

EXPERIMENT NO. 01**FAMILIARISATION WITH MAT- LAB- CONTROL SYSTEM TOOL BOX, MATLAB - SIMULINK TOOL BOX & PSPICE.****Objectives:**

- Using 'MATLAB base program + Control System toolbox', for control systems analysis and design.
- Building simple Simulink simulations.
- Running Simulink simulation to predict a system's behaviour.
- Transient analysis using PSPICE

MATLAB, an abbreviation of **MATrix LABoratory**, is a high-level technical computing environment suitable for solving scientific and engineering problems. The MATLAB family of programs includes the base program plus a variety of application-specific solutions called toolboxes . Toolboxes are comprehensive collections of MATLAB functions that extend the MATLAB environment to solve particular classes of problems.

The MATLAB base program along with the functions from the Control System Toolbox, can be used to analyze and design control systems problems. Control System Toolbox includes interactive analysis and design tools called LTI Viewer, and SISO Design Tool. The LTI Viewer uses a Graphical User Interface (GUI) to generate and view time and frequency response plots of Linear Time-Invariant (LTI) transfer functions and obtain measurements from these plots. The SISO Design Tool uses a GUI to provide a convenient and interactive way to design Single-Input-Single-Output (SISO) control systems by the conventional trial-and-error approach.

ASSIGNMENT - 1***MATLAB basics***

1. Open MATLAB command window. Observe the commands poly, polyval, roots, diff, int, deval, solve, dsolve, laplace, ilaplace, residue, tf, series, parallel, feedback, plot, zp2tf, tf2zp
2. Write a MATLAB program to find the roots of the polynomial

$$2s^5 + 4s^4 + 3s^3 + 5s^2 + 11 = 0$$
3. Find the general solution of the following quadratic equation.
 - a) $x^3 + 6x^2 + 8x + 12 = 0$
 - b) $2x + y + 3z = 15, \quad x + 8y + 9z = 12, \quad 4x + 2y + z = 4$
4. Find the general solution of the following differential equation.

$$\frac{d^2y}{dt^2} + 3\frac{dy}{dt} + 6y + 11 = 0, y(0) = 1, Dy(0) = 2$$

5. Consider the two matrices

$$A = \begin{bmatrix} 4 & 76 & 5 \\ 3 & 5 & 3 \\ 1 & 3 & 7 \end{bmatrix} \text{ and } B = \begin{bmatrix} 7 & 5 & 33 \\ 9 & 3 & -1 \\ 5 & 2 & 8 \end{bmatrix}$$

Write a MATLAB program to determine

- $A+B$
- B^{-1}
- $A^T B^T$

6. Write a MATLAB program to generate an overlay plot of

$$y_1 = \sin 3t$$

$$y_2 = \cos 2t$$

$$y_3 = t$$

$$\text{For } 0 \leq t \leq 2\pi$$

7. i) Write a MATLAB program to find Laplace transform of $-5t \sin \omega t$

ii) Write a MATLAB program to find Inverse Laplace transform of $\frac{(s+4)(s+7)}{s^2(s+2)(s+9)}$

8. Find out the poles, zeros and gain of the following transfer functions using MATLAB.

$$\text{a) } F(S) = \frac{3s^2+2s+6}{s^4+2s^3+7s^2+s+4}$$

$$\text{b) } F(S) = \frac{4s+7}{2s^3+s+9}$$

9. Determine the transfer function from the given poles, zeros and gain.

a) Zeros are at $S = -1$ and -3 , poles are at $S = 0, -4.5198, -0.7401 \pm 2.1522i$ and gain is $k=2$.

b) Zero is at $S = -5$, poles are at $S = -1, -0.3542 \pm 3.546i$ and gain is at $k=2$

10. Form the transfer functions

$$\text{a) } G(S) = \frac{2(S+3)(S+7)}{S(S+6)(S+5)}$$

$$\text{b) } G(S) = \frac{(S+1)}{S^2(S+4)^2}$$

11. Find the overall transfer function.

1. Connecting $G_1(S) = \frac{2(S^2+7s+3)}{S(S+5)(S+2)}$ and $G_2(S) = \frac{(S+7)(S+10)}{(S+6)(S+9)(S+11)}$ in series.

b) Connecting $G_1(S) = \frac{S(S+3)(S+4)}{(S+14)(S+9)(S+5)}$ and $G_2(S) = \frac{(S+1)(S+2)}{S^2(S+5)(S+6)}$ in

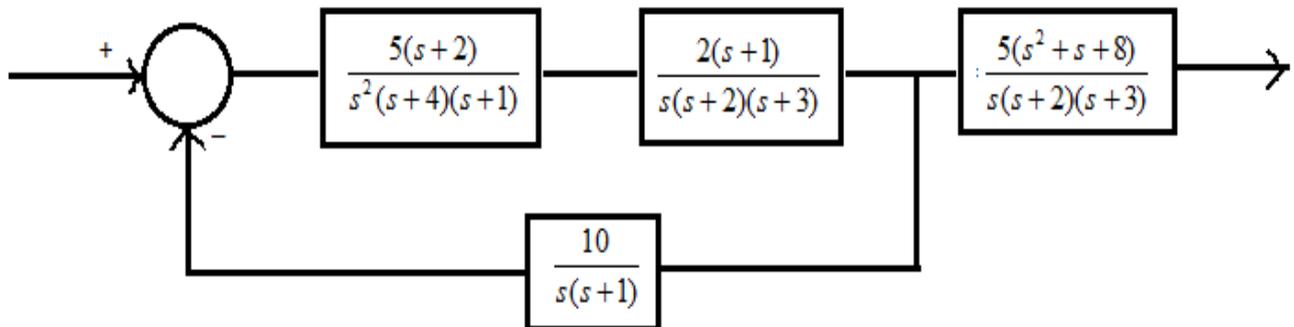
parallel.

12. Find the closed loop transfer function of $G(S) = \frac{3(S+2)}{S^2(S+3)}$

- With unity -ve feedback
- With unity +ve feedback

- With the negative feedback having transfer function $H(S) = \frac{1}{(s+1)}$

13. Find overall transfer function by block diagram reduction technique



14. For the given system compare the step response specifications for open loop and closed loop.

$$G(S) = \frac{(S^2 + 1)}{(S^2 + 2S + 1)}$$

ASSIGNMENT - 2***Running Simulink simulation***

SIMULINK (SIMULATION LINK) is an extension of MATLAB for modeling, simulating, and analyzing dynamic, linear/nonlinear, complex control systems. Graphical User Interface (GUI) and visual representation of simulation process by simulation block diagrams are two key features which make SIMULINK one of the most successful software packages, particularly suitable for control system design and analysis.

Simulation block diagrams are nothing but the same block diagrams we are using to describe control system structures and signal flow graphs. SIMULINK offers a large variety of ready-to-use building blocks to build the mathematical models and system structures in terms of block diagrams. Block parameters should be supplied by the user. Once the system structure is defined, some additional simulation parameters must also be set to govern how the numerical computation will be carried out and how the output data will be displayed.

To start SIMULINK, enter **simulink** command at the MATLAB prompt. Alternatively one can also click on SIMULINK icon .

1. Expand the **Continuous**, **Discontinuities**, **Discrete**, and **Math Operations** sub nodes. Study the purpose of various blocks in these sub nodes in description box.

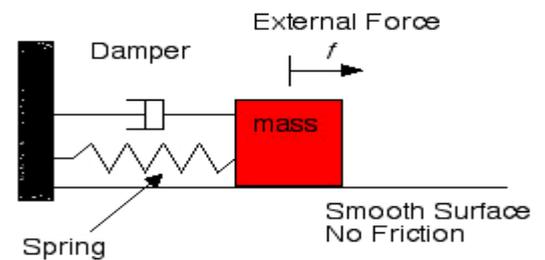
2. Simulate the following equation using SIMULINK blocks

$$x(t) = 3 \sin\left(\omega t + \frac{\pi}{3}\right)$$

ω is 10 rad/sec

3. Consider the mass-spring-dashpot where the spring and the dashpot are connected in parallel to the mass.

The mathematical model for this system is described by $f(t) = 3\ddot{x} + 2\dot{x} + 9x$



Use SIMULINK to simulate the response of this system to unit step input.

HOME WORK:

1. Proof all the experimental results with theoretical calculations.
2. Write a MATLAB program to find the roots of the polynomial
 $9s^4 + s^3 + 5s^2 + 2s + 11 = 0$
3. Find the general solution of the following differential equation.

$$\frac{d^2y}{dt^2} + 2\frac{dy}{dt} + y = 0$$

4. Consider the two matrices

$$A = \begin{bmatrix} 4 & 76 & 5 \\ 3 & 5 & 3 \\ 1 & 3 & 7 \end{bmatrix} \quad \text{and} \quad B = \begin{bmatrix} 7 & 5 & 33 \\ 9 & 3 & -1 \\ 5 & 2 & 8 \end{bmatrix}$$

Write a MATLAB program to determine

- AB
 - B^T
 - A^{-1}
5. Write a MATLAB program to generate the plot of
 $y = 3 \sin t \quad 0 \leq t \leq 2\pi$
 6. i) Write a MATLAB program to find Laplace transform of the following
 $t \cos 3\omega t$
 - ii) Write a MATLAB program to find Inverse Laplace transform of the following

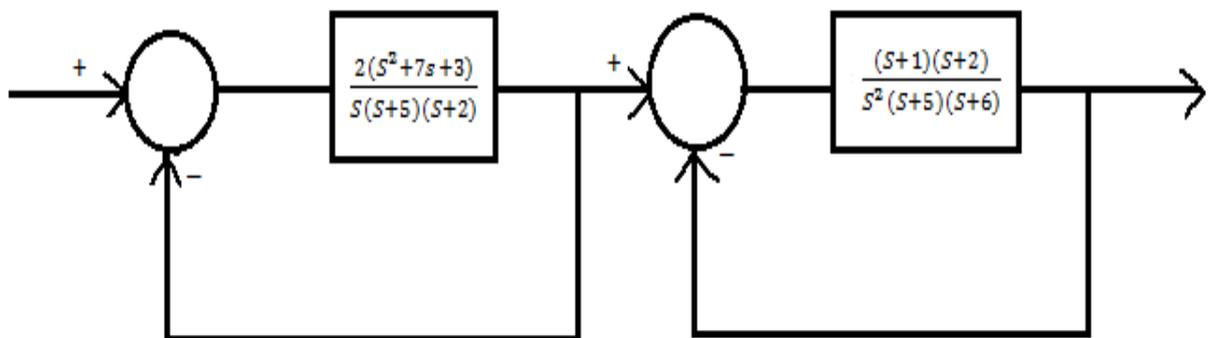
$$\frac{(s^2+1)}{(s^2+2s+1)}$$

7. Find the overall transfer function.

a. Connecting $G_1(s) = \frac{2(s+3)(s+7)}{s(s+6)(s+5)}$ and $G_2(s) = \frac{(s+4)(s+7)}{s^2(s+2)(s+9)}$ in series.

b. Connecting $G_1(s) = \frac{(s+1)}{s^2(s+4)^2}$ and $G_2(s) = \frac{3(s+2)}{s^2(s+3)}$ in parallel.

