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Via 5th APSP Battalion, Jonnada (V), Denkada (M), NH-3, Vizianagaram Dist - 535005, A.P. Website : www.lendi.org
Ph : 08922-241111, 241666, Cell No : 9490344747, 9490304747,e-mail : lendi_2008@yahoo.com

Department of Electrical and Electronics Engineering

LAB MANUAL

Name of the Faculty: Dr Parusharamulu Buduma

Name of the laboratory: CONTROL SYSTEM

Regulation: R23

Subject Code: R23EEE-PC2205

Branch: Electrical and Electronics Engineering

Year & Semester: II B.Tech- II Semester

INSTITUTE VISION, MISSION

DEPARTMENT VISION, MISSION

PEO & PO/PSO

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

VISION

To be a center of excellence in imparting knowledge, skills, and ethical values, while fostering innovation, sustainability and globally competent to make exemplary contributions to the field of Electrical and Electronics Engineering.

MISSION

- To impart technical education using state-of-the-art infrastructure, laboratories, and instructional methods, ensuring students acquire comprehensive knowledge and skills.
- To foster industry-oriented learning by facilitating internships, industrial visits, collaborative projects with industries.
- To create a congenial environment for higher education, employment, and entrepreneurship by delivering quality education, enhancing professional skills and promoting research and innovation.
- To promote societal commitment and ethical leadership by instilling moral values and encouraging responsible engineering practices among students.

PROGRAM EDUCATIONAL OBJECTIVES

1. Graduates will possess a strong foundation in core and interdisciplinary areas of Electrical and Electronics Engineering along with analytical and computational skills, enabling them to tackle global challenges through innovative and critical problem-solving.
2. Graduates will actively engage in research, entrepreneurship, and innovation to address contemporary challenges in Electrical and Electronics Engineering while promoting sustainable and inclusive technological development for the betterment of society.
3. Graduates will exhibit effective communication skills, collaborative abilities, and ethical values, preparing them for successful careers, higher education, and leadership roles in a rapidly evolving competitive environment.

PROGRAM OUTCOMES (POs)

PO1 Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO2 Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3 Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4 Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5 Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6 The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7 Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8 Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9 Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10 Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11 Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12 Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOMES (PSOS):

PSO1: Capable of design, develop, test, verify and implement electrical and electronics engineering systems and products.

PSO2: Succeed in national and international competitive examinations for successful higher studies and employment.

COURSE OUTCOMES (COs)

1. Analyse the time response of system (first order and second order system)
2. Design of PID controllers and compensators
3. Determine the transfer function of D.C Motor
4. Judge the stability in time and frequency domain and Kalman's test for controllability and observability
5. Analyse the potentiometer and determine the state space analysis concepts to represent physical systems as state models in MATLAB

Course code	Course Title	L	T	P	Credits
R23EEE-PC2205	Control Systems Lab	0	0	3	1.5

Course Objectives:

- To impart hands on experience to understand the performance of basic control system components such as magnetic amplifiers, D.C. servo motors, A.C. Servo motors and Synchro's.
- To understand time and frequency responses of control system with and without controllers and compensators.

Course Outcomes: At the end of the course, the student will be able to,

1. Analyse the time response of system (first order and second order system).
2. Design of PID controllers and compensators.
3. Determine the transfer function of D.C Motor
4. Judge the stability in time and frequency domain and Kalman's test for controllability and observability
5. Analyse the potentiometer and determine the state space analysis concepts to represent physical systems as state models in MATLAB

List of Experiments any 10 of the following experiments are to be conducted:

1. Analysis of First order system in time domain (For Step, Ramp Inputs)
2. Analysis of Second order system in time domain (For Step, Ramp Inputs)
3. Effect of P, PD, PI, PID Controller on a second order systems
4. Design of Lag Compensation - Magnitude and phase plot
5. Design of Lead Compensation - Magnitude and phase plot
6. Transfer function of DC Motor
7. Potentiometer as an error detector
8. Stability analysis of Linear Time Invariant system using Root Locus Technique (MATLAB)
9. Stability analysis of Linear Time Invariant system using Bode Plot Technique (MATLAB)
10. Stability analysis of Linear Time Invariant system using Nyquist Plot Technique (MATLAB)
11. Kalman's test of Controllability and Observability using MATLAB.
12. State space model for classical transfer function using MATLAB.

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LIST OF THE EXPERIMENTS WITH CO-PO MAPPING

S. No	Name of the Experiment	CO	PO/PSO
1.	Analysis of Second order system in time domain (For Step, Ramp Inputs)	CO1	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
2.	Effect of P, PD, PI, PID Controller on a second order systems	CO2	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
3.	Design of Lag Compensation - Magnitude and phase plot	CO2	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
4.	Design of Lead Compensation - Magnitude and phase plot	CO2	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
5.	Transfer function of DC Motor	CO3	PO1,PO2,PO3,PO4,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
6.	Stability analysis of Linear Time Invariant system using Root Locus Technique using MATLAB	CO4	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
7.	Stability analysis of Linear Time Invariant system using Bode Plot Technique using MATLAB	CO4	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
8.	Stability analysis of Linear Time Invariant system using Nyquist Plot Technique using MATLAB	CO4	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
9.	State space model for classical transfer function using MATLAB	CO5	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
10.	Potentiometer as an error detector	CO5	PO1,PO2,PO3,PO4, PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
Additional Experiments			
1.	Analysis of First order system in time domain (For Step, Ramp Inputs)	CO1	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2
2.	Kalman's test of Controllability and Observability using MATLAB	CO4	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8, PO9,PO10,PO11,PO12,PSO1,PSO2

Course Outcomes	Bloom's Taxonomy
CO-1: Analyse the time response of system (first order and second order system)	L4
CO-2: Design of PID controllers and compensators	L3
CO-3: Determine the transfer function of D.C Motor	L5
CO-4: Judge the stability in time and frequency domain and Kalman's test for controllability and observability	L5
CO-5: Analyse the potentiometer and determine the state space analysis concepts to represent physical systems as state models in MATLAB	L5

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INDEX

S. No	Name of the Experiment	CO	PO/PSO	Page No:	Remarks
1.	Analysis of Second order system in time domain (For Step, Ramp Inputs)	CO1	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
2.	Effect of P, PD, PI, PID Controller on a second order systems	CO2	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
3.	Design of Lag Compensation - Magnitude and phase plot	CO2	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
4.	Design of Lead Compensation - Magnitude and phase plot	CO2	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
5.	Transfer function of DC Motor	CO3	PO1,PO2,PO3,PO4,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
6.	Stability analysis of Linear Time Invariant system using Root Locus Technique using MATLAB	CO4	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
7.	Stability analysis of Linear Time Invariant system using Bode Plot Technique using MATLAB	CO4	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
8.	Stability analysis of Linear Time Invariant system using Nyquist Plot Technique using MATLAB	CO4	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
9.	State space model for classical transfer function using MATLAB	CO5	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
10.	Potentiometer as an error detector	CO5	PO1,PO2,PO3,PO4, PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
Additional Experiments					
1.	Analysis of First order system in time domain (For Step, Ramp Inputs)	CO1	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		
2.	Kalman's test of Controllability and Observability using MATLAB	CO4	PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2		

EXPERIMENT-1

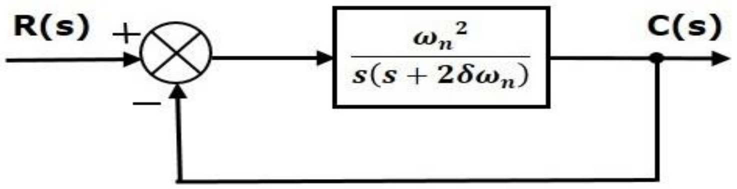
TIME RESPONSE OF SECOND ORDER CONTROL SYSTEM

Aim: To determine the time response specifications of second order system

Apparatus: Time response characteristics apparatus, CRO, patch chords etc or MATLAB software package

Theory:

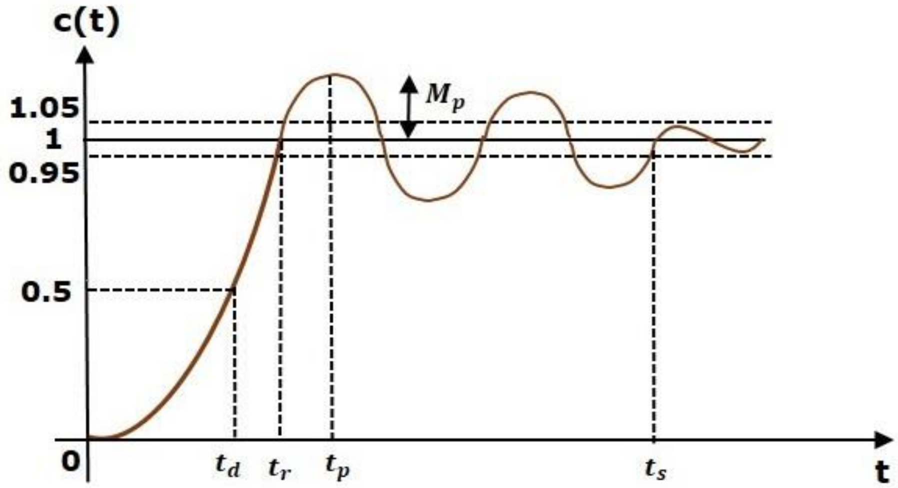
Second order control systems are characterized by two poles and two zeros. For the purpose of transient response studies usually zeros are not considered primarily because of simplicity in calculation and also because the zeros do not affect the internal nodes of the system.



