graph is drawn in Fig. b

(iii) From the signal flow graph the two state variable equations can be written as below

$$\frac{di_L}{dt} = \frac{1}{L}e_L = \frac{1}{L}(-e_L - R_1 i_L + e) = -\frac{R_1}{L}i_L - \frac{1}{L}e_C + \frac{1}{L}e \qquad \ldots (iii)$$ 2

and

$$\frac{de_C}{dt} = \frac{1}{C}i_C = \frac{1}{C}\left(i_C + \frac{e_C}{R_2}\right) = \frac{1}{C}i_L - \frac{1}{R_2 C}e_C \qquad \ldots (iv)$$

Equations (iii) and (iv) can be written in matrix form

$$\begin{bmatrix} di_L/dt \\ di_C/dt \end{bmatrix} = \begin{bmatrix} -R_1/L & -1/L \\ 1/C & 1/R_2 C \end{bmatrix} \begin{bmatrix} i_L \\ e_C \end{bmatrix} + \begin{bmatrix} 1/L \\ 0 \end{bmatrix} e$$

These are also known as state space equations.

(iv) Input $E(s)$, output $E_c(s)$. From the signal flow graph we have,

Forward path $P_1 = \frac{1}{sL} \times \frac{1}{sC} = \frac{1}{s^2 CL}; \Delta_1 = 1$

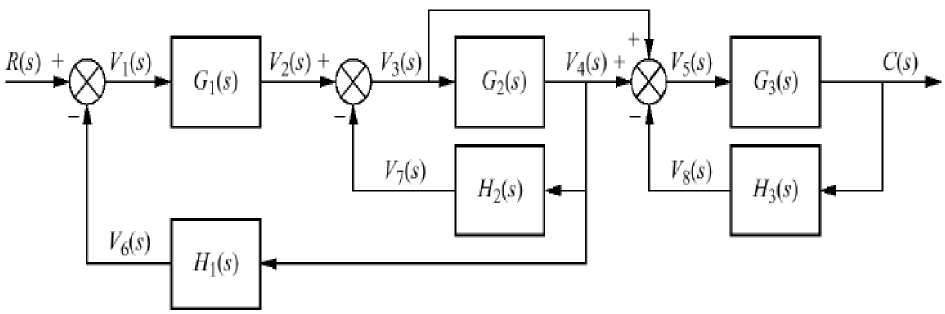
$$P_{11}=\frac{R_1}{sL}, P_{21}=-\frac{1}{sR_2C},\qquad P_{31}=-\frac{1}{s^2LC}$$

$$\Delta= 1+\frac{R_1}{sL}+\frac{1}{sR_2C}+\frac{1}{s^2LC}$$

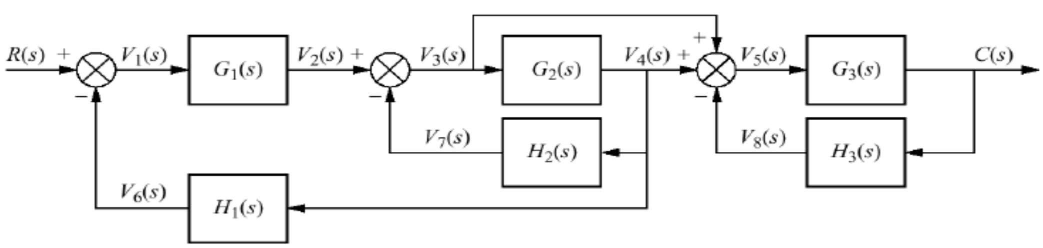
$$\frac{E_C(s)}{E(s)}=\frac{P_1\Delta_1}{\Delta}=\frac{\frac{1}{s^2LC}}{1+\frac{R_1}{sR_2C}+\frac{1}{s^2LC}}=\frac{1}{1+s\left(R_1C+\frac{L}{R_2}\right)+s^2LC}$$

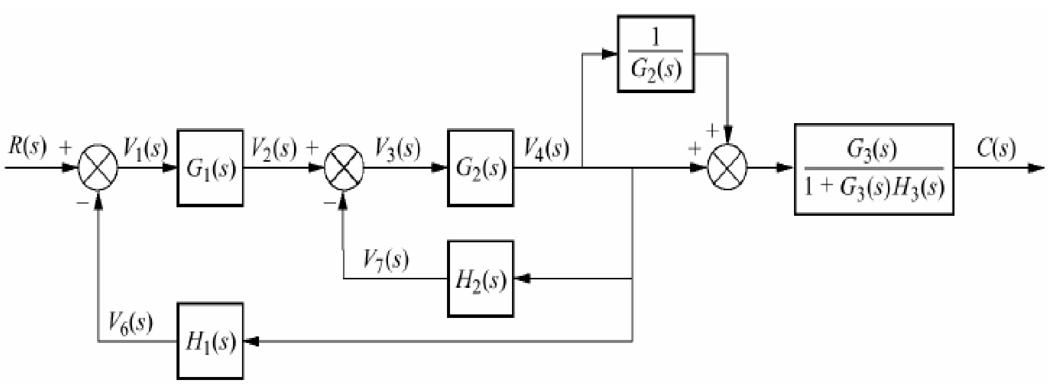
2

Q.3 a. Reduce the system shown in Figure 2 to a single transfer function



Answer:





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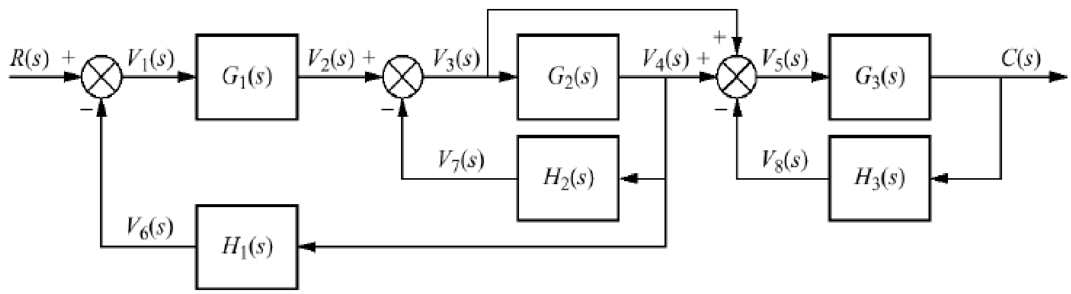

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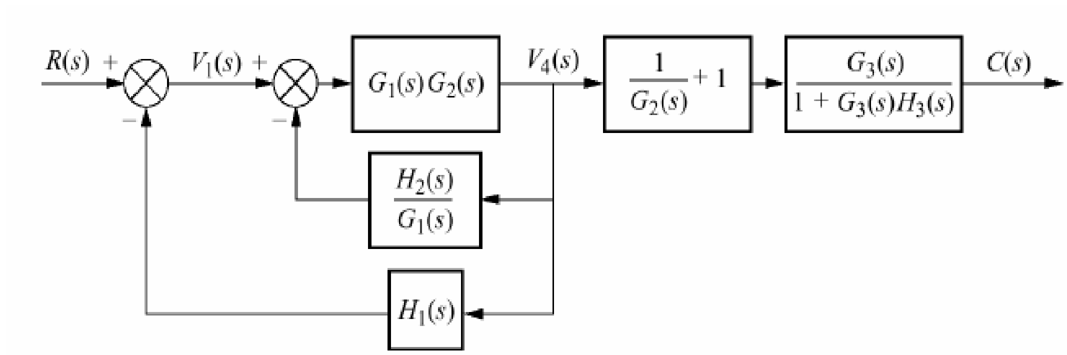

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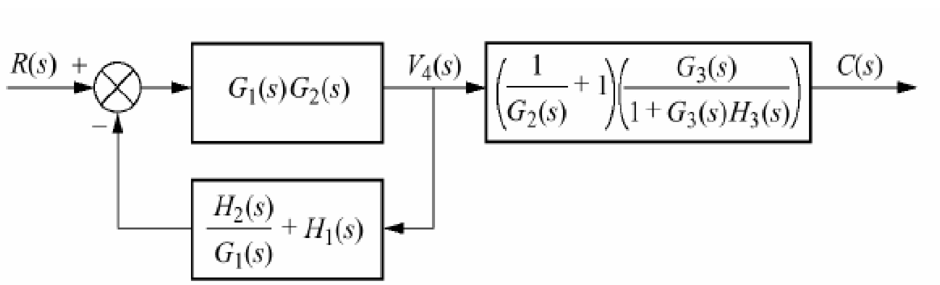

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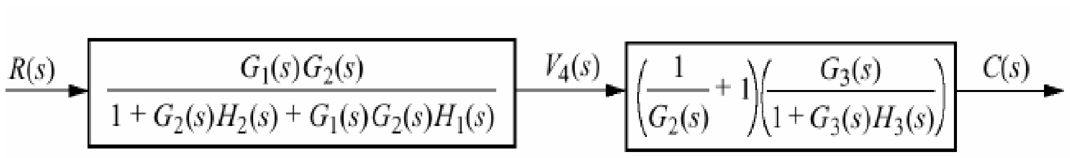