8. Find overall transfer function by block diagram reduction technique



EXPERIMENT NO. 02**DETERMINATION OF STEP RESPONSE FOR FIRST ORDER & SECOND ORDER SYSTEM. WITH UNITY FEEDBACK ON CRO & CALCULATIONS OF CONTROL SYSTEM LIKE TIME CONSTANT, % PEAK OVERSHOOT, SETTLING TIME ETC., FROM THE RESPONSE. SPECIFICATIONS****Objective:**

Determination of step response of 1st & 2nd order system and calculation of control system specification

EQUIPMENT DESCRIPTION

The present set up has been designed to provide a convenient means of studying the transient response of linear systems. Block diagram approach has been employed as a standard technique, with Fig. 1 depicting the features available to in the set up.

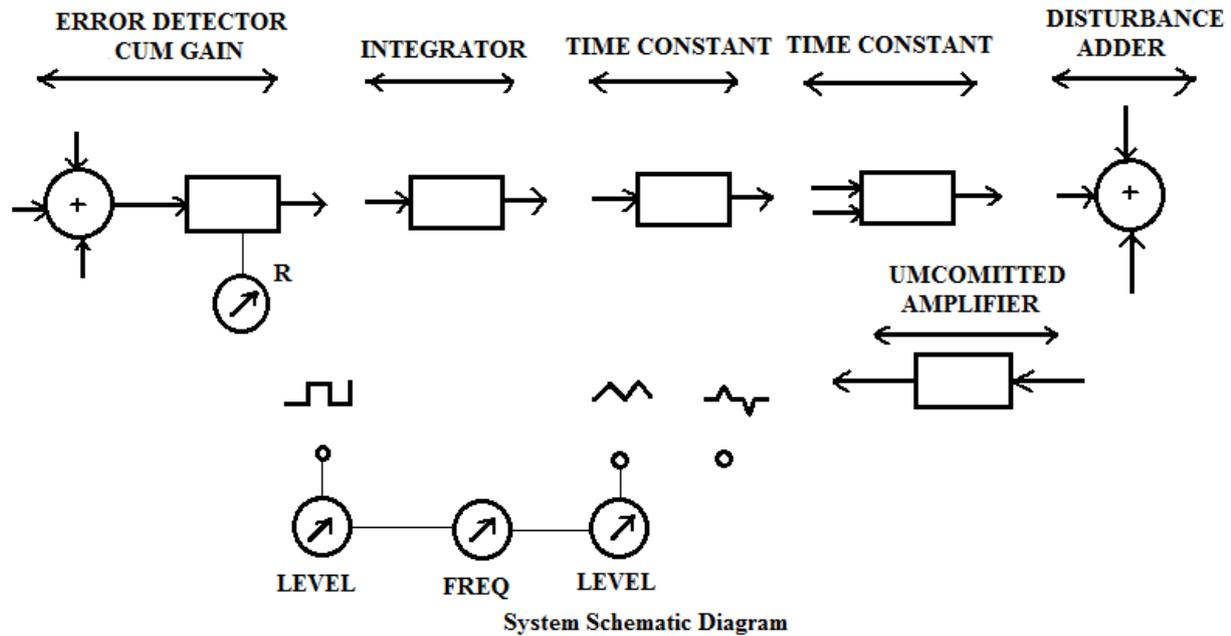
A dynamic system of the desired configuration may be constructed by a suitable interconnection of the basic blocks available. Following type of blocks have been included in the system.

- Error detector-cum Gain
- Integrator
- Time constant
- Disturbance adder
- Uncommitted Amplifier (to invert the feedback signal for getting negative feedback).

The set up has an internal $\pm 12V$ IC regulated Power supply.

With the help of the above sub-systems a very large variety of simulated systems can be constructed. Besides SISO systems this would include MIMO systems as well.

A good quality dual trace oscilloscope is the only external equipment required for the experiments.



FIRST ORDER SYSTEM:

These are characterized by one pole and/or a zero. A pure integrator and a single time constant, having transfer function of the form K/s and $K/(sT + 1)$, are the two commonly studied representatives of this class of systems. Many thermal systems and electrical systems with RC/L-R element are the examples of first order systems.

Unit step response of the systems are computed as follows and are shown in fig.2(a)

$$\frac{C(s)}{R(s)} = G(s) = \frac{K}{s} \text{ then for } R(s) = \frac{1}{s}$$

$$C(s) = \frac{K}{s^2} \text{ and } c(t) = Kt \tag{1}$$

Again if $G(S) = \frac{K}{(sT+1)}$ then with $R(s) = \frac{1}{s}$

$$C(s) = \frac{K}{s(sT + 1)}, \text{ and } c(t) = K(1 - e^{-t/T}) \tag{2}$$

Time constant of the system is defined from eq.(2) as $t=T$ which gives

$$c(t) = K(1 - e^{-1}) = 0.632K$$

This is an important characteristics of the system which is also defined in terms of the slope of the response curve at $t=0$.

For a proper viewing on a CRO, the step input needs to be replaced by a square wave of sufficiently low frequency (to allow $c(t)$ in eq.(2) to reach up to 99% of its final value). This is shown in the figure bellow. A triangular wave output results since a pure integration block does not saturate .it may further be seen that if the square was is of frequency f and peak to peak input amplitude is $1v$,the peak to peak amplitude of the triangular wave at the output of the pure integrator is given as $K/4f$.

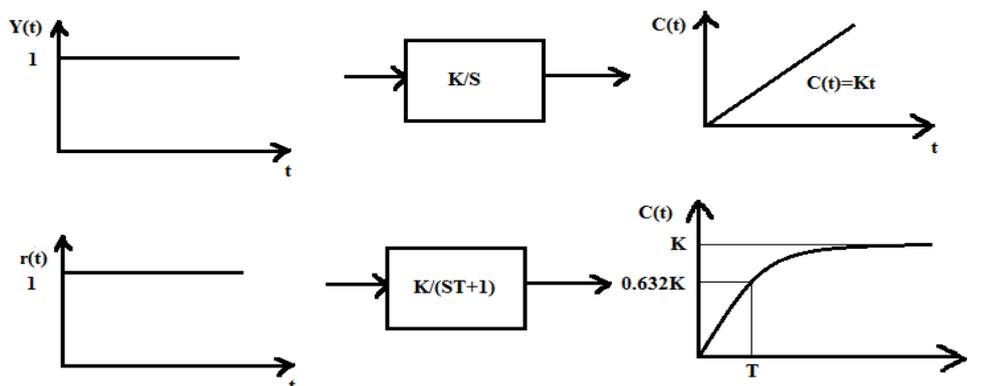
SECOND ORDER SYSTEM:

These systems are characterised by two poles and upto two zeros. For the purpose of transient response studies, zeros are usually not considered primarily because of simplicity in calculations and also because the zeros do not affect the internal modes of the systems. A great deal of analytical results regarding second order systems are available in the textbooks. This forms the basis of studying higher order systems many of which can be approximated to second order.

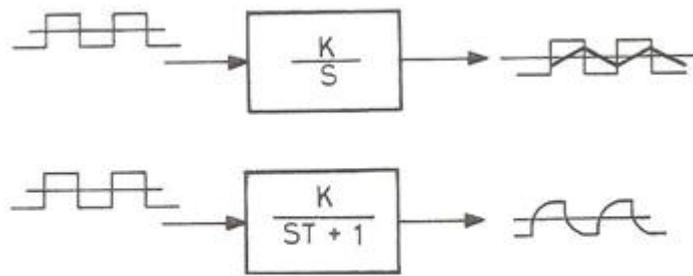
A second order system is represented in the standar form as—

$$G(S) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} ,$$

Where δ is called the damping ratio and ω_n the undamped natural frequency. Depending upon the value of δ , the poles of the system may be real, repeated or complex conjugate which is reflected in the nature of its step response. Results obtained for various cases are:



Unit step response of first order transfer functions



Square wave response of first order transfer functions

(a) Underdamped case($0 < \delta < 1$):

$$c(t) = 1 - \frac{e^{-\delta\omega_n t}}{\sqrt{1-\delta^2}} \sin\left(\omega_d t + \tan^{-1} \frac{\sqrt{1-\delta^2}}{\delta}\right)$$

Where $\omega_d = \omega_n \sqrt{1-\delta^2}$ is termed the damped natural frequency.