Overall transfer function of the second order system in standard form is given by

$$T(S) = \frac{C(S)}{R(S)} = \frac{W_n^2}{S^2 + 2\xi w_n S + w_n^2}$$

When ξ is called damping ratio, W_n is the un-damped natural frequency. In order to analyze the transient behavior of the control systems, the first step is to obtain the mathematical model of the system these dynamic behavior is analyzed under the application of standard test signals is generally used for testing as it can be easily generated. The time response performance is measured by computing time response performance is indicated below.



1. **Delay time (t_d):** It is the time required for the response to read 50% of the final value in first attempt.

$$t_d = \frac{1+0.7\xi}{W_n}$$

2. **Rise time (t_r):** It is the time required by the response to rise from 10% to 90% of final value for over-damped systems and 0 to 100% of the final value for under-damped system.

$$t_r = \frac{\Pi - \theta}{W_d};$$

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

$$W_d = W_n\sqrt{1-\xi^2}$$

3. **Peak time (t_p):** It is the time required for the response to reach the peak of time response or peak overshoot.

$$t_p = \frac{\Pi}{W_n\sqrt{1-\xi^2}}$$

4. **Peak overshoot (μ p):** It indicates the normalized difference between the time response peak and steady state output and is defined as

$$\mu_p = e^{-\xi\,\pi/\sqrt{1-\xi^2}}$$

5. **Settling time (t_s):** It is the time required for the response to reach and stay within a specified Tolerance level (usually 2 % or 5% of its final value)

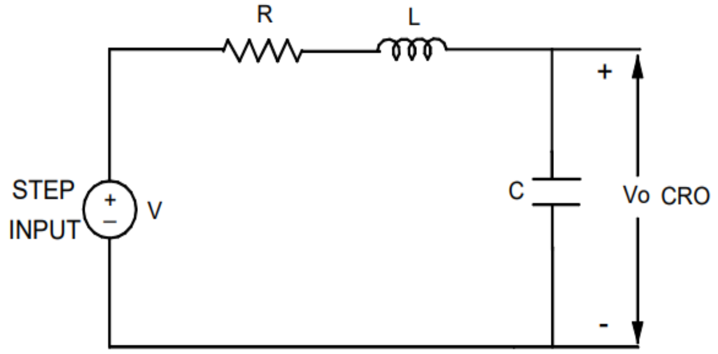
   i. For tolerance band of 2 % $= \frac{4}{\xi W_n}$

   ii. For tolerance band of 5 % $= \frac{3}{\xi W_n}$

6. **Steady state error (e_{ss}):** It indicates the error between the actual and derived o/p as it tends to infinity.

   i. Ess = $\underset{f\to\infty}{lt}\{1-C(t)\}$

Circuit Diagram:



Calculations:

$$\omega_n = \frac{1}{\sqrt{(LC)}}$$

$$R = \frac{2\delta}{\sqrt{(C/L)}}$$

I Under damped case [0 < δ <1]

Let δ = 0.158

C = 0.01 uF L = 100 mH

$$R = \frac{2\delta}{\sqrt{(C/L)}} = \frac{2 \times 0.158}{\sqrt{(0.01 \times 10^{-6} / 100 \times 10^{-3})}} = 1\ k\Omega$$

Therefore Choose R1

II Critically damped case [δ=1]

Let δ = 1.0

C = 0.01 uF L = 100 mH

$$R = \frac{2\delta}{\sqrt{(C/L)}} = \frac{2 \times 1.0}{\sqrt{(0.01 \times 10^{-6} / 100 \times 10^{-3})}} = 6.32\ k\Omega$$

Therefore Choose R2

III Over damped case [δ>1]

Let δ = 1.58

C = 0.01 uF L = 100 mH

$$R = \frac{2\delta}{\sqrt{C/L}} = \frac{2 \times 1.58}{\sqrt{(0.01 \times 10^{-6} / 100 \times 10^{-3})}} = 10\ k\Omega$$

Therefore Choose R3

For under damped case:

$$\omega_n = 1/\sqrt{(LC)} = 1/\sqrt{(100 \times 10^{-3} \times 0.01 \times 10^{-6})}$$

$$= 31622 \text{ rad/sec}$$

$$\omega_d = \omega_n\sqrt{(1-\delta^2)} = 31622\sqrt{(1-0.158^2)}$$

$$= 31224 \text{ rad/sec}$$

1). **Delay time (t_d):**

$$t_d = [1 + 0.7\delta] / \omega_n \quad \text{Sec.}$$

$$t_d = [1 + 0.7 \times 0.158] / 31622$$

$$= 35.12\ \mu S$$

2). **Rise time (t_r):**

$$t_r = \frac{\Pi - \theta}{\omega_d}$$

$$\theta = \tan^{-1}\left(\frac{\sqrt{1-\delta^2}}{\delta}\right) = \mathbf{1.42\ rad}$$

$$t_r = \frac{\Pi - \theta}{\omega_d} = \frac{3.142 - 1.42}{31224} = 55.14\ \mu S$$

3). **Peak time (t_p):**

$$t_p = \Pi / \omega_d = 3.142/31224 = 100.62\ \mu S$$

4). **Peak overshoot (Mp):**

$$\%\ \text{peak overshoot } Mp = [e^{-\delta\Pi / (\sqrt{(1-\delta)})}]\ x100$$

$$= [e\text{-}0.158\Pi / (\sqrt{(1\text{-}0.158)})]\ x100$$

$$= 66.33\ \%$$

5). **Settling time (t_s):**

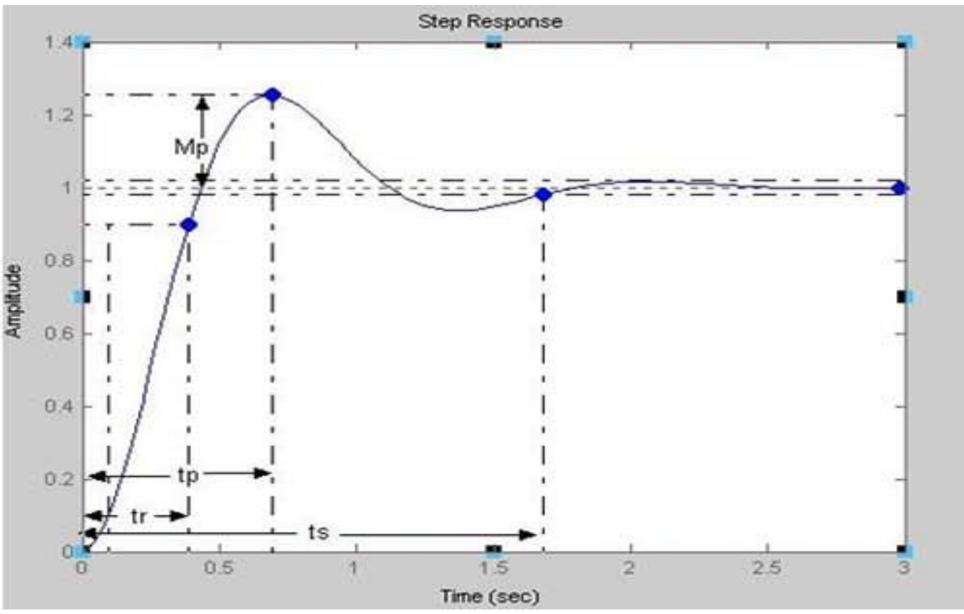
$t_s = 4/\ \delta\omega_n$ for ± 2% tolerance. $t_s = 4/\ 0.158 \text{ x } 31622$

$= 0.\ 8$ mS

$t_s = 3/\ \delta\omega_n$ for ± 5% tolerance. $t_s = 3/\ 0.158 \text{ x } 31622$

$= 0.6$ mS

Model Graph:



Procedure:

1. Connections are made for under damped case.
2. For δ = 0.158 (less than 1) (R = 1kΩ, L = 100 mH, C = 0.01 uF) & find the values of td, tr, tp, Mp, & ts theoretically for under damped case.
3. Connect the square input say (10 Volts) by using signal source.
4. Take the output across the capacitor and observe the output waveforms in the CRO.
5. Find tr, tp, mp, & ts practically from the waveforms for the underdamped conditions.
6. Connections are made for critically damped case note down rise time tr using CRO.
7. Connections are made for over damped case note down rise time tr using CRO.
8. Draw all the three wave forms on the graph sheet for different δ.

OR

Procedure: **(Simulation Method)**

1. Open the MATLAB software.
2. Open file and click new option.
3. Click on the model option.
4. Design the block diagram of given unity feedback controller system by using proper modules that are available in the SIMULINK LIBRARY in the model file.
5. Run the simulink model by clicking on RUN symbol available on the window and Double click on the scope to observe response.
6. Calculate Td, Tr, Tp, Ts and % Mp from the obtained response.

OR

Procedure: **(Program Method)**

1. Open the MATLAB software.
2. Open file and click new M-file option.
3. Enter the below program

```
clc
clear
num=[       ];
den= [             ];
sys= tf(num, den)
step(sys, 20)
```

4. Click on Run symbol available on the window and observe response in command window.
5. Calculate Td, Tr, Tp, Ts and % Mp from the obtained response.

Observatios:

S. No.	Theritical values	Practical values
t_d	35.12 Ms	
t_r	55.14 µS	
t_p	100.62 µS	
M_p	66.33 %	
t_s	0. 8 mS for ± 2%	
	0. 6 mS for ± 5%	

Precautions:

1. Handle the instruments gently and avoid errors while observing the waveforms.

Result: Time domain specifications of the under damped second order system are calculated and compared with practical readings. Influence of damping factor on the time response is observed

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

EXPERIMENT-2

PID CONTROLLER

Aim: To study the effect of P, PD, PI, and PID Controller on a second order system.

