PANDIAN SARASWATHI YADAV ENGINEERING COLLEGE

DEPARTMENT OF ECE

II YEAR / IV SEMESTER

EC6405-CONTROL SYSTEM

TWO MARKS QUESTION AND ANSWERS

UNIT-I CONTROL SYSTEM MODELING

1. **State the basic elements for modeling in translational and rotational systems.**

[MAY/JUN-2013]

Moment of inertia J,f dashpot with rotational frictional coefficient B and torsional spring with stiffness K , Mass, spring and dashpot.

2. Advantages and disadvantages of open loop system.

[MAY/JUN-2014]

Advantages of open loop system:.

1. Such systems are simple in construction.
2. Very much convenient when output is difficult to measure.
3. Such systems are easy when maintenance point is view.
4. Such systems are economical.

Disadvantages of open loop system.:

1. Such systems are inaccurate and unreliable because accuracy of such system

is totally dependent on the accurate recalibration of the controller.

2. Such systems give inaccurate results if there are variations in the external

environment.

3. Similarly they cannot sense internal disturbances in the system, after the controller stage.
4. To maintain the quality and accuracy, recalibration of the controller is necessary, time to time.

3. **What is called a synchronous device? [MAY/JUN-2014]**

A synchronous is a device used to convert an angular motion to an electrical signal or vice versa

4. **What are the basic elements in control systems?[NOV/DEC-2014]**

   the components of feedback control system are plant , feedback path elements, error detector and controller

5. **Compare closed loop and open loop system.[MAY/JUN-2013]**

Open loop	**Closed loop**
Inaccurate	accurate
Simple and economical	Complex and costly
Change in output due to external disturbance are not corrected	Change in output due to external disturbance are corrected
Stable	Efforts needed to make the system as stable

6. **Define transfer function. [NOV/DEC-2014], [APR/MAY 2010]**

   The T.F of a system is defined as the ratio of the laplace transform of output to laplace transform of input with zero initial conditions.

7. **What are the advantages of signal flow graph method?[APR/MAY 2011]**

   A signal flow graph is a diagram that represents a set of simultaneous algebraic equations .By taking L.T the time domain differential equations governing a control system can be transferred to a set of algebraic equations in s-domain

8. Why negative feedback is preferred in control system? [APR/MAY 2011]

The negative feedback results in better stability in steady state and rejects any disturbance signals

9. List the advantages of closed loop control system. [APR/MAY 2010]

application of closed loop system.

1. Human being.
2. Home heating system.
3. Ship stabilization system.
4. Voltage stabilizer

10. Write Mason's Gain formula.

$$\text{Overall T. F} = \frac{\sum T_K \Delta_K}{\Delta},$$

Forward path gain, T_k

Gain of non- touching the forward path ($°_k$)

11. Define Control system.

To control means to regulate, to direct or to command. Hence a control system is an arrangement of different physical elements connected in such a manner so as to regulate, direct or command itself or some other system.

12. What is the basic concept of block diagram representation?

If a given system is complicated, it is very difficult to analyse it as a whole. With the help of transfer function approach, we can find transfer function of each and every element of the complicated system. And by showing connection between the elements, complete system can be splitted into different blocks and can be analyzed conveniently. This is the basic concept of block diagram representation.

13. What are the basic elements of block diagram?

1.Blocks, 2. Transfer functions of elements shown inside the blocks,

3. Summing points, 4. Take off points, 5. Arrows.

14. What are the advantages of block diagram?

1. Very simple to construct the block diagram for complicated systems.
2. The function of individual element can be visualized from block diagram.

15. What are the disadvantages of Block diagram?

1. Block diagram does not include any information about the physical construction of the system.
2. Source of energy is generally not shown in the block diagram. So number of different block diagrams can be drawn depending upon the point of view of analysis. So block diagram for given system is not unique.

16. What is the basis for framing the rules of block diagram reduction technique?

The rules for block diagram reduction technique are framed such that any modification made on the diagram does not alter the input output relation.

17. Write short notes about servomotors.

The servo system is one in which the output is some mechanical variable like position, velocity or acceleration. Such systems are generally automatic control systems which work on the error signals. The error signals are amplified to drive motors used in such systems. These motors used in servo systems are called servomotors.

18. Define path gain and loop gain.

The product of branch gains while going through a forward path is known as path gain. This can be also called as forward path gain. The product of all the gains of the branches forming a loop is called loop gain.

19. What is sink and source?

Source is the input node in the signal flow graph and it has only outgoing branches.

Sink is a output node in the signal flow graph and it has only incoming branches.

20. Write the analogous electrical elements in force voltage analogy for the elements of mechanical translational system.

Force-voltage e

Velocity v-current i

Displacement x-charge q

Frictional coeff B-Resistance R

Mass M- Inductance L

Stiffness K-Inverse of capacitance 1/C

21. Write the analogous electrical elements in force current analogy for the

Elements of mechanical translational system.

Force-current i

Velocity v-voltage v

Displacement x-flux

Frictional coeff B-conductance 1/R

Mass M- capacitance C

Stiffness K-Inverse of inductance 1/L

22. Define non touching loop.

The loops are said to be non touching if they do not have common nodes.

23. What is the basis for framing the rules of block diagram reduction technique?

The rules for block diagram reduction technique are framed such that any modification made on the diagram does not alter the input output relation.

24. What is servomechanism?

The servomechanism is a feedback control system in which the output is mechanical position (or time derivatives of position velocity and acceleration,)

25. Define Plant.

The portion of a system which is to be controlled or regulated is called the plant or the process.

26. Define Controller.

The element of the system itself or external to the system which controls the plant or the process is called controller.

27. What is mean by Principle of superposition?

Principle of superposition means the response to several inputs can be obtained by considering one input at a system and the algebraically adding the individual results.

28. Define Linearity of Laplace transform.

The transform of a finite sum of time functions is the sum of the Laplace transforms of the individual functions. So if F1(s), F2(s), ……, Fn(s) are the laplace transforms of the time functions f1 (t), f2(t),……, fn(t) respectively then,

L{f1(t)+f2(t)+…..+fn(t)}=F1(s)+F2(s)+……Fn(s).

29. Define Initial value theorem.

The Laplace transform is very useful to find the initial value of the time function f (t). Thus if F(s) is the Laplace transform of f (t) then,

$$\lim_{t \to 0} f(t) = \lim_{s \to \infty} sF(s).$$

The only restriction is that f (t) must be continuous or at the most, a step discontinuity at t=0.

30. Define Final value theorem.

The Laplace transform is very useful to find the final value of the time function f (t). Thus if F(s) is the Laplace transform of f (t) then,

$$\lim_{t \to \infty} f(t) = \lim_{s \to 0} sF(s)$$

The only restriction is that the roots of the denominator polynomial of F(s) i.e. poles of F(s) have negative or zero real parts.

UNIT-II TIME RESPONSE ANALYSIS

1. **Find the acceleration error coefficient for**.[MAY/JUN-2013]

$$G(s) = [K(1+s)(1+2s)] / [s^2(s^2+4s+20)].$$

Solution:

Ka= $S^2G(s)$ at Limit s->0

2. **State the effect of PI and PD controller on system performance. [MAY/JUN-2013], [MAY/JUN-2014]**

The PI controller increases the order of the system by one, which results in reducing the steady state error .But the system becomes less stable than the original system. The effect of PD controller is to increase the damping ratio of the system and so the peak overshoot is reduced.

3. **What are the standard test signals used in control systems?**

[MAY/JUN-2014] [APR/MAY 2011]

The commonly used test input signals in control system are impulse, step, ramp, acceleration and sinusoidal signals

4. What is the type and order of the system? [NOV/DEC-2014], [NOV/DEC 2011]

The type number is given by number of poles of loop transfer function at the origin. The type number of the system decides the steady state error

The order of the system is given by the order of the differential equation governing the system. It is also given by the maximum power of s in the denominator polynomial of transfer function. The maximum power of s is also gives the number of poles of the system and so the order of the system is also given by number of poles of the transfer function.

5. Write the PID controller equation. [NOV/DEC-2014]

$$m(t) = K_p e(t) + \frac{K_p}{T_i}\int_0^t e(\tau)d\tau + K_p T_d \frac{de(t)}{dt}$$

6. Define steady state error of a system. [APR/MAY 2011]

The steady state error is defined as the value of error as time tends to infinity.

7. Distinguish between steady state and transient response of the system. [APR/MAY 2010]

The steady state response is the response of the system when it approaches infinity. The transient response is the response of the system when the system changes from one state to another.

8. Define settling time. [APR/MAY 2010]

Settling time is defined as the time taken by the response to reach and stay within specified error

9. what are the advantages of generalized error series?[NOV/DEC 2011]

Steady state is function of time.

Steady state can be determined from any type of input

10. Define Rise time.

It is the time taken for response to raise from 0 to 100% for the very first time. For under damped system, the rise time is calculated from 0 to 100%. But for over damped system, it is the time taken by the response to raise from 10% to 90%. For critically damped system, it is the time taken for response to raise from 5% to 95

11. Define peak time.

The time taken for the response to reach the peak value for the first time is peak time.

12. Define peak overshoot.

Peak overshoot is defined as the ratio of maximum peak value measured from

the maxmium value to final value. It is defined as the ratio of the maximum

peak value measured from final value to final value. Let final value= c( ),

Maximum value=c(tp) Peak over shoot,

13. What is the need for a controller?

The controller is provided to modify the error signal for better control action

14. What are the different types of controllers?

i.Proportional controller

ii.PI controller

iii.PD controller

iv.PID controller

15. What is step signal?

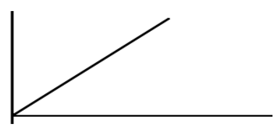
The step signal is a signal whose value changes from zero to A at t= 0 and remains constant at A for t>0. r(t) = A for t>=0 = 0 for t<0

16. What is ramp signal?

The ramp signal is a signal whose value increases linearly with time from an

initial value of zero at t=0.the ramp signal resembles a constant velocity.

Mathematically, r (t) = At for t>=0 = 0 for t<0



17. What is a parabolic signal?

The parabolic signal is a signal whose value varies as a square of time from an

initial value of zero at t=0.This parabolic signal represents constant acceleration

input to the signal. Mathematically, r(t) = (A/2)t2 for t >=0 = 0 for t < 0

18. Define Impulse input.

It is the input applied instantaneously (for short duration of time) of very high amplitude as shown.It is the pulse whose magnitude is infinite while its width tends to zero i.e. t -» 0, applied momentarily. Mathematically, r(t) = A, for t=0 = 0, for t=0

19. What are the three constants associated with a steady state error?

i. Positional error constant

ii. Velocity error constant

iii. Acceleration error constant

20. What are generalized error coefficients?

They are the coefficients of generalized error series. The generalized error series is given by. The Coefficients C0,C1,C2 are called generalized error coefficient or dynamic error coefficients. The nth coefficient, Cn=Lt dnF(s)/dsn, Where F(s)=1/(1+G(s)H(s)).

21. Write any four disadvantages of static error co-efficient method.

- Method cannot give error if inputs are other than the three standard test inputs.
- Most of the times, method gives mathematical answer of the error as '0' or infinite and hence does not provide precise value of the error.
- Method does not provide variation of error with respect to time, which will be otherwise very useful from design point of view.
- The method is applicable only for stable systems

22. Distinguish between type and order of a system.

Type number is specified for loop transfer function but order can be specified for any transfer function. (open loop or closed loop transfer function).

The type number is given by number of poles of loop transfer function lying at origin of s-plane but the order is given by the number of poles of transfer function

23. What are static error constants?

The Kp,Kv and Ka are called static error constants. These constants are associated with steady state error in a particular type of system and for a standard input

24. Define Damping ratio.

Damping ratio is defined as the ratio of actual damping to critical damping.

25. What is the need for a controller?

The controller is provided to modify the error signal for better control action

26. What are the different types of controllers?

Proportional controller, PI controller, PD controller, PID controller

27. What is proportional controller?

It is device that produces a control signal which is proportional to the input error signal.

28. What is PI controller?

It is device that produces a control signal consisting of two terms –one proportional to error signal and the other proportional to the integral of error signal.

29. **What is the significance of integral controller and derivative controller in a PID controller?**

The proportional controller stabilizes the gain but produces a steady state error.

The integral control reduces or eliminates the steady state error.

30. Why derivative controller is not used in control systems?

The derivative controller produces a control action based on the rate of change

of error signal and it does not produce corrective measures for any constant error.

31. Define Steady state error.

The steady state error is defined as the value of error as time tends to infinity.

32. What is the drawback of static coefficients?

The main draw back of static coefficient is that it does not show the variation of error with time and input should be standard input.

33. What is called time constant form?

Those elements are constant of system 'K' and poles of G(s)H(s) at origin of G(s)H(s) is expressed in a particular form called time constant form.

34. Define time response.

The response given by the system which is function of the time, to the applied excitation is called time response of a control system

35. How the system is classified depending on the value of damping?

Depending on the value of damping, the system can be classified into the following four cases

Case 1: Undamped system, =0

Case 2: Underdamped system, 0< <1

Case 3: Critically damped system, =1

Case 4: Over damped system, >1.

36. How the system is classified depending on the value of damping.

Depending on the value of damping, the system cen be classified into the following four cases

Case 1: Undamped system

Case 2: Under damped system

Case 3: critically damped system

Case 4: over damped system

37. Define positional error constant.

The positional error constant Kp = Lt G(s)H(s). The steady state error in type-0 system when the input is unit step is given by 1/(1+Kp).

38. Define Velocity error constant.

The Velocity error constant Kv=Lt sG(s) H(s). The steady state error in type-1 system for unit ramp input is given by 1/Kv.

39. Define acceleration error constant.

The acceleration error constant Ka=Lt s2G(s) H(s). The steady state error in type-2 system for unit parabolic input is given by 1/Ka.

40. What are asymptotes? How will you find the angle of asymptotes?

Asymptotes are straight lines which are parallel to root locus going to infinity and meet the root locus at infinity.

Angles of asymptotes= +_180(2q+1)/(n-m);q=0,1,2,.....,(n-m)

41. What is breakaway and breaking point? How to determine them?

At breakaway point the root locus breaks from the real axis to enter into the complex plane. At breaking point the root locus enters the real axis from the complex plane.

To find the breakaway or breaking points, form an equation for k from the characteristic equation and differentiate the equation of k with respect to s. Then find the roots of equation dk/ds=0.The roots of dk/ds=0 are breakaway or breaking points provided for this value of root the gain k should be positive and real.

42. How to find the crossing point of root locus in imaginary axis?

Method (i): By Routh Hurwitz criterion.

Method (ii): By letting s=jw in the characteristic equation and separate the real and imaginary part. These two equations are equated to zero. solve the two equations for w and k. The value of w gives the point where the root locus crosses imaginary axis and the value of k is the gain corresponding to the crossing point.

UNIT-III FREQUENCY RESPONSE ANALYSIS

1. Draw the polar plot of

$G(s)=10/\left[s^2(1+s)(s+2)\right]$. [MAY/JUN-2013]

2. State phase and gain margin.[MAY/JUN-2013]

The phase margin, is that amount of additional phase lag at the gain cross-over frequency, required to bring the system to the verge of instability. It is given by, 180+ , where is the phase of g(jw) at the gain cross over frequency. Phase Margin, = 180+ The gain margin,kg is defined as the reciprocal of the magnitude of the open loop transfer function at phase cross over frequency.

3. Write the expression for resonance frequency and peak in terms of time response specifications. [NOV/DEC-2014]

Resonant peak, Mr =

Resonant frequency,

4. Define gain margin. [NOV/DEC-2014], [APR/MAY 2010]

The gain margin,kg is defined as the reciprocal of the magnitude of the open

loop transfer function at phase cross over frequency.