(b) Critically damped case ($\delta=1$):

$$c(t) = 1 - e^{-\omega_n t}(1 + \omega_n t)$$

(c) Over damped case ($\delta > 1$):

$$c(t) = 1 + \frac{\omega_n}{2\sqrt{\delta^2-1}} \left(\frac{e^{-s_1 t}}{s_1} - \frac{e^{-s_2 t}}{s_2} \right)$$

Where $s_1 = (\delta + \sqrt{\delta^2-1})\omega_n$ and $s_2 = (\delta - \sqrt{\delta^2-1})\omega_n$

CLOSED LOOP SYSTEM:

Close loop or feedback systems involve a measurement of the output of the system And generation of control signals which are based on decision making under the influence of a command or reference and the measured value of output such systems are of great interest to control engineers due to features like automatic correction, disturbance rejection immunity to noise and parameter variation etc. A study of the performance of closed loop system is the basic objective of this experiment. The closed loop transfer function for different open loop functions are shown below:

(i) For $G(S) = \frac{K}{s}, \frac{C(S)}{R(S)} = \frac{K}{s+K} = \frac{1}{\frac{s}{K}+1}$

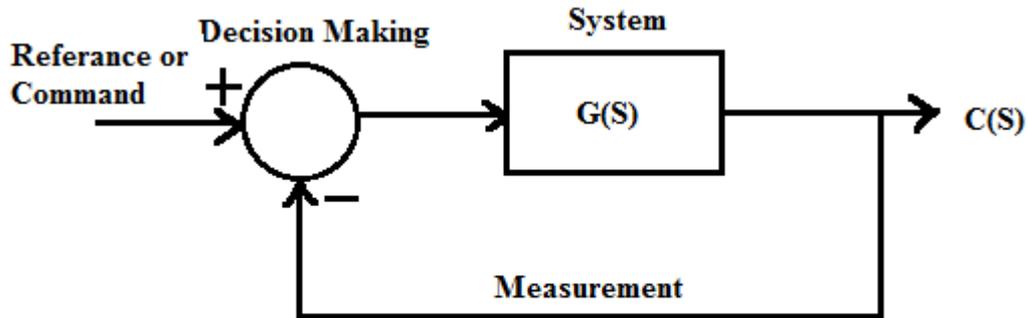
Which gives a step response similar to equation (2) with time constant describing as K increases.

(ii) For $G(S) = \frac{K}{sT+1}$, $\frac{C(S)}{R(S)} = \frac{K}{sT+K+1} = \frac{K/(1+K)}{\frac{sT}{1+K}+1}$

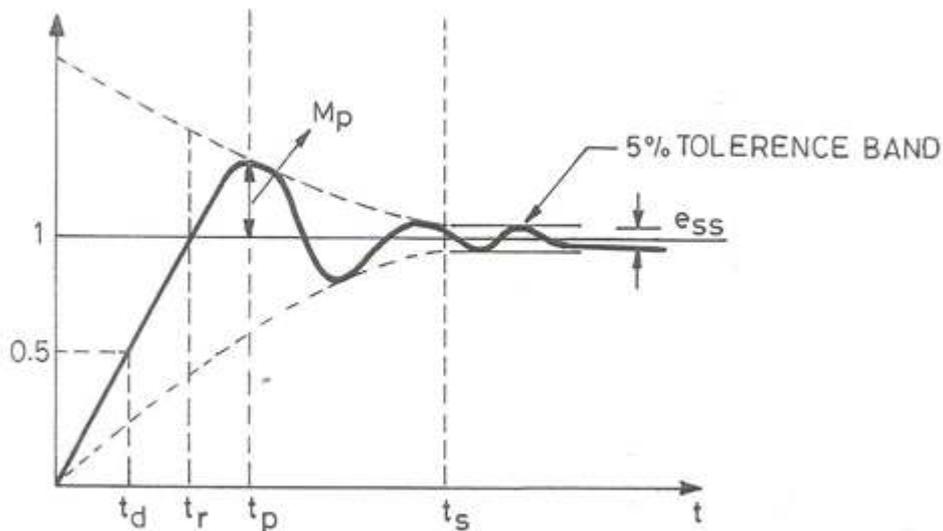
Which has a step response similar in nature as obtained above.

(iii) For $G(S) = \frac{K}{s(ST+1)}$, $\frac{C(S)}{R(S)} = \frac{K}{s^2T+s+K} = \frac{K}{s^2+\frac{s}{T}+\frac{K}{T}}$

Which gives response similar to eq (3), (4), (5) depending upon the value of K.



Block Diagram of a Closed Loop System



Step Response of an Underdamped System

Thus the response of a closed loop system can be altered by varying the open loop gain K and as a consequence it should be possible to choose K to obtain a suitable performance. This leads to the concept of performance characteristics as defined on the step response of an underdamped second order system in above figure.

- (i) **Delay time(t_d):** it is defined as the time needed for the response to reach 50% of the final value

- (ii) **Rise time(t_r):** it is the time taken for the response to reach 100% of the final value for the first time.

$$t_r = \frac{\pi - \beta}{\omega_d}, \text{ where } \beta = \tan^{-1} \frac{\sqrt{1 - \delta^2}}{\delta}$$

- (iii) **Peak time(t_p):** it the time taken for the response to reach the first peak of the overshoot.

$$t_p = \frac{\pi}{\omega_n \sqrt{1 - \delta^2}}$$

- (iv) **Maximum overshoot (M_p):** is straight way difference between the magnitude of the highest peak of time response and magnitude of its steady state. Maximum overshoot is expressed in term of percentage of steady-state value of the response. As the first peak of response is normally maximum in magnitude, maximum overshoot is simply normalized difference between first peak and steady-state value of a response.

$$M_p = \frac{c(t_p) - c(\infty)}{c(\infty)} \times 100\% = e^{-\frac{\pi\delta}{\sqrt{1-\delta^2}} \times 100\%}$$

Its value indicates the relative stability of the system.

- (v) **Settling time(t_s):** is the required by the system response to reach and stay within a prescribed tolerance band, which is usually taken as $\pm 2\%$ or $\pm 5\%$. An approximate calculation base on the envelops of the response for a low damping ratio system yields, $t_s(\pm 5\% \text{ tolerance band}) = 3/\delta\omega_n$

$$t_s(\pm 2\% \text{ tolerance band}) = 4/\delta\omega_n$$

- (vi) **Steady state errors(e_{ss}):** for unity feedback system, e_{ss} is defined as

$$e_{ss} = \lim_{t \rightarrow \infty} (r(t) - c(t))$$

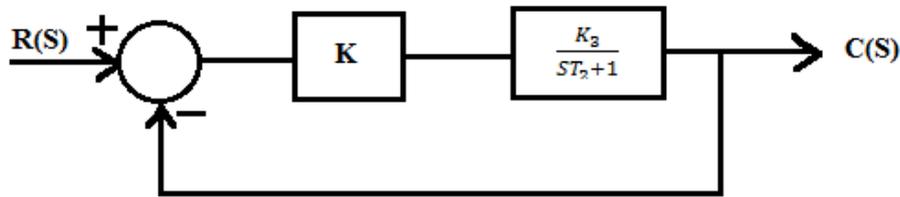
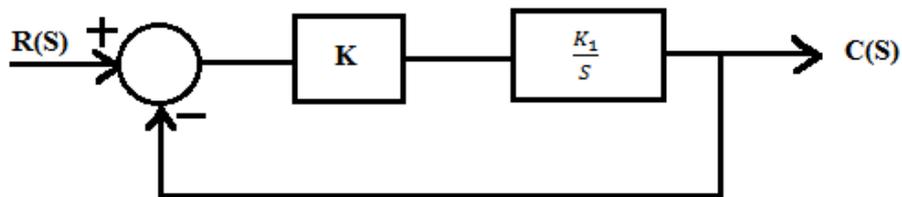
A simpler way to calculate steady state error without actually computing the time response is available in the complex frequency domain. Application of final value theorem of Laplace Transform to unity feedback system gives

$$e_{ss} = \lim_{s \rightarrow 0} sE(s) = \lim_{s \rightarrow 0} \frac{sR(s)}{1 + G(s)}$$

STEP RESPONSE – FIRST ORDER SYSTEM

- Two forms of first order closed loop system, as shown in bellow figure are possible. Make proper connections for the configuration chosen.
- Apply a 1 volt p-p square wave input and trace the output waveform on a tracing paper for $K = 0.5, 1.0, 1.5 \dots\dots$. Calculate the time constant in each case and compare with theoretical results.
- If the open loop transfer function in the chosen configuration was of type-1, the steady state error above would be zero for a step input.
- Tabulate the result in the following table.

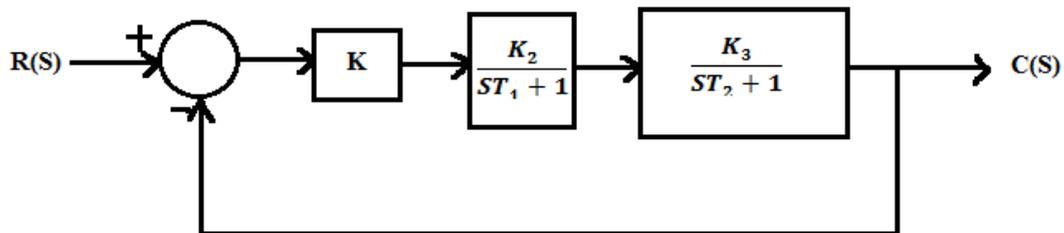
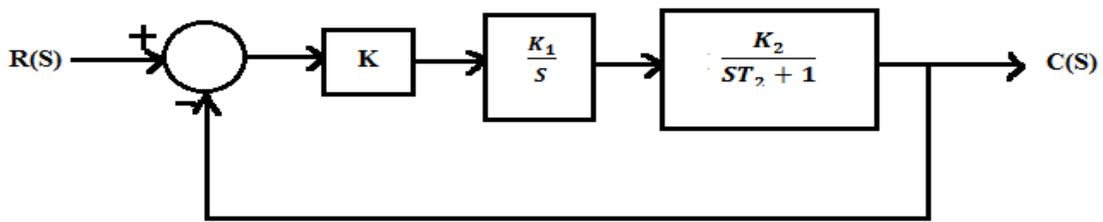
K	Time Constant		Steady State Error	
	Experimental	Theoretical	Experimental	Theoretical



Closed Loop Options for First Order Ststem

STEP RESPONSE – SECOND ORDER SYSTEM

- Form a suitable second order system configuration as shown in the figure below.



- Apply a 1 volt p-p square wave input and trace the output waveform on a tracing paper for different values of K. Obtain peak percent overshoot, settling time, rise time and steady state errors from the tracing and calculate ζ and ω_n . compare with theoretical results.
- Tabulate the result in the following table
- If the open loop transfer function in the chosen configuration was of type-1, the steady state error above would be zero for a step input.
- Tabulate the results in the following table.