Apparatus required:

1. PID controller kit.

2. Connecting wires

Theory:

To meet two independent specifications a second order systems need modifications. This modification is termed as compensation should allow for high open loop gains to specification steady state accuracy and yet preserve a satisfactory dynamic performance. Some of the practical modification schemes are discussed below.

Derivative Error Compensation:

A system is said to possess derivative error compensation when the generation of its output depends in some way on the rate of change of actuating signal. A controller producing such a signal is called a proportional plus derivative controller or PD controller. The advantage here is that as the damping increases due to compensation with ω_n remaining fixed, the system setting time reduces.

Integral Error Compensation:

In this scheme, the output response depends is some manner up on the integral of the actuating signal. This type of compensation is introduced by using a controller, which produces an output signal consisting of two terms, one proportional to the actuating signal and other proportional to its integral. Such a controller is called proportional plus Integral or PI controller. This scheme is used to have high accuracy requirements.

Proportional + Integral Plus Derivative Controller:

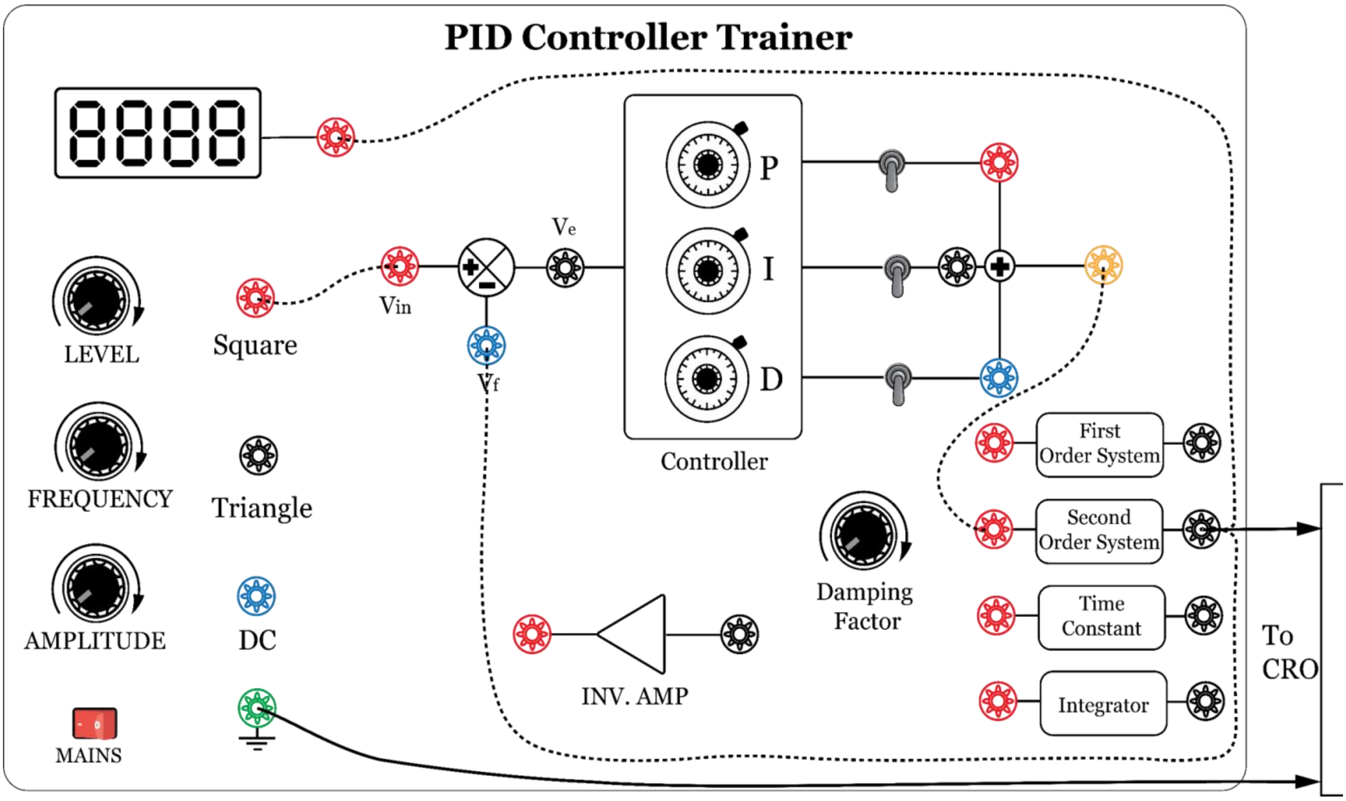
Error integration in the forward path eliminates steady state velocity error but it increases systems order making it more susceptible to instability. It also introduces a zero into the forward path so that peak overshoot to step i/p cannot be easily eliminated. To increase the damping factor of the dominant poles of a PI controlled system, we take advantage of adding with derivative system.

Tuning Rules for PID Controllers:

If a mathematical model of a plant can be derived, then it is possible to apply various design techniques for determining parameters of the controller that will meet the transient and steady state specifications of the closed loop system. However, if the plant is so complicated that its mathematical model cannot be easily obtained, then an analytical approach to the design of a PID controller is not possible. Then we must resist to experimental approaches to the running of PID controllers.

The process of selecting the controller parameters to meet given performance specifications is known as controller tuning. Ziegler and Nichols suggested rules for tuning PID controllers to set values of K_p, Ti, Td based on transient response characteristics of a given plant.

Circuit Diagram:



Procedure:

1. Switch ON the main supply to unit, observe input square wave amplitude in CRO. Set the peak-to-peak voltage of square wave input is equal to 3V by varying the potentiometer.
2. Give the connections as given in the diagram.

3. Connect the CRO at the output terminals.
4. Keep the controllers switches in ON position based on the type of controller.
5. Vary the gain knobs of controllers and take readings of delay time, raise time, peak time, raise time, peak overshoot, settling time, and steady state error.
6. After taking the readings from CRO, turn OFF the supply.

Precautions:

- Handle the instruments gently

Result:

From the observation tables, we can conclude that,

- Proportional controller has steady state error, due to it increases the gain of closed loop system (Note: PD controller also has steady state error).
- For PI controller, steady stare error is zero, because PI controller increases the type number by one (Note: for PID controller also, steady state error is zero)
- For PD controller, transient performance is improved, i.e., rise time, delay time reduced.
- For PID controller, both steady state and transient performance of the system are improved.

Observation Tables:

Proportional Controller:

Proportional Controller Gain, K_p=5	
Delay Time, t_d	5.6 ms
Rise time t_r	26.40 ms
Peak time, t_p	-
Settling time, t_s	26.40
Peak Overshot, M_p (%)	-
Steady Stare Error e_{ss}	0.44V

Proportional-Integral Controller:

Controllers Gain, K_p=5, and K_I=3	
Delay Time, t_d	6 ms
Rise time t_r	47.6ms
Peak time, t_p	-
Settling time, t_s	47.6 ms
Peak Overshot, M_p (%)	-
Steady Stare Error e_{ss}	0

Proportional-Differential Controller:

Controllers Gain, K_P=5, and K_D=4	
Delay Time, t_d	4.5 ms
Rise time t_r	28 ms
Peak time, t_p	-
Settling time, t_s	28 m
Peak Overshot, M_p (%)	-
Steady Stare Error e_{ss}	0.44V

Proportional-Differential Integral Controller:

Controllers Gain, K_p=5, K_D=4, and K_I=3	
Delay Time, t_d	6.40 ms
Rise time t_r	35.60 ms
Peak time, t_p	-
Settling time, t_s	35.60 ms
Peak Overshot, M_p (%)	-
Steady Stare Error e_{ss}	0

Precautions

1. Readings should be taken without any errors.
2. Excessive increase of k_i results in an inferior transient response. Hence experiment is performed at low values of k_i.

Result:

Hence the effect of P, PI, PD and PID Controller on second order system has been conducted.

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

Viva Questions:

1. Write few lines about ‘P’ Controller?
2. Write about ‘I’ controller & how it influence the steady state error?
3. Write about ‘D’ controller & how it influence the peak over shoot?
4. How to set the values of P, I, D?
5. Effect of Integral gain & differential gain on steady state & transient performance of the system?

EXPERIMENT-3

LAG COMPENSATION – MAGNITUDE AND PHASE PLOT

Aim: To plot the response of Lag compensators – magnitude and phase plot.

Components Required:

1. Resistor - 10 kΩ
2. Capacitor – 0.1 μF
3. Lag – Lead Compensation Kit
4. Cathode Ray Oscilloscope
5. Probes and Patch Cords

Theory:

All the control systems are designed to achieve specific objectives. A good control system has less error, good accuracy, good speed of response, good relative stability, good damping which will not cause under overshoots etc. For satisfactory performance of the system, gain is adjusted first. In practice, adjustment of gain alone cannot provide satisfactory results. This is because when gain is increased, steady state behavior of the system improves but results into poor transient response, in some cases may even instability. In such cases it is necessary to redesign the entire system. Practically the design specifications are provided in terms of precise numerical values according to which the system is designed. The set of such specifications include peak overshoot, peak time, W_n , k_p , k_v , k_a , G.M and P.M. etc. In practice, if a system is to be redesigned so as to meet the required specifications, it is necessary to alter the system by adding an external device to it. Such a redesign or alteration of system using an additional suitable device is called compensation of a control system. While an external device, which is used to alter the behavior of the system so, as to achieve given specification is called compensator.

Compensating Networks:

The compensator is a physical device. It may be an electrical network, mechanical unit, pneumatic, hydraulic or combination of various types of devices.