Gain Margin, Kg=1/ |G(jw)| and when expressed in decibels it is 20 log kg.

5. **What are the advantages of frequency response analysis? [APR/MAY 2011]**

   1. The absolute and relative stability of the closed loop system can be estimated from the knowledge of the open loop frequency response.
   2. The practical testing of system can be easily carried with available sinusoidal signal generators and precise measurement equipments.

6. **Define gain cross over frequency. [APR/MAY 2011]**

   The gain cross over frequency is the frequency at which the magnitude of the open loop transfer function is unity.

7. **What is cut off frequency? [APR/MAY 2010]**

   The slope of the log-magnitude curve near the cut-off is called cut-off rate. The frequency related to this rate is called cut off frequency.

8. **what are M and N circles?[NOV/DEC 2011]**

   The magnitude, m of closed loop transfer function with unity feedback will be in the form of circle on complex plane for each constant value of M. The family of these circles is called M circles. Let N=tan where is the phase of closed loop transfer with unity feedback. For each constant value of N, a circle can be drawn in the complex plane. The family of these circles are called N circles.

9. **What is frequency response?**

   A frequency response is the steady state response of a system when the input to the system is a sinusoidal signal.

10. **What is Bode plot?**

    The Bode plot is the frequency response plot of the transfer function of a system. A Bode plot consists of two graphs. One is the plot of magnitude of sinusoidal transfer function versus log _. The other is a plot of the phase angle of a sinusoidal function versus log _.

11. What are the main advantages of Bode plot?

The main advantages are:

- Multiplication of magnitude can be in to addition.
- A simple method for sketching an approximate log curve is available.
- It is based on asymptotic approximation. Such approximation is sufficient if rough information on the frequency response characteristic is needed.
- The phase angle curves can be easily drawn if a template for the phase angle curve of 1+ j_ is available.

12. What is Nichols chart?

The chart consisting if M & N loci in the log magnitude versus phase diagram is called Nichols chart.

13. 18.What are two contours of Nichols chart?

Nichols chart of M and N contours, superimposed on ordinary graph. The M contours are the magnitude of closed loop system in decibels and the N contours are the phase angle locus of closed loop system.

14. What are the advantages of Nichols chart?

The advantages are:

i) It is used to find the closed loop frequency response from open loop frequency response.

ii) Frequency domain specifications can be determined from Nichols chart.

iii) The gain of the system can be adjusted to satisfy the given specification.

15. What is polar plot?

The polar plot of a sinusoidal transfer function g(j) is a polar plot of the magnitude of G(j) versus the phase angle/argument of G(j) on polar or rectangular co-ordinates as is varied from zero to infinity

16. Write short note on the correlation between the time and frequency response?

There exists a correlation between time and frequency response of first or second order systems. The frequency domain specification can be expressed in terms of the time domain parameter and .For a peak overshoot in time domain specification there is a corresponding resonant peak in frequency domain. For higher order systems there is no explicit correlation between time and frequency response

17. What is phase and gain cross over frequency?

The ***gain cross over frequency*** is the frequency at which the magnitude of the open loop transfer function is unity. The ***phase cross over frequency*** is the frequency at which the phase of the open loop transfer function is 180.

18. What are the advantages of frequency response analysis?

1. The absolute and relative stability of the closed loop system can be estimated from the knowledge of the open loop frequency response.
2. The practical testing of system can be easily carried with available sinusoidal signal generators and precise measurement equipments.

19. Define corner frequency?

The magnitude plot can be approximated by asymptotic straight lines. The frequencies corresponding to the meeting point of asymptotes are called corner frequency. The slope of the magnitude plot changes at every corner frequencies.

20. How closed loop frequency response is determined from open loop frequency using M and n circles?

The G(j) locus or the polar plot of open loop system is sketched on the

standard M and n circles chart. The meeting point of M circle with G(j) locus gives the magnitude of closed loop system. The locus with N-circle gives the value of phase of closed loop system.

21. How is the Resonant Peak(M), resonant frequency(W) , and band Width determined from Nichols chart?

i) The resonant peak is given by the value of .contour which is tangent to G(j) locus.

ii) The resonant frequency is given by the frequency of G(j) at the tangency point.

iii) The bandwidth is given by frequency corresponding to the intersection point of G(j) and – 3dB M-contour.

22. What are the advantages of Nichols chart?

The advantages are:

i) It is used to find the closed loop frequency response from open loop frequency response.

ii) Frequency domain specifications can be determined from Nichols chart.

iii) The gain of the system can be adjusted to satisfy the given specification.

23. Define Phase lag and phase lead?

A negative phase angle is called phase lag.

A positive phase angle is called phase lead.

24. State-Magnitude criterion.

The magnitude criterion states that s=sa will be a point on root locus if for

that value of s , | D(s) | = |G(s)H(s) | =1

25. State – Angle criterion.

The Angle criterion states that s=sa will be a point on root locus for that value of s, , _D(s) = _G(s)H(s) =odd multiple of 180°

26. What are the advantages of frequency response analysis?

1. The absolute and relative stability of the closed loop system can be estimated from the knowledge of the open loop frequency response.
2. The practical testing of system can be easily carried with available sinusoidal signal generators and precise measurement equipments.

27. What are the frequency domain specifications?

1. Resonant peak 2. Resonant frequency
3. Band width 4. Cut-off rate
5. Gain margin 6. Phase Margin

28. What is polar plot?

The polar plot of a sinusoidal transfer function g(j) is a polar plot of the magnitude of G(j) versus the phase angle/argument of G(j) on polar or rectangular co-ordinates as is varied from zero to infinity.

29. What is minimum phase system?

The minimum phase systems are systems with minimum phase transfer functions. In minimum phase transfer functions, all poles and zeros will lie on the left half of s-plane.

30. What are All-Pass systems?

The all pass systems are systems with all pass transfer functions. In all pass transfer functions, the magnitude is unity at all frequencies and the transfer function will have anti-symmetric pole zero-pattern.

UNIT-IV STABILITY ANALYSIS

1. **State the necessary and sufficient condition for stability. . [MAY/JUN-2013]**

   The necessary and sufficient condition for stability is that all of the elements in the first column of the routh array should be positive

2. **State Nyquist stability criterion. .[MAY/JUN-2013], [APR/MAY 2010], [APR/MAY 2011]**

   What is Nyquist stability Criterion?

   If G(s) H(s) contour in the G(s) H(s) plane corresponding to Nyquist contour in s-plane encircles the point -1+j0 in the clockwise direction as many times as the number of right half s-plane poles of G(s) H(s).Then the closed loop system is stable.

3. Define the terms: ' resonant peak', and 'resonant frequency'.[MAY/JUN-2014]

   The maximum value of the magnitude of closed loop transfer function is Called resonant peak. The frequency at which resonant peak occurs is called resonant frequency.

4. **What is the effect of adding zeros? [APR/MAY 2011]**

   Adding a zero to a system increases peak overshoot appreciably

5. **What are the locations of roots in s-plane for stability? [NOV/DEC-2014], [MAY/JUN-2014]**

   If the roots of characteristic equation has positive real part then the impulse response of the system is not bounded (the impulse response will be infinite as t**~>** *a)*. Hence the system will be unstable. If the roots have negative real parts then the impulse response is bounded (the impulse response becomes 0 as t**~>** *a).* Hence the system will be stable.

6. What is meant by +20db/dec slope change? [NOV/DEC-2014]

For a simple real pole the piecewise linear asymptotic Bode plot for magnitude is at 0 dB until the break frequency and then drops at 20 dB per decade (i.e., the slope is -20 dB/decade).

7. What is the correlation between phase margin and damping factor? [APR/MAY 2010]

$$\Phi_M = 90 - \tan^{-1}\frac{\sqrt{-2\zeta^2+\sqrt{1+4\zeta^4}}}{2\zeta}$$
$$= \tan^{-1}\frac{2\zeta}{\sqrt{-2\zeta^2+\sqrt{1+4\zeta^4}}}$$

8. Define BIBO stability. [NOV/DEC 2011]

A linear relaxed system is said to have BIBIO stability if every bounded input results in a bounded output

9. What is centroid? [NOV/DEC 2011]

The meeting point of asymptotes with real axis is called centroid. The centroid is given by, Centroid=(sum of poles-sum of zeros)/(n-m)

10. What is routh stability criterion?

Routh Criterion states that the necessary and sufficient condition for stability is that all of the elements in the first coloumn of the routh array be positive .If this condition is not met,the system is unstable and the number of sign changes in the elements of the first column of routh array corresponds to the number of roots of characteristics equation in the right half of the S plane.

The path taken by a root of characteristic equation when open loop gain K is varied from 0 to ∞ is called root locus

11. What is breakaway and breakin point? How to determine them?

At breakaway point the root locus breaks from the real axis to enter into the complex plane. At breakin point the root locus enters the real axis from the complex plane.

To find the breakaway or breakin points, form an equation for k from the characteristic equation and differentiate the equation of k with respect to s. Then find the roots of equation dk/ds=0.The roots of dk/ds=0 are breakaway or breakin points provided for this value of root the gain k should be positive and real.

12. What are root loci?

The path taken by the roots of the open loop transfer function when the loop gain is varied from 0 to _ are called root loci

13. What are asymptotes? How will you find the angle of asymptotes?

Asymptotes are straight lines which are parallel to root locus going to infinity and meet the root locus at infinity. Angles of asymptotes= +_180(2q+1)/(n-m);q=0,1,2,.....,(n-m)

14. What will be the nature of impulse response if the roots of characteristic equation are lying on left half of s-plane?

When the roots are lying on the real axis on the right half of s-plane. The response is exponentially increasing. When the roots are complex conjugate and lying on the right half of s-plane, the response is oscillatory with exponentially increasing amplitude.

15. What are root loci?

The path taken by the roots of the open loop transfer function when the loop gain is varied from 0 to 1 are called root loci

16. What are the main significances of root locus?

i. The main root locus technique is used for stability analysis.

ii. Using root locus technique the range of values of K, for as table system can be determined

17. What is quadrantal symmetry?

The symmetry of roots with respect to both real and imaginary axis called quadrantal symmetry

18. What is limitedly stable system?

For a bounded input signal if the output has constant amplitude oscillations Then the system may be stable or unstable under some limited constraints such a system is called limitedly stable system.

19. Write the rules for constructing the root locus.

Locate poles & Zeros

Find centroid & asymptotes

Find Break away or Break in points

Find crossing point in imaginary axis

20. What is characteristic equation?

The denominator polynomial of C(s)/R(s) is the characteristic equation of the system

21. In routh array what conclusion you can make when there is a row of all zeros?

All zero row in array indicates the existence of an even polynomial as a factor of the given characteristic equation. The even polynomial may have roots on imaginary axis.

22. What is Nyquist stability Criterion?

If G(s) H(s) contour in theG(s) H(s) plane corresponding to Nyquist contour in s-plane encircles the point -1+j0 in the clockwise direction as many times as the number of right half s-plane poles of G(s) H(s).Then the closed loop system is stable.

UNIT-V STATE VARIABLE ANALYSIS

1. what is the necessity of compensation in feed back control system? [MAY/JUN-2014], [NOV/DEC-2014], [APR/MAY 2011]

- ✓ In order to obtain the desired performance of the system, we use compensating networks. Compensating networks are applied to the system in the form of feed forward path gain adjustment.
- ✓ Compensate a unstable system to make it stable.
- ✓ A compensating network is used to minimize overshoot.
- ✓ These compensating networks increase the steady state accuracy of the system. An important point to be noted here is that the increase in the steady state accuracy brings instability to the system.
- ✓ Compensating networks also introduces poles and zeros in the system thereby causes changes in the transfer function of the system. Due to this, performance specifications of the system change.

2. Write the transfer function of lag-lead compensator. [MAY/JUN-2014]

$$G(s) = \frac{\left(s+\frac{1}{\tau_1}\right)\left(s+\frac{1}{\tau_2}\right)}{\left(s+\frac{1}{\alpha\tau_1}\right)\left(s+\frac{\alpha}{\tau_2}\right)} \qquad \text{where } \alpha > 1$$

$$\frac{1}{R_1C_1} + \frac{1}{R_2C_1} + \frac{1}{R_2C_2} = \frac{1}{\alpha\tau_1} + \frac{\alpha}{\tau_2}$$

3. What is the desired performance criteria specified in compensator design? [NOV/DEC-2014]

Compensator type, controller (P,PI and PID), damping factor, gain and feedback gain.

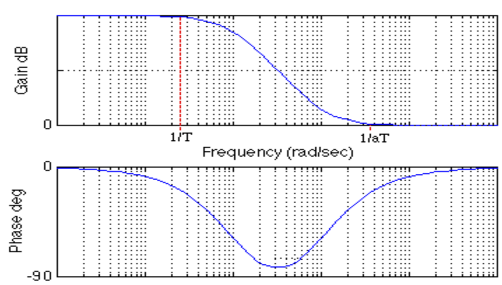
4. Define compensator and list the types of compensator. . [MAY/JUN-2013]

A device inserted into the system for the purpose of satisfying the specifications is called as a compensator

Lag compensator ii. Lead compensator iii. Lag-Lead compensator

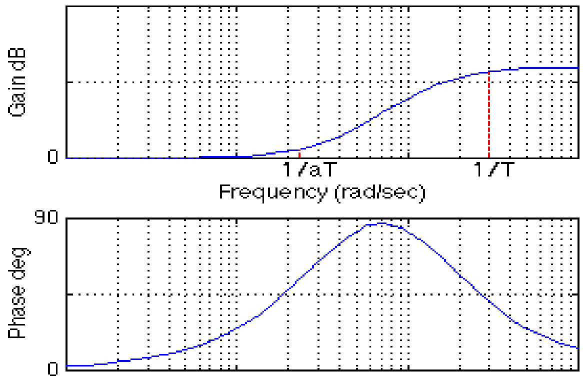
5. Write the transfer function of lag compensator and draw its pole zero plot. [MAY/JUN-2013]

$$G_c(s) = \frac{(1 + \alpha \cdot \tau \cdot s)}{\alpha \cdot (1 + \tau \cdot s)}$$



6. What is the transfer function of lead compensator and draw its pole zero plot. [APR/MAY 2011]

$$G(s) = \frac{s + \frac{1}{\tau}}{s + \frac{1}{\beta\tau}}$$



7. What is the relation between ϕ_m and α. [APR/MAY 2010]

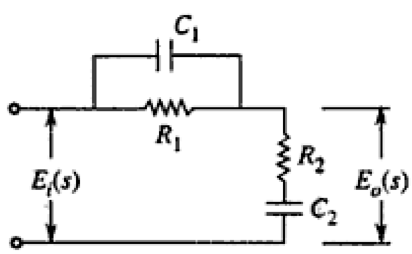
Phase Margin, ϕ_M*:* The change in the open-loop phase shift required at unity gain to make the closed loop unstable. Good range 30 < PM < 60 degrees. (?)

8. What type of compensator suitable for high frequency noisy environment?

[APR/MAY 2010]

Lag compensator Improve the steady state behavior of a system, while nearly preserving its transient response

9. sketch the electrical circuit of a lag-lead compensator.[NOV/DEC 2011]



Lag-lead compensator.

10. Define Phase lag and phase lead?

A negative phase angle is called phase lag. A positive phase angle is called phase lead.

11. What are the uses of lead compensator?

1.speeds up the transient response

2. increases the margin of stability of a system

3. increases the system error constant to a limited extent.

12. What is the use of lag compensator?

Improve the steady state behavior of a system, while nearly preserving its transient response.

