Design and implementation of a lead-lag compensator for a higher-order system by using SISO tool

Submitted by

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ABSTRACT

The compensator designs are essential in control systems and many industries applications. The output of any higher system depends upon the selection of parameters and tuning of the compensator. In this work, the designing lead-lag compensator to get desired response parameters for transient response and steady-state error tuned using SISO tool in MATLAB. Here we design compensators in two parts the lead compensator to improve the quick response and the lag compensator to meet the steady-state error requirement—the optimal values found using the time domain Root-Locus approach. The comparative result is shown with suitable examples.

Keywords: - Lead-Lag Compensators, Root-Locus approach, and SISO tool

CHAPTER I INTRODUCTION

OVERVIEW 1.1

Compensators that use pure integration for improving steady-state error or pure differentiation for improving transient response are defined as ideal compensators. Ideal compensators must be implemented with active networks, which, in the case of electric networks, require the use of active amplifiers and possible additional power sources. An advantage of ideal integral compensators is that steady-state error is reduced to zero. Electromechanical ideal compensators, such as tachometers, are often used to improve transient response, since they can be conveniently interfaced with the plant. Other design techniques that preclude the use of active devices for compensation can be adopted. These compensators, which can be implemented with passive elements such as resistors and capacitors, do not use pure integration and differentiation and are not ideal compensators. Advantages of passive networks are that they are less expensive and do not require additional power sources for their operation. Their disadvantage is that the steady-state error is not driven to zero in cases where ideal compensators yield zero error. Thus, the choice between an active or a passive compensator revolves around cost, weight, desired performance, transfer function, and the interface between the compensator and other hardware.

A lag lead compensator is a type of electrical network that generates phase lag as well as phase lead in the output signal at different frequencies when a steady-state sinusoidal input is provided to it. It is also known as **lag lead network**.

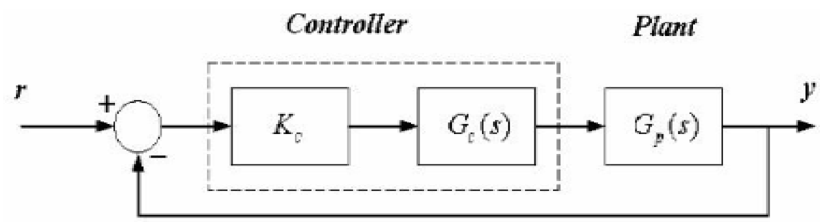


Fig. 1.1 A typical Feed-forward Compensation System

In case of a lag lead compensator, the phase lead and phase lag occur at different frequency regions. Generally, at low-frequency phase lag characteristics is noticed in the output of the circuit. While at high frequency, we have phase lead characteristics. Thus, we can say a phase lag lead network

is a cascade combination of phase lag and phase lead network. Before proceeding towards understanding the design and characteristics of the lag lead network, we will see a brief introduction of the two networks. Lead-lag compensator is applied in this control strategy to keep stability while ensuring better power sharing. During power sharing, it is desired to have high gain at low output power and low gain at high output power. Hence, for better load sharing, this control strategy allows the implementation of higher droop gains. It will damp out the small-signal oscillation to a considerable extent.

1.2 Lag Compensator

A lag compensator is an electrical network that is designed to compensate a control system byadding a phase lag in the generated output signal when an input signal is applied to it.

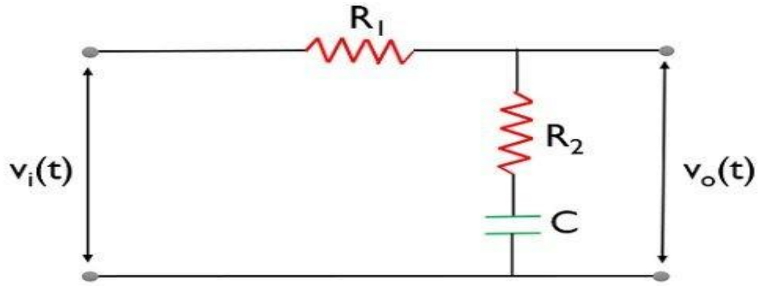


Fig. 1.2 Lag compensator

1.3 Lead Compensator

Unlike a phase lag network, a phase lead compensator introduces a phase lead in the sinusoidal output of the system, whenever a steady-state input is provided to it.

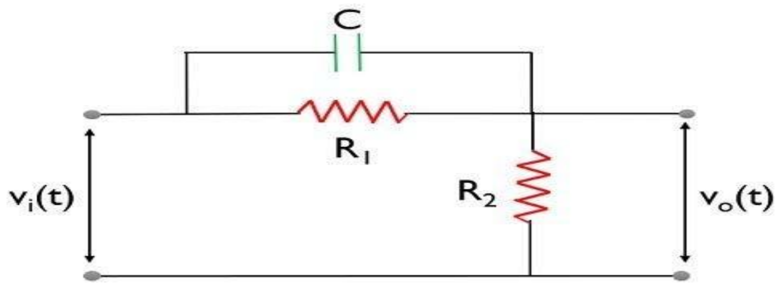


Fig. 1.3 Lead compensator

1.4 Need for Lag Lead Compensator

- Generally, compensation in a control system is majorly done for two main reasons. Likefor an absolutely unstable system, compensation is done in order to stabilize the system.
- While sometimes the system is stable still, we don't achieve the desired performancewhere the desired performance depends on various system parameters.
- More simply, we can say, to have the accurate transient and steady-state response, a combination of lag and lead compensator is used.
- We have already discussed in our previous article that a control system is added with a compensator in order to improve the specifications of the control system.
- However, each of the compensating networks introduces some drawbacks along with improving the characteristics.
- A lag compensator improves the steady-state performance of the system but at the sametime, such a network causes a reduction in the overall bandwidth.
- A lead compensator offers increased bandwidth, thus provides a fast response of thesystem, but this increases the susceptibility of the system towards noise.

1.5 Lag Lead Compensator

The figure below represents the circuit of a lag lead compensator:

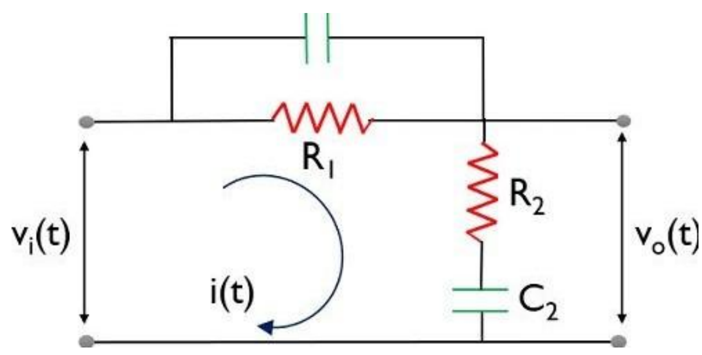


Fig. 1.4 Lead-lag compensator

It is clear from the circuit shown above that if C_1 is eliminated from the above circuit, then thatparticular circuit will be a lag network. While if C_2 is not present, then we get a lead network.

This indicates that the above given network is a cascade combination of the lag as well as lead network.

So, consider the circuit shown above.
he loop current I (t) will be given as:

$$i(t) = C_1 \frac{d(v_i - v_o)}{dt} + \frac{1}{R_1}(v_i - v_o)$$

The output equation is given as:

$$v_o(t) = i(t)R_2 + \frac{1}{C_2}\int i(t)dt$$

We know that the transfer function of the system is the Laplace transform of the response of thesystem to the Laplace transform of the input. So, taking the Laplace transform of the above equations, we will get,

$$I(s) = \frac{1}{R_1}V_i(s) - \frac{1}{R_1}V_o(s) + sC_1V_i(s) - sC_1V_o(s)$$

$$V_o(s) = \left[R_2 + \frac{1}{sC_2}\right]I(s)$$

Now substitute the value of I(s) in the above equation, we will have,

$$V_o(s) = \left[R_2 + \frac{1}{sC_2} \right] \left[\frac{1}{R_1} V_i(s) - \frac{1}{R_1} V_o(s) + sC_1 V_i(s) - sC_1 V_o(s) \right]$$

On simplifying,

$$V_o(s) = \left[R_2 + \frac{1}{sC_2} \right] \left[\left(\frac{1}{R_1} + sC_1 \right) V_i(s) - V_o(s) \left(\frac{1}{R_1} + sC_1 \right) \right]$$

$$V_o(s) = \left[R_2 + \frac{1}{sC_2} \right] \left[\left(\frac{1}{R_1} + sC_1 \right) \{ V_i(s) - V_o(s) \} \right]$$

Further,

$$V_o(s) = \left[\frac{1 + sR_2C_2}{sC_2} \right] \left[\left(\frac{V_i(s)(1 + sR_1C_1) - V_o(s)(1 + sR_1C_1)}{R_1} \right) \right]$$

So,

$$V_i(s) \frac{(1 + sR_1C_1)(1 + sR_2C_2)}{sR_1C_2} = V_o(s) \left[1 + \frac{(1 + sR_1C_1)(1 + sR_2C_2)}{sR_1C_2} \right]$$

Therefore,

$$\frac{V_o(s)}{V_i(s)} = \frac{(1 + sR_1C_1)(1 + sR_2C_2)}{sR_1C_2 + (1 + sR_1C_1)(1 + sR_2C_2)}$$

$$\frac{V_o(s)}{V_i(s)} = \frac{(1 + sR_1C_1)(1 + sR_2C_2)}{s^2 R_1R_2C_1C_2 + s(R_1C_1 + R_2C_2 + R_1C_2) + 1}$$

On simplifying we will get,

$$\frac{V_o(s)}{V_i(s)} = \frac{R_1C_1 \left(\frac{1}{R_1C_1} + s \right) R_2C_2 \left(\frac{1}{R_2C_2} + s \right)}{R_1C_1R_2C_2 \left[s^2 + s\left(\frac{1}{R_1C_1} + \frac{1}{R_2C_2} + \frac{1}{R_2C_1} \right) + \frac{1}{R_1R_2C_1C_2} \right]}$$

$$\frac{V_o(s)}{V_i(s)} = \frac{R_1C_1R_2C_2 \left(\frac{1}{R_1C_1} + s \right) \left(\frac{1}{R_2C_2} + s \right)}{R_1C_1R_2C_2 \left[s^2 + s\left(\frac{1}{R_1C_1} + \frac{1}{R_2C_2} + \frac{1}{R_2C_1} \right) + \frac{1}{R_1R_2C_1C_2} \right]}$$

On cancelling like terms from numerator and denominator, we will get

$$\frac{V_o(s)}{V_i(s)} = \frac{\left(s+\frac{1}{R_1C_1}\right)\left(s+\frac{1}{R_2C_2}\right)}{\left[s^2+s\left(\frac{1}{R_1C_1}+\frac{1}{R_2C_2}+\frac{1}{R_2C_1}\right)+\frac{1}{R_1R_2C_1C_2}\right]}$$

In generalized form

$$\frac{V_o(s)}{V_i(s)} = \frac{\left(s+\frac{1}{T_1}\right)\left(s+\frac{1}{T_2}\right)}{\left(s+\frac{\beta}{T_1}\right)\left(s+\frac{1}{\beta T_2}\right)}$$

So, on comparing,

$$T_1 = R_1C_1$$
$$T_2 = R_2C_2$$
$$\frac{\beta}{T_1}+\frac{1}{\beta T_2} = \frac{1}{R_1C_1}+\frac{1}{R_2C_2}+\frac{1}{R_2C_1}$$
$$\alpha\beta T_1T_2 = R_1C_1R_2C_2$$
$$\alpha\beta = 1$$

Therefore,

$$\frac{V_o(s)}{V_i(s)} = \frac{(1+T_1s)(1+T_2s)}{\left(1+\frac{T_1}{\beta}s\right)(1+T_2\beta s)}$$

Here the value of $\boldsymbol{\beta > 1}$

Here poles are $\mathbf{s = -\beta/T_1, -1/\beta T_2}$ and zeros are at $\mathbf{s = -1/T_1, -1/T_2}$

The figure below shows the pole-zero plot of the lag lead compensator:

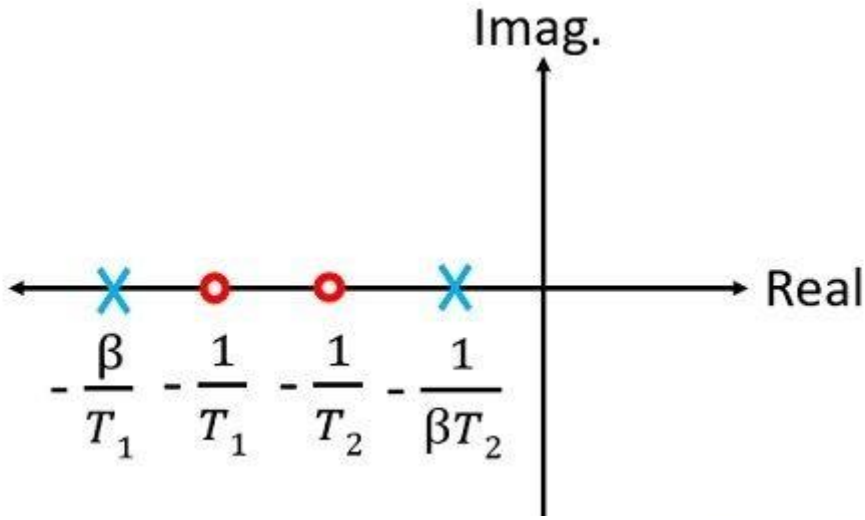


Fig. 1.5 Lag lead compensator

Thus, in case of the lag lead compensator, a lead angle is added by the phase lead portion whereas attenuation near the crossover frequency is provided by the phase lag portion.