The commonly used electrical compensating networks are

1. Lead network or Lead Compensator
2. Lag network or Lag Compensator

1. Lead Network: When a sinusoidal i/p is applied to a network and it produces a sinusoidal

steady o/ p having a phase lead w.r.t. i/p then the network is called Lead network. The transfer Function of Lead Compensator is

$$\frac{E_0(s)}{E_1(s)} = \frac{S+\frac{1}{T}}{S+\frac{1}{\alpha T}} \; ; \text{T = R1C} \; \alpha = \frac{R^2}{R_1+R_2} < 1$$

2. Lag Network: If the steady state output has phase lag then the network is called lag network. The transfer function of lag compensator is

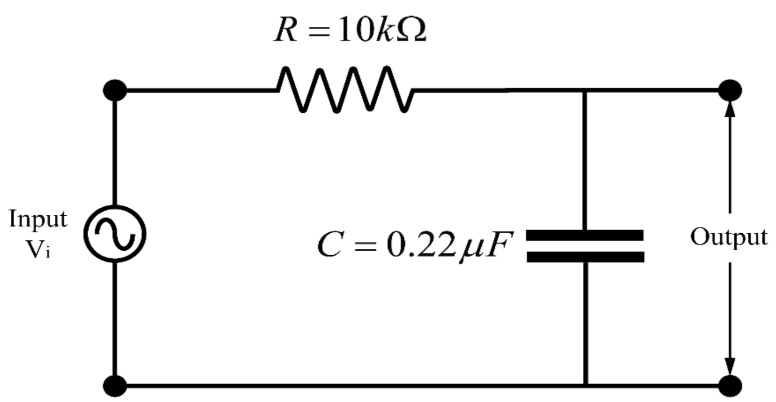
$$\frac{E_0(s)}{E_1(s)} = \frac{1}{\beta}.\frac{S+\frac{1}{T}}{S+\frac{1}{\beta T}} \; ; \text{T = R2C;} \; \beta = \frac{R_1+R_2}{R_2} > 1; \; T(s) = \frac{1+ST}{1+S\beta T}$$

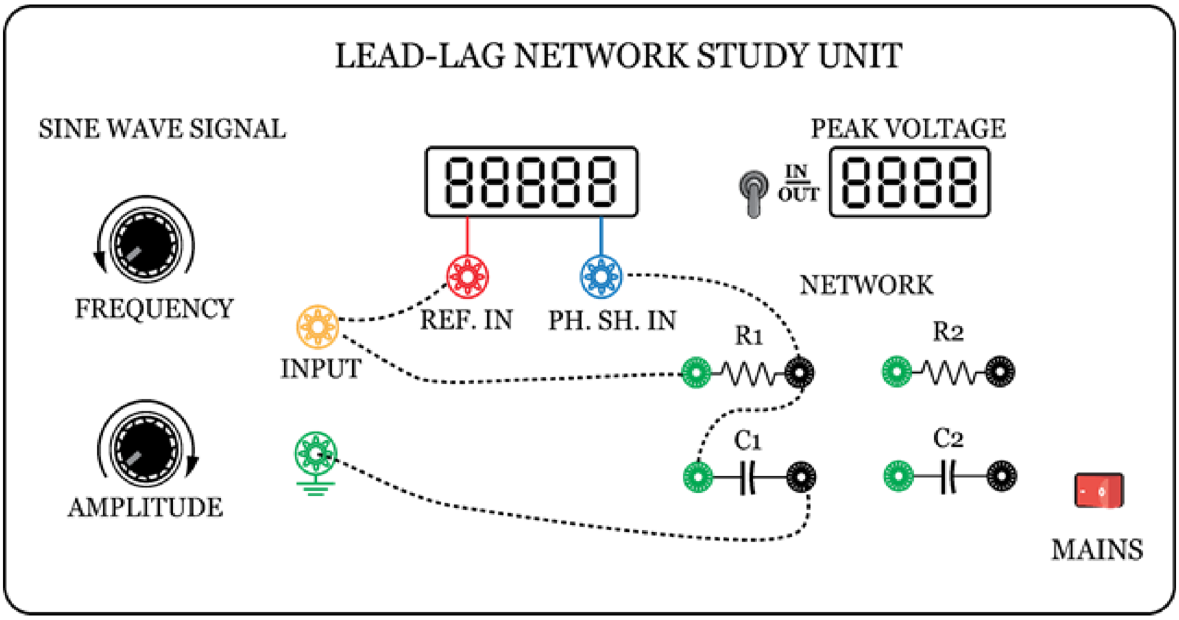
Effects of lag compensation

1. Lag compensator allows high gain at low frequencies then it is basically a low pass filter. If improves the steady state performance.
2. The alternation characteristics is used for the compensation. The phase lag characteristics are of no use in the compensation.
3. The alternation due to lag compensator shifts the gain cross – over frequency to a lower frequency pt. Thus the BW of the system gets reduced.
4. Reduced BW means slower response. Thus rise time & settling are usually longer. The transient response lasts for longer time.
5. The system becomes more sensitive to the parameter variation.
6. It approximately cuts as proportional plus integral controller and then to make system less stable.

Circuit Diagram:-

Lag Compensator Network:





Observations:

Table 1: Observation Table for Lag Compensator

Frequency (Hz)	Phase Angle (degree)	Output, Vo (Volts)	Gain= $20\log\frac{V_o}{V_i}$
84	2	2.79	-0.630
101	3	2.77	-0.692
133	4	2.76	-0.724
164	5	2.76	-0.724
200	6	2.75	-0.755
261	8	2.73	-0.819
327	10	2.71	-0.880
554	16	2.62	-1.176
812	23	2.49	-1.618
1041	28	2.34	-2.150
1655	29	1.96	-3.690
2057	44	1.74	-4.730

Procedure:

Lag Compensator

1. Connections are made as per the Circuit diagram shown in Fig 2 so as to form a phase lag network by selecting R1 = 10kΩ, R2 = 10kΩ and C = 0.22 µF.
2. Switch ON the supply.
3. Using the CRO in X – Y mode, give input of the network to X – input of CRO and output of the network to Y – input of CRO.
4. Set the sine wave amplitude to 3V.
5. Now vary the frequency from 25 Hz to 2000 Hz in steps and note down the readings in the Table given below:
6. Calculate the gain and phase difference from the readings.
7. Now calculate the theoretical values of gain and phase difference.
8. Draw the Bode plot for both the theoretical & Practical Values.

Result:

Frequency response of lag and lead compensators is studied, and magnitude and phase angle pots are drawn. From the output,

- In lag compensator as the frequency increases, output voltage decreases and goes out of phase.

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

Viva Questions:

1. What you mean by gain margin & phase margin?
2. What is the function of a compensation?
3. Write few names of series compensations?
4. Function of lag compensation?

EXPERIMENT-4

LEAD COMPENSATION – MAGNITUDE AND PHASE PLOT

Aim: To plot the response of lead compensators – magnitude and phase plot.

Components Required:

1. Resistor - 10 KΩ
2. Capacitor – 0.1 μF
3. Lag – Lead Compensation Kit
4. Cathode Ray Oscilloscope
5. Probes And Patch Cords

Theory:

All the control systems are designed to achieve specific objectives. A good control system has less error, good accuracy, good speed of response, good relative stability, good damping which will not cause under overshoots etc. For satisfactory performance of the system, gain is adjusted first. In practice, adjustment of gain alone cannot provide satisfactory results. This is because when gain is increased, steady state behavior of the system improves but results into poor transient response, in some cases may even instability. In such cases it is necessary to redesign the entire system. Practically the design specifications are provided in terms of precise numerical values according to which the system is designed. The set of such specifications include peak overshoot, peak time, W_n , k_p , k_v , k_a , G.M and P.M. etc. In practice, if a system is to be redesigned so as to meet the required specifications, it is necessary to alter the system by adding an external device to it. Such a redesign or alteration of system using an additional suitable device is called compensation of a control system. While an external device, which is used to alter the behavior of the system so, as to achieve given specification is called compensator.

Compensating Networks:

The compensator is a physical device. It may be an electrical network, mechanical unit, pneumatic, hydraulic or combination of various types of devices.

The commonly used electrical compensating networks are

1. Lead network or Lead Compensator
2. Lag network or Lag Compensator

1. Lead Network: When a sinusoidal i/p is applied to a network and it produces a sinusoidal

steady o/ p having a phase lead w.r.t. i/p then the network is called Lead network.

The transfer Function of Lead Compensator is

$$\frac{E_0(s)}{E_1(s)} = \frac{S+\frac{1}{T}}{S+\frac{1}{\alpha T}} \; ; T = R1C\alpha = \frac{R^2}{R_1+R_2} < 1$$

2. Lag Network: If the steady state output has phase lag then the network is called lag network. The transfer function of lag compensator is

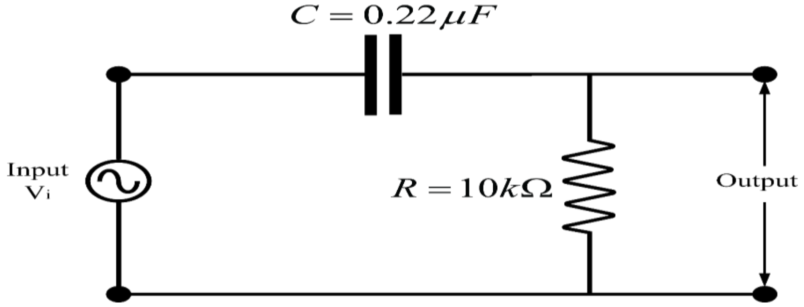
$$\frac{E_0(s)}{E_1(s)} = \frac{1}{\beta}.\frac{S+\frac{1}{T}}{S+\frac{1}{\beta T}} \; ; T = R2C; \; \beta = \frac{R_1+R_2}{R_2} > 1; \; T(s) = \frac{1+ST}{1+S\beta T}$$