13. When is lag lead compensator is required?

The lag lead compensator is required when both the transient and steady state response of a system has to be improved

14. What are the main advantages of Bode plot?

The main advantages are:

i) Multiplication of magnitude can be in to addition.

ii) A simple method for sketching an approximate log curve is available.

iii) It is based on asymptotic approximation. Such approximation is sufficient if rough information on the frequency response characteristic is needed.

iv) The phase angle curves can be easily drawn if a template for the phase angle curve of 1+ j_ is available.

15. **What are the two types of compensation?**

i. Cascade or series compensation

ii. Feedback compensation or parallel compensation

16. What are the three types of compensators?

Lag compensator

Lead compensator

Lag-Lead compensator

17. What are the uses of lead compensator?

- ✓ speeds up the transient response
- ✓ increases the margin of stability of a system
- ✓ increases the system error constant to a limited extent.

18. What is the use of lag compensator?

Improve the steady state behavior of a system, while nearly preserving its transient response.

19. When is lag lead compensator is required?

The lag lead compensator is required when both the transient and steady state response of a system has to be improved

20. What is a compensator?

A device inserted into the system for the purpose of satisfying the specifications is called as a compensator.

21. Define " state " of a system.

The state variable model for any linear system is a set of first-order differential equations. Therefore, the outputs of each integrator in a signal-flow graph of a system are the states of that system

22. Write the state space equation.

The state-space form is given below:

(1)

(2)

23. Define controllability.

A system is **controllable** if there exists a control input, u(t), that transfers any state of the system to zero in finite time. It can be shown that an LTI system is controllable if and only if its controllability matrix, CO, has full rank (i.e. if rank(CO) = n where n is the number of states.

$$CO = [B|AB|A^2B|...|A^{n-1}B];$$

24. Define Observability.

A system is **observable** if the initial state, x(t_0), can be determined from the system output, y(t), over some finite time t_0 < t < t_f. For LTI systems, the system is observable if and only if the observability matrix, OB, has full rank (i.e. if rank(OB) = n where n is the number of states).

$$OB = \begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{n-1} \end{bmatrix}$$

25. What is state transition matrix?

$$X(s) = [sI - A]^{-1} \times x(0) + [sI - A]^{-1} \times BU(s)$$

$$X(t) = \theta(t).x(0) + L^{-1} \times \theta(s)BU(s)$$

The expression ?(t) is known as state transition matrix.

L^{-1}.?(t)BU(s) = zero state response.

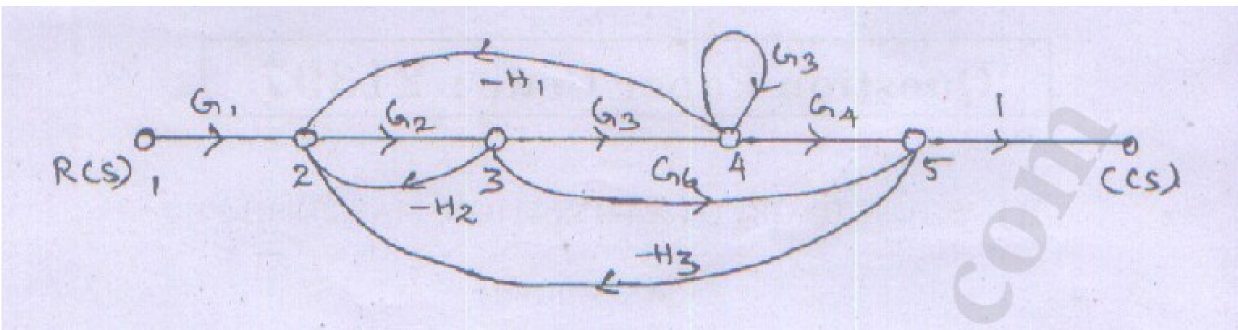
26. What are state variables?

The state variables are those variables that determine the future behavior of a system when the present state of the system and the excitation signals are known. The state variables describe the future response of a system, given the present state, the excitation inputs, and the equations describing the dynamics.

16 MARKS QUESTION AND KEY ANSWERS

UNIT-I

1. **Find the overall gain for the signal flow graph shown. .[MAY/JUN-2013]**



Solution:

Step1: Find the Forward path gain, T_k

Step2: Find the closed loop gain (I)

Step3: Find the loop gain of non-touching loops(II)

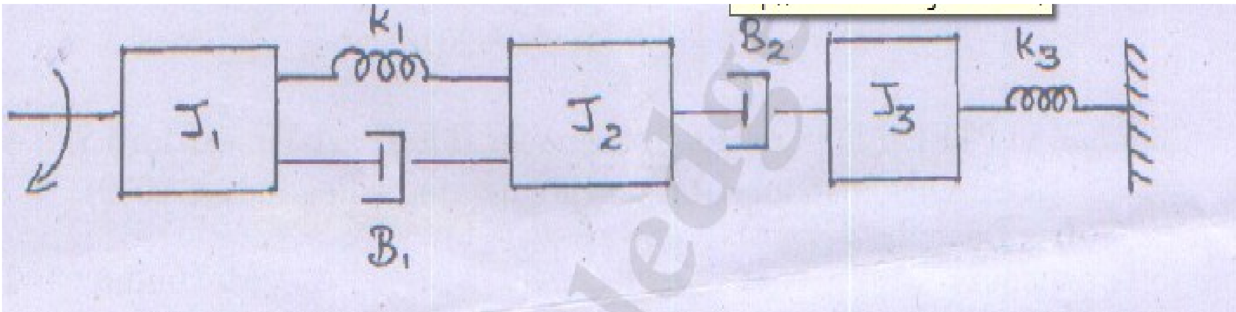
Step4: **Find,° =1- (I+II)**

Step5: Find the gain of non- touching the forward path ($°_k$)

Step6: Apply Masons formula to find the transfer function,

$$\text{Overall T. F} = \frac{\sum T_K \Delta_K}{\Delta}$$

2. **Write the differential equation governing the mechanical rotational system shown and draw the torque-voltage and torque-current electrical analogous circuits and verify by writing mesh equations. [MAY/JUN-2013]**



Solution:

Step1: write the differential equation with J1,B1,K1

Step2: write the differential equation with J2,B2

Step3: write the differential equation with J3,K3

step4: convert the equations as torque-current electrical analogy

Table: 1 Force- Current Analogy

Translational	Electrical	Rotational
Force (f)	Current (i)	Torque (T)
Mass (M)	Capacitance (C)	Inertia (J)
Spring (K)	Reciprocal of Inductance $\left(\frac{1}{L}\right)$	Damper (D)
Damper (D)	Conductance $\left(\frac{1}{K}\right)$	Spring (K)
Displacement (x)	Flux Linkage (ψ)	Displacement (θ)
Velocity $\left(u = \frac{dx}{dt}\right)$	Voltage (v) = $\frac{d\psi}{dt}$	Velocity $\left(\omega = \frac{d\theta}{dt}\right)$

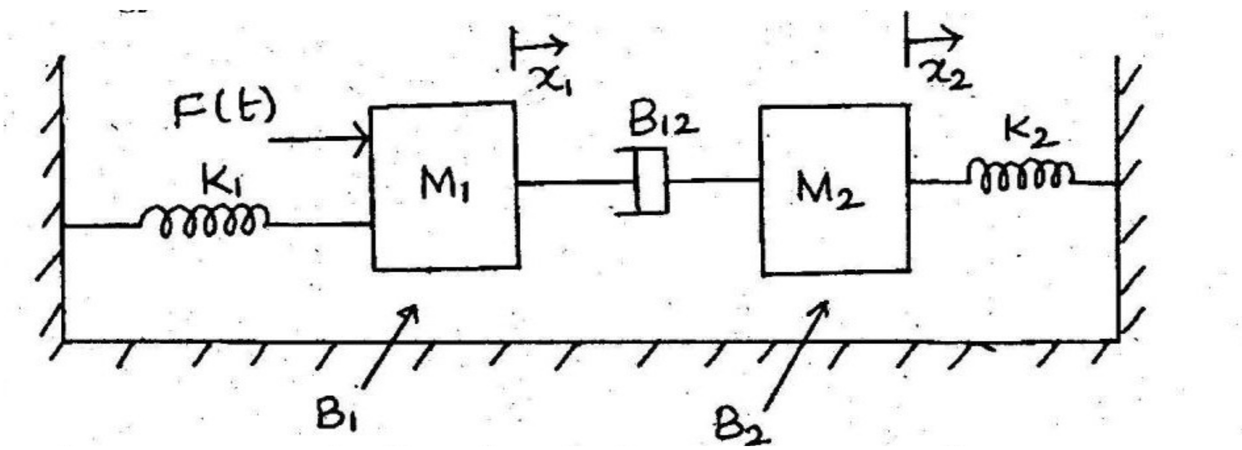
Table: 2 Force- Voltage Analogy

Translational	Electrical	Rotational
Force (f)	Voltage (v)	Torque (T)
Mass (M)	Inductance (L)	Inertia (J)
Damper (D)	Resistance (R)	Damper (D)
Spring (K)	Elastance $\left(\frac{1}{C}\right)$	Spring (K)
Displacement (x)	Charge (q)	Displacement (θ)
Velocity (u)	Current (i)	Velocity (ω)

Step5: convert the equations as torque-voltage electrical analogy

3.

Write the differential equations for the mechanical system shown in Obtain an analogous electric circuit based on force-current analogy[MAY/JUN-2014], [NOV/DEC 2011]



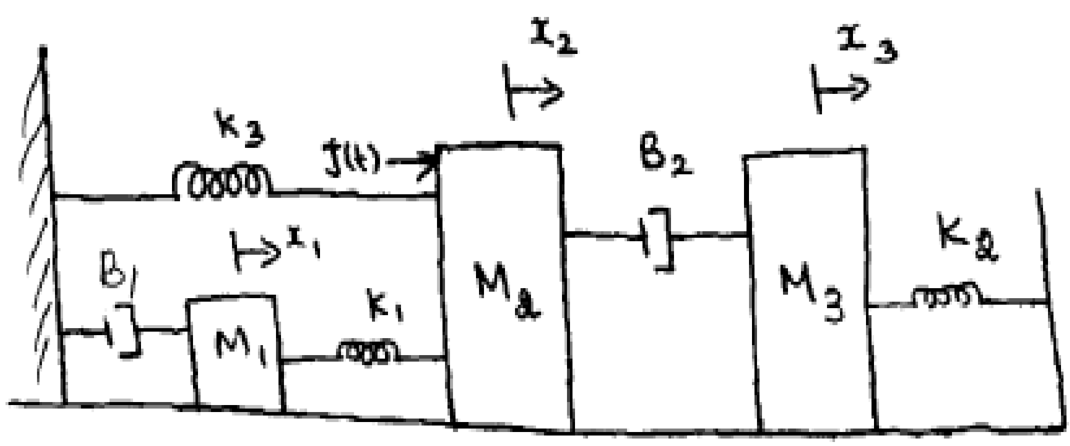
Solution:

Step1: write the differential equation of M1, K1 and B1 with x1

Step2: write the differential equation of M2, B12, B2, k2 with x2

Step3: convert the equations as force-current electrical analogy (Ref.Table:1)

4**. Write the differential equation governing the mechanical rotational system shown and draw the torque-voltage and torque-current electrical analogous circuits. [APR/MAY 2010]**



Solution:

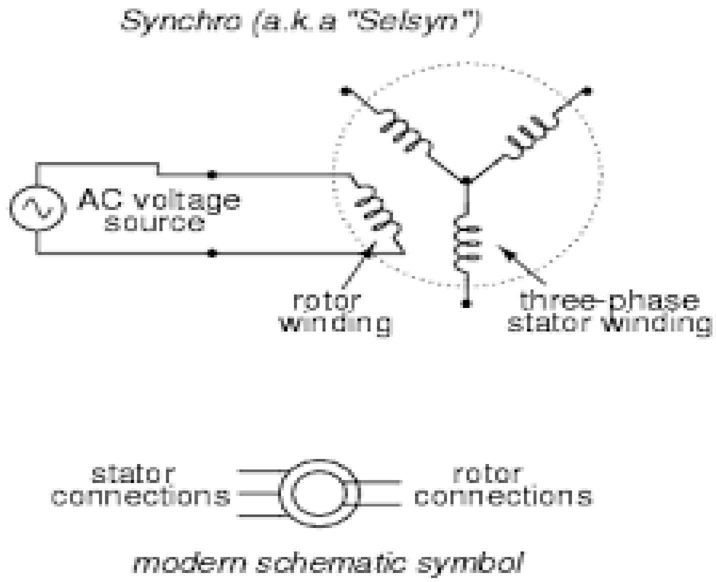
Step1: write the differential equation of M1, K1 and B1 with x1

Step2: write the differential equation of M2, B2, k1, K3 with x2

Step3: write the differential equation of M3, K2 with x3

Step4: convert the equations as torque-voltage (Ref.Table:2) and torque-current electrical analogy (Ref.Table:1)

5. Write the detailed notes on synchros. [APR/MAY 2010]



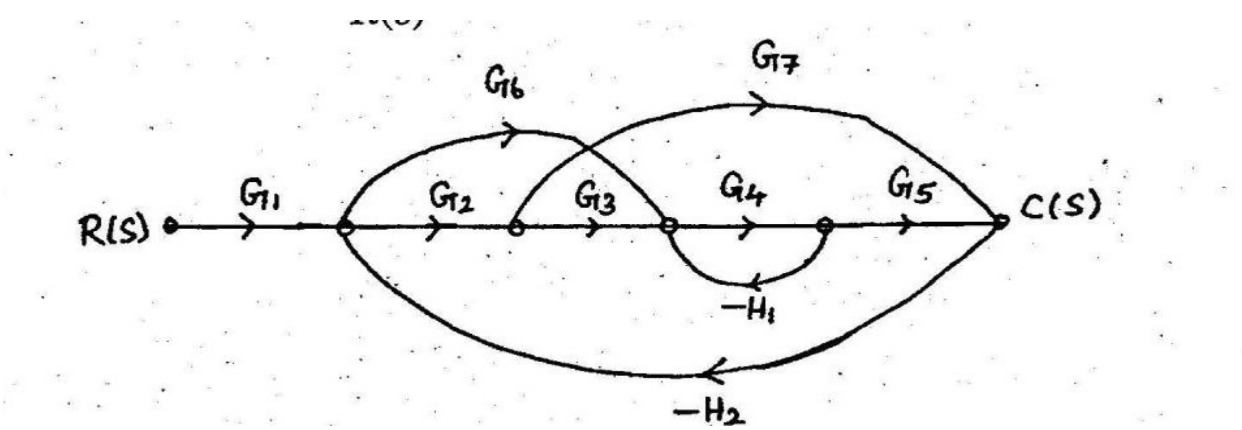
A synchro or "selsyn" is a type of rotary electrical transformer that is used for measuring the angle of a rotating machine such as an antenna platform. In its general physical construction, it is much like an electric motor (See below.) The primary winding of the transformer, fixed to the rotor, is excited by a sinusoidal electric current (AC), which by electromagnetic induction causes currents to flow in three star-connected secondary windings fixed at 120 degrees to each other on the stator. The relative magnitudes of secondary currents are measured and used to determine the angle of the rotor relative to the stator, or the currents can be used to directly drive a receiver synchronous that will rotate in unison with the synchronous transmitter. In the latter case, the whole device (in some applications) is also called a selsyn (a portmanteau of self and synchronizing). U.S. Naval terminology used the term "synchro" exclusively..