Now, substituting s = jω in the above equation, the transfer function will be

$$\frac{V_o(s)}{V_i(s)} = \frac{(1 + T_1 j\omega)(1 + T_2 j\omega)}{\left(1 + \frac{T_1}{\beta} j\omega\right)(1 + T_2 \beta j\omega)}$$

So, the magnitude will be:

$$M = \frac{\sqrt{1+\omega^2 T_1^2}}{\sqrt{1+\frac{T_1^2\omega^2}{\beta^2}}} \frac{\sqrt{1+\omega^2 T_2^2}}{\sqrt{1+\beta^2 T_2^2 \omega^2}}$$

Hence, the phase angle will be

$$\varphi = tan^{-1}\omega T_1 + tan^{-1}\omega T_2 - tan^{-1}\frac{T_1\omega}{\beta} - tan^{-1}\beta\,\omega T_2$$

1.6 Effects of Lag Lead Compensator

- The lead characteristics of the cascaded compensator provide improvement in the overall bandwidth.
- Also, due to the use of the lag network, the steady-state performance of the system gets improved.

So, we can say, a lag lead network provides a **quick response with good accuracy**. The low-frequency gain of the system is increased with this network, thereby improving the steady-state response.

Hence, we use a combination of lag and lead network as a compensator to provide required compensation to the control system.

1.7 Physical Realization of Compensation

We derived compensation to improve transient response and steady-state error in feedback control systems. Transfer functions of compensators used in cascade with the plant or in the feedback path were derived. These compensators were defined by their pole-zero configurations. They were either active PI, PD, or PID controllers or passive lag, lead, or lag-lead compensators. In this section, we show how to implement the active controllers and the passive compensators.

1.7.1 Active-Circuit Realization

$$\frac{V_o(s)}{V_i(s)} = -\frac{Z_2(s)}{Z_1(s)}$$

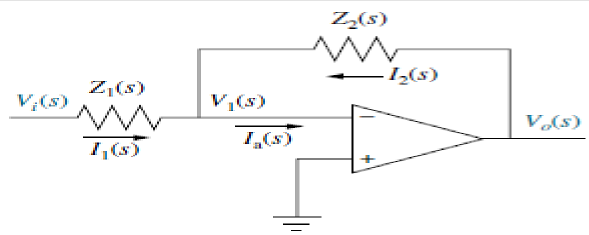
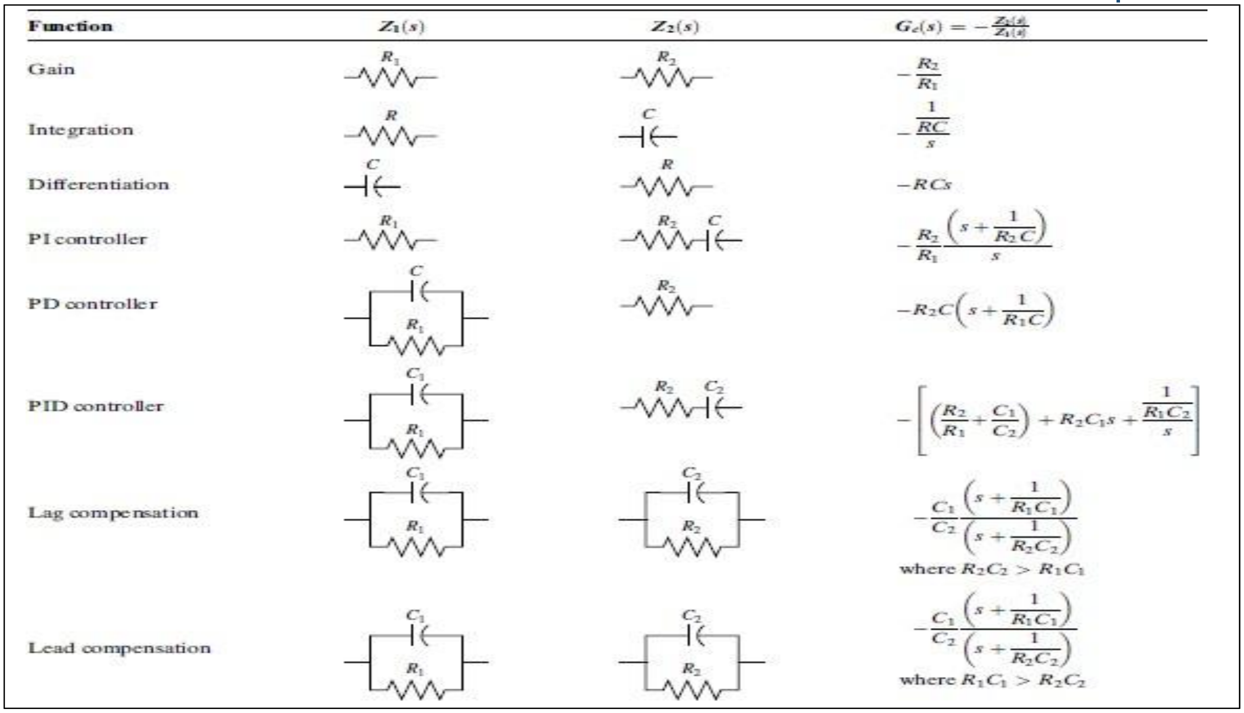


Fig 1.6 Operational amplifier configured for transfer function realization

As the transfer function of an inverting operational amplifier whose configuration is repeated here in Figure 1.5 By judicious choice of Z_1(s) and Z_2(s), this circuit can be used as a building block to implement the compensators and controllers, such as PID controllers, summarizes the realization of PI, PD, and PID controllers as well as lag, lead, and lag-lead compensators using operational amplifiers.



Function	$Z_1(s)$	$Z_2(s)$	$G_c(s) = -\frac{Z_2(s)}{Z_1(s)}$
Gain	R_1	R_2	$-\frac{R_2}{R_1}$
Integration	R	C	$-\frac{\frac{1}{RC}}{s}$
Differentiation	C	R	$-RCs$
PI controller	R_1	R_2 C	$-\frac{R_2}{R_1}\frac{\left(s+\frac{1}{R_2C}\right)}{s}$
PD controller	C, R_1	R_2	$-R_2C\left(s+\frac{1}{R_1C}\right)$
PID controller	C_1, R_1	R_2 C_2	$-\left[\left(\frac{R_2}{R_1}+\frac{C_1}{C_2}\right)+R_2C_1s+\frac{\frac{1}{R_1C_2}}{s}\right]$
Lag compensation	C_1, R_1	C_2, R_2	$-\frac{C_1}{C_2}\frac{\left(s+\frac{1}{R_1C_1}\right)}{\left(s+\frac{1}{R_2C_2}\right)}$ where $R_2C_2 > R_1C_1$
Lead compensation	C_1, R_1	C_2, R_2	$-\frac{C_1}{C_2}\frac{\left(s+\frac{1}{R_1C_1}\right)}{\left(s+\frac{1}{R_2C_2}\right)}$ where $R_1C_1 > R_2C_2$

Table No. 1. 1 Active realization of controllers and compensators, using an operational amplifier

1.8 Root Locus Technique

The **root locus technique in control system** was first introduced in the year 1948 by Evans.

Any physical system is represented by a transfer function in the form of

$$G(s) = k \times \frac{numerator\ of\ s}{denomerator\ of\ s}$$

We can find poles and zeros from G(s). The location of poles and zeros are crucial keeping view stability, relative stability, transient response and error analysis. When the system is put to service stray inductance and capacitance get into the system, thus changes the location of poles and zeros. In **root locus technique in control system** we will evaluate the position of the roots, their locus of movement and associated information. These information will be used to commentupon the system performance. Now before I introduce what is a root locus technique, it is very essential here to discuss a few ofthe advantages of this technique over other stability criteria. Some of the advantages of root locus technique are written below.

1.8.1 Advantages of Root Locus Technique

1. Root locus technique in control system is easy to implement as compared to other methods.
2. With the help of root locus we can easily predict the performance of the whole system.
3. Root locus provides the better way to indicate the parameters.

Now there are various terms related to root locus technique that we will use frequently in thisarticle.

1. Characteristic Equation Related to Root Locus Technique: 1 + G(s)H(s) = 0 is known as characteristic equation. Now on differentiating the characteristic equation and on equating DK/DS equals to zero, we can get break away points.
2. Break away Points: Suppose two root loci which start from pole and moves in opposite direction collide with each other such that after collision they start moving in different directions in the symmetrical way. Or the breakaway points at which multiple roots of thecharacteristic equation 1 + G(s)H(s) = 0 occur. The value of K is maximum at the points where the branches of root loci break away. Break away points may be real, imaginary orcomplex.
3. Break in Point: Condition of break in to be there on the plot is written below: Root locus must be present between two adjacent zeros on the real axis.
4. Centre of Gravity: It is also known centroid and is defined as the point on the plot from where all the asymptotes start. Mathematically, it is calculated by the difference of summation of poles and zeros in the transfer function when divided by the difference of total number of poles and total number of zeros. Centre of gravity is always real and it isdenoted by σ_A.

$$\sigma_A = \frac{(Sum\ of\ real\ parts\ of\ poles) - (Sum\ of\ real\ parts\ of\ zeros)}{N - M}$$

   Where, N is number of poles and M is number of zeros.
5. Asymptotes of Root Locus: Asymptote originates from the center of gravity or centroid and goes to infinity at definite some angle. Asymptotes provide direction to the root locuswhen they depart break away points.
6. Angle of Asymptotes : Asymptotes makes some angle with the real axis and this anglecan be calculated from the given formula,

$$Angle\ of\ asymptotes = \frac{(2p+1) \times 180}{N - M}$$

   Where, p = 0, 1, 2 ……. (N-M-1)N is the
   total number of poles
   M is the total number of zeros.
7. Angle of Arrival or Departure: We calculate angle of departure when there exists complex poles in the system. Angle of departure can be calculated as 180-{(sum of angles to a complex pole from the other poles)-(sum of angle to a complex pole from thezeros)}.
8. Intersection of Root Locus with the Imaginary Axis: In order to find out the point of intersection root locus with imaginary axis, we have to use Routh Hurwitz criterion. First, we find the auxiliary equation then the corresponding value of K will give the value of the point of intersection.

9. Gain Margin: We define gain margin by which the design value of the gain factor can be multiplied before the system becomes unstable. Mathematically it is given by the formula

$$Gain\ margin = \frac{Value\ of\ K\ at\ the\ imaginary\ axes\ cross\ over}{Design\ value\ of\ K}$$

10. Phase Margin : Phase margin can be calculated from the given formula:

$$Phase\ margin = 180 + \angle(G(jw)H(jw))$$

11. Symmetry of Root Locus: Root locus is symmetric about the x axis or the real axis.

How to determine the value of K at any point on the root locus Now there are two ways ofdetermining the value of K, each way is described below.

1. Magnitude Criteria: At any points on the root locus we can apply magnitude criteria as

$$|G(s)H(s)| = 1$$

   using this formula we can calculate the value of K at any desired point.
2. Using Root Locus Plot : The value of K at any s on the root locus is given by

$$K = \frac{product\ of\ all\ of\ the\ vector\ lengths\ drawn\ from\ the\ poles\ of\ G(s)H(s)\ to\ s}{product\ of\ all\ of\ the\ vector\ lengths\ drawn\ from\ the\ zeros\ of\ G(s)H(s)\ to\ s}$$

1.8.2 Root Locus Plot

This is also known as root locus technique in control system and is used for determining the stability of the given system. Now in order to determine the stability of the system using the rootlocus technique we find the range of values of K for which the complete performance of the system will be satisfactory and the operation is stable.