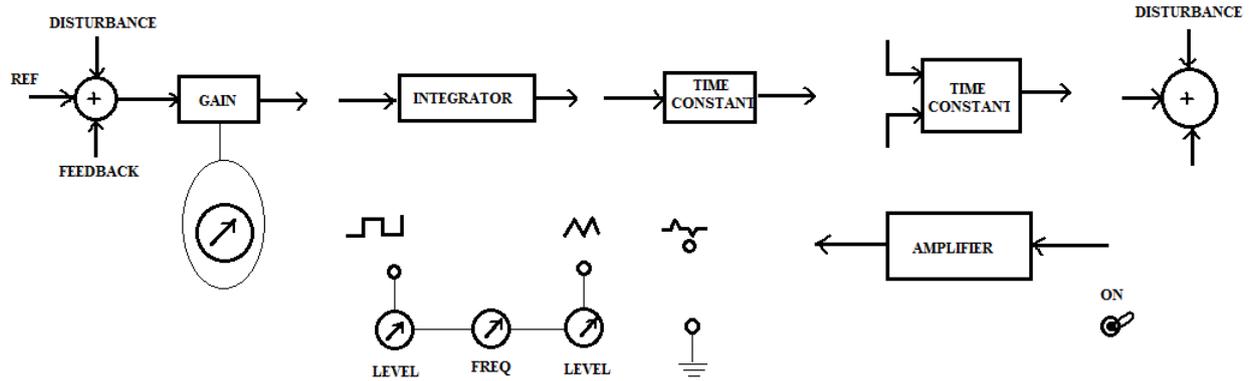
K	M_p	t_r	t_p	t_s	ζ		ω_n	
					Expt.	Theo	Expt.	Theo

LIMITATIONS OF THE SYSTEM

The accuracy of the results in an experimental measurement is always limited. Most measurements are done using a CRO which may not be better than $\pm 5\%$

QUESTIONS

1. Give an example of 1st order & 2nd order system.
2. Write down the merits & demerits of a closed loop system.
3. Develop the circuit configurations which simulate the ‘Integrator’.



PANEL DRAWING

EXPERIMENT NO. 03

SIMULATION OF STEP RESPONSE & IMPULSE RESPONSE FOR TYPE-0 , TYPE-1 & TYPE-2 SYSTEM WITH UNITY FEEDBACK USING MATLAB & PSPICE.

Objectives:

- Developing MATLAB Program to find the step & impulse response of a system.
- Building simple Simulink simulations to find step & impulse response of a closed loop system.
- Transient analysis using PSPICE

To determine the response of a system using MATLAB first the system is to be modeled to get the transfer function. The transfer function is to be expressed as a ratio of two polynomials, *numerator* polynomial & *denominator* polynomial.

Two MATLAB-vectors, one containing the coefficients of the numerator polynomial (denoted by “**num**”) taken in descending orders - and one for the denominator polynomial (denoted by “**den**”) of the transfer function are created.

Once **num** & **den** are known, MATLAB command

step(num,den) or *step(num,den,t)*

Will generate plots of the unit step responses of the given system. The user specified time is given by ‘t’ in the step command.

The unit impulse response of a system can be obtained using MATLAB command

impulse(num,den,t)

To determine the response to an arbitrary input, the command *lsim* may be used.

lsim(num,den,r,t), r is the input time function.

Another way to find the step & impulse response using MATLAB is to use **LTI Viewer**. It is a graphical user interface for viewing and manipulating response plots of LTI system.

The MATLAB command *ltiview('step',sys)* will open a window displaying the step response of the LTI model sys.

ASSIGNMENT

1. Open MATLAB command window. Observe the commands step, ramp, lsim, ltiview
2. Form a type-0, 1st order system with unity feedback. Find the step & impulse response of the system.
3. Form a type-0, 2nd order system with unity feedback. Find the step & impulse response of the system.
4. Form a type-1, 2nd order system with unity feedback. Find the step & impulse response of the system.
5. Form a type-2, 3rd order system with unity feedback. Find the step & impulse response of the system.
6. Use LTI Viewer to find the step response of the system $\frac{C(s)}{R(s)} = \frac{8}{s^2+2s+15}$. From the response determine the step response specifications.
7. Use **lsim** command to find the ramp response of the system $\frac{C(s)}{R(s)} = \frac{2}{s^2+2s+5}$
8. Use SIMULINK to compare the response obtained from the unit step input for the systems considered in question 3 and 4.

HOMEWORK:

1. Form a type-0, 3rd order system with feedback $H(S) = \frac{S}{(S+1)(S+2)}$. Find the step and impulse response of the system.
2. Use LTI Viewer to find the step response of the system $\frac{C(s)}{R(s)} = \frac{(S+2)}{(S+5)(S+7)}$. From the response determine the step response specifications.
3. Use SIMULINK to compare the response obtained from the impulse response for the system considered in question 1 and a type-1, 3rd order system with unity feedback.

EXPERIMENT NO. 04**DETERMINATION OF ROOT LOCUS, BODE- PLOT, NYQUIST PLOT USING MATLAB CONTROL SYSTEM TOOLBOX FOR 2ND ORDER SYSTEM & DETERMINATION OF DIFFERERNT CONTROL SYSTEM SPECIFICATIONS FROM THE PLOT.****Objectives:**

- Developing MATLAB Program to find the Root locus, Bode plot, Nyquist plot of open loop transfer function.
- Determining the closed loop poles from the root locus.
- To determine Frequency domain specifications from the Bode plot.

Consider open loop transfer function $sys = \frac{num}{den}$ where numerator polynomial is denoted by “**num**” & for the denominator polynomial it is denoted by “**den**”.

STABILITY USING ROUTH HURWITZ

routh(poly) makes a routh array and checks the stability of the system by finding if there are any roots on right half of the s-plane. It also displays the routh array and the reports about the stability of the system.

PLOTTING ROOT LOCI

rlocus(sys) computes and plots the root locus of the single-input, single-output LTI model denoted by open loop transfer function ‘sys’ .

rlocus(sys,k) uses a user-specified vector K of gain values.

sgrid(z,wn) plots the grid lines for the given values of damping ratio z and natural frequency wn in row vector. If it is desired to omit either the constant z lines or constant wn circles, empty brackets [] can be used in the corresponding arguments of sgrid command. For example, *sgrid(0.6, [])* will draw a line for damping ratio z=0.6 only and will not draw any circle.

rlocfind Find root locus gains for a given set of roots.

[k,poles] = rlocfind(sys) is used for interactive gain selection from the root locus plot of the SISO system SYS generated by *rlocus*. *rlocfind* puts up a crosshair cursor in the graphics window which is used to select a pole location on an existing root locus. The root locus gain associated with this point is returned in K and all the system poles for this gain are returned in POLES.

PLOTTING BODE PLOT

bode(sys) draws the Bode plot of the LTI model sys (created with either TF, ZPK, SS, or FRD). The frequency range and number of points are chosen automatically.

To specify the frequency range, use the command

w=logspace(d1,d2,n)

bode(sys,w)

Here MATLAB generates n points logarithmically equally spaced between decades 10^{d1} to 10^{d2} .

[gm,pm,wcg,wcp] = margin(sys) computes the gain margin Gm, the phase margin Pm, and the associated frequencies Wcg and Wcp, for the SISO open-loop model SYS.

DRAWING NYQUIST PLOT

The command ***nyquist(sys)*** draws the Nyquist plot of the LTI model sys (created with either TF, ZPK, SS, or FRD).

The command ***nyquist(sys,w)*** calculates the frequency response at the frequency point ω in rad/sec.

ASSIGNMENT

1. Open MATLAB command window. Observe the commands rlocus, bode, nyquist, margin.
2. Plot root locus and examine the stability of the following system using MATLAB:

$$G(S)H(S) = \frac{0.4K}{S^3 + 2S^2 + 4S + 5}$$

If the gain K is varied over a range of:

- a) K=2,4,6,8
 - b) K=2,4,6,8,10
3. Find the values of K for damping ratios mentioned in the following transfer functions using MATLAB:

- a) $\frac{K}{S(S+4)(S+5)}$ for $\xi=0.5$

- b) $\frac{K(2S+2)}{S(S+3)(S+4)}$ for $\xi=0.4$

4. Obtain the Bode diagrams for the following transfer functions in the specified frequency range using MATLAB:

$$G(S) = \frac{(S+5)}{S(S^2+3S+1)}, \omega=0.01 \text{ to } 1000 \text{ rad/sec}$$

5. Obtain the Bode plot of the system $\frac{50}{S^3+9S^2+30S+40}$. using MATLAB. From the plot determine gain margin, phase margin, gain cross-over frequency & phase cross-over frequency.
6. Consider unity feedback system with the following open-loop transfer function $G(s) = \frac{1}{s^2+s+1}$. Determine the Nyquist plot using MATLAB and examine the stability of the closed loop system.

7. Sketch a Nyquist plot for a system with the open loop transfer function (for K=10);

$$G(S) = \frac{K(1 + 0.5S)(S + 2)}{(1 + 5S)(S - 2)}$$

HOMEWORK:

1. Proof all the experimental results with theoretical calculations.
2. Consider the characteristic equations of a system are given by:

$$\text{a) } S^5 + 2S^4 + 4S^3 + 8S^2 + 3S + 1 = 0$$

$$\text{b) } S^5 + 2S^4 + 2S^3 + 4S^2 + 4S + 8 = 0$$

Check the stability with Routh-Hurwitz criterion using MATLAB.

3. Consider a unity feedback system with the following transfer function:

$$G(S) = \frac{K}{S(S^2 + 2S + 3)}$$

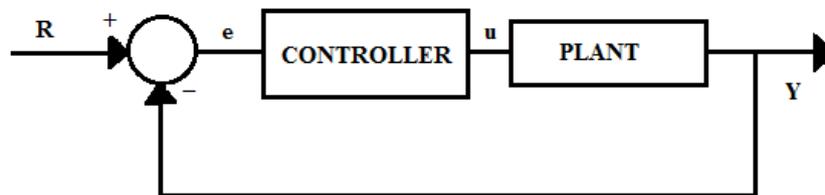
Plot the root locus and draw grid line for damping ratio, $\xi=0.5$. Determine closed loop poles that have the damping ratio $\xi=0.5$ and find the gain value, K at this point.

4. Obtain the gain and phase margins, phase cross over and phase cross over frequencies of the following transfer function: $G(S) = \frac{50}{S^3 + 9S^2 + 30S + 40}$
5. Draw a Nyquist plot using MATLAB for the following transfer function: $G(S) = \frac{S+2}{S^2-1}$ and comment on stability.