Voltages induced in the stator windings from the rotor's AC excitation are not phase-shifted by 120o as in a real three-phase generator. If the rotor were energized with DC current rather than AC and the shaft spun continuously, then the voltages would be true three-phase. But this is not how a synchronous is designed to be operated. You could think of it as a transformer with one primary winding and three secondary windings, each secondary winding oriented at a unique angle. As the rotor is slowly turned, each winding in turn will line up directly with the rotor, producing full voltage, while the other windings will produce something less than full voltage.

6.

Consider the signal flow graph shown in Fig. 2. Obtain the closed loop transfer function $\frac{C(s)}{R(s)}$ by the use of Mason's gain formula.

[MAY/JUN-2014]



Solution:

Step1: Find the Forward path gain, T_k

Step2: Find the closed loop gain (I)

Step3: Find the loop gain of non-touching loops(II)

Step4: **Find,° =1- (I+II)**

Step5: Find t

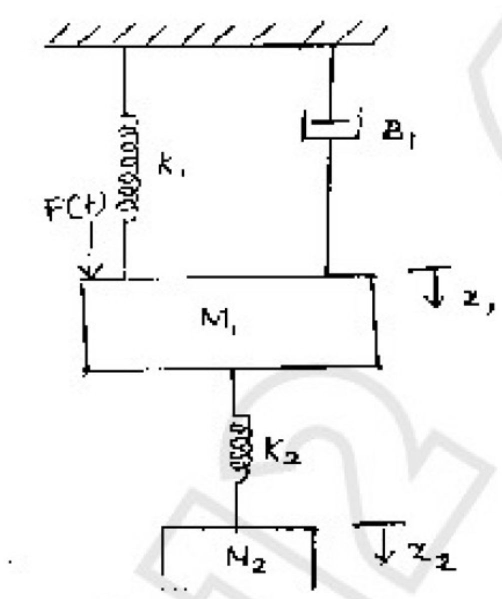
Step6: Apply

Overall T. F

Δ

7. Write the differential equations governing the behavior of the mechanical system shown in Figure.1 Draw the force voltage and force current electrical analogous circuits and verify by writing mesh and node equations. (16)

[APR/MAY 2011]



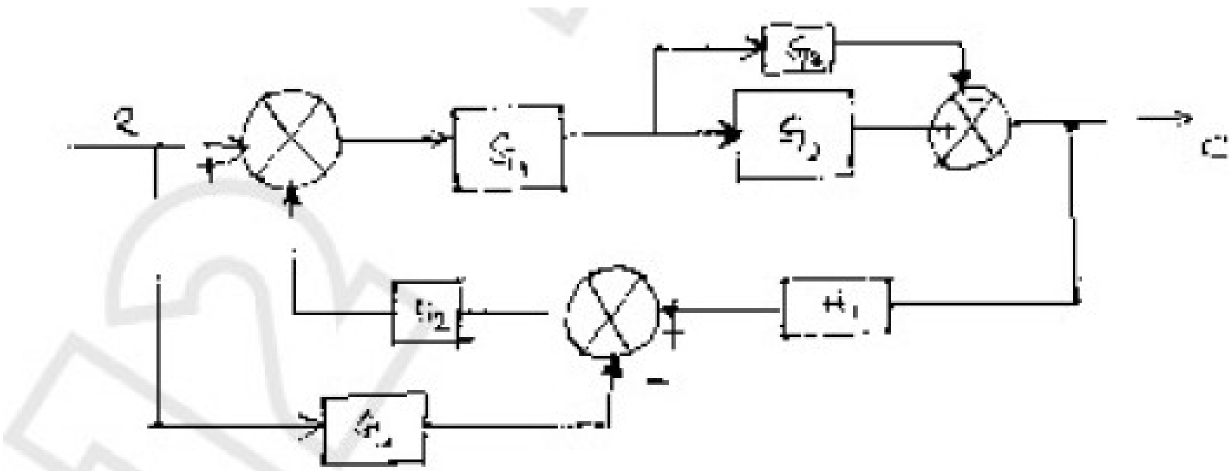
Solution:

Step1: write the differential equation of M1, K1 and B1 with x1

Step2: write the differential equation of M2, k2 with x2

Step3: convert the equations as force-current electrical analogy (Ref.Table:1) and force-voltage (Ref.Table:2)

8. Using block diagram reduction technique finds the transfer function C/R for the system shown in Figure.2 and verify it by using signal flow graph method (16)



Solution:

Step 1: Reduce the blocks connected in series

Step 2: Reduce the blocks connected in parallel

Step 3: Reduce the minor feedback loops

Step 4: Try to shift take off points towards right and Summing point towards left

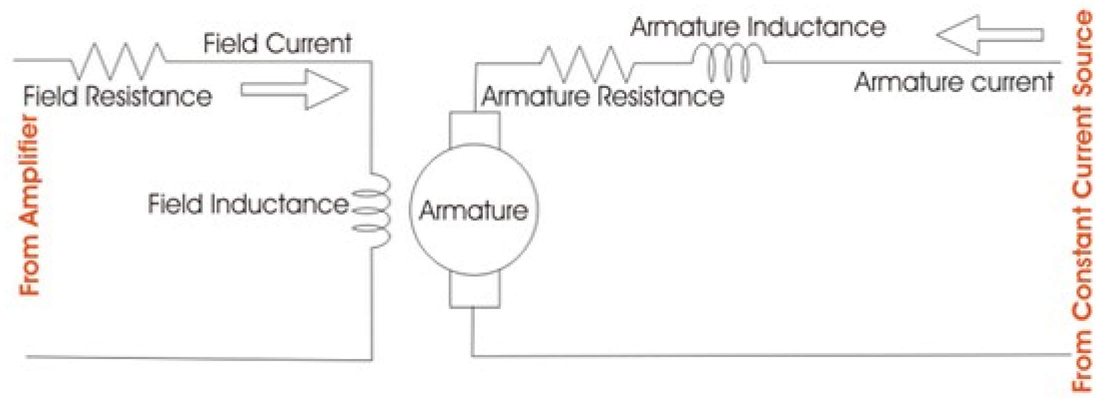
Step 5: Repeat steps 1 to 4 till simple form is obtained

Step 6: Obtain the Transfer Function of Overall System

9. With neat diagrams, explain the working of AC and DC servomotors. [NOV/DEC 2014]

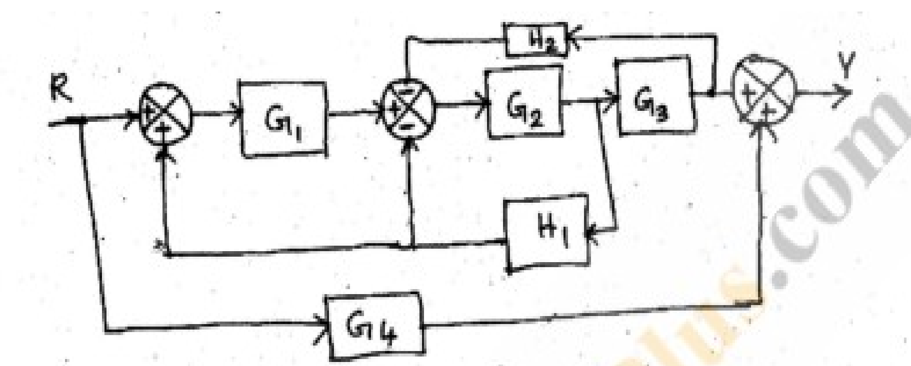
DC servomotor:

The motors which are utilized as DC servo motors, generally have separate DC source for field winding and armature winding. The control can be archived either by controlling the field current or armature current. Field control has some specific advantages over armature control and on the other hand armature control has also some specific advantages over field control. Which type of control should be applied to the DC servo motor, is being decided depending upon its specific applications.



AC Servomotor:

10. Using block diagram reduction rules, convert the block diagram to a simple loop. [NOV/DEC 2014]



Solution:

Step 1: shift take off points towards right (G2)

Step 2: Reduce the blocks connected in parallel

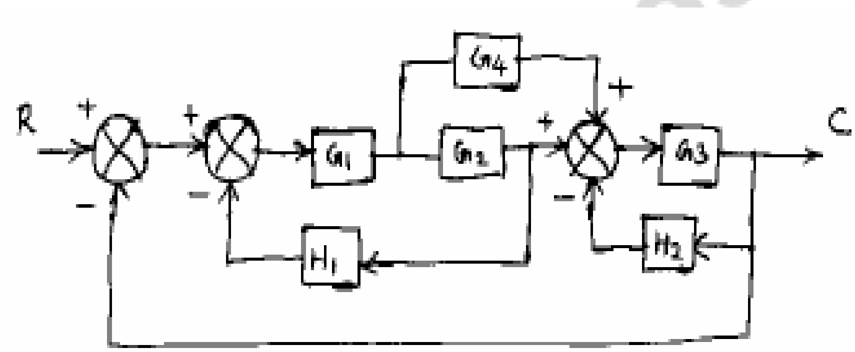
Step 3: Reduce the minor feedback loops

Step 4: Try to shift Summing point towards left

Step 5: Repeat steps 2 to 4 till simple form is obtained

Step 6: Obtain the Transfer Function of Overall System

11. (i) Using block diagram reduction technique, find C/R. (8)



[NOV/DEC 2011]

Solution:

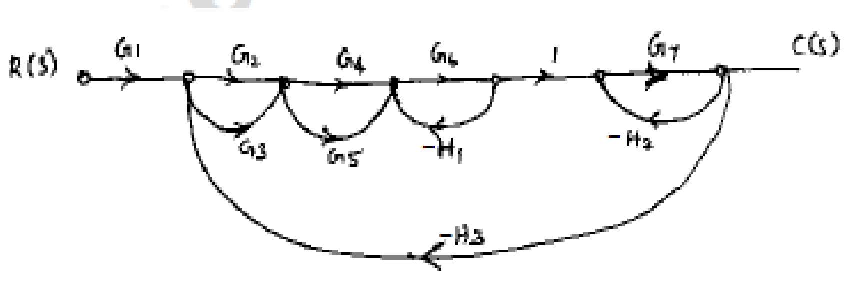
Step1: Find the closed loop transfer function (G1,G2, H1)

Step2: Find the closed loop transfer function (G3,H2)

Step3: Reduce the minor feedback loops

Step4: Obtain the Transfer Function of Overall System

12. (ii) For the given signal flow graph find $\frac{C(S)}{R(S)}$ using Mason's gain formula. (8)



Sol

Step1: Find the Forward path gain, T_k

Step2: Find the closed loop gain (I)

Step3: Find the loop gain of non-touching loops(II)

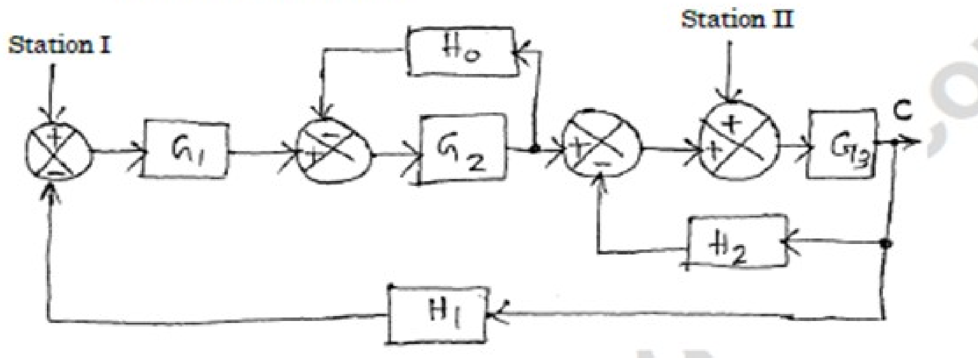
Step4: **Find,° =1- (I+II)**

Step5: Find the gain of non- touching the forward path (°$_k$)

Step6: Apply Masons formula to find the transfer function,

$$\text{Overall T. F} = \frac{\sum T_K \Delta_K}{\Delta}$$

13. For the system represented by the block diagram shown in Fig. 1, evaluate the closed-loop transfer function, when the input R is (i) at station, I, (ii) at station II.



[NOV/DEC 2010]

Solution:

Step1: obtain the transfer funciton of G2,H0 (I)

Step2: Reduce the blocks connected in series (I with G1)

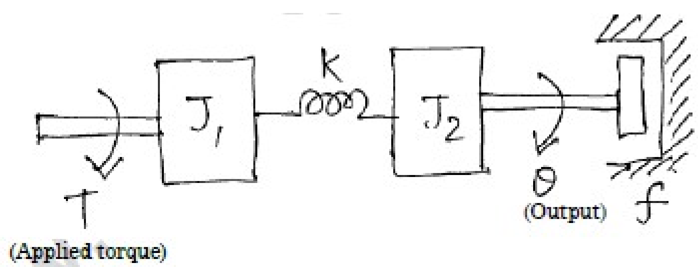
Step3: Try to shift Summing point towards left

Step4: obtain the transfer funciton of G3,H2 (II)

Step5: Reduce the blocks connected in series (I with G1, II)

Step6: Obtain the Transfer Function of Overall System

14. Write the differential equation governing the mechanical rotational system shown and draw the torque-voltage and torque-current electrical analogous circuits.



[NOV/DEC 2010]

Solution:

Step1: write the differential equation of J1, K with q

Step2: write the differential equation of J2, k, f with q

Step3: convert the equations as force-current electrical analogy (Ref.Table:1) and force-voltage (Ref.Table:2)

UNIT-II

1. **Discuss the unit step response of second order system. Obtain the unit step response and unit impulse response of the following system. [APR/MAY 2010]**

$$\frac{C(s)}{R(s)} = \frac{10}{s^2+2s+10}.$$

Solution:

i) unit step response of second order system

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

$$(s^2 + 2\zeta\omega_n s + \omega_n^2)\, C(s) = \omega_n^2 R(s)$$

$$c(t) + 2\zeta\omega_n c(t) + \omega_n^2\, c(t) = \omega_n^2 r(t)$$

ii) Substitute R(s) as 1/s for step response

Substitute R(s) as 1 for impulse response

2. **Write short notes on dynamic error coefficients. [APR/MAY 2010]**

Explanation about Kp, Ka, Kv

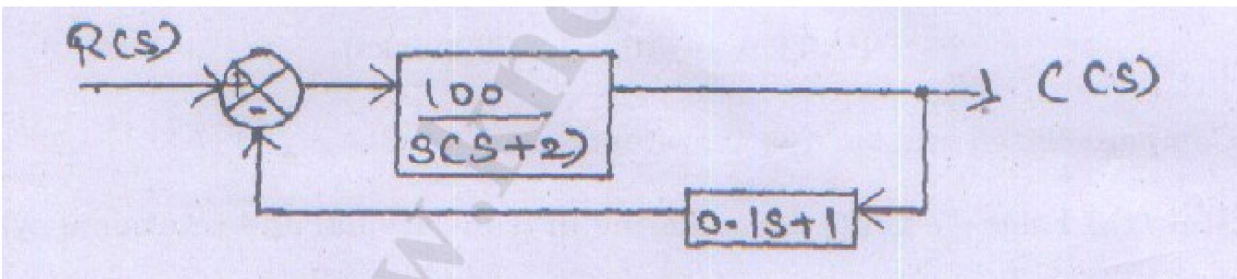
3. **For a unity feedback second order system, the open loop transfer function is**

$$G(s) = \frac{w_n^2}{s(s^2+2\varepsilon w_n)}.$$ **Calculate the generalized error coefficients and find error series. [APR/MAY 2010]**

Solution:

Type of system	Error constants			Steady state error e_{ss}		
	K_p	K_v	K_a	Unit step input	Unit ramp input	Unit parabolic input
0	K	0	0	1/(1+K)	∞	∞
1	∞	K	0	0	1/K	∞
2	∞	∞	K	0	0	1/K
3	∞	∞	∞	0	0	0

4. **A position control system with velocity feedback is shown. Determine the response of the system for unit step input. [MAY/JUN-2013]**



Solution:

Step1: Find the closed loop transfer function of the given system.(C(s)/R(s))

Step2: Substitute R(s) as 1/s

Step3: Find the response of the system.