Now there are some results that one should remember in order to plot the root locus. These results are written below:

1. Region where root locus exists: After plotting all the poles and zeros on the plane, we can easily find out the region of existence of the root locus by using one simple rule which is written below, Only that segment will be considered in making root locus if the total number of poles and zeros at the right hand side of the segment is odd.
2. How to calculate the number of separate root locus: A number of separate root loci are equal to the total number of roots if number of roots are greater than the number of poles otherwise number of separate root loci is equal to the total number of poles if number of roots are greater than the number of zeros.

1.8.3 Procedure to Plot Root Locus

Keeping all these points in mind we are able to draw the **root locus plot** for any kind of system.Now let us discuss the procedure of making a root locus.

1. Find out all the roots and poles from the open loop transfer function and then plot them on the complex plane.
2. All the root loci starts from the poles where k = 0 and terminates at the zeros where K tends to infinity. The number of branches terminating at infinity equals to the difference between the number of poles & number of zeros of G(s)H(s).
3. Find the region of existence of the root loci from the method described above after finding the values of M and N.
4. Calculate break away points and break in points if any.
5. Plot the asymptotes and centroid point on the complex plane for the root loci by calculating the slope of the asymptotes.
6. Now calculate angle of departure and the intersection of root loci with imaginary axis.
7. Now determine the value of K by using any one method that I have described above.
   By following above procedure you can easily draw the **root locus plot** for any open looptransfer function.
8. Calculate the gain margin.
9. Calculate the phase margin.
10. You can easily comment on the stability of the system by using Routh Array.

1.9 Design single-input, single-output (SISO) controllers

The **Control System Designer** app lets you design single-input, single-output (SISO) controllers for feedback systems modeled in MATLAB® or Simulink® (requires Simulink Control Design™ software).

Using this app, we can:

- Design controllers using:
  - Interactive Bode, root locus, and Nichols graphical editors for adding, modifying, and removing controller poles, zeros, and gains.
  - Automated PID, LQG, or IMC tuning.
  - Optimization-based tuning (requires Simulink Design Optimization™ software).
  - Automated loop shaping (requires Robust Control Toolbox™ software).
- Tune compensators for single-loop or multi-loop control architectures.

- Analyze control system designs using time-domain and frequency-domain responses, such as step responses and pole-zero maps.
- Compare response plots for multiple control system designs.
- Design controllers for multi-model control applications.

1.9.1 Root Locus Controller Design Using the MATLAB 'SISO Tool' Toolbox

In this Paper (Presentation) we will explore the use of the root locus controller design methodology. The root locus indicates the achievable closed-loop pole locations of a system as a parameter (usually the controller gain) varies from zero to infinity. For a given plant it may or may not be possible to implement a simple proportional controller (i.e., select a gain that specifies closed-loop pole locations along the root locus)to achieve the specified performance constraints. In fact, in most cases it will not be possible. When this occurs, it is the control engineer's job to select a controller structure (a gain and numbers of poles and zeros of a controller transfer function) and the respective controller parameters (values for the gain and poles and zeros) to change the shape of the root locus so that for some values of the controller gain, the dominant second order closed-loop poles lie within the performance region. In this lab we are investigating several controller structures on individual plants and comparing the design process and performance. We will be using the MATLAB 'SISO Tool' toolbox to complete the root locus designs

1.9.2 Objectives

At the conclusion of this laboratory experience, students should be able to:

- To successfully design P, I, PD, PI, and PID controllers to meet closed-loop performancespecifications including transient performance and steady-error.

1.9.3 Deliverables

A completed worksheet including the following:

- Figures with plots of closed-loop step responses.
- Controller parameters, gain, pole(s), and zero(s), for each of the controller designs.
- Answer all the questions on the worksheet.

1.9.4 Background

For this lab, we will assume a unity feedback controller of the form shown in Figure 1, whereC(s) is thecontroller transfer function and P(s) is the plant transfer function.

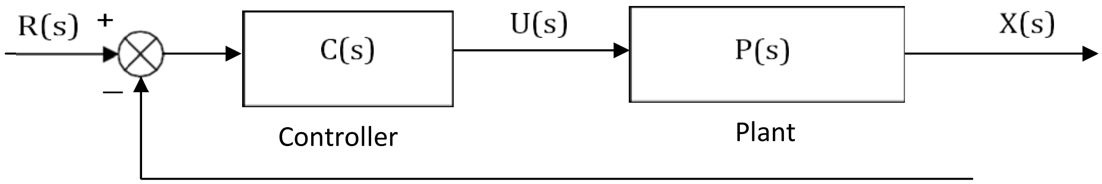


Figure 1.7 – Generic Unity Feedback Control System.

Note, in controller design there are multiple possible solutions, some better than others. It is possible to have multiple designs that satisfy the given performance constraints, but practical implementation issues and cost could be prohibitive for some designs. As a general rule, it is a good idea to keep your controller as simple as possible while meeting the prescribed performance criteria. In this lab we will be investigating several controller structures on individual plants and comparing the design process and performance. The common controller structures we will be using in this lab are listed in Table 1.1 along with their respective transferfunctions

Controller Type	Controller Structure
Proportional (P)	$C(s) = k_p$
Integral (I)	$C(s) = \frac{k_i}{s}$
Proportional + Integral (PI)	$C(s) = k_p + \frac{k_i}{s} = \frac{k \cdot (s+z)}{s}$
Lag Controller	$C(s) = \frac{K_c \cdot (s+z)}{(s+p)}$ where $\lvert z\rvert > \lvert p\rvert$
Proportional + Derivative (PD)	$C(s) = k_p + k_d s = k \cdot (s+z)$
Lead Controller	$C(s) = \frac{k \cdot (s+z)}{(s+p)}$ where $\lvert p\rvert > \lvert z\rvert$
Proportional + Integral + Derivative (PID) (Real Zeros)	$C(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k \cdot (s+z_1)(s+z_2)}{s}$
Proportional + Integral + Derivative (PID) (Complex Conjugate Zeros)	$C(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k \cdot (s+z)(s+z^*)}{s}$

Table 1.2 – Common Controller Types

Note that the I, PI, and PID controller's will produce a position error (ep) of zero as long as the plant does not contain a zero at the origin, which would cancel the controllers pole at the origin.

1.10 Introduction to MATLAB 'SISO TOOL'

1.10.1 Getting Started

1. Enter the transfer function for the plant, P(s), in your workspace (i.e., from theMATLAB command prompt).
2. Type 'SISOTOOL' at the command prompt.
3. Click **Close** when the help window comes up.
4. Click on **View** → **Open Loop Bode** to turn off the bode plot. (Whatever is checked in his list willbe displayed in the window.)

1.10.2 Loading the Transfer Function

1. Click on **File** → **Import**.
2. A window on the left will show you the transfer functions in your workspace, whilethe windowon the right will let you choose the control system configuration.
3. We will usually be assigning P(s) to block 'G' (the plant). Double-click the space next to 'G' andtype your transfer function name and hit **Enter**. You must hit enter ornothing will happen.
4. Once you hit enter, you should be able to click the **OK** button at the bottom of thewindow.Then the window will close.
5. After you enter the transfer function, the root locus will be displayed. Double check to makesure that the open-loop poles and zeros of your plant are in thecorrect locations.

1.10.3 Generating the Step Response

1. Click on **Analysis** → **Response to Step Command**.
2. You will probably two curves on your step response plot. To fix this click on **Analysis** → **OtherLoop Responses…** Make sure only r to y is checked, and thenclick OK.
3. You can now click on the pink boxes on the root locus (the current closed-loop poles for thegiven gain) and move them along the root locus. Essentially, you are exploring different controller gain values by doing this. Note how the step response changes as you move the closed-loop pole locations.
4. The values of the closed-loop poles will appear at the bottom of the root locus windowas you click and hold the mouse on the pink boxes representing them. This only gives you the value ofthe closed-loop pole you are clicking on. If you need the other closed-loop pole locations, you will have to click on them on each of the other branches.

1.10.4 Entering the Compensator (Controller)

1. Click **Compensators** →**Edit** → **C**. Click on **Add Real Zero** or **Add Real Pole** toenter controller zeros or poles. You will be able to make changes to these values later. After you are done, click**OK** to exit this window.
2. Look at the form of C (s) to be sure it is correct. Then look at the root locus windowand see howit changed once the compensator was added.
3. You can again see how the step response changes with the compensator by c licking on theclosed-loop poles (the pink squares) and dragging them along theroot locus.
4. You can also change the location of the poles/zeros of the compensator by clicking onthem anddragging them. Be careful not to inadvertently change the poles and zeros ofthe plant!

1.10.5 Adding Design Constraints

1. Click Edit → **Root Locus** → **Design Constraints** then either **New** to add new constraints or **Edit** to edit existing constraints.

2. At this point you can choose from settling time, percent overshoot, damping ratio, and naturalfrequency constraints.

1.10.6 Printing/Saving the Figures

To save a figure 'SISOTOOL' created during your session, click **File** → **Print toFigure**.
This opens afigure window and puts the current figure there.

1.10.7 Odds and Ends

1. You may want to adjust the axes. To do this, click **Edit** → **Root Locus** → **Properties**,click on **Limits**, and set the desired axis limits.
2. You may also want to turn the grid on. Click **Edit** → **Root Locus** → **Grid**.
3. It is convenient to use the zero/pole/gain format for the compensators. To do this, clickon **Edit** → **SISO Tool Preferences** → **Options** and click on **zero/pole/gain**.

1.11 Objectives of the dissertation

- To design and Implements lead-lag compensator controller using SISO Tool (MATLAB)
- To performance analysis of designed phase lead-lag compensator controller by root locus and step response.

CHAPTER II REVIEW OF LITERATURE

St. Louis and Missouri (1981) Presented a procedure is given for designing multi variable controlsystems in the direct NYQUIST plane using the principle of diagonal dominance. It is shown that Bode technique s can be extended to the multivariable case and that dominance can be verified by using straight line approximations to the frequency response. In addition, Rosenbrock's idea of using the union of Gershgor in discs for stability assessment is extended to the Bode diagram where Gershgor in gain and phase band s are used. The methods proposed enable mu 1tivariab1e control systems of moderate size to be designed using pen ci l and paper techniques without the assistance of expensive, computer-drive and interactive graphic displays.

A. P. Loh et al (2004) Developed tuning for phase lead/lag compensators, knowledge of speci1c points on the frequency response of the plant are required. Such points are speci1edby their frequency, gain and phase and are not readily available without an accurate model of the plant. Yet such information is important for any auto-tuning procedure to succeed. In this paper, relays with hysterics are tuned to determine points on the frequency response of a plant with a user- speci1edgain, g0 or phase, 0. On-line algorithms are developed to tune the operating point of the relay feedback system so that the resulting oscillations correspond to the frequency response of the plant with either gain, g0 or phase, 0. Tuning involves setting either the amplitude of the relay or its hysteris is width. Improvement over the simple application of the describing function is also shown. The results are applied to the auto-tuning of phase lead and lag compensators. Simulationsare presented to illustrate the auto-tuning procedures.

Frank S. Cheng et al (2004) has presented the development of a MATLAB-based control system design and analysis (CSDA) tool for aiding engineering students to learn feedback control system theories and design techniques. As a result, the developed CSDA tool provides users with user- friendly MATLAB graphical user interfaces (GUIs) that integrate the existing functions of Simulink and SISO Design Tool for enhanced functions in control system analysis and controllerdesign.

P. D. Rohitha et al (2005) has presented the development procedure of a fully automated software based One-Touch-and-Go PID controller and Lead/Lag compensator design tool. The key goal is to help industrial process control engineers by providing underlying theory and implementation techniques behind some PID controller design tools already available in the market and to present how these techniques could be developed to automatically tune other controllers. The design tool is designed to communicate with the plant and handle the controller tuning and control tasks automatically. Results obtained by implementing the developed design tool to an experimental liquid level control and temperature control systems show promise.

Xu Jian Xin (2008) Develop the lead compensator is one of the most import topics in any undergraduate control engineering courses owing to its wide industrial applications. Traditionally the lead compensator was designed in a trial and error manner. This gives rise to difficulties not only in achieving precise compensation, but also in class teaching. In this paper, a new lead compensator design algorithm is first presented by using computation technology, which is precise, simple and non-trial-and-error. Hence the new design algorithm overcomes the difficulties in the traditional design. Next, two lead compensator design algorithms, either with the maximum phase margin or maximum bandwidth, are proposed. For practical applications, the new design based on Bode plots is also exploited. Design examples are provided to facilitate the course teaching and implementation.