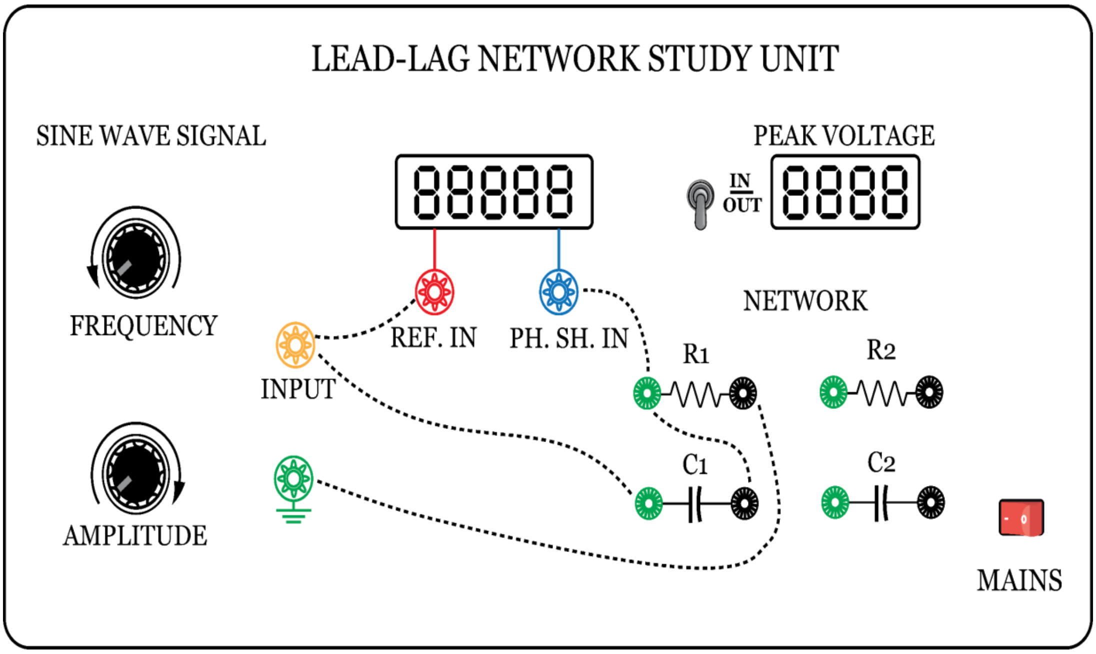
Effects of lead compensation

1. The lead compensator adds a dominant zero and a pole. This increases the damping of the closed loop system.
2. The increased damping means less overshoot, less rise time, less settling time.
3. It improves the phase margin of the closed loop system.
4. It increases bandwidth of the closed loop system. More the BW, faster is the response.
5. The steady state error doesn't get affected.
6. The slope of magnitude plot in Bode diagram of the forward path T.F. is reduced at the gain cross over frequency.
7. This improves gain & phase margins improve the relative stability.

Circuit Diagram:-

Lead Compensator Network:





Observations:

Table 1: Observation Table for Lead Compensator

Frequency (Hz)	Phase Angle (degree)	Output, Vo (Volts)	Gain= $20\log\frac{V_o}{V_i}$
84	72	0.14	-26.61
100	73	0.17	-24.93
128	74	0.19	-23.96
139	76	0.23	-22.30
196	77	0.33	-19.17
362	75	0.60	-13.98
474	72	0.78	-11.70
859	62	1.31	-7.196
919	61	1.38	-6.74
1071	57	1.54	-5.79
2053	41	2.22	-2.61

Procedure:

Lead Compensator

1. Connections are made as per the Circuit diagram shown in Fig 1 so as to form a phase lead network by selecting R1 = 10kΩ and C = 0.22µF
2. Switch ON the supply.
3. Using the CRO in X-Y mode, give input of the network to X – input of CRO and output of the network to Y – input of CRO.
4. Set the sine wave amplitude to 3V.
5. Now vary the frequency from 25 Hz to 2000 Hz in steps and note down the readings in the Table given below:
6. Calculate the gain and phase difference from the readings.
7. Now calculate the theoretical values of gain and phase difference.
8. Draw the Bode plot for both the theoretical & Practical Values.

Result:

Frequency response of lag and lead compensators is studied, and magnitude and phase angle pots are drawn. From the output,

- In lead compensator, at higher frequency output voltage is high and output come to in-phase with input.

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

Viva Questions:

1. What you mean by gain margin & phase margin?
2. What is the function of a compensation?
3. Write few names of series compensations?
4. Function of lead compensation?

EXPERIMENT-5

TRANSFER FUNCTION OF DC SHUNT MOTOR

Aim: To determine the transfer function of the given dc motor.

Name Plate Details of D.C. Motor:

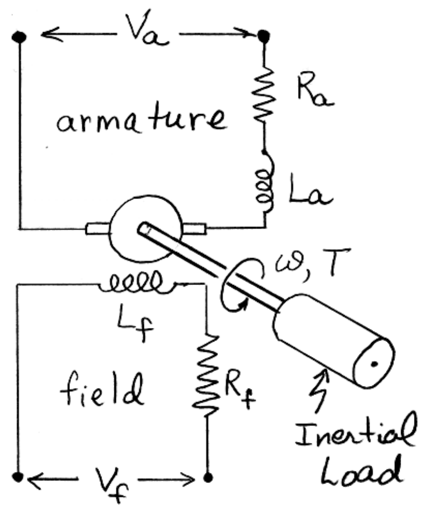
Power: 3HP
Armature voltage: 220 V
Armature current: 12 A
Excitation voltage: 220
Speed: 1500 RPM

Apparatus:

S.No.	Name of the item	Type	Range	Quantity
1	Voltmeter			
2	Ammeter			
3	Rheostat			
4	Tachometer			
5	Single Phase Variac			

Theory:

The figure below represents a DC motor attached to an inertial load.The voltages

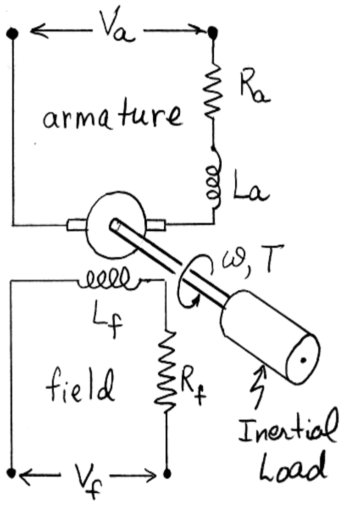


applied to the field and armature sides of the motor are represented by V_f and V_a. The resistances and inductances of the field and armature sides of the motor are represented by

R_f , L_f , R_a , and L_a . The torque generated by the motor is proportional to i_f and i_a the currents in the field and armature sides of the motor.

$$\boxed{T_m = K\, i_f\, i_a}$$

Armature-Current Controlled:



In a armature-current controlled motor, the field current I_f is held constant, and the armature current is controlled through the armature voltage V_a . In this case, the motor torque increases linearly with the armature current. We write

T_m □ $K_{ma}\, i_a$

The transfer function from the input armature current to the resulting motor torque is

$$\boxed{\frac{T_m(s)}{I_a(s)} = K_{ma}}$$

The voltage/current relationship for the armature side of the motor is

V_a □ V_R □ V_L □ V_b

Where V_b represents the "back EMF" induced by the rotation of the armature windings in a magnetic field.The back EMF V_b is proportional to the speed □ , i.e. $V_b(s)$ □ K_b□(s)

Taking Laplace transforms of Equation (1.9) gives

$$\boxed{V_a(s) - V_b(s) = \left(R_a + L_a s\right) I_a(s)}$$

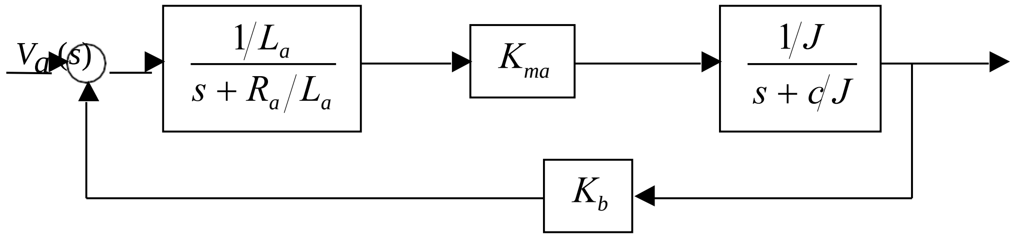
or

$$\boxed{V_a(s) - K_b \sigma(s) = \left(R_a + L_a s\right) I_a(s)}$$

As before, the transfer function from the input motor torque to rotational speed changes is

$$\frac{\sigma(s)}{T_m(s)} = \frac{(1|J)}{s+(c/J)}$$

Equations (1.8), (1.11) and (1.12) together can be represented by the closed loop block diagram shown below.