5. **Explain the effect of adding P,PI,PD and PID controllers in feedback control systems. [MAY/JUN-2013],2times**

Proportional Control

A proportional controller attempts to perform better than the On-off type by applying power in proportion to the difference in temperature between the measured and the set-point. As the gain is increased the system responds faster to changes in set-point but becomes progressively underdamped and eventually unstable. The final temperature lies below the set-point for this system because some difference is required to keep the heater supplying power.

Proportional, Derivative Control

The stability and overshoot problems that arise when a proportional controller is used at high gain can be mitigated by adding a term proportional to the time-derivative of the error signal. The value of the damping can be adjusted to achieve a critically damped response.

Proportional - Integral

The integral controller (Ki) decreases the rise time, increases both the overshoot and the settling time, and eliminates the steady-state error

Proportional+Integral+Derivative Control

Although PD control deals neatly with the overshoot and ringing problems associated with proportional control it does not cure the problem with the steady-state error. Fortunately it is possible to eliminate this while using relatively low gain by adding an integral term to the control function

6. A unity feedback system is characterized by an open loop transfer function $G(s) = \dfrac{K}{s(s+10)}$.

Determine the gain K so that the system will have a damping ratio of 0.5. For this value of K, determine settling time, peak overshoot and time to peak overshoot for a unit step input.

[MAY/JUN-2014]

Solution:

Step1: find the transfer function of the given system.

Step2: find the characteristics equation

Step3: determine settling time, peak overshoot

7. The open loop transfer function of a servo system with unity feedback is

$$G(s) = \frac{10}{s(0.1s+1)}.$$

Evaluate the static error constants (K_p, K_v, K_a) for the system. Obtain the steady state error of the system when subjected to an input given by the polynomial $r(t) = a_0 + a_1 t + \frac{a_2}{2} t^2$.

[MAY/JUN-2014]

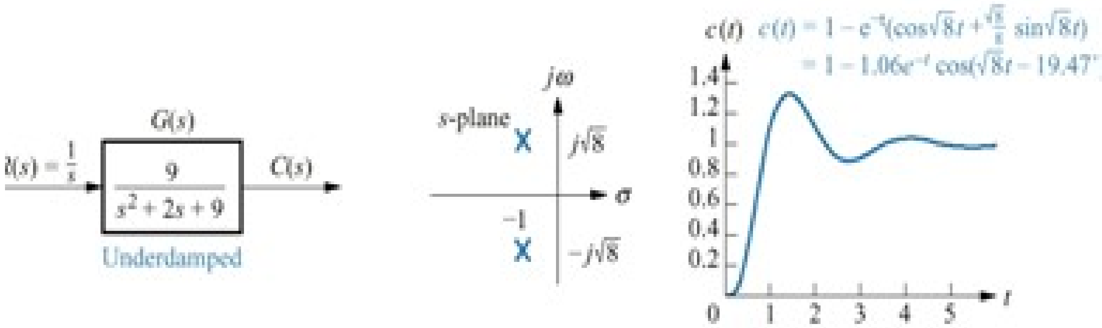
Solution:

Kp= G(s) s limit 0

Kv=SG(s) s limit 0

Ka=S^2 G(s) s limit 0

8. **Derive an expression for unit step response of under damped second order system. [NOV/DEC 2014]**



9**. Obtain the expression for dynamic error coefficients of the following system** $G(S)=\frac{10}{S(1+S)}$ **[NOV/DEC 2014]**

<u>Solution :</u>

Find the transfer function of the given system.

Find the error coefficients Kp,Kv,Ka

10. A unity feedback control system has an open loop transfer function G(s) = 5/s(s+1). Find the rise time, percentage overshoot, peak time, settling time for a step input of 10 units. Also determine the peak overshoot. (8)

Solution :

Step1: find the transfer function of the given system.

Step2: substitute R(s) as 10

Step3: find the characteristics equation

Step3: determine rise time, peak time, settling time, peak overshoot

11. A unity feedback system has $G(s) = 1/s(s+1)$. The input to the system is described by $r(t) = 4+6t+2t^3$. Find the generalized error coefficients and steady state error. (8).

Solution:

Step1: determine the value of R(s) from the given r(t)

Step2: find the transfer function C(s)/R(s)

Step3: from transfer function G(s), Find the error coefficients

Step4: find the steady state error using

$$e_{ss} = \lim_{t\to\infty} e(t) \lim_{s\to 0} sE(s) = \lim_{s\to 0} \frac{sR(s)}{1+G(s)}$$

12. Define the time domain specifications.

The time domain specifications are

1. Delay time : It is the time taken for response to reach 50% of the final value, for the very first time.

2. Rise time : It is the time taken for response to raise from 0 to 100% for the very first time. For under damped system, the rise time is calculated from 0 to 100%. But for over damped system, it is the time taken by the response to raise from 10% to 90%. For critically damped system, it is the time taken for response to raise from 5% to 95%.

3. Peak time : It is the time taken for the response to reach the peak value for the very first time (or) It is the time taken for the response to reach peak overshoot, Mp.

4. Maximum peak overshoot : It is defined as the ratio of the maximum peak value measured from final value to final value. Let final value= c( ), Maximum value=c(tp)

5. Settling time. It is defined as the time taken by the response to reach and stay with in a specified error and the error is usually specified as % of final value. The usual tolerable error is 2% or 5% of the final value..

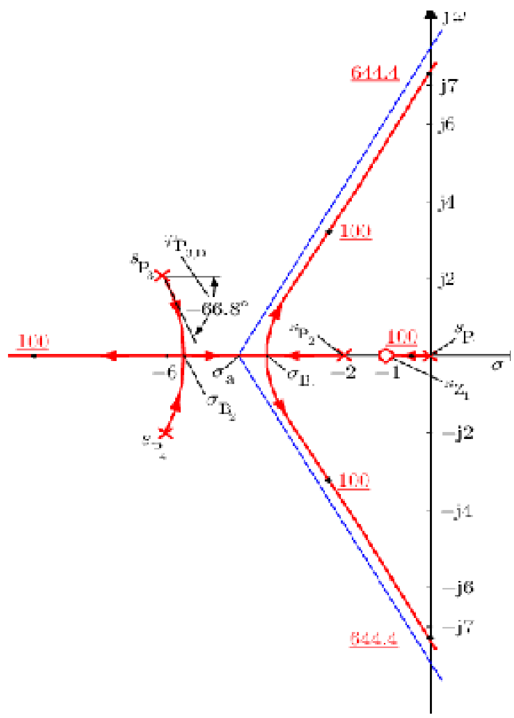
13. Derive the expression for rise time and peak over shoot.

rise time and peak over shoot. – each 8 Marks

14. Construct The Root Locus For The Open-Loop Transfer Function .

$$G_0(s) = \frac{k_0(s+1)}{s(s+2)(s^2+12s+40)}\ .$$

The degree of the numerator polynomial is . This means that the transfer function has one zero ( ). The degree of the denominator polynomial is and we have the four poles (, , , 2). First the poles (x) and the zeros (o) of the open loop are drawn on the plane as shown in Figure 1. According to rule 3 these poles are just



We have branches that go to infinity and the asymptotes of these three branches are lines which intercept the real axis according to rule 6.The crossing is at and the slopes of the asymptotes are

$$\sigma_a = \frac{(0-2-6-6)-(-1)}{3} = -\frac{13}{3} = -4.33$$

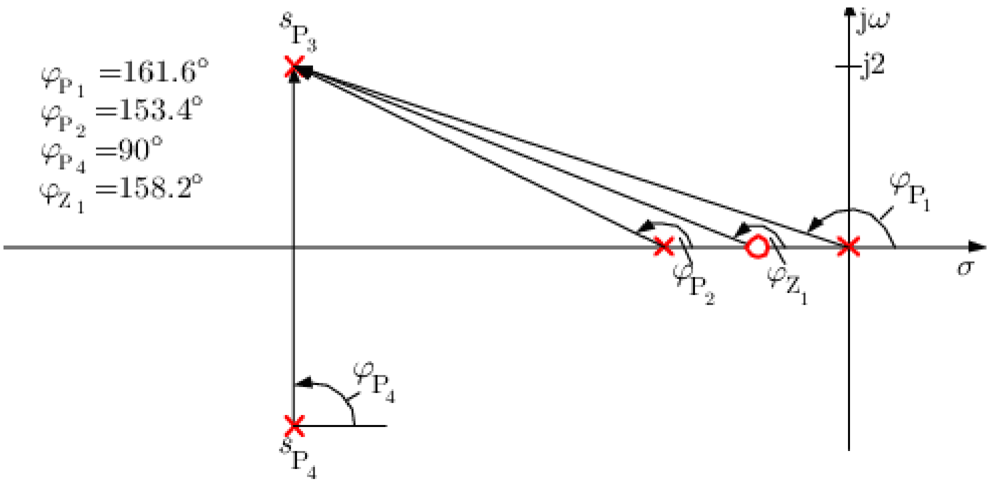
$$\alpha_k = \frac{\pm 180^\circ(2k+1)}{3} = \pm 60^\circ(2k+1) \quad k = 0, 1, 2, \ldots$$

The asymptotes are shown in Figure 1as blue lines. Using Rule 4 it can be checked which points on the real axis are points on the root locus. The points with and belong to the root locus, because to the right of them the number of poles and zeros is odd. According to rule 7 breakaway and breakin points can only occur pair wise on the real axis to the left of -2. Here we have

$$\frac{1}{s}+\frac{1}{s+2}+\frac{1}{s+6-j2}+\frac{1}{s+6+j2}=\frac{1}{s+1}$$

This equation has the solutions , and .The real roots and are the positions of the breakaway and the break-in point. The angle of departure of the root locus from the complex pole at can be determined from Figure 2

$$= -90^\circ - 153.4^\circ - 161.6^\circ + 158.2^\circ \pm 180^\circ(2k+1)$$

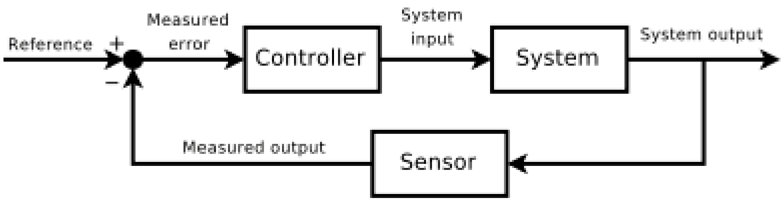


Calculating the angle of departure of the complex pole With these specifications the root locus can be sketched. Using rule 9 the value of can be determined for some selected points.

The value at the intersection with the imaginary axis is $k_{0,\mathrm{crit}} = \frac{7.2 \cdot 7.4 \cdot 7.9 \cdot 11.1}{7.25} = 644.4$.

15. Write Short Notes On Effects Of Feedback.

Control theory is an interdisciplinary branch of, that deals with the behavior of feedback systems. The desired output of a system is called the reference. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system



The concept of the feedback loop to control the dynamic behavior of the system:

this is negative feedback, because the sensed value is subtracted from the desired value to create the error signal which is amplified by the controller. An example Consider an automobile which is a device designed to maintain a constant vehicle speed; the *desired* or *reference* speed, provided by the driver. The *system* in this case is the vehicle. The system output is the vehicle speed, and the control variable is the engine's throttle osition which influences engine torque output. A primitive way to implement cruise control is simply to lock the throttle position when the driver engages cruise control. However, on mountain terrain, the vehicle will slow down going uphill and accelerate going downhill. In fact, any parameter different than what was assumed at design time will translate into

a proportional error in the output velocity, including exact mass of the vehicle, wind resistance, and tire pressure. This type of controller is called an open loop controller because there is no direct connection between the output of the system (the vehicle's speed) and the actual conditions encountered; that is to say, the system does not and can not compensate for unexpected forces.

UNIT-III

1. **Explain the frequency domain specifications of a typical system. [APR/MAY 2010]**

$$\mathrm{Mpw} = \left[2\cdot\zeta\cdot\left(\sqrt{1-\zeta^2}\right)\right]^{-1}$$

$$\mathrm{wr} = \mathrm{wn}\cdot\sqrt{1-2\cdot\zeta^2}$$

2. **Draw the bode plot of the open loop transfer function [APR/MAY 2010]**

$$G(s) = \frac{200\,(s+10)}{s(s+5)\,(s+20)}.$$

Plots of the magnitude and phase characteristics are used to fully describe the frequency response

• A **Bode plot** is a (semilog) plot of the transfer function magnitude and phase angle as a function of frequency

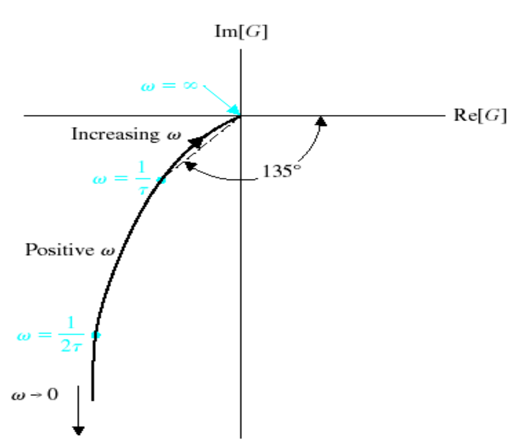
• The gain magnitude is many times expressed in terms of decibels (dB)

dB = 20 log10 A

PROCEDURE:

1. sinusoidal T.F of G(s) is obtained by replacing s by jw in the given T.F
2. Choose a lower corner frequency and a higher Corner frequency
3. Calculation of Gain (A) (MAGNITUDE PLOT)
4. Calculation of Phase angle for different values of frequencies [PHASE PLOT]

3. **What is the effect on polar plot if a pole at origin is added to the transfer function? Explain. Draw the polar plot of a first order system. [APR/MAY 2010]**
   - For Minimum Phase Systems with only poles
   - Type No. determines at what quadrant the polar plot starts.
   - Order determines at what quadrant the polar plot ends.
   - Type No. → No. of poles lying at the origin
   - Order → Max power of 's' in the denominator polynomial of the transfer function.



4. For the following system, sketch the polar plot, [APR/MAY 2010]

$$G(s)H(s) = \frac{500}{s(s+6)(s+9)}.$$

Solution:

1. Express the given expression of OLTF in (1+sT) form.
2. Substitute s = j? in the expression for G(s)H(s) and get G(j?)H(j?).
3. Get the expressions for | G(j?)H(j?)| & G(j?)H(j?).
4. Tabulate various values of magnitude and phase angles for different values of ? ranging from 0 to ∞.
5. Usually the choice of frequencies will be the corner frequency and around corner frequencies.
6. Choose proper scale for the magnitude circles.
7. Fix all the points in the polar graph sheet and join the points by a smooth curve.
8. Write the frequency corresponding to each of the point of the plot

5. Sketch the bode plot for the following transfer function and determine the value of K for the gain cross over frequency of 5 rad/sec [MAY/JUN-2013]

$$G(s) = Ks^2/[(1+0.2s)(1+0.02s)].$$

Solution :

1. sinusoidal T.F of G(s) is obtained by replacing s by jw in the given T.F
2. Choose a lower corner frequency and a higher Corner frequency
3. Calculation of Gain (A) (MAGNITUDE PLOT)
4. Calculation of Phase angle for different values of frequencies [PHASE PLOT]

5. Calculations of Gain cross over frequency: the frequency at which the dB magnitude is Zero

6. **Sketch the polar plot for the following transfer function and determine the gain and phase margin [MAY/JUN-2013]**

$$G(s)=1/[s(1+s)(1+2s)].$$

Solution:

1. Express the given expression of OLTF in (1+sT) form.
2. Substitute s = j? in the expression for G(s)H(s) and get G(j?)H(j?).
3. Get the expressions for | G(j?)H(j?)| & G(j?)H(j?).
4. Tabulate various values of magnitude and phase angles for different values of ? ranging from 0 to ∞.
5. Usually the choice of frequencies will be the corner frequency and around corner frequencies.
6. Choose proper scale for the magnitude circles.
7. Fix all the points in the polar graph sheet and join the points by a smooth curve.
8. Write the frequency corresponding to each of the point of the plot.