Robert Zanasi et al (2011) has approached based on inversion formulae is used for the design of lead–lag compensators which satisfy frequency domain specifications on phase margin, gain margin and phase (or gain) crossover frequency. An analytical and graphical procedure for the compensator design on the NY Quist and Nichols planes is presented with some numerical examples.

Roberto Zanasi et al (2011) Published article an approach based on inversion formulae is used for the design of lead–lag compensators which satisfy frequency domain specifications on phase margin, gain margin and phase (or gain) crossover frequency. An analytical and graphical procedure for the compensator design on the Nyquist and Nichols planes is presented with some numerical examples.

Huey Yang Horng (2012) discussed in conference for the PID controllers are the most commonly used controllers in industrial applications. As is well known, the PID controllers are susceptible to noise interference and windup effect. More practical alternatives are lead-lag controllers. Traditionally, time-domain or frequency-domain methods are used to design a lead-lag controller to meet the design specifications. The main task of this article is to design a required lead-lag controller using genetic algorithms (GAs). A main feature of our approach is to include the design specifications directly into the cost function or fitness function in GA iterations. Computer simulations show that the performances of our proposed controllers are quite good.

Gallal A. Hassan et al (2013) Published article for Lag-lead compensators are well known in automatic control engineering. They have 4 parameters to be adjusted (tuned) for proper operation. The frequency responses of the control system or the root locus plot are traditionally used to tune the compensator in a lengthy procedure. A first order with an integrator process in a unity feedback loop of 67.3 % maximum overshoot and 12 seconds settling time is controlled using a lag-lead compensator (through simulation). The lag-lead compensator is tuned by minimizing the sum of absolute error of the control system using MATLAB. Four functional constrains are used to control the performance of the lag-lead compensated control system. The result was reducing the process oscillation to 2.438 % overshoot and an 0.648 seconds settling time. The performance of the lag- lead compensated system with the present tuning approach is compared with the classical tuning using the root locus technique. The comparison showed that the present tuning technique is superior

MD Mafizul Islam and MD Abdul Salam (2013) developed a combined PID and Model Predictive Controller (MPC) controller for an air to water heat pump system that supplies domestichot water (DHW) to the users. The current control system is PLC based but because of its big size and expensive maintenance it must be replaced with a robust controller for the heat pump. The main goal of this project has been to find a suitable improvement strategy. By constructing a model of the system, the control system has been evaluated. First a model of the system is derived usingsystem identification techniques in MATLAB-Simulink; since the system is nonlinear and dynamic a model of the system is needed before the controller is implemented. The data has beenestimated and validated for the final selection of the model in system identification toolbox and then the controller is designed for the selected model. The combined PID and MPC controller

utilizes the obtained model to predict the future behavior of the system and by changing the constraints an optimal control of the system is achieved. In this thesis work, first the PID and MPC controller are evaluated and their results are compared using transient and frequency response plots. It is seen that the MPC obtained better control action than the PID controller, after some tuning the MPC controller is capable of maintaining the outlet water temperature to the reference or set point value. Both the controllers are combined to remove the minor instabilities from the system and also to obtain a better output. From the transient response behavior it is seen that the combined MPC and PID controller delivered good output response with minimal overshoot, rise time and settling time.

Galal A. Hassan (2014) has presented Lag-lead compensators are well known in automatic control engineering. They have 3 or 4 parameters to be adjusted (tuned) for proper operation depending on the compensator order. The frequency response of the control system or the root locus plot is traditionally used to tune the compensator in a lengthy procedure. A selected simple pole plus double integrator process is controlled using a first-order lag-lead compensator (through simulation). The lag-lead compensator is tuned by minimizing the sum of square of errors of phasemargin plus gain margin of the compensated system using MATLAB. Two functional constrains are used to guarantee the stability of the lag-lead compensated control system. The result was maintaining the gain margin and phase margin of the control system exactly at the desired values.The maximum percentage overshoot and the settling time depends on the desired gain margin. Thesteady-state error of closed-loop control system using the first-order lag-lead compensator with the studied process is zero. The results are compared with that in a published work.

Anuli Dass et al (2014) has presented Controlling the solar panels to extract maximum solar energy is an important concern of control engineers these days. An approximate second order model of a sun seeker control system is controlled using lead, lag, and lead-lag controller. The response of these controllers is compared with the proposed robust controller. Subsequently it is observed that the robust controller outperforms in providing reliability and stability in case of parameter variations under practical circumstances. The results are simulated in MATLAB.

Awadesh Kumar Singh et al (2014) Presented review note on compensator design for control education and engineering for the compensators are one of the most important aspects in any undergraduate control engineering courses owing to their widespread industrial applications. The

degree of convergence of the output waveform for any compensator depends upon proper selection and tuning of the compensator. In this paper the compensator parameters (α, β, τ) of the lead, lag and lag-lead compensators are tuned to their optimum values using the conventional root locus as well as frequency response approach. The compensator algorithm is studied using MATLAB and usefulness of these compensators for controlling process variables are demonstrated using proper tuning. The comparative studies showing promising results are discussed with suitable examples.

Gaurav Verma et al (2015) Introduced In the last few years Digital controllers are widely used because of their excellent qualities of simplicity, effectiveness and they are applicable for broad class of systems at present their involvement in industrial processes is more than 95%.They generally relate to accuracy, relative stability and speed of the response so as to yield an optimal control system for the given purpose. In this paper, the control of gimbal has been stated for the defence application mounted on the tank. A gimbal is a mechanical arrangement, which is used toisolate the payload from the moving vehicle. This is particularly used in line of stabilization systems and inertial guidance systems. These systems require very fast and accurate control withina particular bandwidth. In the present problem, the digital controller is implemented using frequency domain approach in order to control the rate of motion of platform, meeting the stringentrequirements of disturbance attenuation and robust stability.

Ahilash D. Karmankar et al (2016) had introduces design of different compensators and their output response for speed control of DC motor. With this paper, engineers would be able to rapidly design compensators for speed control of DC motor. As shown by the example, the method can improve the efficiency as required. Also, with this paper we can compares the effect of different compensators on system and compare their parameters side by side. In this paper compensator is designed by using Bode Plot Techniques and MATLAB Programming, therefore it is easier to simulate any programing with the help of basic bode plot formulae and simple programming key.

Sumant Kumar et al (2016) had presented the procedure for designing a lead compensator using MULTISIM®. The stability of a process model is determined by its Phase Margin and Gain Margin. For the robust design of a closed loop system, it is required to keep these margins to be greater than zero. Lead, lag and lead-lag Compensators are used to ensure that the stability marginsare at the desired levels. In this paper, we present the stepwise procedure for designing a lead compensator to obtain the required stability margins with the help of suitable example.

Zuwwar Khan Jadoon et al (2017) had conducted a comprehensive comparative analysis between five different controllers for a drug infusion system in total intravenous anesthesia (TIVA) administration Methods. The proposed method models a dilution chamber with first order exponential decay characteristics to represent the pharmacokinetic decay of a drug. The dilution chamber is integrated with five different control techniques with a simulation-based comparative analysis performed between them. The design process is conducted using MATLAB SISOTOOLResults. The findings show that each controller has its own merits and demerits. The results generated using MATLAB signify and confirm the effectiveness of PI and cascaded lead controllers, with cascaded lead controller as the best control technique to automate and control the propofol delivery. Conclusion In these paper, different control techniques for measurement-based feedback-controlled propofol delivery is confirmed with promising results Significance. The comparative analysis showed that this drug infusion platform, merged with the proper control technique, will perform eminently in the field of total intravenous anesthesia.

CHAPTER III MATHEMATICAL FORMULATION

In this chapter, we will see that the root locus graphically displayed both transient response and stability information. The locus can be sketched quickly to get a general idea of the changes in transient response generated by changes in gain. Specific points on the locus also can be found accurately to give quantitative design information. The root locus typically allows us to choose theproper loop gain to meet a transient response specification. As the gain is varied, we move through different regions of response. Setting the gain at a particular value yields the transient response dictated by the poles at that point on the root locus. Thus, we are limitedto those responses that exist along the root locus.

3.1 Improving Transient Response

Flexibility in the design of a desired transient response can be increased if we can design for transient responses that are not on the root locus. Figure 3.1 illustrates the concept. Assume that the desired transient response, defined by percent overshoot and settling time, is represented by point B. unfortunately, on the current root locus at the specified percent overshoot, we only can obtain the settling time represented by point A after a simple gain adjustment. Thus, our goal is tospeed up the response at A to that of B, without affecting the percent overshoot. This increase in speed cannot be accomplished by a simple gain adjustment, since point B does not lie on the root locus. Figure 3.2 illustrates the improvement in the transient response we seek: The faster response has the same percent overshoot as the slower response

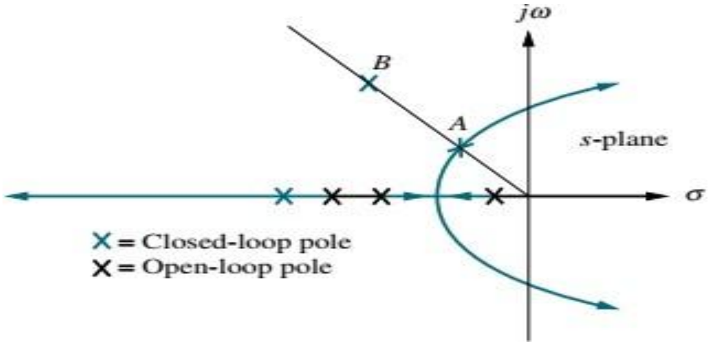


Fig. 3.1 Sample root locus, showing possible design point via gain adjustment (A) and desired design point that cannot be met via simple gain adjustment (B)

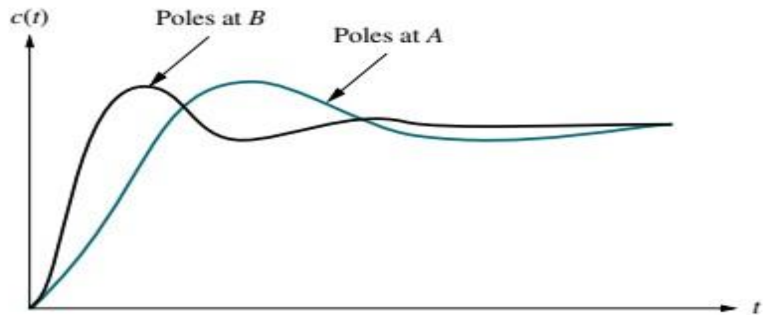


Fig. 3.2 responses from poles at A and B

3.2 Improving Steady-State Error

Compensators are not only used to improve the transient response of a system; they are also used independently to improve the steady-state error characteristics. Previously, when the system gain was adjusted to meet the transient response specification, steady-state error performance deteriorated, since both the transient response and the static error constant were related to the gain. The higher the gain, the smaller the steady-state error, but the larger the percent overshoot. On the other hand, reducing gain to reduce overshoot increased the steady-state error. If we use dynamic compensators, compensating networks can be designed that will allow us to meet transient and steady-state error specifications simultaneously. We no longer need to compromise between transient response and steady-state error, as long as the system operates in its linear range.