EXPERIMENT NO. 05**DETERMINATION OF PI, PD, PID CONTROLLER ACTION OF FIRST ORDER SIMULATED PROCESS.****Objectives:**

- To determine the effect of controller on a system.

To achieve the desired control action a controller is used to modify the error signal to be finally fed to the plant.



Controller can be on-off type or continuous type.

There are three basic modes of continuous control actions.

Proportional (P)

A proportional controller attempts to perform better than the On-off type by producing a control action that is proportional to the error. i.e. controller output = $K_p e$, with K_p being the proportional gain.

Derivative (D)

A derivative controller produces a control action that is proportional to the rate of change of the error. i.e. controller output = $K_d (de/dt)$, with K_d being the derivative gain.

Integral (I)

An integral controller produces a control action that is proportional to the integral of the error. i.e. controller output = $K_i \int e. dt$, with K_i being the integral gain.

The transfer function of the PID controller looks like the following:

$$K_P + \frac{K_I}{S} + K_D S = \frac{K_D S^2 + K_P S + K_I}{S}$$

The Characteristics of P, I, and D controllers are as tabulated

CLOSE LOOP RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change

Tips for Designing a PID Controller

1. Obtain an open-loop response and determine what needs to be improved.
2. Add a proportional control to improve the rise time
3. Add a derivative control to improve the overshoot
4. Add an integral control to eliminate the steady-state error
5. Adjust each of Kp, Ki, and Kd until you obtain a desired overall response.

ASSIGNMENT

1. Consider unity feedback system with the following open-loop transfer function $G(s) = \frac{10}{(s^2+s+2)}$. Determine closed loop transfer function of the system. Also determine the closed loop transfer function of the system with PD controller in the forward path with $K_P=1$ and $K_D=0.2$.

Compare the step responses for the systems –

- a. Without PD controller
- b. With PD controller

2. Consider a unity feedback system with the following open-loop transfer function

$$G(s) = \frac{1}{(s+3)}$$

Design a PI controller satisfying the following requirements :

$$\zeta = 1 \text{ and } \omega_n = 5 \text{ rad/sec}$$

EXPERIMENT NO. 06

DETERMINATION OF APPROXIMATE TRANSFER FUNCTION EXPERIMENTALLY FROM BODE PLOT.

Objectives:

- To set up a 1st order system using RC circuit.
- Determine the frequency response to develop Bode Plot Experimentally
- Determine the Transfer function from the Bode plot.

A graphical approach is usually the easiest way to analyze and design feedback systems. Bode's method consists of plotting two curves, the log of gain, and phase, as functions of the log of frequency.

Usually the gain in decibels, abbreviated dB, and the phase are plotted linearly along the y axis on graph paper that has several cycles of a log scale on the x axis. Each cycle represents a factor of ten in frequency. This special paper is known as semilog graph paper

In this experiment, we will measure the Magnitude and Phase response of a RC-electrical circuit to a sinusoid at various frequencies.

The RC circuit is as shown in the figure.

By viewing the circuit as a voltage divider, the voltage across the capacitor is:

$$V_C(s) = \frac{1/Cs}{R + 1/Cs} V_{in}(s) = \frac{1}{1 + RCs} V_{in}(s)$$

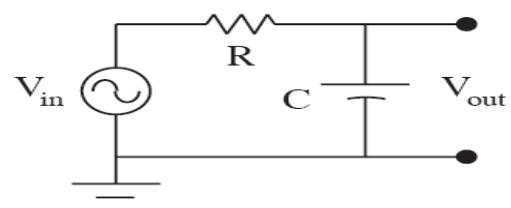
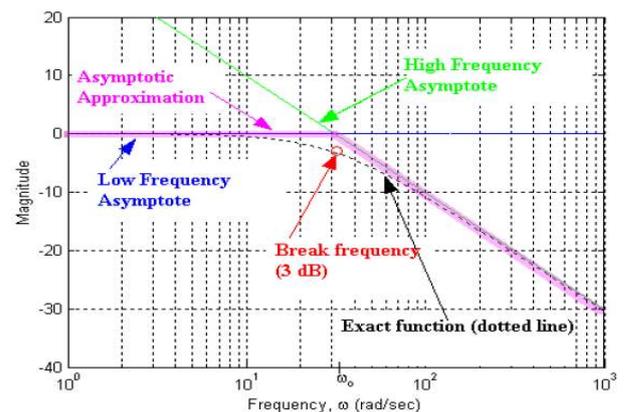
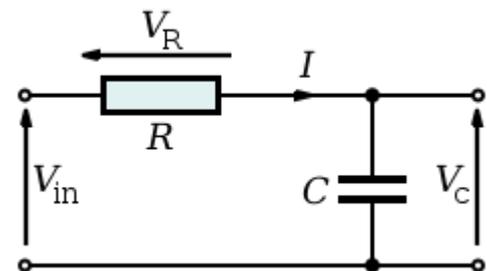
The transfer function for the circuit is

$$H_C(s) = \frac{V_C(s)}{V_{in}(s)} = \frac{1}{1 + RCs}$$

The bode plot for the system is given by as shown in the plot.

The break frequency or the corner frequency will be at

$$\omega_c = \frac{1}{RC}$$



Procedure

- Set up the RC circuit using $C = 0.1\mu\text{F}$ and $R = 1\text{K}\Omega$.
- A signal generator is used to generate variable frequency sine wave.
- Set the amplitude of the signal generator to 5 volt.
- The oscilloscope is connected to measure v_{in} and v_{out} . The peak-to-peak magnitudes of v_{in} and v_{out} are measured. The ratio of these magnitudes is equal to the transfer function magnitude.
- To measure the phase using an oscilloscope, the oscilloscope is triggered by $v_{in}(t)$, and the time per division is adjusted so that one period of v_{in} nearly fills the entire width of the screen (from the left edge of the graticule to the right edge). The trigger and horizontal position controls are adjusted so that a positive-going zero crossing of $v_{in}(t)$ occurs at the center of the screen. The positive-going zero crossing of $v_{out}(t)$ is then found, and the horizontal distance between the positive-going zero crossings of v_{out} and v_{in} is measured. The phase shift between v_{out} and v_{in} is then given by

$$\begin{aligned} \angle H(j\omega) &= \angle \hat{V}_{out} - \angle \hat{V}_{in} \\ &= (360^\circ) \frac{\text{(time between zero crossing)}}{\text{(waveform period)}} \end{aligned}$$

- Change the frequency of the signal generator and tabulate the data in Table – I.
- Draw the Bode plot using the experimental results.
- Determine the slope of the Bode plot (dB per decade) in the high or low frequency limit . Make a plot of your data together with a theoretical function drawn through (or near?) the data.
- Determine the frequency at which low frequency asymptote meets with the high frequency asymptote. This gives the corner frequency.
- Compare your measured value to the calculated value.

Table - I

Frequency(f)	V_{IN}	V_{OUT}	$ M = \left \frac{V_{OUT}}{V_{IN}} \right $	$20\text{Log}_{10} M $	Δt	φ

EXPERIMENT NO. 07

EVALUATION OF STEADY STATE ERROR, SETTING TIME, PERCENTAGE PEAK OVERSHOOT, GAIN MARGIN, PHASE MARGIN WITH ADDITION OF LEAD COMPENSATOR & BY COMPENSATOR IN FORWARD PATH TRANSFER FUNCTION FOR UNITY FEED BACK CONTROL SYSTEM USING PSPICE OR OTHERWISE.

Objectives:

- To determine the effect of adding a Lead compensator in forward path transfer function.
- To compare the unit step response parameter of an uncompensated & compensated system.

Software used – MATLAB

The most important thing for the design of the controller to control one process or a system is to select the controller that fits to the process. Selecting the appropriate controller that is suitable for the process is no less than completing 90% of the design work.

Lead Compensator or Lead Controller is the same terminology and let's call it $G_c(s)$. This consists of one pole point and one zero point and can be expressed as



$$G_c(s) = \frac{s+a}{s+b}$$

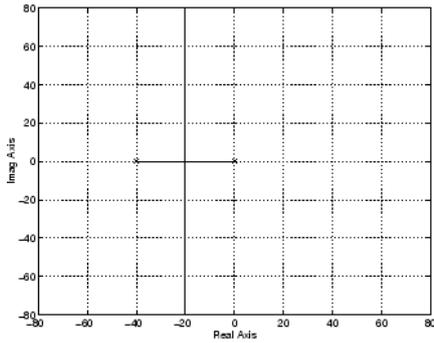
Goal of compensation is to improve system dynamics in **transient** and **steady-state** responses

Lead compensation: typically used when substantial improvement in damping is required. The effect of lead compensator is similar to that of adding a PD controller.

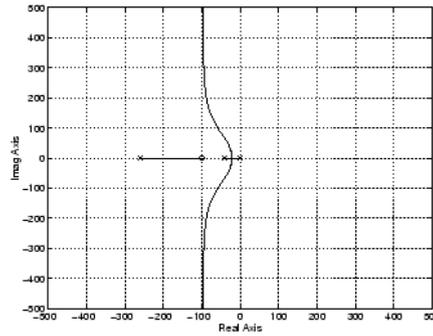
Lag compensation: to improve steady-state response characteristics without changing transient response characteristics significantly. The effect of Lag compensator is similar to that of adding a PI controller

Lead+Lag compensation : when improvements in both phase margin and low- frequency gain are needed

The lead compensator helps speed the response of the system by moving the closed-loop poles to the left. Without the lead compensator, the root locus has a vertical asymptote halfway between the integrator ($s=0$) and the open loop pole (as shown below).

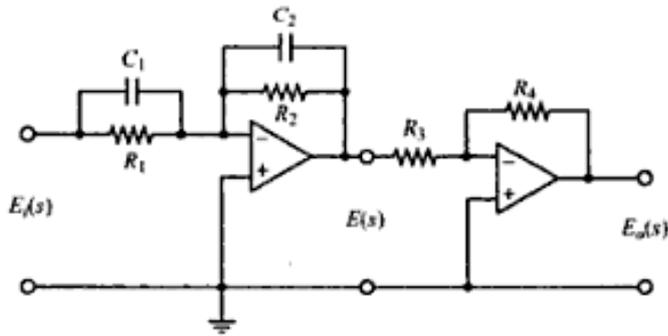


Uncompensated Root Locus



Compensated Root Locus

The lead compensator can be realized using the following circuit.