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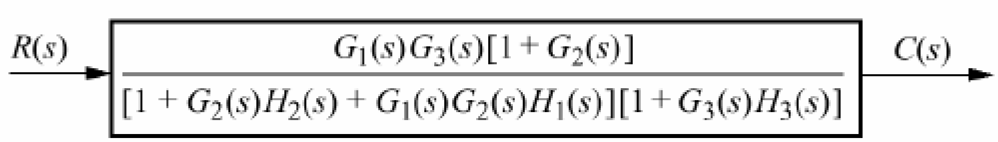


b. **For the system shown in Figure 3, determine the gain between y1 and y5** 08

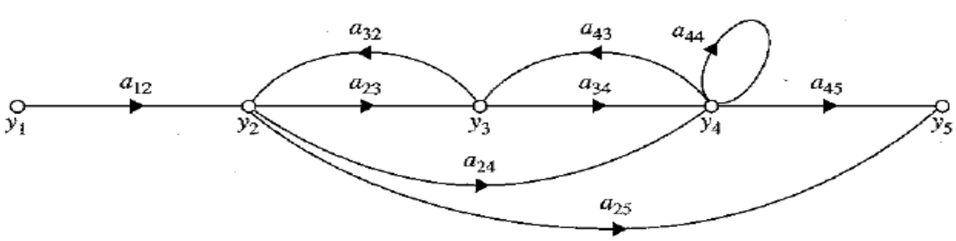


Fig.3

Answer:

1. There are three forward paths
   Path 1: $y_1 - y_2 - y_3 - y_4 - y_5$ $P_1 = a_{12}\, a_{23}\, a_{34}\, a_{45}$

   Path 2: $y_1 - y_2 - y_4 - y_5$ $P_2 = a_{12}\, a_{24}\, a_{45}$

   Path 3: $y_1 - y_2 - y_5$ $P_3 = a_{12}\, a_{25}$ 2

2. There are four loops
   Loop 1: $y_2 - y_3 - y_2$ $L_1 = a_{23}\, a_{32}$

   Loop 2: $y_3 - y_4 - y_3$ $L_2 = a_{34}\, a_{43}$

   Loop 3: $y_2 - y_4 - y_3 - y_2$ $L_3 = a_{24}\, a_{43}\, a_{32}$

   Loop 4: $y_4 - y_4$ $L_4 = a_{44}$ 2

3. Non-touching loops: $y_2 - y_3 - y_2$ and $y_4 - y_4$ Thus the product of the gains of the two non-touching loops: $L_1L_4 = a_{23}\, a_{32}\, a_{44}$ 1

4. $\Delta = 1 - (L_1 + L_2 + L_3 + L_4) + L_1L_4 = 1 - (a_{23}\, a_{32} + a_{34}\, a_{43} + a_{24}\, a_{43}\, a_{32} + a_{44}) + a_{23}\, a_{32}\, a_{44}$ 1

5 All the loops are in touch with forward path P_1,

Thus $\Delta_1 = 1$. All the loops are in touch with forward path P_2, thus $\Delta_2 = 1$.

Two loops ($y_3 - y_4 - y_3$ and $y_4 - y_4$) are not touching with forward path P_3. 1

Thus, $\Delta_3 = 1 - a_{34}a_{43} - a_{44}$. 5. Thus,

$$M = \frac{y_5}{y_1} = \frac{P_1\Delta_1 + P_2\Delta_2 + P_3\Delta_3}{\Delta}$$

$$= \frac{(a_{12}a_{23}a_{34}a_{45}) + (a_{12}a_{24}a_{45}) + (a_{12}a_{25})(1 - a_{34}a_{43} - a_{44})}{1 - (a_{23}a_{32} + a_{34}a_{43} + a_{24}a_{32}a_{43} + a_{44}) + a_{23}a_{32}a_{44}}$$ 1

Q.4 a. Consider the feedback control system shown in Figure 4. The normal value of process parameter *K is* 1. Let us evaluate the sensitivity of transfer function T(s)=*C(s)/R(s)* to variations in parameter *K*