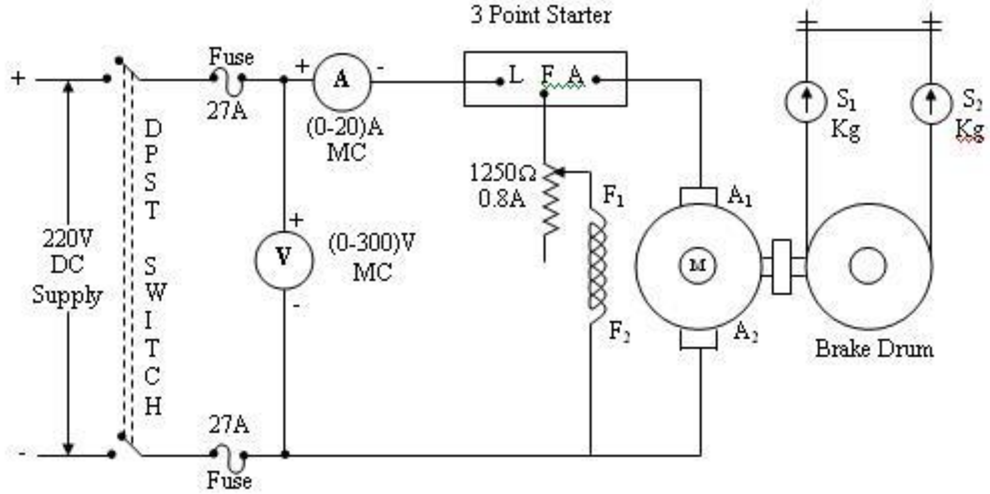


Block diagram reduction gives the transfer function from the input armature voltage to the resulting speed change

$$\frac{\sigma(s)}{V_a(s)} = \frac{(K_{ma}/L_aJ)}{(s+R_a/L_a)(s+c/J)+(K_bK_{ma}/L_aJ)}$$

The transfer function from the input armature voltage to the resulting angular position change is found by multiplying above Equation by 1 /*s*.

CIRCUIT DIAGRAM:



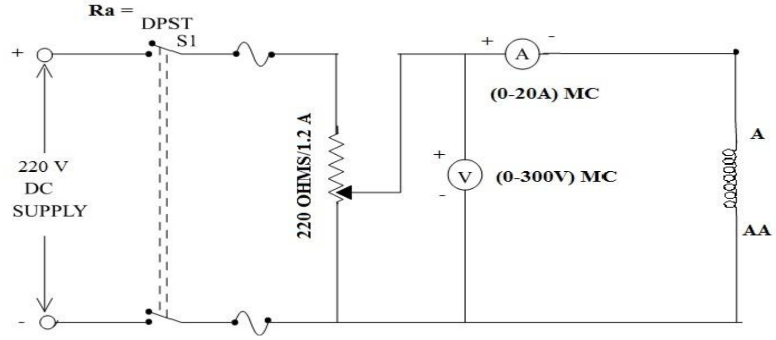
FUSE RATING:

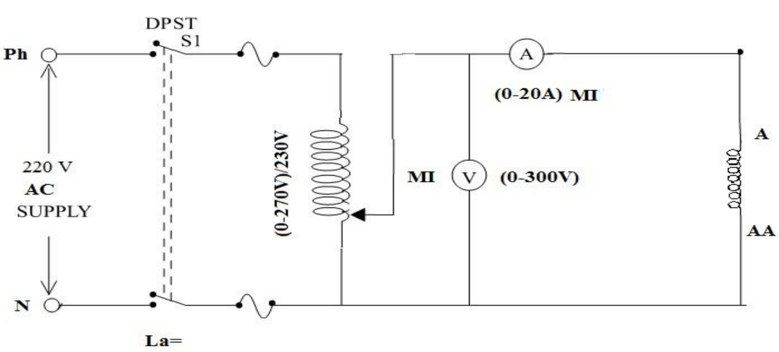
125% of rated current

$$\frac{125 \times 21}{100} = 26.25A$$

NAME PLATE DETAILS:

Rated Voltage : 220V
Rated Current : 21A
Rated Power : 3.5KW
Rated Speed : 1500 RPM





Observations:

R_a :

S.NO	Voltage	Armature Current I_a (A)	Armature resistance $R_a = V_t / I_a (\Omega)$

La :

S.NO	VOLTAGE(V)	CURRENT(I)	Z=Va/Ia	La

S.NO	VOLTAGE	Ia	If	SPEED	WEIGHTS		TORQUE	OUTPUT
					S1	S2		

Procedure:

1. Connect the circuit as per circuit diagram
2. Switch on the main supply by closing DPST switch.
3. Start the motor by using 3-point starter.
4. Run the motor with rated speed by varying the field rheostat.
5. Apply loading on the motor and note down the readings up to rated current.
6. Remove the load and set field rheostat to original position.
7. Switch off the supply

To determine Ra:

1. Connect the circuit as per circuit diagram.
2. By varying the field rheostat to different voltages.
3. Note down the values of voltages and currents.
4. Calculate Ra.

$$R_a = 1.5 \times R \text{ average}$$

To determine La:

1. Connect the circuit as per the circuit diagram.
2. By varying the single phase variac note down different values of voltage and current.
3. Switch off the supply.
4. Calculate La.

$$Z_a = \sqrt{R_a{}^2 + (WL_a)^2}$$

$$X_{La} = \sqrt{Z_a{}^2 - R_a^2}$$

$$L_a = \frac{\sqrt{Z_a{}^2 - R_a^2}}{W}$$

Result:

The transfer function of a dc motor is determined.

T.F =

Outcomes: PO1,PO2,PO3,PO4,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

EXPERIMENT-6

POTENTIOMETER ERROR DETECTOR

Aim: To study potentiometer as an error detector..

Apparatus Required:

a) Potentiometer error detector study unit.

b) Digital multimeter.

Theory:-

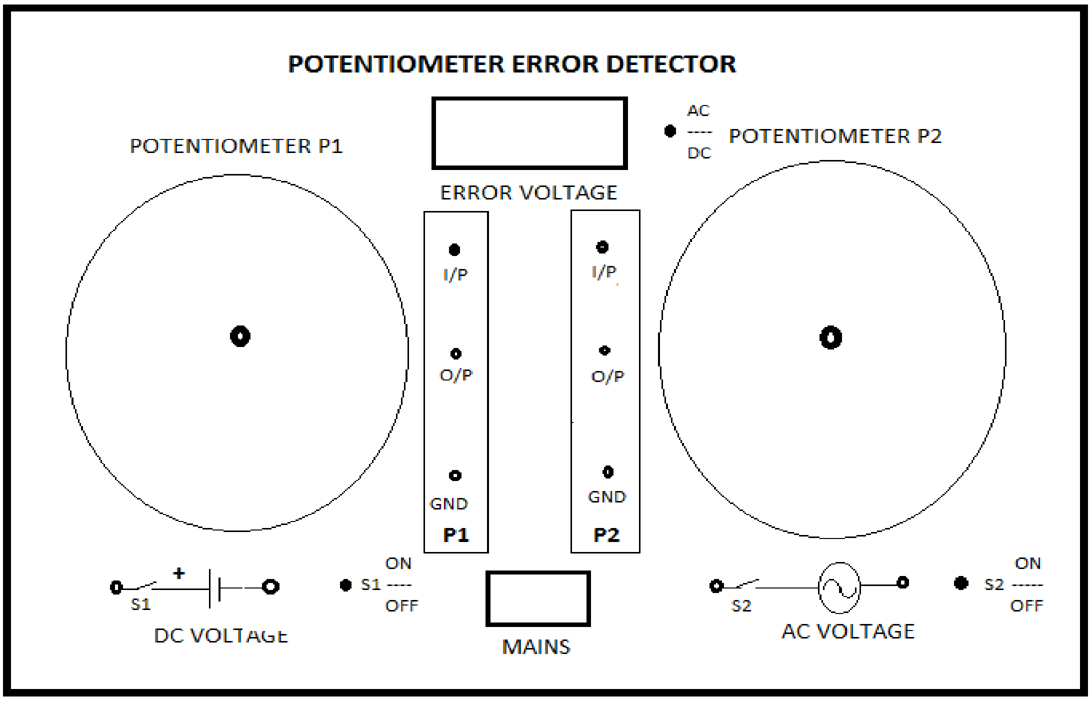
All feedback control systems operate from the error signal which is generated by a comparison of the reference and the output. Error detectors perform the crucial task of comparing the reference and output signals. In a purely electrical system where the reference and output are voltages, the error is a simple comparator. In some other systems with non-electrical outputs, the out signal is converted into electrical form through a measurement or transducer block, and then error detection is performed on the electrical signals. A position control system, with both input and output variables as mechanical positions (linear or angular), may however consist of two potentiometers – reference and output, which function as an error detector. Other devices which could be used in similar application include synchro sets (for a.c. systems), since cosine potentiometer, hall effect potentiometers etc, which unfortunately are not readily available. The present setup is designed to study the important characteristics of a Two potentiometer angular position error detector. These include

1. Linearity
2. Sensitivity
3. Maximum angle of rotation.

Good quality wire wound servo potentiometers with full 360° rotation have been used for this purpose. Accurately marked dials with least count of 1° are fixed on the shafts for position indication. The error voltage is read on a built-in 3 ½ digit DVM. An I.C regulated internal reference voltage is available of D.C studies.

Description of study unit:-

This unit consists of input servo potentiometer, output servo potentiometers, error detector using opamp and digital voltmeter to study the potentiometric error detector in DC and AC voltage operation.



Procedure for Potentiometer Error Detector for DC Voltage Operation:-

1. Connections are made as shown in fig.
2. Connect the input DC supply to both input potentiometer (P1) and output potentiometer (P2) terminals I/P and GND terminals.
3. Set the input potentiometer at 0°angular position and also set the output potentiometer at 10° and measure the O/P DC voltage at O/P terminals of both potentiometers using digital multi meter to calculate the error and also note down error voltage indicating in DVM on the front panel.
4. Vary the input potentiometer and out potentiometer in steps of 10° and note down the error voltage.
5. It is better to operate in the region of 0 ° to 340 ° to avoid zero crossing and possible damage of potentiometers.

TABLE – 1: Tabular column for potentiometer error detector for DC voltage excitation.

DC Voltage =5 Volts.