For stable systems,

ωgc ωpc

G(j)H(j) at ω=ωpc 1

GM = in positive dB

More positive the GM, more stable is the system.

For marginally stable systems,

ωgc = ωpc

G(j)H(j) at ω=ωpc = 1

GM = 0 dB

For Unstable systems,

ωgc ωpc

G(j)H(j) at ω=ωpc > 1

GM = in negative dB

Gain is to be reduced to make the system stable

PHASE MARGIN

- Let 'A' be the point of intersection of G(j)H(j) plot and a unit circle centered at the origin.
- Draw a line connecting the points 'O' & 'A' and measure the phase angle between the line OA and +ve real axis.
- This angle is the phase angle of the system at the gain cross over frequency.
- G(j gc)H(j gc) = gc
- If an additional phase lag of PM is introduced at this frequency, then the phase angle G(j gc)H(j gc) will become 180 and the point ?A' coincides with (-1+j0) driving the system to the verge of instability.

- This additional phase lag is known as the Phase Margin.

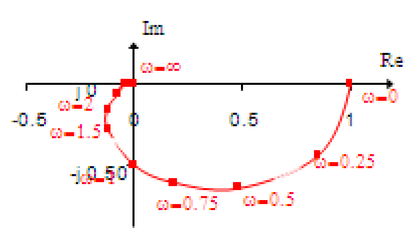
  = 180 + G(j gc)H(j gc)

  = 180 + gc

[Since gc is measured in CW direction, it is taken as negative]

For a stable system, the phase margin is positive.

A Phase margin close to zero corresponds to highly oscillatory system.



A polar plot may be constructed from experimental data or from a system transfer function

If values of w are marked along the contour, a polar plot has the same information as a Bode plot

7. Sketch the Bode plot showing the magnitude in decibels and phase angle in degrees as a function of log frequency for the transfer function

$$G(s) = \frac{75(1 + 0.2s)}{s(s^2 + 16s + 100)}.$$

From the Bode plot, determine the gain cross-over frequency.

Solution :

1. sinusoidal T.F of G(s) is obtained by replacing s by jw in the given T.F
2. Choose a lower corner frequency and a higher Corner frequency
3. Calculation of Gain (A) (MAGNITUDE PLOT)
4. Calculation of Phase angle for different values of frequencies [PHASE PLOT]
5. Calculations of Gain cross over frequency: the frequency at which the dB magnitude is Zero

8. [MAY/JUN-20 Discuss the correlation between time and frequency response of second order system. (8)

Solution :

Open and closed-loop frequency responses are related by:

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

$$M_{pw} = \frac{1}{2\cdot\zeta\cdot\sqrt{1-\zeta^2}} \qquad \zeta < 0.707$$

$$G(\omega) = u + j\cdot v \qquad M = M(\omega)$$

$$M(\omega) = \left|\frac{G(j\omega)}{1+G(j\omega)}\right| = \left|\frac{u + jv}{1 + u + jv}\right| = \frac{\sqrt{u^2+v^2}}{\sqrt{(1+u)^2+v^2}}$$

Squaring and rearrenging

$$\left(u - \frac{M^2}{1-M^2}\right)^2 + v^2 = \left(\frac{M}{1-M^2}\right)^2$$

which is the equation of a circle on u-v planwe with a center at

$$u = \frac{M^2}{1-M^2} \qquad v = 0$$

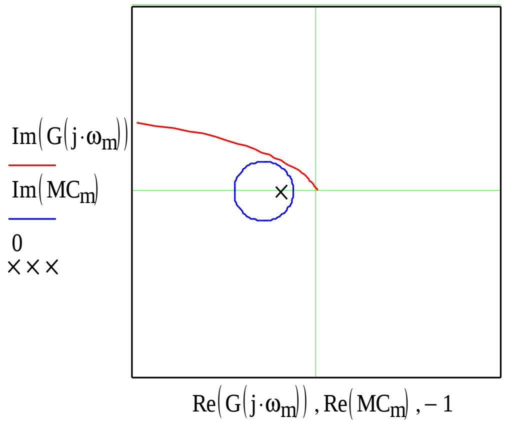
9. **How the closed loop frequency response is determined from the open loop frequency response using Nichols chart? Explain how the gain adjustment is carried out on the Nichols chart. (8)**

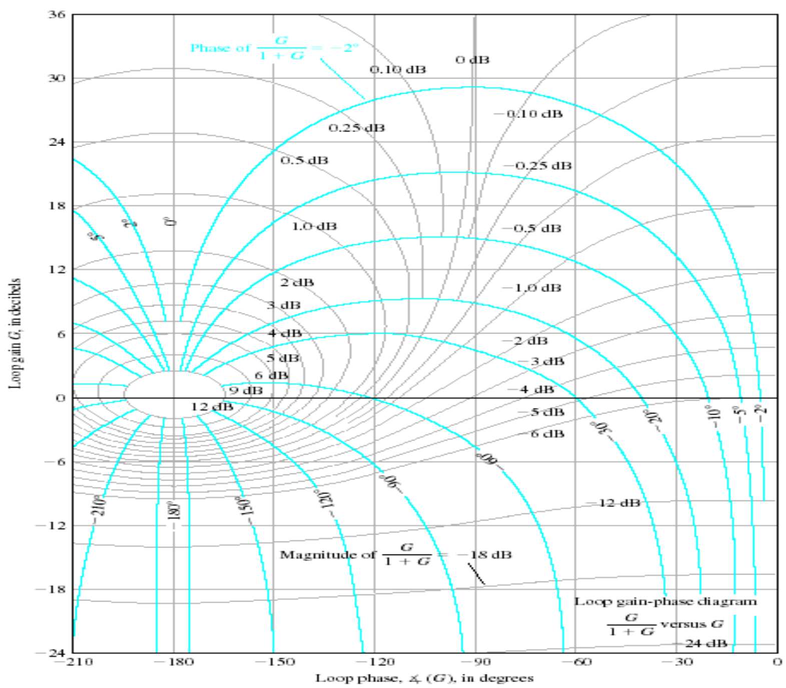
Solution:

The G(j) locus or the Nicholas plot is sketched on the standard Nicholas chart.

The meeting point of M-contour with G(j) locus gives the magnitude of closed loop system and the meeting point with N circle gives the argument/phase of the closed loop system

The first plot shows **G**, the contour of constant closed-loop magnitude **M,** and the Nyquist of the open loop system

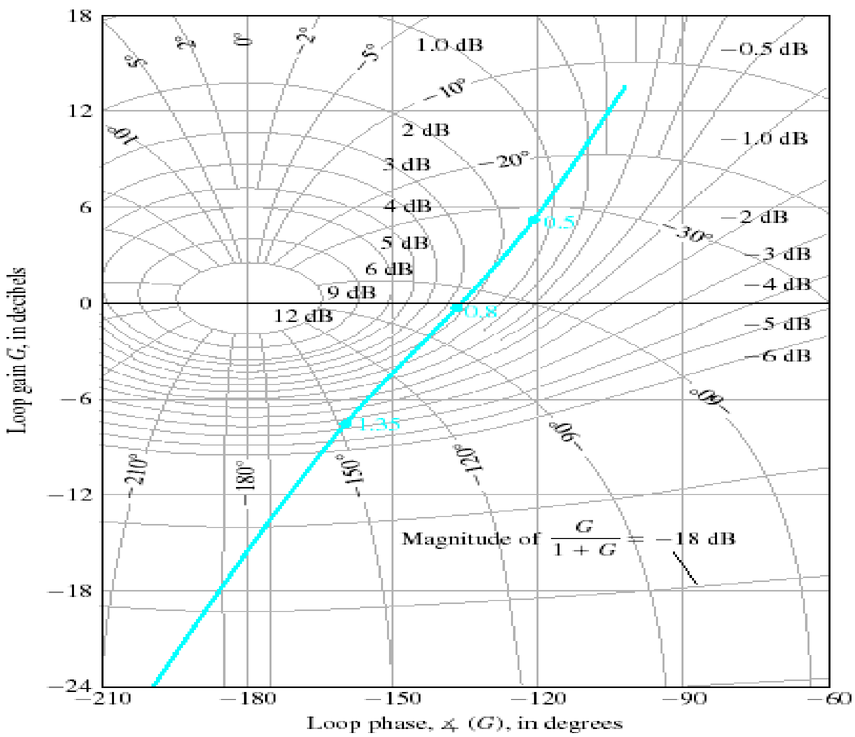




$$G(\omega) := \frac{1}{j\cdot\omega\cdot(j\cdot\omega + 1)\cdot(0.2\cdot j\cdot\omega + 1)}$$

$M_{pw} := 2.5$ dB $\qquad \omega_r := 0.8$

The closed-loop phase angle
at ωr is equal to -72 degrees and ωb = 1.33
The closed-loop phase angle at ωb is equal to
-142 degrees



10. The characteristic equation of a feedback control system is given by $s^4 + 20s^3 + 15s^2 + 2s + K = 0$ (10)

(1) Determine the range of values of K for the system to be stable.

(2) Determine the value of K which will cause sustained oscillations in the closed loop system. What are the corresponding oscillating frequencies?

Solution :

the root locus is the set of paths traced by the roots of

$$1 + KG(s) = 0$$

as K varies from zero to infinity. As K changes, the solution to this equation changes. This equation is called the characteristic equation. This equation defines where the poles will be located for any value of the root locus gain, K. In other words, it defines the characteristics of the system behavior for various values of controller gain.

11. Sketch the root locus of the system whose open loop transfer function is $G(s) = \frac{K}{s(s+1)(s+3)}$. Determine the value of K for damping ratio equal to 0.5 (16)

Solution:

Application of the Root Locus Procedure

Step 1: Write the characteristic equation as 1 $F(s)$ 0

Step 2: Rewrite preceding equation into the form of poles and zeros as follows

$$1+K\frac{\prod_{j=1}^{m}(s-z_j)}{\prod_{i=1}^{n}(s-p_i)}=0$$

Step 3: Locate the poles and zeros with specific symbols, the root locus begins at

The Open-loop poles and ends at the open loop zeros as K increases from 0 to

Infinity If open-loop system has n-m zeros at infinity, there will be n-m branches

of the Root locus approaching the n-m zeros at infinity

Step 4: The root locus on the real axis lies in a section of the real axis to the left

of an odd number of real poles and zeros

Step 5: The number of separate loci is equal to the number of open-loop poles

Step 6: The root loci must be continuous and symmetrical with respect to the

Horizontal real axis

Step 7: The loci proceed to zeros at infinity along asymptotes centered at

centroid and with angles

$$\sigma_a=\frac{\sum_{i=1}^{n}p_i-\sum_{j=1}^{m}z_j}{}$$

$$\phi_a=\frac{(2k+1)\pi}{n-m} \qquad (k=0,1,2,\cdots n-m-1)$$

Step 8: The actual point at which the root locus crosses the imaginary axis is

readily evaluated by using Routh‘s criterion

Step 9: Determine the breakaway point d (usually on the real axis)

Step 10: Plot the root locus that satisfy the phase criterion

$$\angle P(s)=(2k+1)\pi \qquad k=1,2,\cdots$$

Step 11: Determine the parameter value *K1* at a specific root using the Magnitude criterion

$$K_1 = \left. \frac{\prod_{i=1}^{n} |(s - p_i)|}{\prod_{j=1}^{m} |(s - z_j)|} \right|_{s=s_1}$$

12. Draw the bode plot of the following system and hence obtain gain cross over frequency. [NOV/DEC 2014] $GH(S) = \frac{10}{S(0.1S+1)(0.01S+1)}$

Solution :

1. sinusoidal T.F of G(s) is obtained by replacing s by jw in the given T.F
2. Choose a lower corner frequency and a higher Corner frequency
3. Calculation of Gain (A) (MAGNITUDE PLOT)
4. Calculation of Phase angle for different values of frequencies [PHASE PLOT]
5. Calculations of Gain cross over frequency: the frequency at which the dB magnitude is Zero

13. Using polar plot, determine gain cross over frequency, phase cross over frequency, gain margin and phase margin of feedback system with open loop transfer function. [NOV/DEC 2014]

$$G(S)H(S) = \frac{10}{S(1+0.2S)(1+0.002S)}.$$

Solution :

9. Express the given expression of OLTF in (1+sT) form.
10. Substitute s = jω in the expression for G(s)H(s) and get G(jω)H(jω).
11. Get the expressions for | G(jω)H(jω)| & G(jω)H(jω).
12. Tabulate various values of magnitude and phase angles for different values of ωranging from 0 to ∞.

13. Usually the choice of frequencies will be the corner frequency and around corner frequencies.
14. Choose proper scale for the magnitude circles.
15. Fix all the points in the polar graph sheet and join the points by a smooth curve.
16. Write the frequency corresponding to each of the point of the plot.

For stable systems,

ωgc ωpc

G(j)H(j) at ω=ωpc 1

GM = in positive dB

More positive the GM, more stable is the system.

For marginally stable systems,

ωgc = ωpc

G(j)H(j) at ω=ωpc = 1

GM = 0 dB

For Unstable systems,

ωgc ωpc

G(j)H(j) at ω=ωpc > 1

GM = in negative dB

Gain is to be reduced to make the system stable

<u>PHASE MARGIN</u>

- Let 'A' be the point of intersection of G(j)H(j) plot and a unit circle centered at the origin.
- Draw a line connecting the points 'O' & 'A' and measure the phase angle between the line OA and +ve real axis.
- This angle is the phase angle of the system at the gain cross over frequency.
- G(j gc)H(j gc) = gc

- If an additional phase lag of PM is introduced at this frequency, then the phase angle G(j gc)H(j gc) will become 180 and the point ‗A‘ coincides with (-1+j0) driving the system to the verge of instability.

- This additional phase lag is known as the Phase Margin.

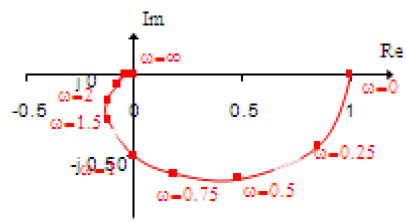
  = 180 + G(j gc)H(j gc)

  = 180 + gc

[Since gc is measured in CW direction, it is taken as negative]

For a stable system, the phase margin is positive.

A Phase margin close to zero corresponds to highly oscillatory system.



A polar plot may be constructed from experimental data or from a system transfer function

If values of w are marked along the contour, a polar plot has the same information as a Bode plot.

Gain Cross Over Frequency, G(J Gc)H(J Gc) = Gc

Phase Cross Over Frequency.