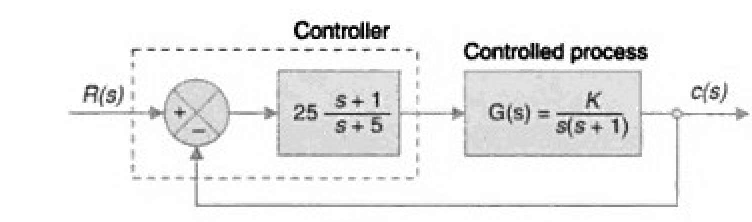
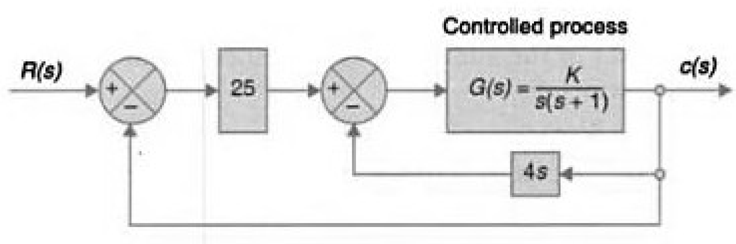
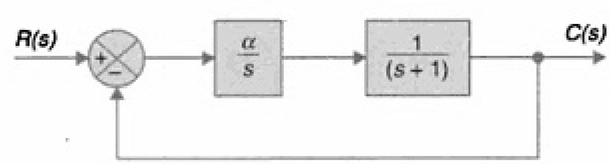


Fig.4

Answer: $T(s)=\frac{C(s)}{R(s)}=\frac{25K}{s^2+5s+25k}=\frac{1}{1+\frac{s^2+5s}{25K}}$	1
Therefore $S_K^T=\frac{\partial T}{\partial K}\times\frac{K}{T}=\frac{s(s+5)}{s^2+5s+25k}$	1
$S_K^T=\frac{\partial T}{\partial K}\times\frac{K}{T}=\frac{s(s+5)}{s^2+5s+25K}$	2
Since The Normal Value of K is 1 , we have $S_K^T=\frac{s(s+5)}{s^2+5s+25K}$	1
S_K^T may be evaluated at various values of frequency . At a particular frequency ω=5, the magnitude of sensitivity is approximately $\lvert S_K^T \rvert$ =1.41.	
$T(s)=\frac{25K}{s^2+(1+4K)s+25K}=\frac{25K}{s(s+1)+K(4s+25)}$	1
$S_K^T=\frac{s(s+1)}{s(s+1)+K(4s+25)}=\frac{s(s+5)}{s^2+5s+25K}$ for K=1	2
The magnitude of sensitivity at ω=5is $\lvert S_K^T \rvert$ =1.  A two-loop configuration for T(s)	
b. For the block diagram of Figure 5, determine the sensitivity S_α^T, T(s)= C(s)/R(s). Evaluate it at ω = 0.1 and 2 rad (for α = 2).  **Fig.5**	
Answer: $T(s)=\frac{\alpha}{s(s+1)+\alpha}$	1

To find S_α^T $\quad \dfrac{\partial In(\alpha)}{\partial In(\alpha)} = 1$	
$\dfrac{\partial In[s(s+1)+\alpha]}{\partial In(\alpha)} = \dfrac{\alpha}{s(s+1)+\alpha}$	
Then $S_\alpha^T = 1 - \dfrac{\alpha}{s(s+1)+\alpha} = \dfrac{s(s+1)}{s(s+1)+\alpha}$	2
To evaluate S_α^T, at s =jω=j0.1and j1	1
$s(s+1) = j0.1(j0.1+1) = -0.01 + j0.1$	
$S_2^T(j0.1) = \dfrac{-0.01 + j0.1}{(2-0.01)+j0.2} = 0.05\angle 93^0$	1
$S_2^T(j2) = \dfrac{-1+j1}{(2-1)+j1} = 1\angle 90^0$	2
In terms of absolute values	
$\lvert S_2^T(j0.1)\rvert = 0.05, \lvert S_2^T(j2)\rvert = 1$	1
It is observed that sensitivity increases with frequency.	
Q.5 a. A unity feedback control system is characterized by an open-loop transfer function. $G(s)H(s) = \dfrac{K}{s(s+10)}$ **Determine the system gain K, so that the system will have a damping ratio of 0.5. For this value of K, find the rise time, peak time, settling time and peak overshoot. Assume that the system is subjected to a step of 1V.**	
Answer:	
The characteristic equation for the present problem is	
$1 + G(s)H(s) = 0.$	
$1 + \dfrac{K}{s(s+10)} = 0$	
$s^2 + 10s + K = 0.$	1
For the reference system shown in figure, the characteristic equation is given by	
$1 + \dfrac{\omega_n^2}{s(s+2\zeta\omega_n)} = 0$	
$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0.$	1
Compare equation we get	
$2\zeta\omega_n s = 10$ and $\omega_n^2 = K$	