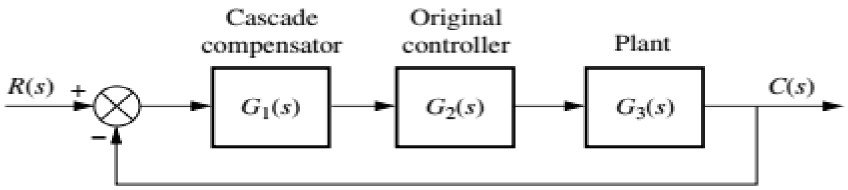


Fig 3.3 Cascade Compensation techniques

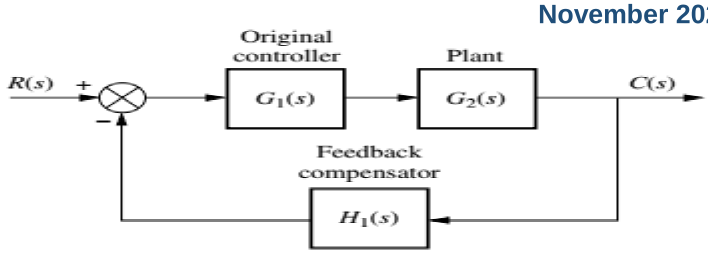


Fig 3.4 Feedback Compensation techniques

3.3 Lag Compensation

We can use passive networks, the pole and zero are moved to the left, close to the origin, asshown in Figure 3.5

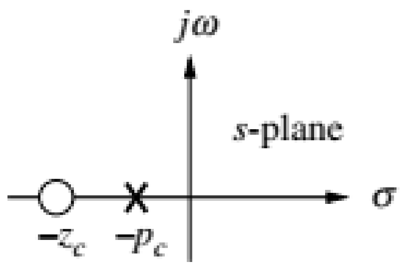


Fig 3.5 compensator pole-zero plot

Assume the uncompensated system shown in Figure 3.6. The static error constant, Kvo, for thesystem is

$$K_{v_o} = \frac{K z_1 z_2 \cdots}{p_1 p_2 \cdots}$$

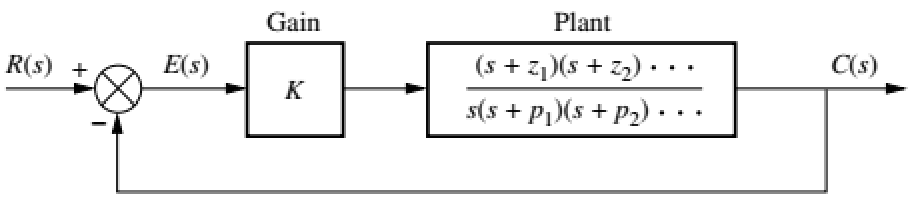


Fig 3.6 uncompensated system;

Assuming the lag compensator shown in Figure 3.7 and 3.5, the new static error constant is

$$K_{v_N} = \frac{(K z_1 z_2 \cdots)(z_c)}{(p_1 p_2 \cdots)(p_c)}$$

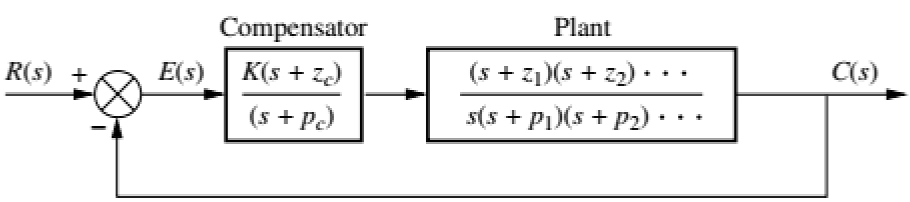


Fig. 3.7 compensated system

The uncompensated system's root locus is shown in Figure 3.8, where point P is assumed to bethe dominant pole. If the lag compensator pole and zero are close

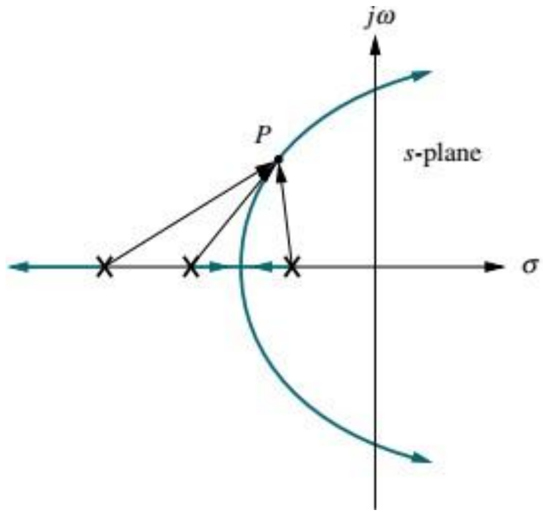


Fig 3.8 before lag compensation

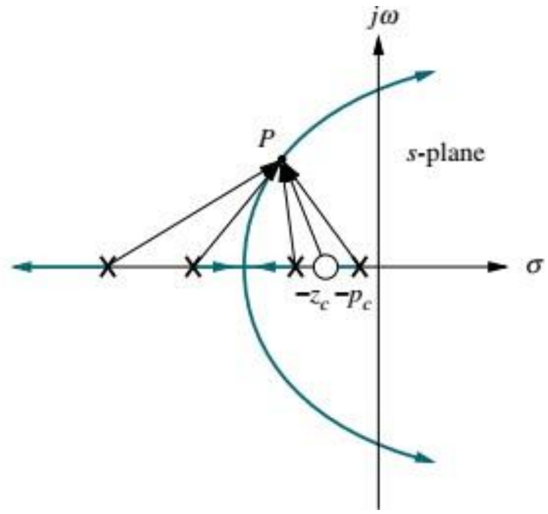


Fig 3.9 After lag compensation

together, the angular contribution of the compensator to point P is approximately zero degrees. Thus, in Figure 3.9, where the compensator has been added, point P is still at approximately thesame location on the compensated root locus.

3.4 Lead Compensation

Let us first look at the concept behind lead compensation. If we select a desired dominant, second-order pole on the s-plane, the sum of the angles from the uncompensated system's poles and zeros

to the design point can be found. The difference between 180 and the sum of the angles must be the angular contribution required of the compensator.

For example, looking at Figure 9.10, we see that

$$\theta_2 - \theta_1 - \theta_3 - \theta_4 + \theta_5 = (2k+1)180^\circ$$

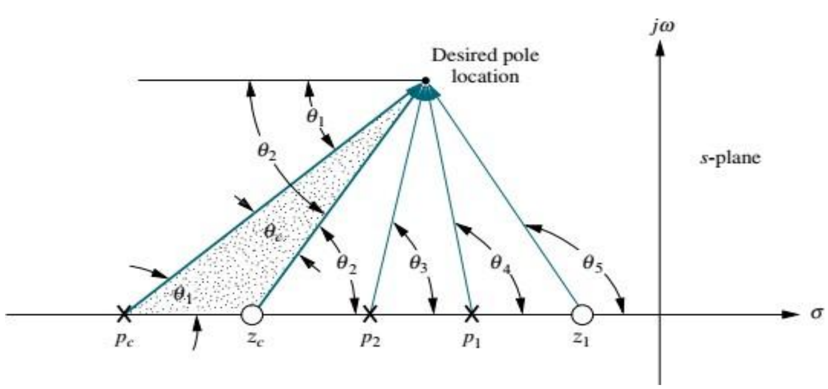


Fig 3.10 Geometry of lead compensation

Where $(\theta_2 - \theta_1) = \theta_c$ is the angular contribution of the lead compensator? From Figure 3.10 we see that θ_c is the angle of a ray extending from the design point and intersecting the real axis at the pole value and zero value of the compensator. Now visualize this ray rotating about the desired closed-loop pole location and intersecting

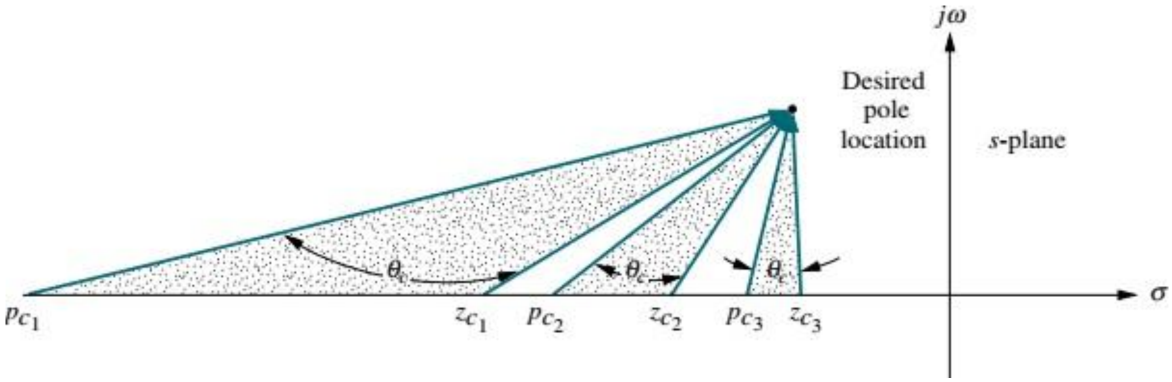


Fig 3.11 Three of the infinite possible lead compensator solutions

The real axis at the compensator pole and zero, as illustrated in Figure 3.11. We realize that an infinite number of lead compensators could be used to meet the transient response requirement. The difference between this angle and 180 is the required contribution of the remaining compensator pole or zero.

3.5 Lag-Lead Compensator Design

We first design the lead compensator to improve the transient response. Next we evaluate the improvement in steady-state error still required. Finally, we design the lag compensator to meet the steady-state error requirement. Later in the chapter we show circuit designs for the passive network. The following steps summarize thedesign procedure:

1. Evaluate the performance of the uncompensated system to determine how much improvement in transient response is required.
2. Design the lead compensator to meet the transient response specifications. Thedesign includes the zero location, pole location, and the loop gain.
3. Simulate the system to be sure all requirements have been met.
4. Redesign if the simulation shows that requirements have not been met.
5. Evaluate the steady-state error performance for the lead-compensated system to determine how much more improvement in steady-state error is required.
6. Design the lag compensator to yield the required steady-state error.
7. Simulate the system to be sure all requirements have been met.
8. Redesign if the simulation shows that requirements have not been met.

Function	Compensator	Transfer function	Characteristics
Improve steady-state error	PI	$K\frac{s+z_c}{s}$	1. Increases system type. 2. Error becomes zero. 3. Zero at $-z_c$ is small and negative. 4. Active circuits are required to implement.
Improve steady-state error	Lag	$K\frac{s+z_c}{s+p_c}$	1. Error is improved but not driven to zero. 2. Pole at $-p_c$ is small and negative. 3. Zero at $-z_c$ is close to, and to the left of, the pole at $-p_c$. 4. Active circuits are not required to implement.
Improve transient response	PD	$K(s+z_c)$	1. Zero at $-z_c$ is selected to put design point on root locus. 2. Active circuits are required to implement. 3. Can cause noise and saturation; implement with rate feedback or with a pole (lead).
Improve transient response	Lead	$K\frac{s+z_c}{s+p_c}$	1. Zero at $-z_c$ and pole at $-p_c$ are selected to put design point on root locus. 2. Pole at $-p_c$ is more negative than zero at $-z_c$. 3. Active circuits are not required to implement.
Improve steady-state error and transient response	PID	$K\frac{(s+z_{\text{lag}})(s+z_{\text{lead}})}{s}$	1. Lag zero at $-z_{\text{lag}}$ and pole at origin improve steady-state error. 2. Lead zero at $-z_{\text{lead}}$ improves transient response. 3. Lag zero at $-z_{\text{lag}}$ is close to, and to the left of, the origin. 4. Lead zero at $-z_{\text{lead}}$ is selected to put design point on root locus. 5. Active circuits required to implement. 6. Can cause noise and saturation; implement with rate feedback or with an additional pole.
Improve steady-state error and transient response	Lag-lead	$K\frac{(s+z_{\text{lag}})(s+z_{\text{lead}})}{(s+p_{\text{lag}})(s+p_{\text{lead}})}$	1. Lag pole at $-p_{\text{lag}}$ and lag zero at $-z_{\text{lag}}$ are used to improve steady-state error. 2. Lead pole at $-p_{\text{lead}}$ and lead zero at $-z_{\text{lead}}$ are used to improve transient response. 3. Lag pole at $-p_{\text{lag}}$ is small and negative. 4. Lag zero at $-z_{\text{lag}}$ is close to, and to the left of, lag pole at $-p_{\text{lag}}$. 5. Lead zero at $-z_{\text{lead}}$ and lead pole at $-p_{\text{lead}}$ are selected to put design point on root locus. 6. Lead pole at $-p_{\text{lead}}$ is more negative than lead zero at $-z_{\text{lead}}$. 7. Active circuits are not required to implement.

Table 3.1 itemizes the types, functions, and characteristics of these compensators.

3.6 SISO Tool Description

Use MATLAB, the Control System Tool box, and the following steps to use SISOTOOL toperform the design of Example.

1. Type SISOTOOL in the MATLAB Command Window.
2. Select Import in the File menu of the SISO Design for SISO Design Task Window.
3. In the Data field for G, type zpk([],[0,-4,-6],1) and hit ENTER on the keyboard. Click OK.

4. On the Edit menu choose SISO Tool Preferences . . . and select Zero/pole/gain: under theOptions tab. **click OK.**

5. Right-click on the root locus white space and choose Design Requirements/New.

6. Choose Percent overshoot and type in 16. Click OK.

7. Right-click on the root locus white space and choose Design Requirements/New.

8. Choose Settling time and click OK.

9. Drag the settling time vertical line to the intersection of the root locus and 16% overshootradial line.

10. Read the settling time at the bottom of the window.

11. Drag the settling time vertical line to a settling time that is 1/3 of the value found in Step 9.

12. Click on a red zero icon in the menu bar. Place the zero on the root locus real axis by clickingagain on the real axis.