Sl No	P1 position in degrees	P2 position in degrees	ERROR VOLTAGE (indicating)
1	10°	10°	
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Procedure Potentiometer Error Detector for AC Voltage Operation:-

1. Connections are made as shown in fig.
2. Connect the input AC supply to both input potentiometer (P1) and output potentiometer (P2) terminals I/P and GND terminals.
3. Set the input potentiometer at 0° angular position and also set the output potentiometer at 10°and measure the O/P DC voltage at O/P terminals of both potentiometers using digital multi meter to calculate the error and also note down error voltage indicating in DVM on the front panel.
4. And vary the input potentiometer and out potentiometer in steps of 10° and note down the output and error voltage.
5. It is better to operate in the region of 0 ° to 340 ° to avoid zero crossing and possible damage of potentiometers.

TABLE – 2: Tabular column for potentiometer error detector for AC voltage excitation.

AC Voltage =5 Volts.

Sl No	P1 position in degrees	P2 position in degrees	ERROR VOLTAGE (indicating)
1	10°	10°	
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Result: - Performance of potentiometer error detector is studied.

Outcomes: PO1,PO2,PO3,PO4,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

EXPERIMENT-7

ROOT LOCUS FOR CLASSICAL TRANSFER FUNCTION USING MATLAB.

Aim: To Plot Root locus for a given transfer function using MATLAB.

Apparatus Required:

1. PC compatible with MATLAB software.
2. Control System Toolbox.

Theory:

MATLAB has a rich collection of functions immediately useful to the control engineer or system theorist. Complex arithmetic, eigen values, root-finding, matrix inversion, and FFTs are just a few examples of MATLAB's important numerical tools. More generally, MATLAB's linear algebra, matrix computation and numerical analysis capabilities provide a reliable foundation for control system engineering as well as many other disciplines.

The Control System Toolbox builds on the foundations of MATLAB to provide functions designed for control engineering. The Control system Toolbox is a collection of algorithms, written mostly as M-files, that implements common control system design, analysis and modeling techniques. Convenient graphical user interfaces (GUI's) simplify typical control tasks.

Control systems can be modeled as transfer functions, in zero-pole-gain, or state-space form, allowing you to use both classical and modern control techniques. We can manipulate both continuous-time and discrete-time systems. Systems can be single-input / single-output (SISO) or multiple-input / multiple-output (MIMO). In addition, we can store several LTI models in an array under a single variable name. Conversions between various model representations are provided. Time responses, frequency responses, and root loci can be computed and graphed. Other functions allow pole placement, optimal control, and estimation. Finally, the Control System Toolbox is open and extensible. We can create custom M-files to suit your particular application.

Typically, control engineers begin by developing a mathematical description of the dynamical system that they want to control. This to-be-controlled system is called a plant. The Control System Toolbox contain LTI viewer, a graphical user interface (GUI) that simplifies the analysis of linear, time-invariant systems. The time responses and pole/zero plots are available only for transfer function, state-space, and zero/pole/gain models.

The Control System Toolbox provides a set of functions that provide the basic time and frequency domain analysis plots used in control system engineering. These functions apply to any kind of linear model (continuous or discrete, SISO or MIMO, or arrays of models). Time responses investigate the time-domain transient behavior of linear models for particular classes of inputs and disturbances. We can steady-state error from the time response. The Control System Toolbox provides functions for step response, impulse response, initial condition response, and general linear simulations.

In addition to time-domain analysis, the Control System Toolbox provides functions for frequency-domain analysis using the following standard plots: Bode plots, Nichols plots, Nyquist plots and Singular value plots.

Theoretical Calculations:

Let us choose the open loop transfer function as

$$G(S)\ H(S) = \frac{75}{S^3 + 15S^2 + 50S}$$

Root locus:

1. Root locus is symmetrical about real axis.
2. The root locus plot starts at an open loop pole and ends at an open loop zero.
3. The poles are

   S = 0 ; S = - 5 ; S = -10

   No. of poles = 3

   No. of zero's = 0

   No. of root loculs branches, N = 3

   P if P > Z

   Z if Z > P

4. No. of asymptotic lines, n = p – z = 3
5. Angle of asymptotic

$$\theta = \frac{(2q+1)}{p-z} \times 180 \quad , \ q = 0, 1, 2$$

$$= 60,\ 180,\ 300$$

6. Centroid

$$S = \frac{\varepsilon\ poles - \varepsilon\ zero's}{p-z}$$

$$= -5$$

7. Break away point ⟶

   The characteristic equation is given by

$$1 + G(S)\ H(S) = 0$$

$$1 + \frac{k}{S(S+5)(S+10)} = 0$$

$$S^3 + 15S^2 + 50S + k = 0$$

$K = -(S^3 + 15S^2 + 50S)$

$$\frac{dk}{ds} = -\left(3S^2 + 30S + 50\right) = 0$$

S = -2.113 S = -7.866

K = 182.05 K = 187.55

8. Intersection points of the roots locus branches with imaginary axis

C E is $S^3 + 15S^2 + 50\,S + K = 0$

S^3	1 50	
S^2	15 K	
S	$\frac{750-K}{15}$	0
S^0	K 0	

For stable systems,

$$\frac{750-K}{15} > 0$$

$$750 - K > 0$$

$$K < 750$$

For marginal stability K = 750

The auxiliary equation is

$$15S^2 + K = 0$$

$$S = j\,7.0710$$

Procedure:

1. Open MATLAB command window by clicking on the MATLAB.exe icon.
2. Enter the given transfer function in the command window by using the syntax – SYS=TF (NUM, DEN) where ‘num’ is the matrix containing the elements of numerator and ‘den’ is the matrix containing the elements of denominator.
3. Enter the command: RLOCUS (NUM, DEN) to generate root locus of the given transfer function.
4. Copy the obtained plot.
5. Type: EXIT at the command window to close MATLAB.

Example: Obtain the Root Locus of the given transfer function:

G(S).H(S) = K/S^3+3S^2+5S+8)

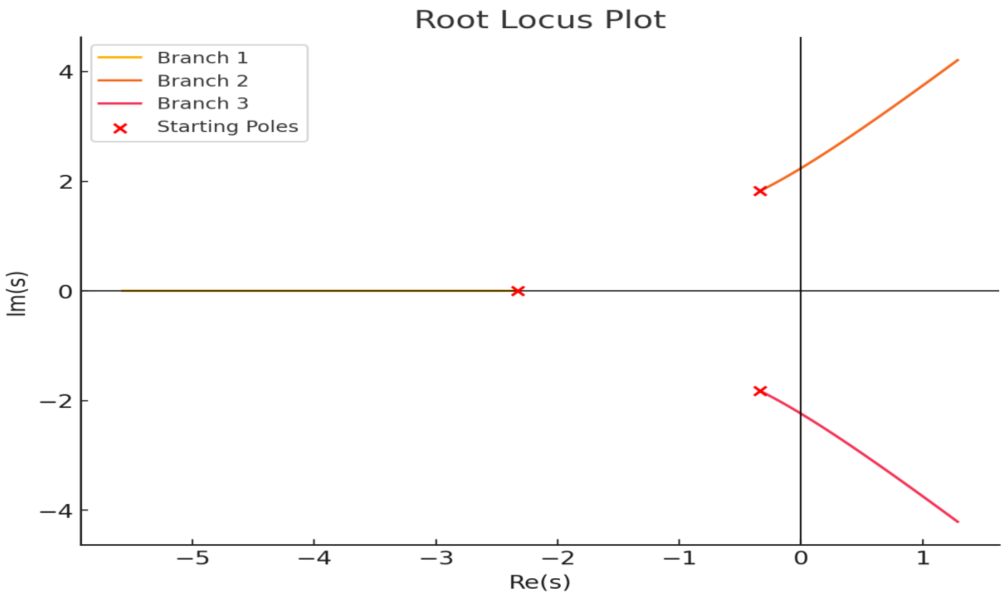
Solution: NUM = [K]

DEN = [1 2 5 8]

SYS = TF (NUM, DEN)

RLOCUS (SYS)

Plots Obtained:



Result: The Root locus for a given transfer function has been plotted using MATLAB.

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

EXPERIMENT-8

BODE PLOT FOR CLASSICAL TRANSFER FUNCTION

Aim: To obtain the Bode plot for a given transfer function using MATLAB.

Apparatus Required:

1. PC compatible with MATLAB software.

2. Control System Toolbox.

Theory:

MATLAB has a rich collection of functions immediately useful to the control engineer or system theorist. Complex arithmetic, eigen values, root-finding, matrix inversion, and FFTs are just a few examples of MATLAB's important numerical tools. More generally, MATLAB's linear algebra, matrix computation and numerical analysis capabilities provide a reliable foundation for control system engineering as well as many other disciplines.

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Control systems can be modeled as transfer functions, in zero-pole-gain, or state-space form, allowing you to use both classical and modern control techniques. We can manipulate both continuous-time and discrete-time systems. Systems can be single-input / single-output (SISO) or multiple-input / multiple-output (MIMO). In addition, we can store several LTI models in an array under a single variable name. Conversions between various model representations are provided. Time responses, frequency responses, and root loci can be computed and graphed. Other functions allow pole placement, optimal control, and estimation. Finally, the Control System Toolbox is open and extensible. We can create custom M-files to suit your particular application.

Typically, control engineers begin by developing a mathematical description of the dynamical system that they want to control. This to-be-controlled system is called a plant. The Control System Toolbox contain LTI viewer, a graphical user interface (GUI) that simplifies the analysis of linear, time-invariant systems. The time responses and pole/zero plots are available only for transfer function, state-space, and zero/pole/gain models.

The Control System Toolbox provides a set of functions that provide the basic time and frequency domain analysis plots used in control system engineering. These functions apply to any kind of linear model (continuous or discrete, SISO or MIMO, or arrays of models). Time responses investigate the time-domain transient behavior of linear models for particular classes of inputs and disturbances. We can steady-state error from the time response. The Control System Toolbox provides functions for step response, impulse response, initial condition response, and general linear simulations.