Since $\zeta = 0.5$

We get, $2 \times 0.5\omega_n = 10$

$\omega_n = 10 rad/\sec$

Hence, K=10^2=100 2

From the formulae derived in the last section, we get

- Rise time $t_r = \dfrac{\pi - \tan^{-1}\left(\dfrac{\sqrt{1-\zeta^2}}{\zeta}\right)}{\omega_n\sqrt{1-\zeta^2}} = 0.242\,\text{seconds}$ 1
- Reak time $t_P = \dfrac{\pi}{\omega_n\sqrt{1-\zeta^2}} = 0.363\,\text{seconds}$ 1
- Settling time $t_s = \dfrac{4}{\zeta\omega_n} = 0.8\,\text{seconds}$ 1
- Peak overshoot $M_P = e^{-\frac{\pi\zeta}{\sqrt{1-\zeta^2}}} = 0.163 = 16.3\%$ 1

b. A unity negative feedback control system has an open-loop transfer function consisting of two poles Two zeros and variable gain K. The zeros are located at –2 and –1: and the poles at –0.1 and +1. Using Routh stablity criterion, determine the range of values of K for which the closed-loop system has 0, 1 and 2 poles in the right-half of s-plane.

Answer:

$$G(s) = \frac{K(s+1)(s+2)}{(s+0.1)(s-1)}$$

The characteristic quaion of the system is given as

1+G(s) = 0

(s+0.1)(s-1)+K(s+1)(S+2) = 0 1

(1+K)s^2+(3K-0.9)s+(2K-0.1)=0

Applying Routh criteria

S^2	(1+K)	(2K-0.1)
S^2	(3K-0.9)	0
S^0	(2K-0.1)	0

i) No poles in right half s-plane (system stable) 1

K+1>0 or K>-1

3K-0.9>0 or K>0.3

2K-0.1>0 or K>0.05 2

Hence, K>0.3

ii) 1pole in right half s-plane (=one change of sign in first column terms) 2
-1<K<0.05

iii) 2 pole in right half s-plane (+two changes in sign in first column terms)

0.05<K<0.3. 2

Q.6 a. Briefly discuss rules followed to plot the root locus. 08

Answer:

RULES FOR ROOT LOCUS PLOTTING

$$1+KG(s)H(s)=1+F(s)=1+\frac{K\prod_{i=1}^{m}(s+z_i)}{\prod_{j=1}^{n}(s+p_j)}=0$$

$$;\quad m\le n\quad ;\quad K\ge 0$$

1. The root locus plot consists of **n** root loci (branches) as *K* varies from 0 to ∞ . The loci are symmetric with respect to real axis.

2. As *K* increases from 0 to ∞ , each root locus starts from an open-loop pole with *K = 0* and ends on an open-loop zero or on ∞ with *K* = ∞ . The number of root loci ending at ∞ equals the number of open-loop poles minus zeros.

3. The (n - m) root loci which tend to ∞ do so along straight line asymptotes radiating out from a single point $s = -\sigma_a$ on the real axis (called the centroid) where

$$-\sigma_a=\frac{\sum(\text{real part of open}-\text{loop poles})-\sum(\text{real part of open}-\text{loop zer}}{n-m}$$

These (n - m) asymptotes have angles

$$\phi_a=\frac{(2q+1)180^0}{n-m}\quad ;\quad q=0,1,\cdots,(n-m-1)$$

4. A point on the real axis lies on the locus if the number of open-loop poles plus zeros on the real axis to the right of this point is odd. By use of this fact, the real axis can be divided into segments on-locus and not-on-locus; the dividing points being the real open-loop poles and zeros.

5. The intersections (if any) of root loci with the imaginary axis can be determined by use of Routh criterion.

6. The angle of departure θ_p of a locus from a complex open-loop pole is given by $\theta_p = 180^0 + \phi$, where ϕ is the net angle contribution at this pole of all other open-loop poles and zeros.

7. The angle of arrival θ_z of a locus at a complex zero is given by $\theta_z = 180^0 - \phi$, where ϕ is the net angle contribution at this zero of all other open-loop poles and zeros.

8. Points at which multiple roots of the characteristic equation occur (breakaway points of root loci)

are the solutions of $\frac{dK}{ds} = 0$ where $K = -\frac{\prod_{j=1}^{n} |(s + p_j)|}{\prod_{i=1}^{m} |(s + z_i)|}$

b. A unity feedback control system has an open-loop transfer function of

$$G(s) = \frac{K(s + 4/3)}{s^2(s+12)}$$

Plot the root locus. Find the value of K for which all the roots are equal. What is the value of these?