13. Left-click on the real-axis zero and drag it along the real axis until the root locus intersectsthe settling time and percent overshoot lines.

14. Drag a red square along the root locus until it is at the intersection of the root locus, settlingtime line, and the percent overshoot line.

15. Click the Compensator Editor tab of the Control and Estimation Tools Manager window tosee the resulting compensator, including the gain.

3.7 SISO tool command windows

The single input single output design tool is part of MATLAB's Control Systems Toolbox that enables us to analyze simple SISO system interconnections. The optimal tool for this task is Simulink, but this toolbox helps us understand the basic capabilities of MATLAB, so we can then proceed to Simulink. This will be a simple introduction to the toolbox, so it is assumed that the reader is familiar with the theory behind transfer functions (and consequently zero-pole-gain,

simple transfer functions or state space commands) and system interconnections (series, paralleland feedback).

We open the toolbox from:

Start → Toolboxes → Control System → SISO Design Tool

This will open up two windows, the main toolbox window (Control and Estimation Tools Manager) where we make all the design changes and another one with figures (SISO Design forSISO Design Task) that displays different system characteristics, like Root Locus & Bode.

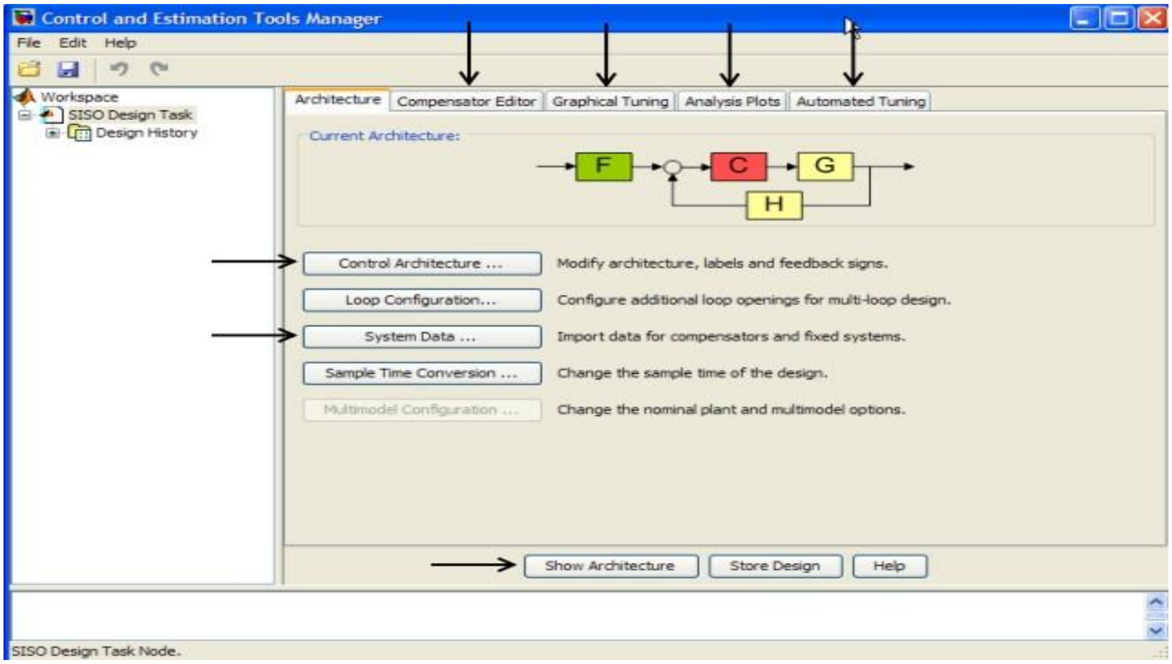


Figure 3.12 Control and Estimation Tool Manager

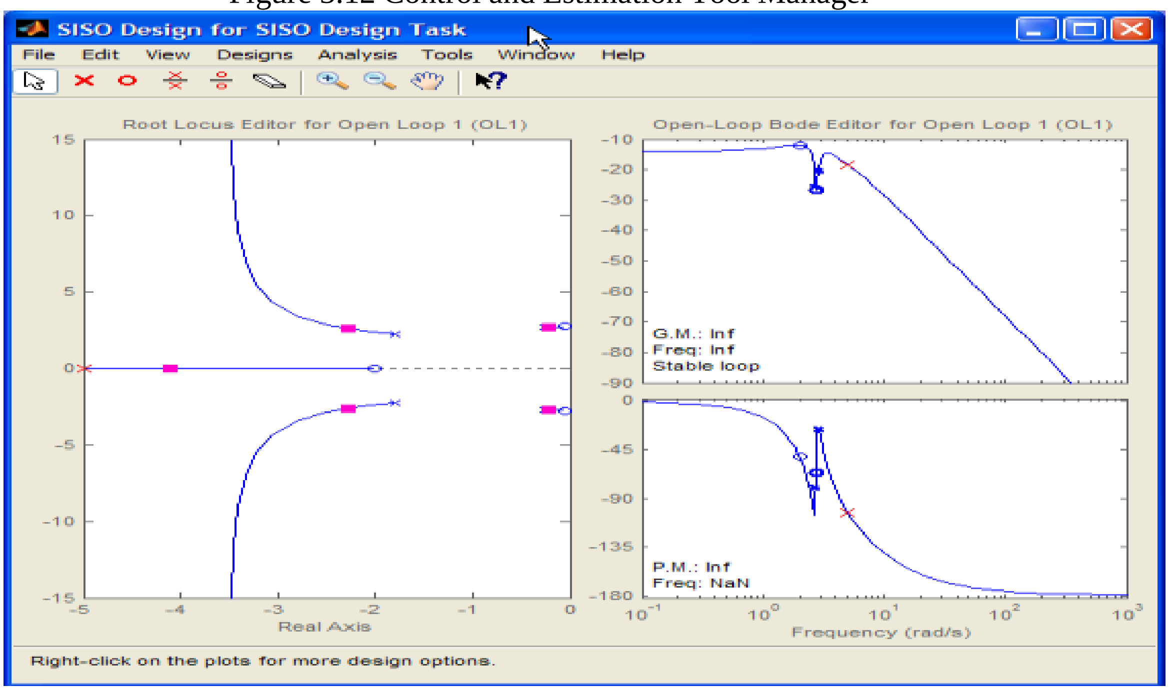


Figure 3.13 SISO Design for SISO Design Task

Control Architectures of SISO Tool

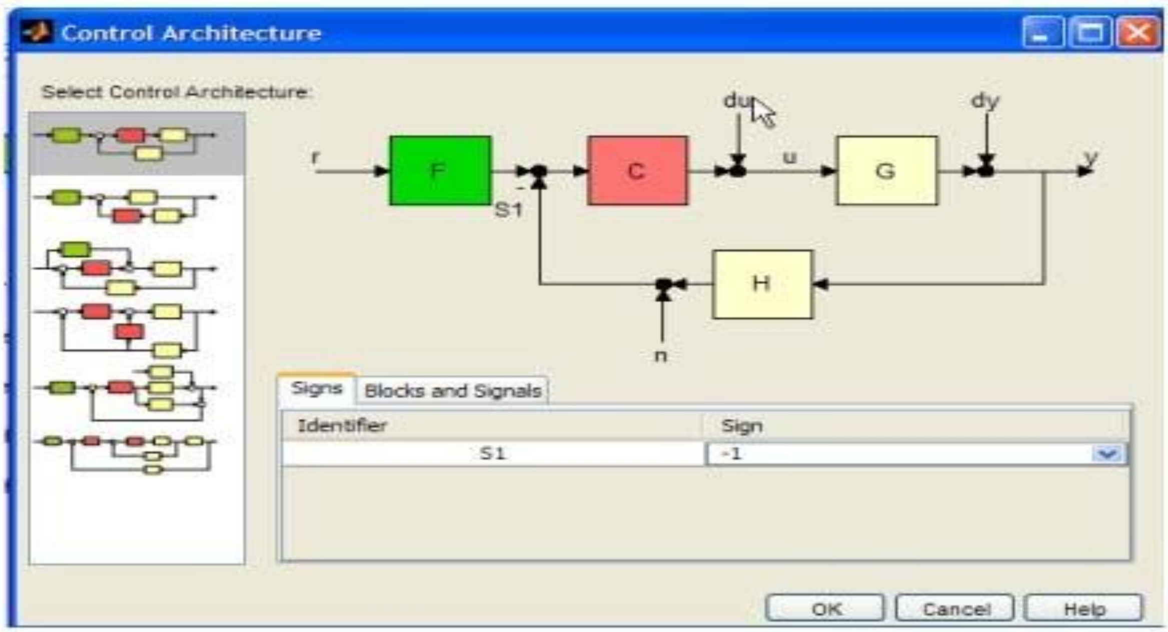


Figure 3.14 Control Architecture

In Control Architecture we choose among ready block architectures the model we desire. In Signs & Blocks and Signals we change the feedback signs and give the names we want to eachblock.

System Data

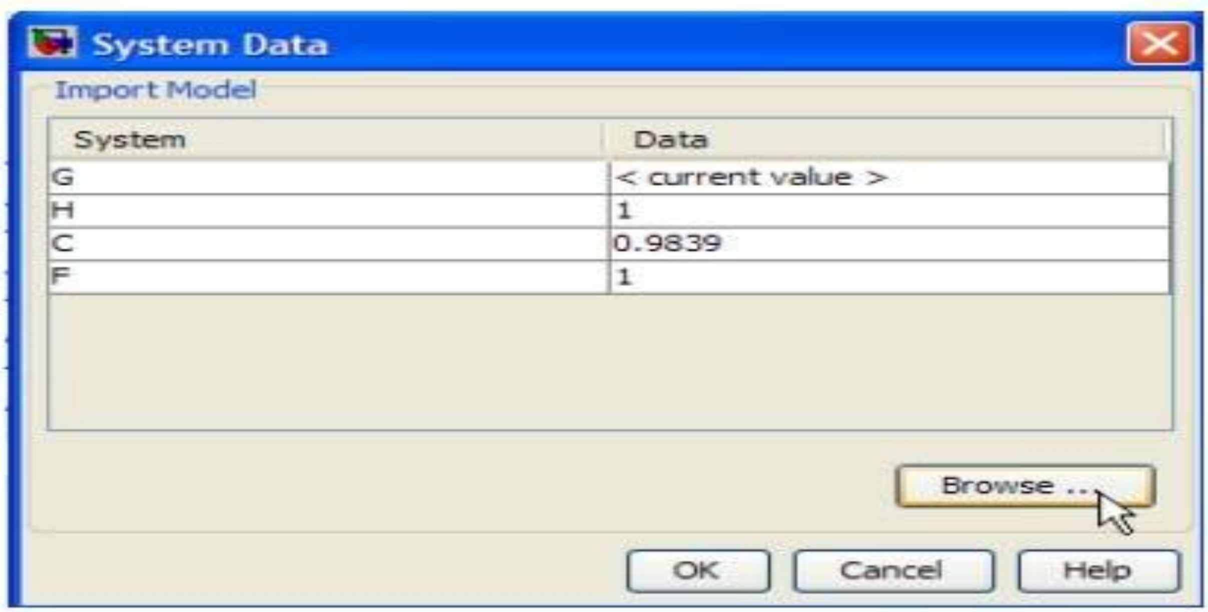


Figure 3.15 System Data

The System Data window allows us to change the values of the different blocks. The big bonus of this tool is that it allows us to import data from the workplace or a Mat file. Choosing Browseopens the Model Import window.

Figure 3.16 Model Import

Here, we choose block G and import the transfer function G that we previously defined in the Command Window.

3.8 Transient Response

Transient response is the response of a system to a change from equilibrium or a steady state. The transient response is not necessarily tied to abrupt events but to any event that affects the equilibrium of the system. The impulse response and step response are transient responses to a specific input (an impulse and a step, respectively).

In electrical engineering specifically, the transient response is the circuit's temporary response that will die out with time. It is followed by the steady state response, which is the behavior of the circuit a long time after an external excitation is applied.