GM = Kg = 1 / G(j)H(j) = pc

GM

Sketch the bode-plot for the following transfer function and determine the phase margin and gain margin of the system

$$G(s) = \frac{10}{s(1+0.5s)(1+0.1s)}. \qquad (16)$$

Solution:

1. sinusoidal T.F of G(s) is obtained by replacing s by jw in the given T.F
2. Choose a lower corner frequency and a higher Corner frequency

3. Calculation of Gain (A) (MAGNITUDE PLOT)
4. Calculation of Phase angle for different values of frequencies [PHASE PLOT]
5. Calculations of Gain cross over frequency: the frequency at which the dB magnitude is Zero

15. Sketch the polar plot for the following transfer function

$$G(S)H(S) = \frac{10(S+2)(S+4)}{s(s^2 - 3s + 10)}.$$

Soluti

- Express the given expression of OLTF in (1+sT) form.
- Substitute s = jω in the expression for G(s)H(s) and get G(jω)H(jω).
- Get the expressions for | G(jω)H(jω)| & G(jω)H(jω).
- Tabulate various values of magnitude and phase angles for different values of ωranging from 0 to ∞.
- Usually the choice of frequencies will be the corner frequency and around corner frequencies.
- Choose proper scale for the magnitude circles.
- Fix all the points in the polar graph sheet and join the points by a smooth curve.
- Write the frequency corresponding to each of the point of the plot.

16.

Sketch the Bode plot for the following transfer function and obtain gain and phase cross over frequencies.

$$G(s) = \frac{20}{s(1+0.4s)(1+0.1s)} \qquad (16)$$

Refer the procedure of qn.no.18

17. The open loop transfer function of a unity feedback system is given by $G(s) = \dfrac{1}{s^2(1+s)(1+2s)}$. Sketch the polar plot and determine the gain margin and phase margin. (16)

Refer the procedure of qn.no.18

18. **Draw The Bode Plot Of The Transfer Function**

G(S)= 64(S+2) / S(S+0.5)(S2+3.2s+64

The sinusoidal transfer function in time-constant form is,

$$G(j\omega) = \frac{4(1+j\omega/2)}{j\omega(1+2j\omega)(1+0.4j\left(\frac{\omega}{8}\right)-\left(\frac{\omega}{8}\right)^2}.$$

$4/j\omega$	-	Straight line of slope -20 db/decade, passing through $20\log 4 = 12$ db point at $\omega = 1$.	Constant -90°
$1/1+2j\omega$	ω_1=0.5	Straight line of 0 db for $\omega < \omega_1$, straight line of slope -20 db/decade for $\omega > \omega_1$.	0 to -90°, $-45°$ at ω_1.
$1+j0.5\omega$	ω_2=2	Straight line of 0 db for $\omega < \omega_2$, straight line of slope +20 db/decade for $\omega > \omega_2$.	0 to +90°, 45° at ω_2.
$1+j0.4\left(\frac{\omega}{8}\right)-\left(\frac{\omega}{8}\right)$; $\omega_n = 8,\ \zeta = 0.2$	ω_3=8	Straight line of 0 db for $\omega < \omega_3$, straight line of slope -40 db/decade for $\omega > \omega_3$.	0 to $-180°$ $-90°$ at ω_3.

The phase angle curve may be drawn using the following procedure.

1. For the factor $K/(jw)^r$, draw a straight line of *-90 r*.

2. The phase angles of the factor $(1+jwT)^{-1}$ are

a. 45 at w=1/T o

b. 26.6 at w=1/2T o

c. 5.7 at w=1/10T o

d. 63.4 at w=2/T o

e. 84.3 at w=10/T o

3. The phase angles for the quadratic factor are

a. $_n$ –90 at w=w $_o$

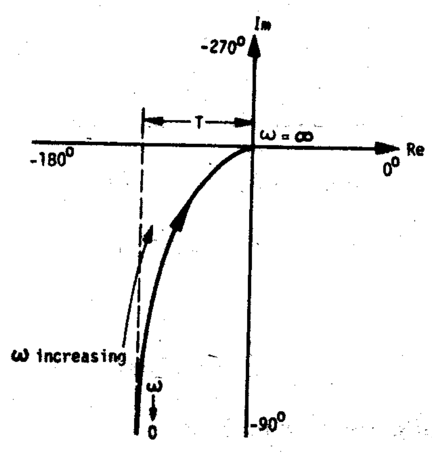
b. A few points of phase angles are read off from the normalized

20. Explain Polar Plot.

The polar plot of a sinusoidal transfer function $G(jw)$ is a plot of the Magnitude of $G(jw)$ versus the phase angle of $G(jw)$ on polar coordinates as w is Varied from zero to infinity. An advantage of using polar plot is that it depicts the

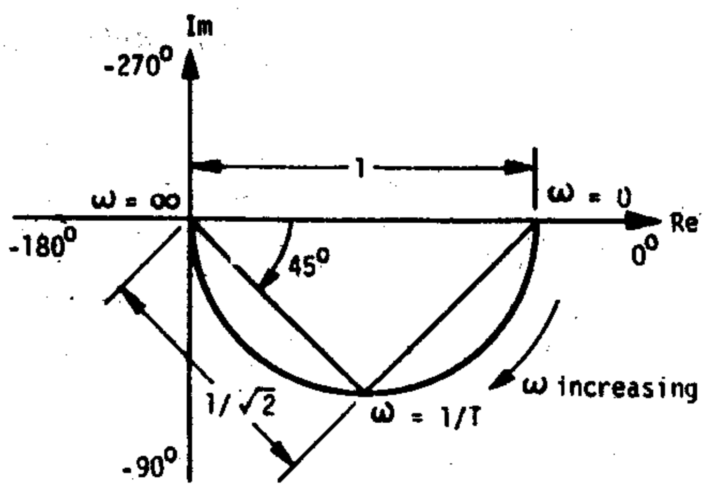
frequency response characteristics of a system over the entire frequency range in a single plot.

The polar plot of



Polar plot of $1/j\omega(1+j\omega T)$.

The plot is asymptotic to the vertical line passing through the point *(-T, 0)*.



Polar plot of $1/(1+j\omega T)$.

UNIT-IV

1. For each of the characteristics equation of feedback control system given, determine the range of K for stability. Determine the value of K so that the system is marginally stable and the frequency of sustained oscillations. [APR/MAY 2010]

(i) $s^4 + 25s^3 + 15s^2 + 20s + K = 0$

(ii) $s^4 + Ks^3 + s^2 + s + 1 = 0$

(iii) $s^3 + 3Ks^2 + (K+2)s + 4 = 0$

(iv) $s^4 + Ks^3 + 5s^2 + 10s + 10K = 0$.

Solution:

The Routh-Hurwitz criterion states that the number of roots of q(s) with positive real parts is equal to the number of changes in sign of the first column of the Routh array

Therefore the requirement for a stable second-order system is simply that all coefficients be positive or all the coefficients be negative.

With simple roots on the jw-axis, the system will have a marginally stable behavior. This is not the case if the roots are repeated. Repeated roots on the jw-axis will cause the system to be unstable. Unfortunately, the routh-array will fail to reveal this instability.

Write short notes on Root locus construction.

2.

$$G(s)\,H(s) = \frac{1}{s^4\,(s+1)}.$$

[APR/MAY 2010]

Solution:

Constructing Root Locus

- Locate the OL poles & zeros in the plot
- Find the branches on the real axis
- Find angle of asymptotes & centroid
- § Φa= ±180º(2q+1) / (n-m)
- § ζa = (Σpoles - Σzeroes) / (n-m)
- Find BA and BI points
- Find Angle Of departure (AOD) and Angle Of Arrival (AOA)
- AOD = 180º- (sum of angles of vectors to the complex pole from all other poles) +
- (Sum of angles of vectors to the complex pole from all zero)
- AOA = 180º- (sum of angles of vectors to the complex zero from all other zeros) + (sum of angles of vectors to the
- complex zero from poles)
- Find the point of intersection of RL with the imaginary axis

3. Construct Routh array and determine the stability of the system represented by the characteristics equation and comment on the location of the roots.

[MAY/JUN-2013]

(i) $s^5 + s^4 + 2s^3 + 2s^2 + 3s + 5 = 0$

(ii) $s^7 + 5s^6 + 9s^5 + 9s^4 + 4s^3 + 20s^2 + 36s + 36 = 0$.

Solution:

Method for determining the Routh array

Consider the characteristic equation

$$a(s) = 1 \times s^n + a_1 s^{n-1} + a_2 s^{n-2} + a_3 s^{n-3} + \ldots + a_{n-1} s^1 + a_0 s^0$$

Routh array method

Then add subsequent rows to complete the Routh array

Compute elements for the 3rd row:

$$b_1 = -\frac{1 \times a_3 - a_2 a_1}{a_1},$$
$$b_2 = -\frac{1 \times a_5 - a_4 a_1}{a_1},$$
$$b_3 = -\frac{1 \times a_7 - a_6 a_1}{a_1}$$
$$\ldots$$

All the coefficients are positive and nonzero

Therefore, the system satisfies the necessary condition for stability

We should determine whether any of the coefficients of the first column of the Routh array are negative

4. **Sketch the root locus of the system whose open loop transfer function is Find the value of K so that damping ratio is 0.5. [MAY/JUN-2013]**

$G(s) = K/[s(s+2)(s+4)]$.

Solution:

Constructing Root Locus

- Locate the OL poles & zeros in the plot
- Find the branches on the real axis
- Find angle of asymptotes & centroid
- § Φa= ±180º(2q+1) / (n-m)
- § ζa = (Σpoles - Σzeroes) / (n-m)
- Find BA and BI points
- Find Angle Of departure (AOD) and Angle Of Arrival (AOA)
- AOD = 180º- (sum of angles of vectors to the complex pole from all other poles) +
- (Sum of angles of vectors to the complex pole from all zero)
- AOA = 180º- (sum of angles of vectors to the complex zero from all other zeros) + (sum of angles of vectors to the
- complex zero from poles)
- Find the point of intersection of RL with the imaginary axis

5. The open loop transfer function of a unity feedback control system is given by $G(s) = \dfrac{K}{(s+2)(s+4)(s^2+6s+25)}$.

By applying Routh criterion, discuss the stability of the closed loop system as a function of K. Determine the values of K which will cause sustained oscillations in the closed loop system. What are the corresponding oscillation frequencies?

Solution :

<u>Necessary Condition for Routh's Stability</u>

A necessary condition for stability of the system is that all of the roots of its characteristic equation have negative real parts, which in turn requires that all the coefficients be positive.

A necessary (but not sufficient) condition for stability is that all the coefficients of the polynomial characteristic equation are positive & none of the co-efficient vanishes.

Routh's formulation requires the computation of a triangular array that is a function of the coef

A system is stable

array are positive

6. Sketch the root locus plot of a unity feedback system with an open loop transfer function $G(s) = \dfrac{K}{s(s+2)(s+4)}$. Find the value of K so that the damping ratio of the closed loop system is 0.5.

[MAY/JUN-2014]

Solution:

Constructing Root Locus

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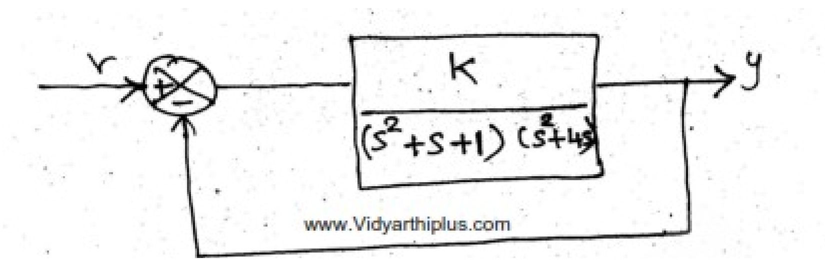
- AOA = 180º- (sum of angles of vectors to the complex zero from all other zeros) + (sum of angles of vectors to the
- complex zero from poles)

➢ Find the point of intersection of RL with the imaginary axis

7. Consider the closed loop system; determine the range of K for which the system is stable. [NOV/DEC 2014]



Solution :

Find the closed loop transfer function of the given system.

Determine the characteristics equation.

Then apply stability criterion

- ➢ All the coefficients are positive and nonzero
- ➢ Therefore, the system satisfies the necessary condition for stability
- ➢ We should determine whether any of the coefficients of the first column of the Routh array are negative

$$G(S).H(S) = \frac{K}{S(S+1)(S+2)}$$

8. Draw the root locus of the following system [NOV/DEC 2014]

Solution:

- ➢ Locate the OL poles & zeros in the plot
- ➢ Find the branches on the real axis
- ➢ Find angle of asymptotes & centroid
- ➢ § Φa= ±180º(2q+1) / (n-m)
- ➢ § ζa = (Σpoles - Σzeroes) / (n-m)
- ➢ Find BA and BI points
- ➢ Find Angle Of departure (AOD) and Angle Of Arrival (AOA)
- ➢ AOD = 180º- (sum of angles of vectors to the complex pole from all other poles) +

- (Sum of angles of vectors to the complex pole from all zero)
- AOA = 180º- (sum of angles of vectors to the complex zero from all other zeros) + (sum of angles of vectors to the
- complex zero from poles)

9. Construct Routh array and determine the stability of the system whose characteristic equation is

$$S^6 + 2S^5 + 8S^4 + 12S^3 + 20S^2 + 16S + 16 = 0.$$

Also determine the number of roots lying on right-half of s-plane,
left-half of s-plane and on imaginary axis. (12)

Solution:

Example 6.1 Second-order system

The Characteristic polynomial of a second-order system is:

$$q(s) = a_2 \cdot s^2 + a_1 \cdot s + a_0$$

The Routh array is written as:

where:

$$b_1 = \frac{a_1 \cdot a_0 - (0) \cdot a_2}{a_1} = a_0$$

Therefore the requirement for a stable second-order system is simply that all coefficients be positive or all the coefficients be negative.

10. Discuss the difficulties encountered in the Routh stability test.(4)

The Routh-Hurwitz criterion is a method for determining whether a linear system is stable or not by examining the locations of the roots of the characteristic equation of the system. In fact, the method determines only if there are roots that lie outside of the left half plane; it does not actually compute the roots

11. Plot the root-locus for a unity feedback closed loop system whose open loop transfer function is

$$G(S) = \frac{1}{s(s+4)(s^2+2s+2)}. \quad (16)$$

Solution:

- Locate the OL poles & zeros in the plot
- Find the branches on the real axis
- Find angle of asymptotes & centroid
- § $\Phi a = \pm 180^{\circ}(2q+1) / (n-m)$
- § $\zeta a = (\Sigma poles - \Sigma zeroes) / (n-m)$
- Find BA and BI points
- Find Angle Of departure (AOD) and Angle Of Arrival (AOA)
- AOD = 180º- (sum of angles of vectors to the complex pole from all other poles) +
- (Sum of angles of vectors to the complex pole from all zero)
- AOA = 180º- (sum of angles of vectors to the complex zero from all other zeros) + (sum of angles of vectors to the
- complex zero from poles)
- Find the point of intersection of RL with the imaginary axis

UNIT-V

Draw the Bode Plot of a typical lag-lead compensator. (4)

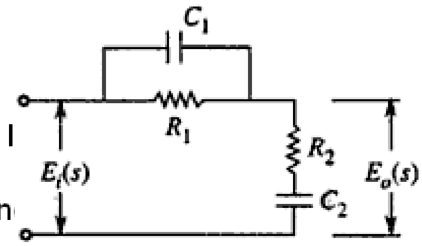
Design a lead compensator for a type-2 system with an open loop transfer function $G(s) = \frac{K}{s^2(0.2s+1)}$. Assume that the system is required to be compensated to meet the following specifications: (12)

(1) Acceleration error constant $K_a = 10$;

(2) Phase margin = 35°.