Answer:

Poles: s=0, 0, -12 1

Zeros: s= -4/3

$$-\sigma_A = \frac{-12 + 4/3}{3-1} = -16/3$$ 1

$$\phi_A = \frac{\pm 180^0 (2q+1)}{3-1} = \pm 90^0$$ 1

$$K = \frac{s^2 + 24s}{(s+4/3)} + \frac{s^2(s+12)}{(s+4/3)} = 0$$

or $-3s(s+8)(s+4/3) + s^2(s+12) = 0$ or $s(s+4)^2 = 0$

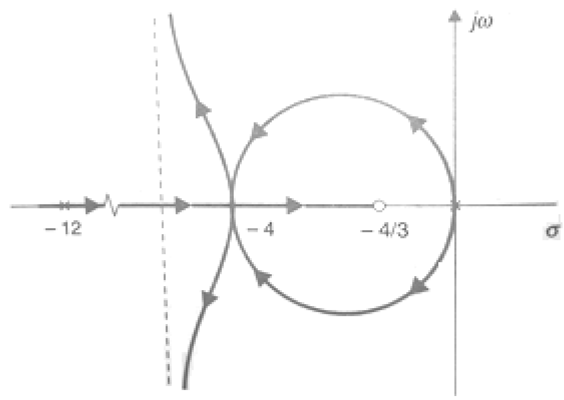
$$s = 0, s = -4, -4$$ 2

Breakaway point is at s=-4

Equal roots (3Nos) are at s=-4

$$K(s=-4)=\frac{4\times4\times8}{4-4/3}=\frac{128\times3}{8}=48$$ 1

The root locus



2

Q.7 a. Draw polar plot for the system with the transfer function

$$G(s)=\frac{10}{s\,(s+1)(s+2)}$$

Answer:

$$G(j\omega)=\frac{10}{j\omega(j\omega+1)(j\omega+2)}$$ 2

$$|G(j\omega)|=\frac{10}{\omega\sqrt{(\omega^2+1)}\sqrt{(\omega^2+2)}}$$ 2

$$\angle G(j\omega)=-90^\circ-\tan^{-1}\frac{\omega}{2}-\tan^{-1}\omega$$ 2

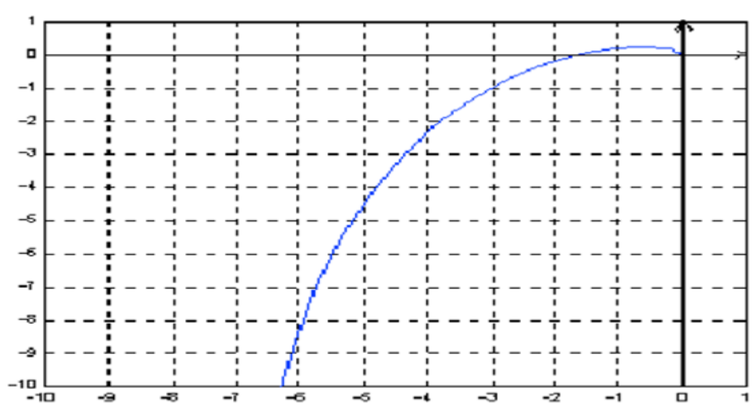


Figure: Polar plot for the system

4

b. Explain in detail Nyquist stability criteria.

Answer:

NYQUIST STABILITY TEST

The Cauchy criterion (from complex analysis) states that when taking a closed contour in the complex plane, and mapping it through a complex function $G(s)$, the number of times, N, that the plot of $G(s)$ encircles the origin is equal to the number of zeros, Z, of G(s) enclosed by the frequency contour minus the number of poles, P, of G(s) enclosed by the frequency contour.

$N = Z - P$

Encirclements of the origin are counted as positive if they are in the same direction as the original closed contour or negative if they are in the opposite direction. When studying feedback control, we are not as interested in $G(s)H(s)$ as in the closed-loop transfer function $G(s)H(s)/[1+G(s)H(s)]$

If $1+G(s)H(s)$ encircles the origin, then $G(s)H(s)$ will enclose the point -1. Since we are interested in the closed-loop stability, we want to know if there are any closed-loop poles (zeros of $1+G(s)H(s)$) in the right-half plane. 3

The Nyquist Stability Criterion usually written as $Z = P + N$, where

> Z is the number of right hand plane poles for the closed loop system (or zeros of $1+G(s)H(s)$)

> P is the number of open-loop poles (in the RH side of the s-plane) of $G(s)H(s)$ (or poles of $1+G(s)H(s)$), and

> N is the number of clockwise encirclements of (-1,0)

"A feedback control system is stable if and only if the number of counter-clockwise encirclements of the critical point (-1,0) by the GH polar plot is equal to the number of poles of GH with positive real parts." (Nyquist Stability Criterion Definition) 3

Q.8 a. A unity negative feedback system has an open-loop transfer function of $G(s) = \dfrac{K}{(s+4)}$