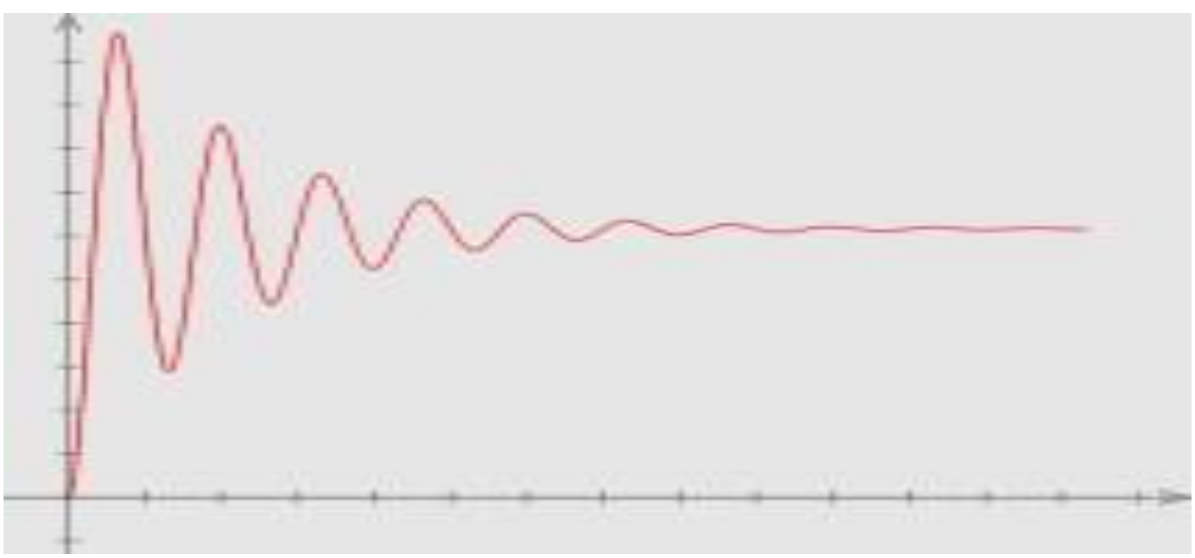


Figure 3.17 Transient response

3.8.1 Damping

The response can be classified as one of three types of damping that describes the output in relation to the steady-state response.

3.8.2 Under-damped

An under-damped response is one that oscillates within a decaying envelope. The more under- damped the system, the more oscillations and longer it takes to reach steady-state. Here dampingratio is always less than one.

3.8.3 Critically damped

A critically damped response is that response that reaches the steady-state value the fastest without being under-damped. It is related to critical points in the sense that it straddles the boundary of under-damped and over-damped responses. Here, the damping ratio is always equal to one. There should be no oscillation about the steady-state value in the ideal case.

3.8.4 Over-damped

An over-damped response is the response that does not oscillate about the steady-state value buttakes longer to reach steady-state than the critically damped case. Here damping ratio is greater than one.

3.8.5 Properties

Transient response can be quantified with the following properties.

3.8.6 Rise time

Rise time refers to the time required for a signal to change from a specified low value to a specified high value. Typically, these values are 10% and 90% of the step height.

3.8.7 Overshoot

Overshoot is when a signal or function exceeds its target. It is often associated with ringing.

3.8.8 Settling time

Settling time is the time elapsed from the application of an ideal instantaneous step input to the time at which the output has entered and remained within a specified error band, the time after which the following equality is satisfied:

{\displaystyle |h(t)-h_{st}|\leqslant \epsilon }Where {\displaystyle h_{st}}the steady-state is value, and {\displaystyle \epsilon } defines the width of the error band.

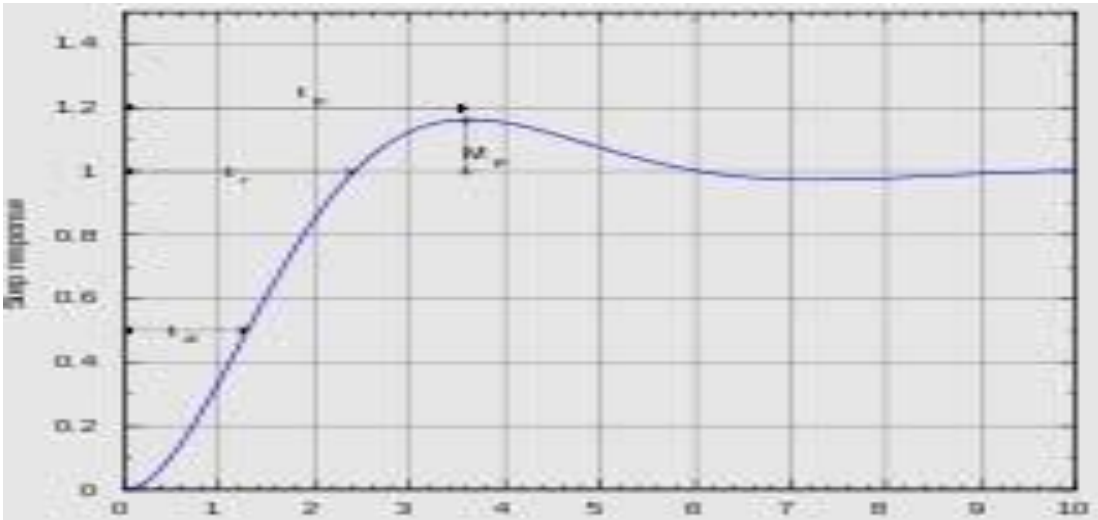
3.8.9 Delay-time

The delay time is the time required for the response to initially get halfway to the final value. Peak time. The peak time is the time required for the response to reach the first peak of the overshoot.

3.8.10 Steady-state error

Steady-state error is the difference between the desired final output and the actual one when thesystem reaches a steady state, when its behavior may be expected to continue if the system is undisturbed.

Figure 3.18 Steady-state error



CHAPTER IV

RESULTS & DISSCUSION

This work focuses on the comparative analysis of uncompensated and compensated system usingroot locus control techniques and their design process on SISO tools, in a closed-loop feedback system. The comparative analysis is conducted with respect to different time domain specifications like gain, percentage overshoot, settling time, and rise time. The design process of phase-lead, lag, lead-lag, and compensator is performed by applying the principles of the root locus technique [25-27], using MATLAB SISOTOOL [28-32]. The simulation study canbe done based on the model developed by Myers et al. in [33].

4.1 Control Schemes

As we have discusses compensator designing process in chapter 1 and chapter 3, here we can seecontrol schemes for compensators design in short.

Here we consider 3rd order a uncompensated system as given fig below (4)

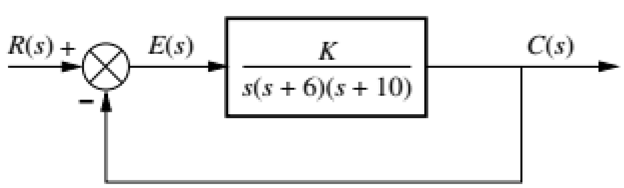


Fig.4.1 Uncompensated 3rd order system

4.1.1 Lead compensator

As the name suggests, a phase lead controller introduces a positive phase to the system over some frequency range. It is a high-pass filter. The transfer function of a simple lead controller is given as:

$$G_c(s) = K_c \frac{s + z_1}{s + p_1}$$ Where $P_1 > Z_1$

Continue by designing the lag compensator to improve the steady-state error. Since the uncompensated system's open-loop transfer function is $G = \frac{192.1}{s(s+6)(s+10)}$

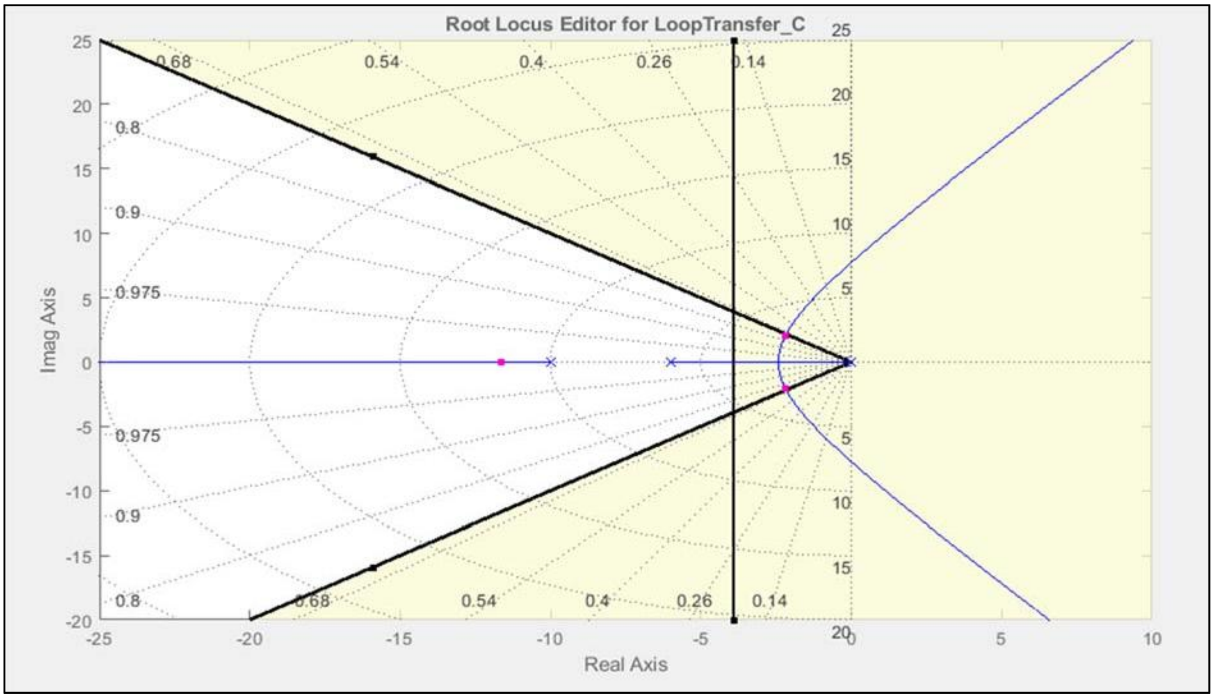


Fig 4.2. Root locus plot of the uncompensated system by using SISO tool

In the above described system (k=l), a lead controller with the following transfer function is incorporated, $G_{ld} = \frac{1971}{s(s+29.1)(s+10)}$

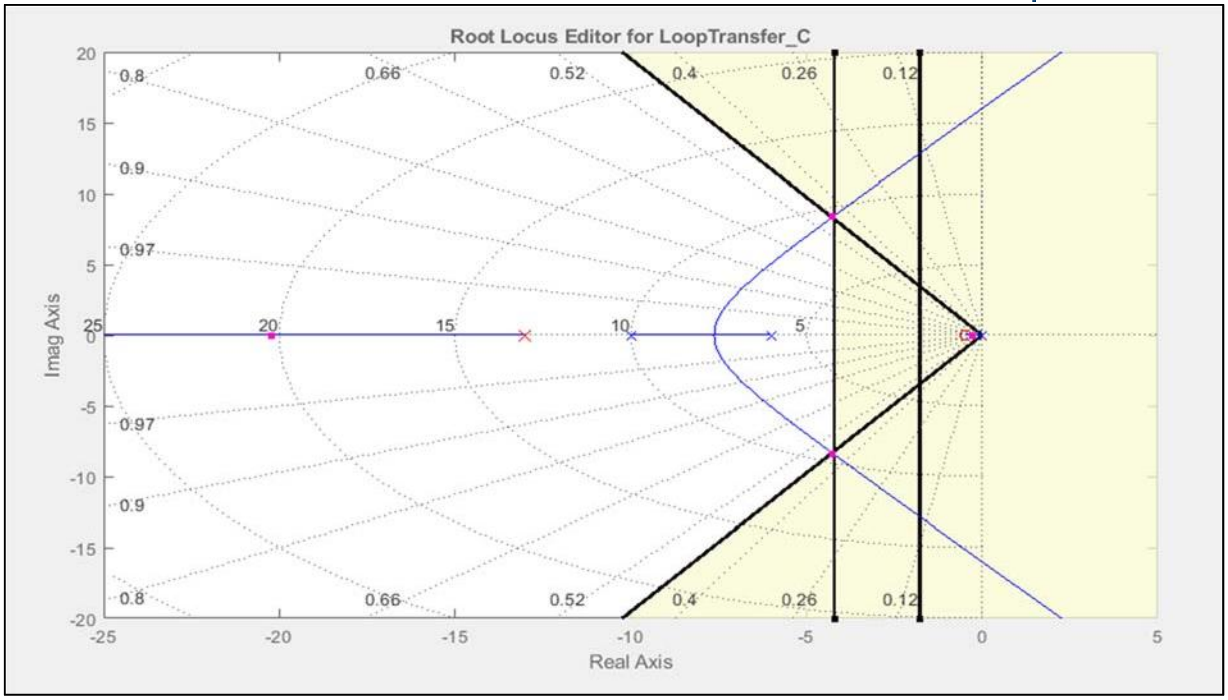


Fig 4.3 Root locus plot of the lead of compensated system by using SISO tool

A remarkable improvement in the system performance is found. In terms of time-domain specifications, some of the changes are:

l. Improved the damping of the system.