The transfer function is given by

$$\frac{E_o(s)}{E_i(s)} = \frac{R_2 R_4 R_1 C_1 s + 1}{R_1 R_3 R_2 C_2 s + 1} = \frac{R_4 C_1}{R_3 C_2} \frac{s + \frac{1}{R_1 C_1}}{s + \frac{1}{R_2 C_2}}$$

$$= K_c \alpha \frac{T s + 1}{\alpha T s + 1} = K_c \frac{s + \frac{1}{T}}{s + \frac{1}{\alpha T}}$$

where

$$T = R_1 C_1, \quad \alpha T = R_2 C_2, \quad K_c = \frac{R_4 C_1}{R_3 C_2}$$

$$\frac{E_o(S)}{E_i(S)} = \frac{R_2 R_4 R_1 C_1 S + 1}{R_1 R_3 R_2 C_2 S + 1} = \frac{R_4 C_1 S + \frac{1}{R_1 C_1}}{R_3 C_2 S + \frac{1}{R_2 C_2}}$$

$$\alpha \frac{\quad + 1}{\quad}$$

ASSIGNMENT - 1

Open-loop transfer function of a unity feedback system is given by

$$G(s) = \frac{1}{s(1 + 0.2s)}$$

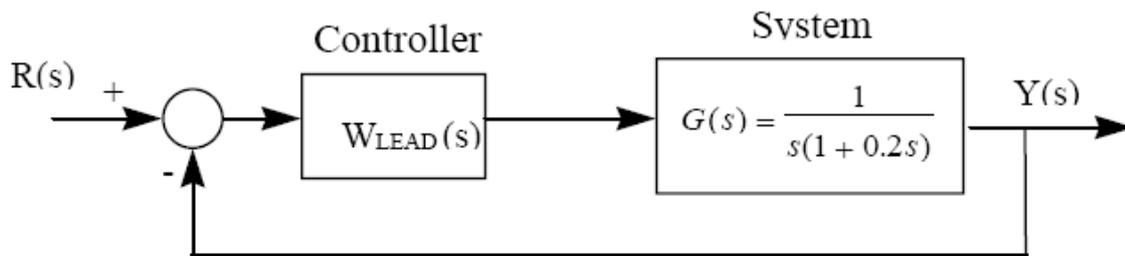
Using MATLAB plot the unit step response of the uncompensated & compensated system using lead compensator given by

$$G_c(s) = \frac{s + 0.088}{s + 0.022}$$

Compare the performance characteristics.

ASSIGNMENT - 2

Consider a unity feedback system



A lead compensator is introduced into the forward path where,

$$W_{LEAD}(s) = \frac{s + 0.3}{s + 0.03}$$

Determine the bode plot of the compensated system.

Determine the peak magnitude & the bandwidth of the closed loop frequency response.

EXPERIMENT NO. 08

STUDY OF A PRACTICAL POSITION CONTROL SYSTEM & DETERMINATION OF CONTROL SYSTEM SPECIFICATIONS FOR VARIATION OF SYSTEM PARAMETERS.

Objectives:

- To study & observe the performance characteristics of a dc angular position control system.

The schematic diagram in Fig. 1 shows the various built-in subsystems of the set up. The position control is achieved through a good quality permanent magnet dc gear motor having the specifications :

- Operating voltage – 12 V dc
- Full load current – 1.2 amp
- Rated speed – 50 rpm
- Torque (basic) – 750 gm-cm (approx)

Angular position of the motor shaft is sensed by a special 360° potentiometer attached to it. A calibrated disk mounted on the potentiometer indicates its angular position in degrees.

BACKGROUND

3.1 Position Control - a second order system

A second order system is represented in the standard form as,

$$G(s) = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

where δ is called the damping ratio and ω_n the undamped natural frequency. Depending upon the value of δ , the poles of the system may be real, repeated or complex conjugate which is reflected in the nature of its step response. Results obtained for various cases are :

(a) *underdamped case* ($0 < \delta < 1$)

$$c(t) = 1 - \frac{e^{-\delta\omega_n t}}{\sqrt{(1-\delta^2)}} \sin\left(\omega_d t + \tan^{-1} \frac{\sqrt{(1-\delta^2)}}{\delta}\right) \quad (1)$$

where, $\omega_d = \omega_n \sqrt{(1-\delta^2)}$ is termed the damped natural frequency. A sketch of the unit step response for various values of δ is available in the text books.