Solution.

lead compensation: z<p (place zero below the desired root location or to the l
real poles)
lag compensation: z>p (locate the pole and zero near the origin of the s-plan



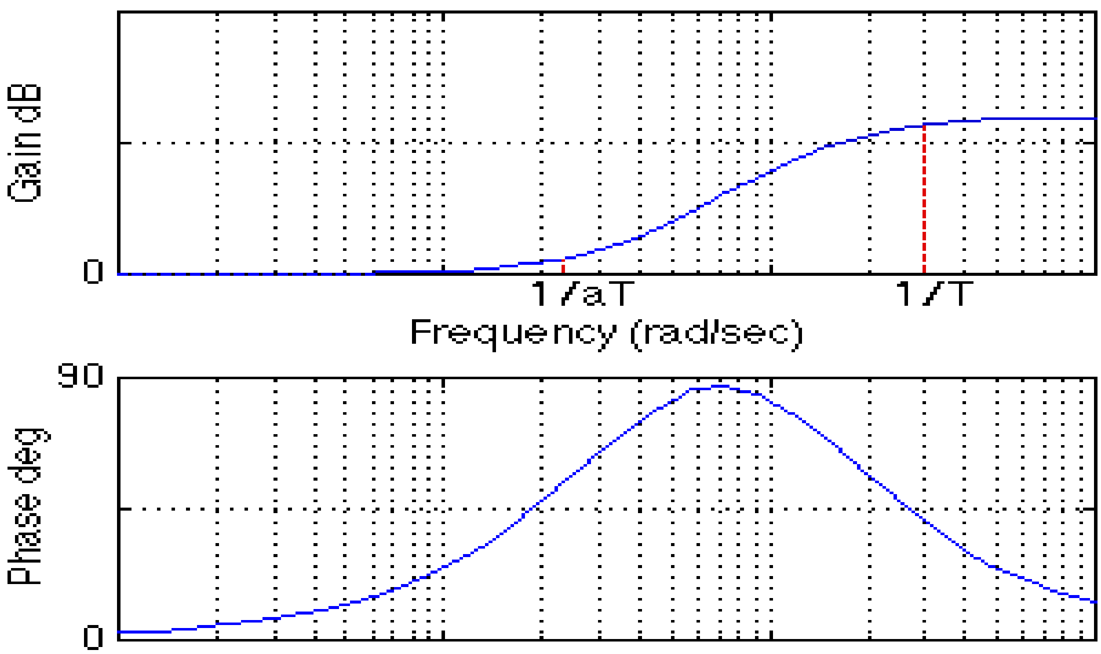
Lag-lead compensator.

(i) List out the characteristics of lag compensator. (4)

(ii) The open loop transfer function of the uncompensated system is $G(s) = \frac{5}{s(s+2)}$. Design a suitable lag compensator for the system so that the static velocity error constant K_V is 20 sec^{-1}, the phase margin is atleast 55° and the gain margin is atleast 12 dB. (12)

Lead compensator:

$$G(s) = \frac{s + \frac{1}{\tau}}{s + \frac{1}{\beta\tau}}$$



2.

i) A first-order lag compensator can be designed using the root locus. A lag compensator in root locus form is given by

$$G_c(s) = \frac{(s+z)}{(s+p)}$$

where the magnitude of z is greater than the magnitude of p. A phase-lag compensator tends to shift the root locus to the right, which is undesirable. For this reason, the pole and zero of a lag compensator must be placed close together (usually near the origin) so they do not appreciably change the transient response or stability characteristics of the system.

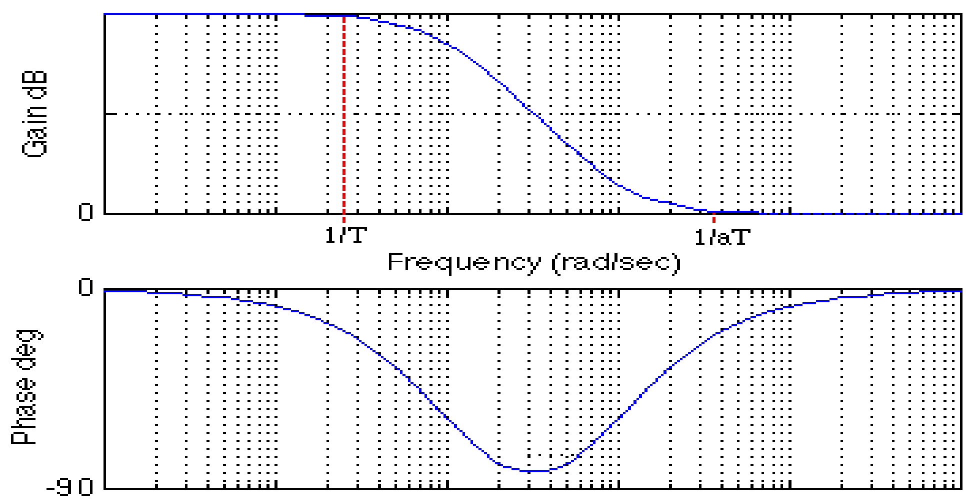
When a lag compensator is added to a system, the value of this intersection will be a smaller negative number than it was before. The net number of zeros and poles will be the same (one zero and one pole are added), but the added pole is a smaller negative number than the added zero. Thus, the result of a lag compensator is that the asymptotes' intersection is moved closer to the right half plane, and the entire root locus will be shifted to the right.

ii) <u>Lag compensator</u>

A first-order phase-lag compensator can be designed using the frequency response. A lag compensator in frequency response form is given by

$$G_C(s) = \frac{(1 + \alpha \cdot \tau \cdot s)}{\alpha \cdot (1 + \tau \cdot s)}$$

The phase-lag compensator looks similar to a phase-lead compensator, except that a is now less than 1. The main difference is that the lag compensator adds negative phase to the system over the specified frequency range, while a lead compensator adds positive phase over the specified frequency. A bode plot of a phase-lag compensator looks like the following



3. Design a lead compensator for a unity feedback system with open loop transfer function, to satisfy the following specifications [MAY/JUN-2013]

I) **K_v>50 ii) phase margin >20^0**

- Additional positive phase increases the phase margin and thus increases the stability of the system. This type of compensator is designed by determining **alfa** from the amount of phase needed to satisfy the phase margin requirements, and determining **tal** to place the added phase at the new gain-crossover frequency.
- Another effect of the lead compensator can be seen in the magnitude plot. The lead compensator increases the gain of the system at high frequencies (the amount of this gain is equal to alfa. This can increase the crossover frequency, which will help to decrease the rise time and settling time of the system.

4. Describe the procedure for designing of a lag compensator [MAY/JUN-2013], [MAY/JUN-2014]

A first-order phase-lag compensator can be designed using the frequency response. A lag compensator in frequency response form is given by

$$G_c(s) = \frac{(1 + \alpha\cdot\tau\cdot s)}{\alpha\cdot(1 + \tau\cdot s)}$$

The phase-lag compensator looks similar to a phase-lead compensator, except that a is now less than 1. The main difference is that the lag compensator adds negative phase to the system over the specified frequency range, while a lead compensator adds positive phase over the specified frequency.

5. **Describe the design procedure of lag-lead compensator.(2 times)**

$$G(s) = \frac{\left(s+\frac{1}{\tau_1}\right)\left(s+\frac{1}{\tau_2}\right)}{\left(s+\frac{1}{\alpha\tau_1}\right)\left(s+\frac{\alpha}{\tau_2}\right)} \quad \text{where } \alpha > 1$$

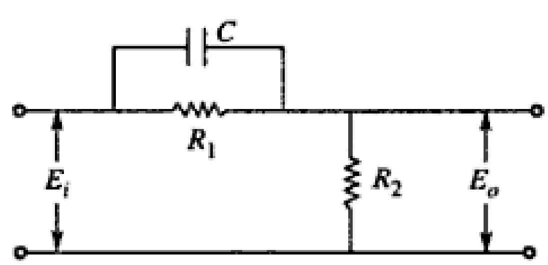
$$\frac{1}{R_1C_1} + \frac{1}{R_2C_1} + \frac{1}{R_2C_2} = \frac{1}{\alpha\tau_1} + \frac{\alpha}{\tau_2}$$

A lead-lag compensator combines the effects of a lead compensator with those of a lag compensator. The result is a system with improved transient response, stability and steady-state error. To implement a lead-lag compensator, first design the lead compensator to achieve the desired transient response and stability, and then add on a lag compensator to improve the steady-state response

6. **Explain the electric network realization of a lead compensator and also its frequency response characteristics.**

[MAY/JUN-2014]

Solution :



Lead compensator.

Here,

$$E_o(s) = \frac{E_1(s)R_2}{\dfrac{R_1 \times \dfrac{1}{Cs}}{R_1 + \dfrac{1}{Cs}} + R_2}$$

$$\frac{E_o(s)}{E_i(s)} = \frac{R_2}{\dfrac{R_1 \times \dfrac{1}{Cs} + R_2\left(R_1 + \dfrac{1}{Cs}\right)}{R_1 + \dfrac{1}{Cs}}} = \frac{R_2R_1 + \dfrac{R_2}{Cs}}{R_1R_2 + \dfrac{1}{Cs}(R_1 + R_2)}$$

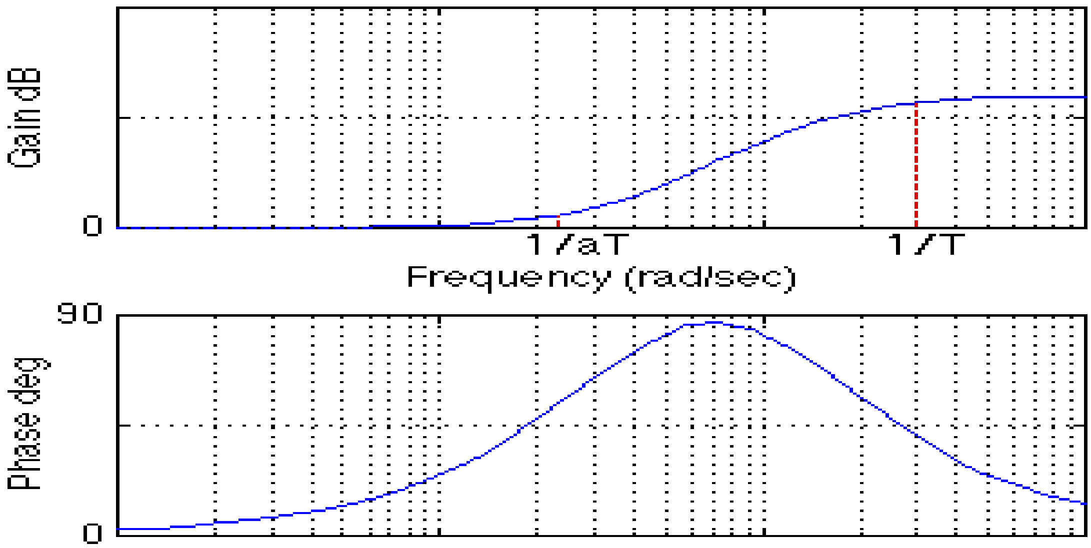
$$\frac{E_o(s)}{E_i(s)} = \frac{R_2}{\dfrac{R_1 \times \dfrac{1}{Cs} + R_2\left(R_1 + \dfrac{1}{Cs}\right)}{R_1 + \dfrac{1}{Cs}}} = \frac{R_2R_1 + \dfrac{R_2}{Cs}}{R_1R_2 + \dfrac{1}{Cs}(R_1 + R_2)}$$

$$= \frac{Cs\,R_1R_2 + R_2}{Cs\,R_1R_2 + R_1 + R_2}$$

$$= \frac{R_2(Cs\,R_1 + 1)}{(R_1 + R_2)\left(\dfrac{CsR_1R_2}{R_1 + R_2} + 1\right)}$$

$$= \left(\frac{R_2}{R_1 + R_2}\right)\frac{CR_1s + 1}{\left(\dfrac{CR_1R_2s}{R_1 + R_2} + 1\right)}$$

In frequency response design, <u>the phase-lead compensator adds positive phase to the system over the frequency range</u>. A bode plot of a phase-lead compensator looks like the following



7. Design a lead compensator for a unity feedback system with open loop transfer function, $G(s) = \frac{K}{s(s+1)(s+5)}$ to satisfy the following specifications

(i) Velocity error constant, $K_v \geq 50$

(ii) Phase margin is $\geq 20°$. (16)

(2 times)

Solution:

A first-order phase-lead compensator can be designed using the frequency response. A lead compensator in frequency response form is given by

In frequency response design, <u>the phase-lead compensator adds positive phase to the system over the frequency range</u>. A bode plot of a phase-lead compensator looks like the following

Additional positive phase increases the phase margin and thus increases the stability of the system. This type of compensator is designed by determining **alfa** from the amount of phase needed to satisfy the phase margin requirements, and determining **tal** to place the added phase at the new gain-crossover frequency.

Another effect of the lead compensator can be seen in the magnitude plot. The lead compensator increases the gain of the system at high frequencies (the amount of this gain is equal to alfa. This can increase the crossover frequency, which will help to decrease the rise time and settling time of the system.

8. **A unity feedback system has an open loop transfer function**

$$G(S) = \frac{5}{S(S+1)(0.5S+1)}$$ **[NOV/DEC 2014]**

Design a suitable compensator to maintain phase margin of at least 40^0.

Consider the unity feedback system whose open loop transfer function is

The system is to be compensated to meet the following specifications

i) **Velocity error constant K_v=30**

ii) **Phase margin $Ø_m \geq 50^0$**

iii) **Bandwidth w_1=12 rad/sec**

Solution:

- Additional positive phase increases the phase margin and thus increases the stability of the system. This type of compensator is designed by determining **alfa** from the amount of phase needed to satisfy the phase margin requirements, and determining **tal** to place the added phase at the new gain-crossover frequency.

- Another effect of the lead compensator can be seen in the magnitude plot. The lead compensator increases the gain of the system at high frequencies (the amount of this gain is equal to alfa. This can increase the crossover frequency, which will help to decrease the rise time and settling time of the system.

9. To open loop transfer function of a system is given below

$$G(S) = \frac{K}{s(s+1)(s+4)}$$

Design a suitable lag compensator to meet the following specifications.

Phase margin = 43° ; Bandwidth = 1.02 rad/sec ;

Velocity error constant $K_v \geq 5\,\text{sec}^{-1}$. (16)

Solution :

A first-order phase-lag compensator can be designed using the frequency response. A lag compensator in frequency response form is given by

$G_C(s) = \dfrac{(1 + \alpha\cdot\tau\cdot s)}{\alpha\cdot(1 + \tau\cdot s)}$ The phase-lag compensator looks similar to a phase-lead compensator, except that a is now less than 1. The main difference is that the lag compensator adds negative phase to the system over the specified frequency range, while a lead compensator adds positive phase over the specified frequency.

10. With Examples Discuss About The Stability.

Conceptually, a stable system is one for which the output is small in magnitude
whenever the applied input is small in magnitude. In other words, a stable system will not “blow up” when bounded inputs are applied to it. Equivalently, a stable system’s output will always decay to zero when no input is applied to it at all. However, we will need to express these ideas in a more precise definition.

Stability (asymptotic stability): A linear system of the form

$$\dot{x} = Ax + Bu, \quad x(0) = x_0$$
$$y = Cx + Du$$

is a stable system if $x(t) \to 0$ as $t \to \infty$ for any initial condition x_0 and $u(t) = 0$.

Notice that *u(t)* = 0 results in an unforced system:

$$\dot{x} = Ax, \quad x(0) = x_0$$
$$y = Cx$$

By the variation of parameters formula, the state *x(t)* for such an unforced system satisfies

In this case, the system output *y(t)* = *Cx(t)* is driven only by the initialconditions.