Consider a cascade compensator

$$G_c(s) = \frac{s+\alpha}{s}$$

a. Select the values of K and α to achieve

(i) Peak overshoot of about 20%

(ii) Setting time (2%basis) ≈1 sec

For the values of K and α found in part (a) calculate the unit ramp input steady-state error

Answer:

In this simple example we can proceed analytically. Compensated forward path transfer function is

$$G_c(s)G(s) = \frac{K(s+\alpha)}{s(s+4)} \qquad \text{....(i)}$$

Its characteristic equation is

$$1 + G_c(s)G(s) = 0 \qquad \text{or} \qquad s(s+4) + K(s+\alpha) = 0$$

or

$$s^2 + (4+K)s + K\alpha = 0$$ 1

Required :

$$M_p = e^{-\pi\xi/\sqrt{(4-\xi^2)}} = 0.2$$

Which yields $\xi = 0.456$ 1

Settling time $t_s = \dfrac{4}{\xi\omega_n} = 1$ 1

Which gives $\omega_n = \dfrac{4}{0.456} = 8.77 rad/\sec$ 2

From the characteristic equation

$$K\alpha = \omega_n^2 = (8.77)^2 = 76.9$$

$$K + 4 = 2\xi\omega_n = 8$$ 2

Transfer function of pre-filter

$$G_p(s) = \frac{1}{s+19.23}$$ 1

b) $R(s) = \dfrac{1}{s^2}, unit\ ramp$	
$e_{ss} = \lim_{s\to 0} \dfrac{1}{sG_c(s)G(s)} = \lim_{s\to 0} \dfrac{(s+4)}{K(s+\alpha)} = \dfrac{4}{K\alpha}$	1
$e_{ss} = \dfrac{4}{4\times 19.23} = 0.05$	1
b. Give the comparisons between phase lag and phase lead compensator. **Answer:**	06

Phase lead compensator	Phase Lag Compensator
• Bandwidth increases High frequency gain increases	Bandwidth decreases
• Dynamic response becomes faster	Dynamic response slows down
• Susceptable to high frequency noise	High frequency noise suppressed
• No significant decreases in steady-state error	Steady-state error reduced
• Application: When fast dynamics response is required	Application; When low steady-sta required.
• Cannot be applied when phase angle of uncompensated system is decreasing rapidly near crossover frequency	Cannot be applied if uncompensa phase angle in low frequency re sufficient to provide requisite pha

Q.9 a. The simplified block diagram of the controller and the wheelchair is depicted in figure 6. Write down the canonical state variable form for the complete system, Also draw its block diagram (in state variable form).

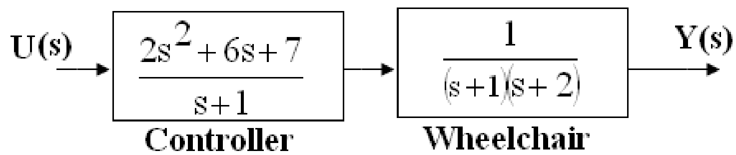


Fig.6

Answer:

The transfer function of the complete system is

$$\frac{Y(s)}{U(s)} = \frac{2s^2+6s+7}{(s+1)^2+(s+2)}$$

Notice that the system has repeated roots. Decomposing the above transfer function by the method of partial fractions yields

$$\frac{Y(s)}{U(s)} = \frac{-1}{(s+1)} + \frac{3}{(s+1)^2} + \frac{3}{(s+2)}$$ 1

We shall define the state variables term by term. Because of repeated root at s +-1, the state variable of the second term will feed into first term.

$$\frac{X_2(s)}{(s+1)} = X_1(s) \Rightarrow x_2 = \dot{x}_1 + x_1 \Rightarrow \dot{x}_1 = -x_2 + x \qquad \text{....(i)}$$

$$\frac{U(s)}{(s+1)} = X_2(s) \Rightarrow u = \dot{x}_2 + x_2 \Rightarrow \dot{x}_2 = -x_2 + u \qquad \text{....(ii)}$$

$$\frac{U(s)}{(s+2)} = X_3(s) \Rightarrow u = \dot{x}_3 + 2x_3 \Rightarrow \dot{x}_3 = -2x_3 + u \qquad \text{....(iii)}$$ 2

Output $y = -x_1 + 3x_2 + 3x_3$

The state variable model in matrix from is written below from the above wqns.