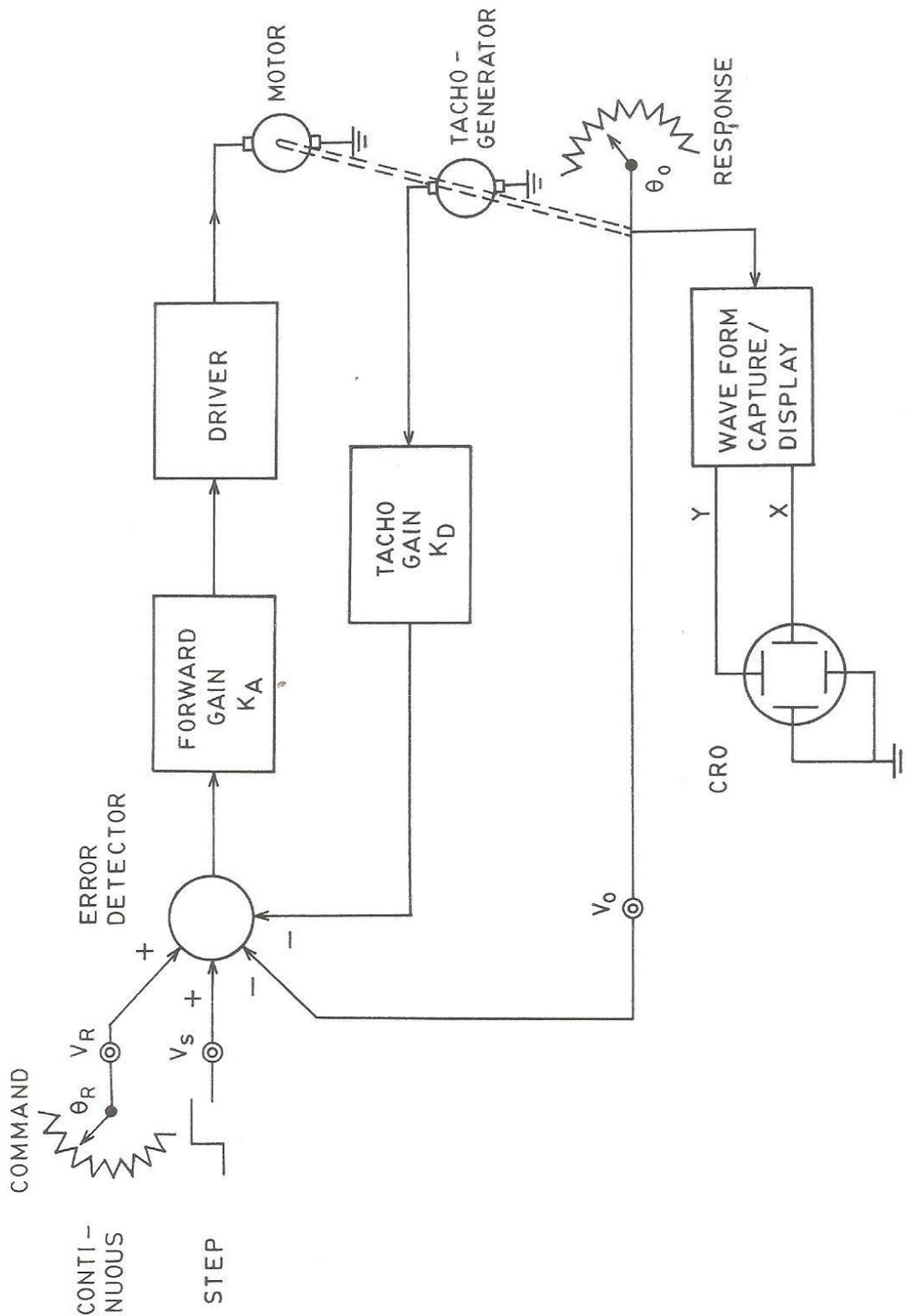


FIG. 1 SYSTEM SCHEMATIC

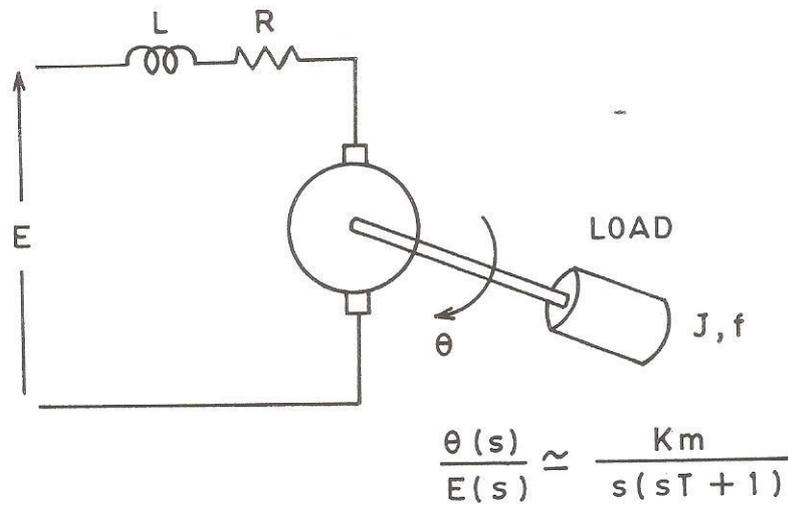


FIG. 2 TRANSFER FUNCTION OF A D.C. MOTOR

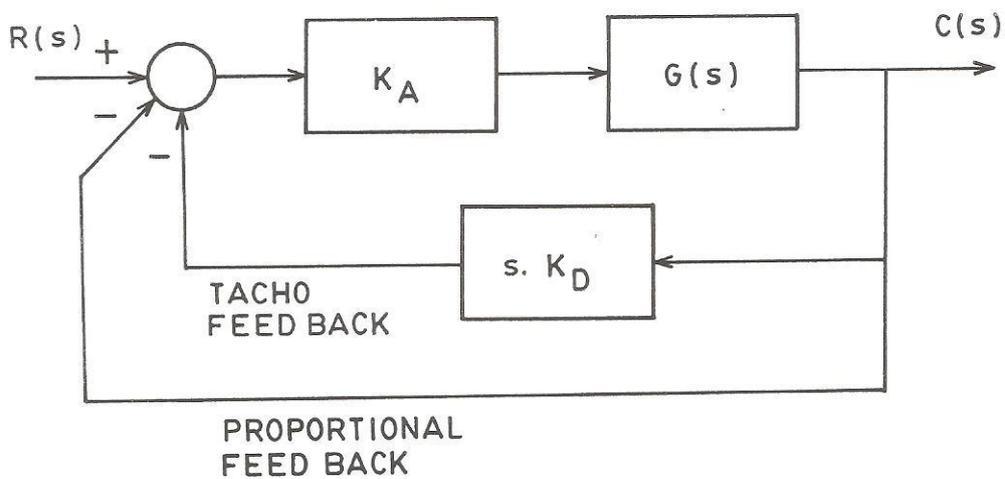


FIG. 3 SIMPLIFIED BLOCK DIAGRAM

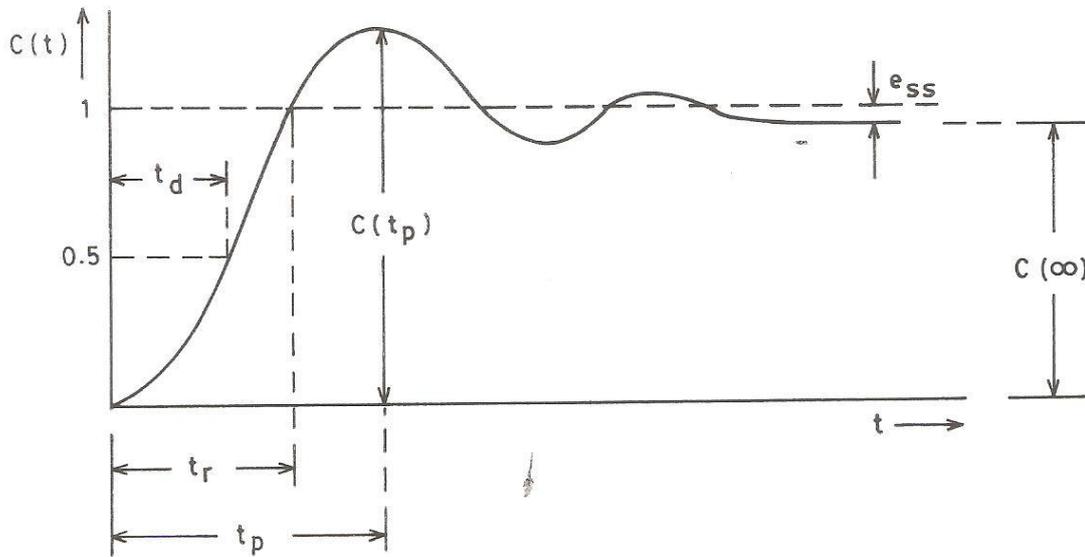


FIG. 4 NORMALIZED STEP RESPONSE OF THE SECOND ORDER SYSTEM

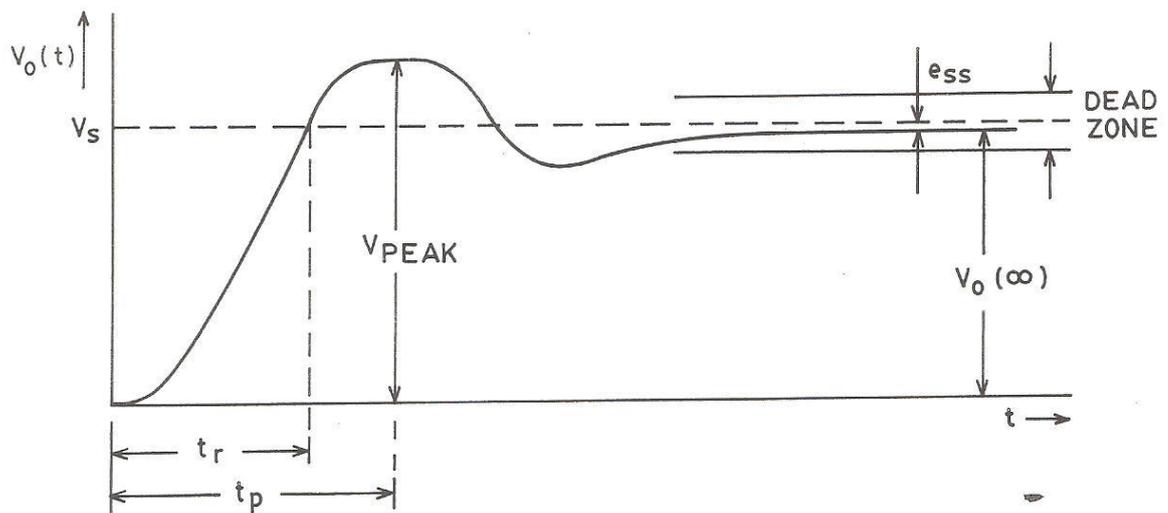


FIG. 5 TYPICAL STEP RESPONSE OF THE POSITION CONTROL SYSTEM

(b) *Critically damped case* ($\delta=1$)

$$c(t) = 1 - e^{-\omega_n t} (1 + \omega_n t) \quad (2)$$

(c) *Overdamped case* ($\delta>1$)

$$c(t) = 1 - \frac{\omega_n}{2\sqrt{(\delta^2 - 1)}} \left(\frac{e^{-s_1 t}}{s_1} - \frac{e^{-s_2 t}}{s_2} \right) \quad (3)$$

where $s_1 = (\delta + \sqrt{(\delta^2 - 1)})\omega_n$ and $s_2 = (\delta - \sqrt{(\delta^2 - 1)})\omega_n$

Referring to Fig. 2, the transfer function $G(s)$ of an armature controlled d.c. motor may be derived as [1],

$$\frac{\theta(s)}{E(s)} = G(s) = \frac{K_m}{s(sT + 1)}$$

where K_m is Motor gain constant, and T the Mechanical time constant.

Considering proportional feedback only, the close loop transfer function of the system of Fig. 3 may be obtained as,

$$\frac{C(s)}{R(s)} = \frac{K_A G(s)}{1 + K_A G(s)} = \frac{K_A K_m / T}{(s^2 + s/T + K_A K_m / T)} \quad (4)$$

This gives unit step response similar to equations (1), (2) or (3) depending upon the value of K_A . Thus the response of the position control system can be altered by varying the amplifier gain K_A , and a 'satisfactory' performance may usually be obtained. This leads to the concept of performance characteristics as defined on the step response of an underdamped second order system in Fig. 4 and explained in brief here.

(i) **Delay time**, t_d , is defined as the time needed for the response to reach 50% of the final value.

(ii) **Rise time**, t_r , is the time taken for the response to reach 100% of the final value for the first time. This is given by

$$t_r = \frac{\pi - \beta}{\omega_d}, \text{ where } \beta = \tan^{-1} \frac{\sqrt{1 - \delta^2}}{\delta}$$

(iii) **Peak time**, t_p , is the time taken for the response to reach the first peak of the overshoot and is given by

$$t_p = \frac{\pi}{\omega_n \sqrt{1 - \delta^2}}$$

(iv) **Maximum Overshoot, M_p** , is defined by

$$M_p = \frac{c(t_p) - c(\infty)}{c(\infty)} \times 100\%$$

(v) **Settling time, t_s** , is the time required by the system response to reach and stay within a prescribed tolerance band which is usually taken as $\pm 2\%$ or $\pm 5\%$. An approximate calculation based on the envelopes of the response for a low damping ratio system yields

$$t_s (\pm 5\% \text{ tolerance band}) = 3/\delta\omega_n$$

$$t_s (\pm 2\% \text{ tolerance band}) = 4/\delta\omega_n$$

Another important characteristic of a closed loop system is the steady state error, e_{ss} . For unity feedback systems e_{ss} is defined as

$$e_{ss} = \lim_{t \rightarrow \infty} e(t) = \lim_{t \rightarrow \infty} \{r(t) - c(t)\}$$

A simpler way to calculate steady state error without actually computing the time response is available in the complex frequency domain. Application of the final value theorem of Laplace Transform to unity feedback system gives,

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

CLOSED LOOP STUDY

The steps are as follows.

- Ensure that the step command is switched off
- Set $K_D = 0$.
- Set $K_A = 2$.
- Calculate $\theta_R, V_R, \theta_0, V_0$ in Table - I.
- Calculate $\Delta\theta_R, \Delta\theta_0$
- Repeat for $K_A = 4.6, 8, 10$
- Now set $K_A = 2$ and choose various values of $K_D = 0.1, 0.3, 0.5, 0.7$ and repeat the above observations in Table - II

TABLE - I

K	θ_R	$\Delta\theta_R$	θ_0	$\Delta\theta_0$	V_R	V_0

TABLE - II

K_D	θ_R	$\Delta\theta_R$	θ_0	$\Delta\theta_0$	V_R	V_0

Step response

The steps are as follows

- Set $K_D = 0$.
- Adjust reference potentiometer to get $V_R = 0$.
- Set $K_A = 5$.
- Connect the CRO, calibrate the time scale and switch to CAPTURE mode.
- Apply step input
- Trace the waveform from the CRO.
- Compute $M_p, \xi, t_p, t_r, e_{ss}$.
- Repeat for $K_A = 8, 10$
- Tabulate the results in Table - III

TABLE - III

K_A	M_p	t_p (ms)	t_r (ms)	ξ	e_{ss} (volt)	w_n

CALCULATIONS

$e_{ss} = V_s - V_o$, where V_s & V_o may be measured by DVM.

$$M_p = \frac{V_{PEAK} - V_o(\alpha)}{V_o(\alpha)} \times 100\%$$

t_p and t_r may be obtained from CRO

ξ may be calculated from M_p using the standard relation

$$M_p = \exp[-\pi\xi/(\sqrt{1-\xi^2})]$$

Thus,

$$\xi = \text{Ln } M_p / \sqrt{\pi^2 + (\text{Ln } M_p)^2}$$

ω_n is calculated from the expression of t_p which is given by $t_p = [\pi/\omega_n(\sqrt{1-\xi^2})]$

Thus

$$\omega_n = \pi / t_p (\sqrt{1-\xi^2})$$

EXPERIMENT NO. 09

DESIGN OF LEAD AND LAG COMPENSATION USING CACSAD TOOLS (Plant transfer function will be provided. Step response is to be obtained. (PSPICE, MATLAB, SciLab may be used).