2. The rise time and settling time are improved.

3. Does not affect the steady-state error.

The same has been shown by SISO tool on MATLAB.

4.1.2 Lag Compensators

As the name suggests, a phase lag compensator introduces a negative phase to the system over some frequency range. It is a low-pass filter. The transfer function of a simple lag controller is given as:

$$G_c(s) = K_c \frac{s+z_1}{s+p_1} \quad \text{Where } p_1 < z_1$$

Now a phase lag controller with the following transfer function is incorporated if we arbitrarily choose the lag compensator pole at 0.01, which then places the lag compensator zero at 0.04713, yielding

$$G_{lg} = \frac{(s+0.04713)}{(s+0.01)}$$

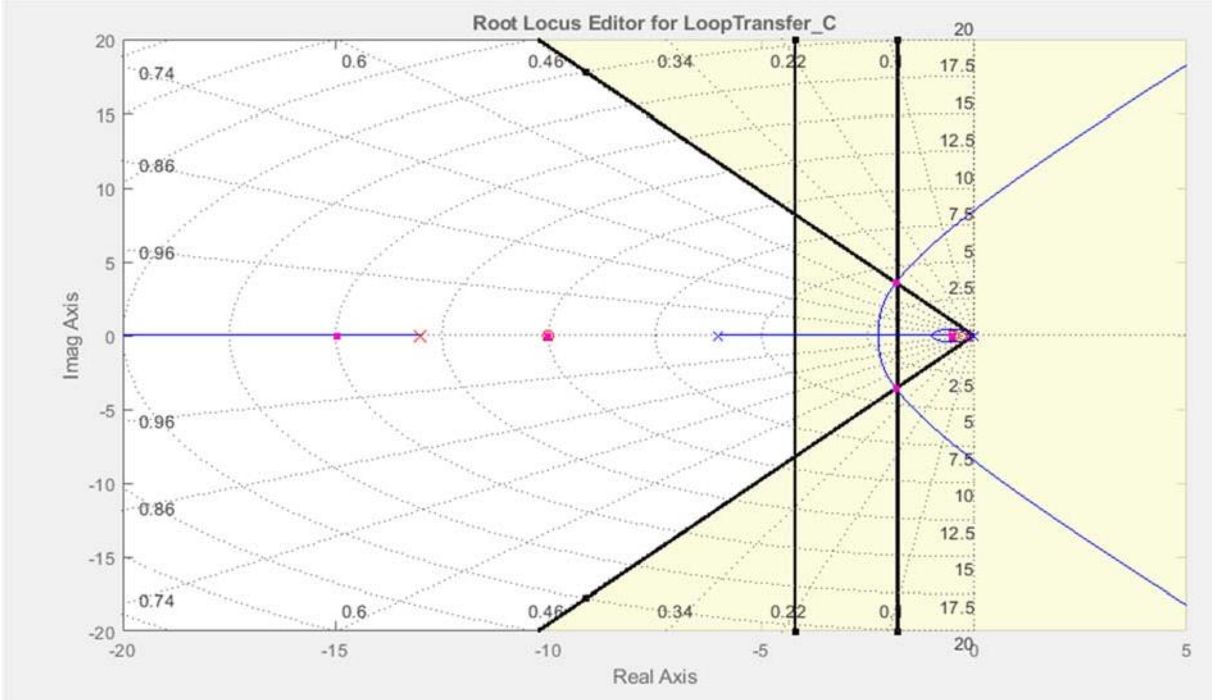


Fig 4.4 Root locus plot of the lag of compensated system by using SISO tool

The impact of a lag controller on the system can be summarized as:

l. Improves stability of the system can be improves

2. Bandwidth of the system may be decreased.

3. Increases Rise time and settling time of the system

The above mentioned impacts have been illustrated using SISO tools.

4.1.3 Lead-lag Compensator

As we have seen above a lead compensator gives improved Tr and Ts but at the same time increasesthe natural frequency of the system. Also a lag compensators although, gives good damping and enhances the stability of the system, but it results in longer Tr and Ts. Thus as we know that each

scheme has its own merits and demerits. In all such situations it is required to use a combined oflead - lag compensator, so that one can get goodness of both. The transfer function of a simple lead-lag controller is given as,

$$G_c(s) = \frac{1 + a_1 T_1 s}{1 + T_1 s} \frac{1 + a_2 T_2 s}{1 + T_2 s}$$

Where $a_1 > 1, a_2 < 1$ Now,

the overall transfer function of the system will be now given as,

$$G_{ld-\lg} = \frac{1971(s + 0.04713)}{s(s + 10)(s + 29.1)(s + 0.01)}$$

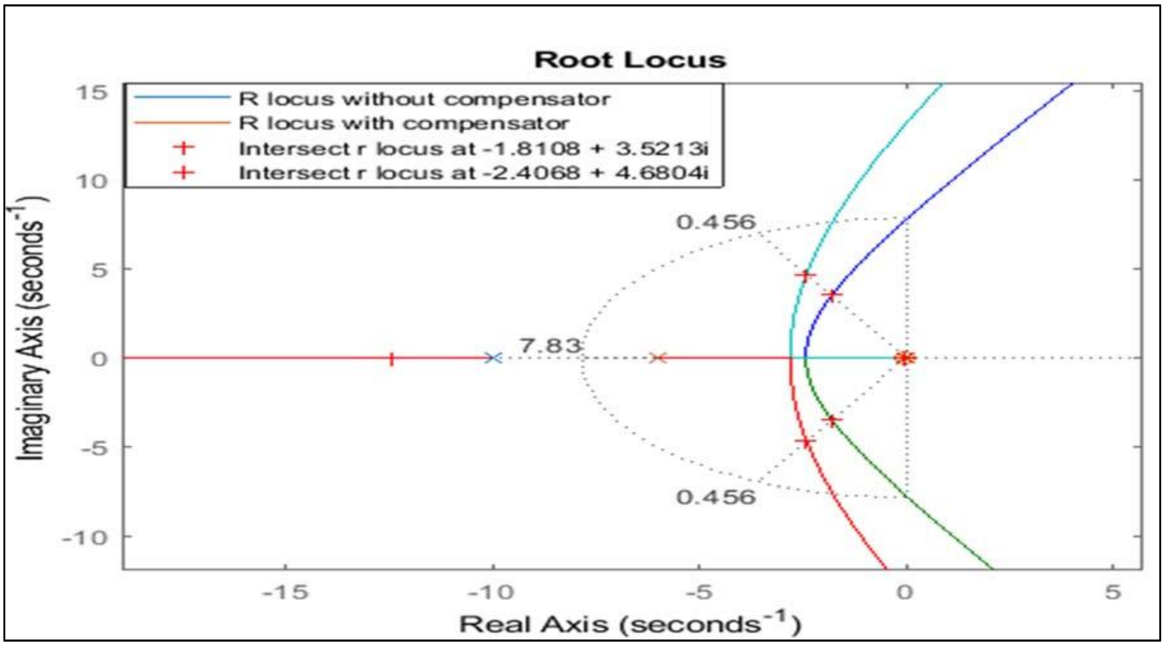


Fig 4.5 Root locus plot of the lead-lag of compensated system

The step response of the given in fig. 6 of above uncompensated system versus compensatedsystem

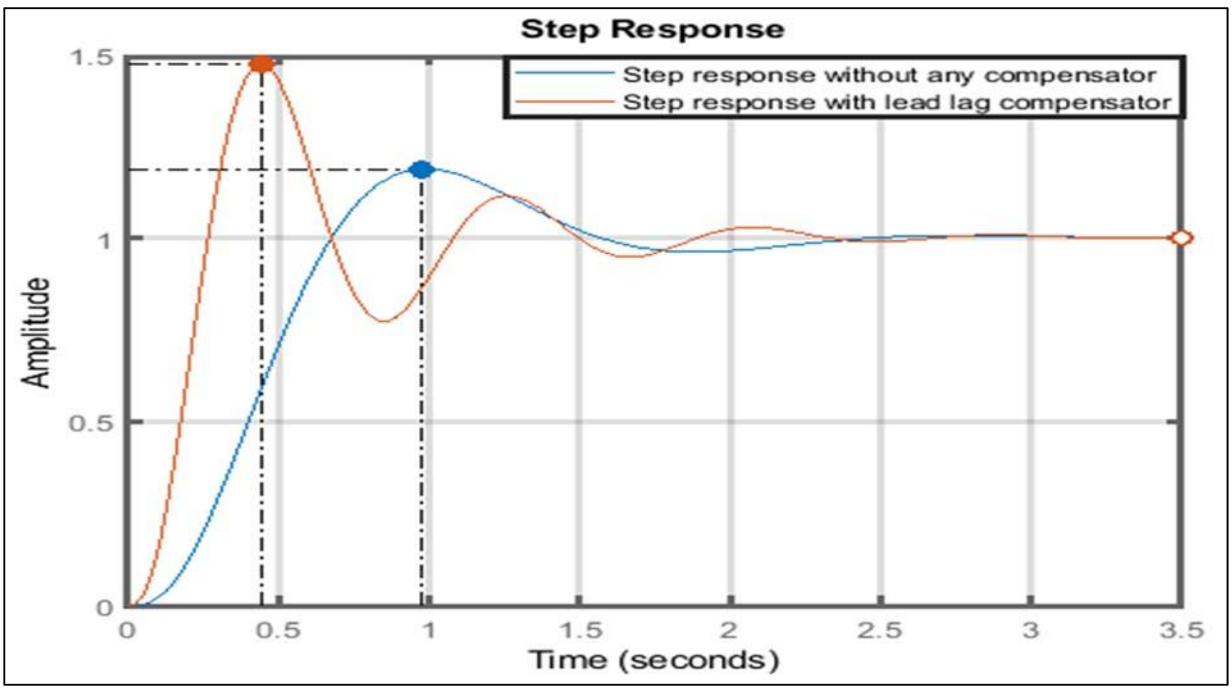


Fig 4.6 Step response of the compensated and uncompensated system for lead- lag compensatorusing root locus approach

Parameters	Uncompensated System Value	Compensated System Value
Rise Time	0.4231	0.1639
Settling Time	2.1943	2.1942
Settling Min	0.9159	0.7735
Settling Max	1.1884	1.4763
Overshoot	18.8417	47.6336
Peak Time	0.9758	0.4449
Steady state error	0.312	0.147

TABLE I: 4.1 Specification parameters for lag-lead compensator using root locus approach

4.2 DISCUSSIONS

This lag-lead compensator technique is superior to designs based on classical parameter identification such as frequency domain or time-domain plans. Using a proposed SISO tools technique, it was possible to reduce the maximum percentage overshoot of uncompensated process with unit feedback from 60 per cent to 2 per cent compared with other time approaches. Using the SISO tool the proposed technique, it was possible to reduce the settling time from about 15 seconds to 0.5 seconds compared with using the different time approach.

Even though Ogata used the time constant parameter b in the less then 1, the present study showed that its value is less than one (typically 0.0385). The optimization in response to the time approach used in this work is simple, straightforward, and accurate in attaining good control system specifications. It provides the compensator parameters in a minimal time using SISO tools.

CHAPTER V

SUMMARY AND CONCLUSION

The system has been designed for its root locus and step response using lead-lag compensator designing techniques using SISO tools. The responses have been plotted root locus and step response for comparison. Firstly the uncompensated system was plotted, and then different compensators such as lead-lag controllers were used to compensate the system. Subsequently, to ensure system stabilization under parametric variations due to various imperfections, a compensator has been designed, and the system performance has been seen on plots using MATLAB. Finally, a comparison between uncompensated and compensated is made under parameter variations. It is observed that the transient response is not quite well in terms of parameters, but the steady-state error is good variations in the step response.

By comparing TABLE I it can be noted that in root locus approach the transient response specifications like maximum overshoot, rise time etc. are not so satisfactory. Although the steady-state response is quite normal. But in the other hand [Awadhesh et. al] in the frequency response technique both the transient as well as steady-state behavior are quite satisfactory.
Therefore the selection of frequency response
technique will be more technically appropriate. Also in lag-lead compensator bode plot technique is more suitable for higher order system. Because in higher order system the angle contributed by lead portion of lag-lead compensator is too large.

Mostly all compensators design and process control system has a general block diagram like a feedback control system shown on the Fig 1.1 It contains a compensator (Gc) or controller and aplant which have to control with the help of the compensators or controller. Such controller is known as compensator. The physical parameters of a control system which are generally controlledin the industries and laboratories are temperature, pressure, flow, level etc. The proper selection ofa compensator is a very tough work. After selecting the proper compensator the control of these plant variables will become quite effortless.

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