Jordan block

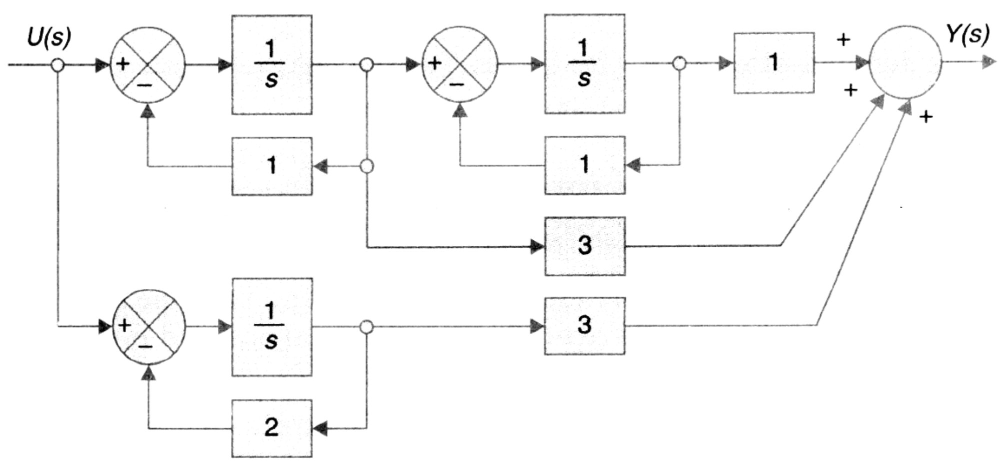
$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix}=\begin{bmatrix}-1 & 1 & | & 0\\ \underline{0} & \underline{-1} & | & 0\\ 0 & 0 & & -2\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}+\begin{bmatrix}0\\ 1\\ 1\end{bmatrix}[u] \qquad \text{....(v)}$$

1

$$y=\begin{bmatrix}-1 & 3 & 3\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} \qquad \text{....(vi)}$$

1

The state variable block diagram is drawn



3

b. Obtain the time response of the following system:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix}=\begin{bmatrix}1 & 0\\ 1 & 1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}+\begin{bmatrix}1\\ 1\end{bmatrix}u$$

Where u(t) is a unit step occurring at t=0 and $x^T(0)=[1 \ \ 0]$

Answer:

We have in this case

$$A = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}; B = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

The state transition matrix $\Phi(t)$ is given by

$$e^{At} = I + At + \frac{1}{2!}A^2t^2 + \frac{1}{3!}A^3t^3 + \ldots$$

Substituting values of A and collecting terms, we get

$$e^{At} = \begin{bmatrix} 1 + t + 0.5t^2 + \ldots & 0 \\ t + t^2 + \ldots & 1 + t + 0.5t^2 + \ldots \end{bmatrix}$$

$$= \begin{bmatrix} \Phi_{11} & \Phi_{12} \\ \Phi_{21} & \Phi_{22} \end{bmatrix}$$ 1

The terms Φ_{11} and Φ_{22} are easily recognized as series expansion of e^t. To recognize Φ_{21}, more terms of the infinite series should be evaluated. In fact Φ_{21} is te^t.

The computation of e^{At} by expanding it into a power series in t and then adding the corresponding elements in the matrix terms of the infinite series, is practical only for simple cases.

The state transition matrix is

2

$$\Phi(t) = \begin{bmatrix} e^t & o \\ te^t & e^t \end{bmatrix}$$

The time response of the system is given by

1

$$x(t) = \Phi(t)\left[x_0 = \int_0^t \Phi(-\tau)Bu \quad d\tau \right]$$

Now with u=1,

1

$$\Phi(-\tau)Bu = \begin{bmatrix} e^{-\tau} & o \\ \tau e^{-\tau} & e^{-\tau} \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} e^{-\tau} \\ e^{-\tau}(1-\tau) \end{bmatrix}$$

$$\int_0^t \Phi(-\tau)Bud\tau = \begin{bmatrix} \int_0^t e^{-\tau} \\ \int_0^t e^{-\tau}(1-\tau)d\tau \end{bmatrix} = \begin{bmatrix} 1 - e^{-t} \\ te^{-1} \end{bmatrix}$$ 1

Then the solution x(t)is given by $$x = \begin{bmatrix} e^t & o \\ te^t & e^t \end{bmatrix} \left\{ \begin{bmatrix} 1 \\ 0 \end{bmatrix} + \begin{bmatrix} 1-e^{-t} \\ te^{-1} \end{bmatrix} \right\}$$ $$= \begin{bmatrix} 2e^t - 1 \\ 2e^t \end{bmatrix}$$	1 1

TEXT BOOK

1. **Control Systems Engineering,), I.J. Nagrath and M. Gopal, Fifth Edition (2007 New Age International Pvt. Ltd**