Objectives:

- Introduction to SISOTOOLS.
- Design of a Compensator for a given system and its step response.

A lead-lag compensator is a component in a control system that improves an undesirable frequency response in a feedback control system.

We can realize lead and lag compensation by introducing a cascade compensator of the form

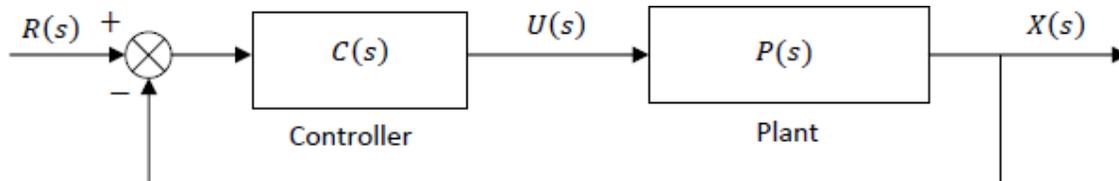
$$C(s) = \frac{K_c \cdot (s + z)}{(s + p)}$$

For Lag Compensator

$$C(s) = \frac{K_c \cdot (s + z)}{(s + p)} \text{ where } |z| > |p|$$

For Lead Compensator

$$C(s) = \frac{k \cdot (s + z)}{(s + p)} \text{ where } |p| > |z|$$

Introduction to Matlab 'sisotool'

Generic Unity Feedback Control System

A. Getting Started

- Enter the transfer function $P(s)$ for the plant, in your workspace (i.e., from the Matlab command prompt).
- Type 'sisotool' at the command prompt.
- Click **Close** when the help window comes up.
- Click on **View** → **Open Loop Bode** to turn off the bode plot. (Whatever is checked in this list will be displayed in the window.)

B. Loading the Transfer Function

1. Click on **File** → **Import**.
- A window on the left will show you the transfer functions in your workspace, while the window on the right will let you choose the control system configuration.

- We will usually be assigning $P(s)$ to block 'G' (the plant). Double-click the space next to 'G' and type your transfer function name and hit Enter. You must hit enter or nothing will happen.
- Once you hit enter, you should be able to click the OK button at the bottom of the window. Then the window will close.
- After you enter the transfer function, the root locus will be displayed. Double check to make sure that the open-loop poles and zeros of your plant are in the correct locations.

C. Generating the Step Response

- Click on **Analysis** → **Response to Step Command** .
- You will probably two curves on your step response plot. To fix this click on Analysis → Other Loop Responses... Make sure only r to y is checked, and then click OK.
- You can now click on the pink boxes on the root locus (the current closed-loop poles for the given 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.
- The values of the closed-loop poles will appear at the bottom of the root locus window as you click and hold the mouse on the pink boxes representing them. This only gives you the value of the 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.

D. Entering the Compensator (Controller)

- Click **Compensators** → **Edit** → **C**. Click on **Add Lead** or **Add Lag** to enter Compensator. You will be able to make changes to these values later. After you are done, click **OK** to exit this window.
- Look at the form of $C(s)$ to be sure it is correct. Then look at the root locus window and see how it changed once the compensator was added.
- You can again see how the step response changes with the compensator by clicking on the closed-loop poles (the pink squares) and dragging them along the root locus.
- You can also change the location of the poles/zeros of the compensator by clicking on them and dragging them. Be careful not to inadvertently change the poles and zeros of the plant.

E. Adding Design Constraints

- Click Edit → **Root Locus** → **Design Constraints** then either **New** to add new constraints or **Edit** to edit existing constraints.
- At this point you can choose from settling time, percent overshoot, damping ratio, and natural frequency constraints.

Assignment - 1

The feedback control system has

$H(s)=1$ and

$G(s) = \frac{K}{s(s+2)(s+3)}$, K is the last two digits of your roll number

Using sisotool determine

- a. The range of controller gain for the system to be stable
- b. Value of controller gain for the complex dominant-poles damping ratio of 0.6. for this value of gain obtain the frequency response GM and PM. Also obtain step response and the time-domain specifications.

Assignment - 2

For the above system design a lead-lag compensator for the following unit step response specifications.

- a. Dominant poles damping ratio $\zeta=0.707$
- b. Settling time less than 8 seconds.
- c. Peak response less than 1.2

EXPERIMENT NO. 10

Determination of Transfer Function of a given system from State Variable model and vice versa.**Objectives:**

- a. Familiarization with the MATLAB commands for state variable analysis.
 - Obtaining transfer function from a given SV model using MATLAB programming.
- b. Obtaining SV model from a given transfer function using MATLAB programming.

ASSIGNMENT - 1

1. Open MATLAB command window. Observe the commands ss2tf, tf2ss, ss2zp, eig, inv, ctrbf, obsv, lyap, canon, size, initial, rank, dsolve, plot
2. Write a matlab program to input the following two matrices

$$A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \quad B = \begin{bmatrix} 5 & 6 \\ 7 & 8 \end{bmatrix}$$

Also determine the followings

- i) $P=A+B$
- ii) $Q=\text{transpose of } B$
- iii) $R=\text{inverse of } A$
- iv) determinant of B

Check the results with theoretical calculations.

3. Find out the Eigen Values & Eigen Vectors of the following matrices.

$$\text{a) } A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$$

$$\text{b) } A = \begin{bmatrix} 4 & -1 & 5 \\ 2 & 1 & 3 \\ 6 & -7 & 9 \end{bmatrix}$$

verify the result with theoretical calculations.

ASSIGNMENT - 2

1. Given the dynamic equation

$$\frac{d^3 y}{dt^3} + 6 \frac{d^2 y}{dt^2} + 11 \frac{dy}{dt} + 6y = u, \quad t \geq 0$$

Using MATLAB program, find

a) $x(t)$ when all the initial conditions are zerob) $x(t)$ when $x(0) = 1$ & $x'(0) = 2$

(Hint : Use 'dsolve')

2. Obtain the state-space representation of the following system using MATLAB

$$\text{a) } \frac{C(s)}{R(s)} = \frac{12s + 7}{s^3 + 5s^2 + 32s + 7}$$

$$\text{b) } \frac{C(s)}{R(s)} = \frac{s^4 + 3s^3 + 12s^2 + 7s + 8}{s^5 + 9s^4 + 5s^3 + 7s^2 + 7}$$

Draw the State Diagram of the above systems.

3. Find the Transfer Function of the following systems using MATLAB program

$$\text{a) } \dot{x}(t) = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$$

$$y(t) = [1 \ 0] x(t)$$

Check the result with theoretical calculation.

$$\text{b) } \dot{x}(t) = \begin{bmatrix} 0 & 3 & 7 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -5 & -6 & 9 & 5 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 5 \\ 7 \\ 2 \end{bmatrix} u(t)$$

$$y(t) = [1 \ 3 \ 6 \ 5] x(t)$$

4. Find the Unit Step response of the following systems using MATLAB program

$$\text{a) } \dot{x}(t) = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$$

$$y(t) = [1 \ 0] x(t)$$

EXPERIMENT NO. 11

Analysis of performance of a physical system using State variable technique by simulation. Study of step response and initial condition response for a single input, two-output system in SV form by Study simulation.

Objectives:

- Familiarization with the MATLAB commands for state variable analysis.
- Obtaining step response and initial condition response for a SISO system given in SV form using MATLAB programming
- Obtaining step response and initial condition response for a Two input system given in SV form using MATLAB programming .

ASSIGNMENT – 1

- Open MATLAB command window. Observe the commands jordan, fliplr, flipud, ctrbf, obsv, initial, kalman, acker, place.
- Write a MATLAB program to determine the STM for the given A matrix as

$$a. \quad A = \begin{bmatrix} 0 & -1 \\ 2 & -3 \end{bmatrix}$$

Verify the result by theoretical calculation.

$$b. \quad A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -6 & -11 & -5 \end{bmatrix}$$

ASSIGNMENT – 2

- Find the Unit Step response of the following system using MATLAB program

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -5 & -17 & -5 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} u$$

$$y = \begin{bmatrix} 0 & 25 & 5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

Also find out the response for the initial conditions

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 2 \\ 0 \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 5 \\ 7 \end{bmatrix}$$

2. Solve the problem stated in 1. Using SIMULINK
3. Find the Unit Step response of the following system using MATLAB program

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -1 & -1 \\ 7 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Also find out the response for the initial conditions

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 1 \\ 5 \end{bmatrix}$$

Verify the result with theoretical calculation.

ASSIGNMENT – 3

1. Test the Controllability and Observability of the following systems

a)
$$\dot{x}(t) = \begin{bmatrix} -0.5 & 0 \\ -0 & -2 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$$

$$y(t) = \begin{bmatrix} 0 & 1 \end{bmatrix} x(t)$$

b)
$$\dot{x}(t) = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & -3 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} u(t)$$

$$y(t) = \begin{bmatrix} 1 & 0 & 2 \end{bmatrix} x(t)$$

2. Write a MATLAB program to determine the state feedback gain matrix so that closed loop poles are located at -2, -5 & -6

c)
$$\dot{x}(t) = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -30 & -11 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u(t)$$

$$y(t) = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} x(t)$$

Verify obtained result with theoretical calculations

HINTS : Use 'place' or 'acker' command

3. For the system below using SIMULINK consider:

$$\dot{x}(t) = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -2 & -3 & -4 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} u(t) \quad \text{and} \quad y(t) = [1 \ 0 \ 0] x(t)$$

find the response due to initial condition $x(0) = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}$

- a. find the response due to an input $u(t)$, shown below.