In addition to time-domain analysis, the Control System Toolbox provides functions for frequency-domain analysis using the following standard plots: Bode plots, Nichols plots, Nyquist plots and Singular value plots.

Theoretical Calculations:

Let us choose the open loop transfer function as

$$G(S)\,H(S) = \frac{75}{S^3 + 15S^2 + 50S}$$

Bode plot:

1. The open loop transfer function is

$$G(S)\,H(S) = \frac{75}{S(S+5)(S+10)}$$

$$G(S) = \frac{75}{S\;5\left(\frac{S}{5}+1\right)\;10\left(\frac{S}{10}+1\right)}$$

$$= \frac{1.5}{S(0.2\;S+1).(0.1\;S+1)}$$

To set the sinusoidal transfer function put S = jw

$$= \frac{1.5}{jw(1+0.2\,jw)(1+0.1\,jw)}$$

$$\theta = -\,90 - \tan^{-1}(0.2\text{ w}) - \tan^{-1}(0.1\text{ W})$$

2. Phase Plot:

W	θ

3. Magnitude Plot:

Type of the system is 1

Initial slope = - 20 db / du

Intersection point on the db axis or given value,

= 20 + 20 log K

= 20 + 20 log 1.5

= 23.52

Corner frequency = 5, 10.

Factor		Corner Frequency	Slope db/sec	Change in slope	Asymptotic log magnitude characteristic

Procedure:

1. Open MATLAB command window by clicking on the MATLAB.exe icon.
2. Enter the given transfer function in the command window by using the syntax – SYS=TF (NUM, DEN) where ‘num’ is the matrix containing the elements of numerator and ‘den’ is the matrix containing the elements of denominator.
3. Enter the command: BODE (NUM, DEN) to generate bode plot of the given transfer function.
4. Copy the obtained plot.
5. Type: EXIT at the command window to close MATLAB.

Example: Obtain the bode for the given transfer function:

G(S).H(S) = K/S^3+3S^2+5S+8)

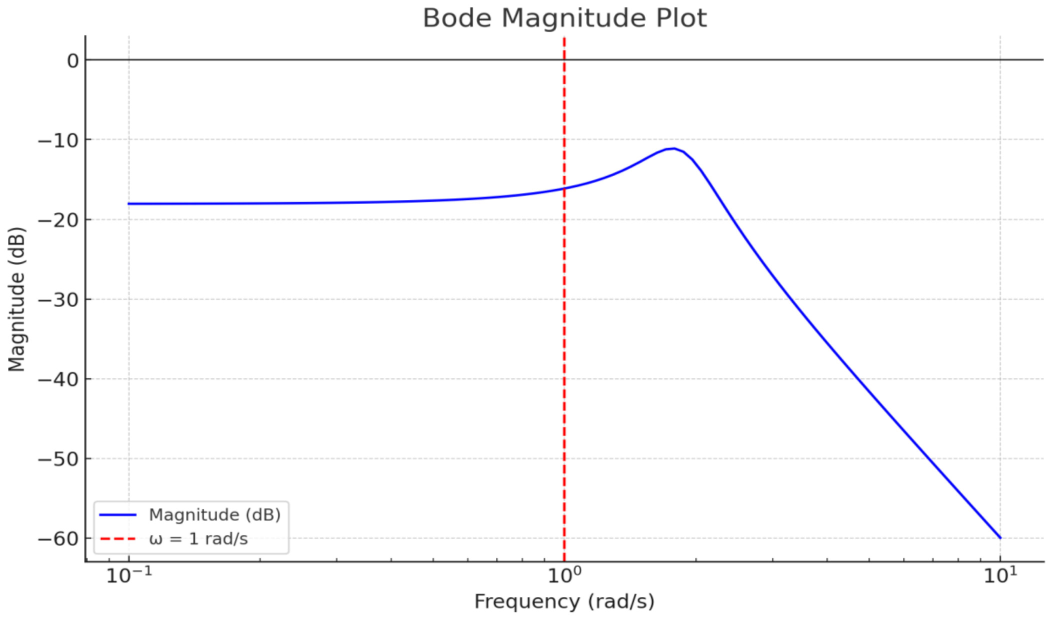
Solution: NUM = [K]

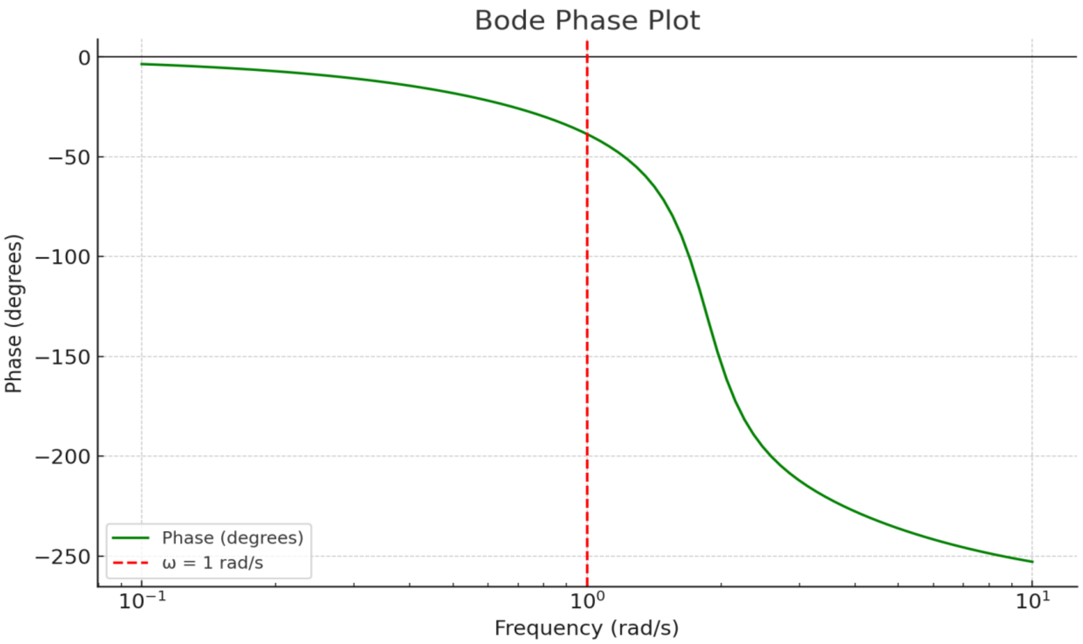
DEN = [1 2 5 8]

SYS = TF (NUM, DEN)

BODE (SYS)

Plots Obtained:





Result: The Bode plot for a given transfer function has been plotted using MATLAB

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

EXPERIMENT-9

NYQUIST PLOT FOR CLASSICAL TRANSFER FUNCTION USING MATLAB.

Aim: To obtain the Nyquist plot for a given transfer function using MATLAB.

Apparatus Required:

1. PC compatible with MATLAB software.
2. Control System Toolbox.

Theory:

MATLAB has a rich collection of functions immediately useful to the control engineer or system theorist. Complex arithmetic, eigen values, root-finding, matrix inversion, and FFTs are just a few examples of MATLAB's important numerical tools. More generally, MATLAB's linear algebra, matrix computation and numerical analysis capabilities provide a reliable foundation for control system engineering as well as many other disciplines.

The Control System Toolbox builds on the foundations of MATLAB to provide functions designed for control engineering. The Control system Toolbox is a collection of algorithms, written mostly as M-files, that implements common control system design, analysis and modeling techniques. Convenient graphical user interfaces (GUI's) simplify typical control tasks.

Control systems can be modeled as transfer functions, in zero-pole-gain, or state-space form, allowing you to use both classical and modern control techniques. We can manipulate both continuous-time and discrete-time systems. Systems can be single-input / single-output (SISO) or multiple-input / multiple-output (MIMO). In addition, we can store several LTI models in an array under a single variable name. Conversions between various model representations are provided. Time responses, frequency responses, and root loci can be computed and graphed. Other functions allow pole placement, optimal control, and estimation. Finally, the Control System Toolbox is open and extensible. We can create custom M-files to suit your particular application.

Typically, control engineers begin by developing a mathematical description of the dynamical system that they want to control. This to-be-controlled system is called a plant. The Control System Toolbox contain LTI viewer, a graphical user interface (GUI) that simplifies the analysis of linear, time-invariant systems. The time responses and pole/zero plots are available only for transfer function, state-space, and zero/pole/gain models.

The Control System Toolbox provides a set of functions that provide the basic time and frequency domain analysis plots used in control system engineering. These functions apply to any kind of linear model (continuous or discrete, SISO or MIMO, or arrays of models). Time responses investigate the time-domain transient behavior of linear models for particular classes of inputs and disturbances. We can steady-state error from the time response. The Control System Toolbox provides functions for step response, impulse response, initial condition response, and general linear simulations.

In addition to time-domain analysis, the Control System Toolbox provides functions for frequency-domain analysis using the following standard plots: Bode plots, Nichols plots, Nyquist plots and Singular value plots.

Theoretical Calculations:

Procedure:

1. Open MATLAB command window by clicking on the MATLAB.exe icon.
2. Enter the given transfer function in the command window by using the syntax - SYS=TF (NUM, DEN) where 'num' is the matrix containing the elements of numerator and 'den' is the matrix containing the elements of denominator.
3. Enter the command: NYQUIST (NUM, DEN) to generate bode plot of the given transfer function.
4. Copy the obtained plot.
5. Type: EXIT at the command window to close MATLAB.

Example: Obtain the nyquist plot for the given transfer function:

G(S).H(S) = K/S^3+3S^2+5S+8)

Solution:

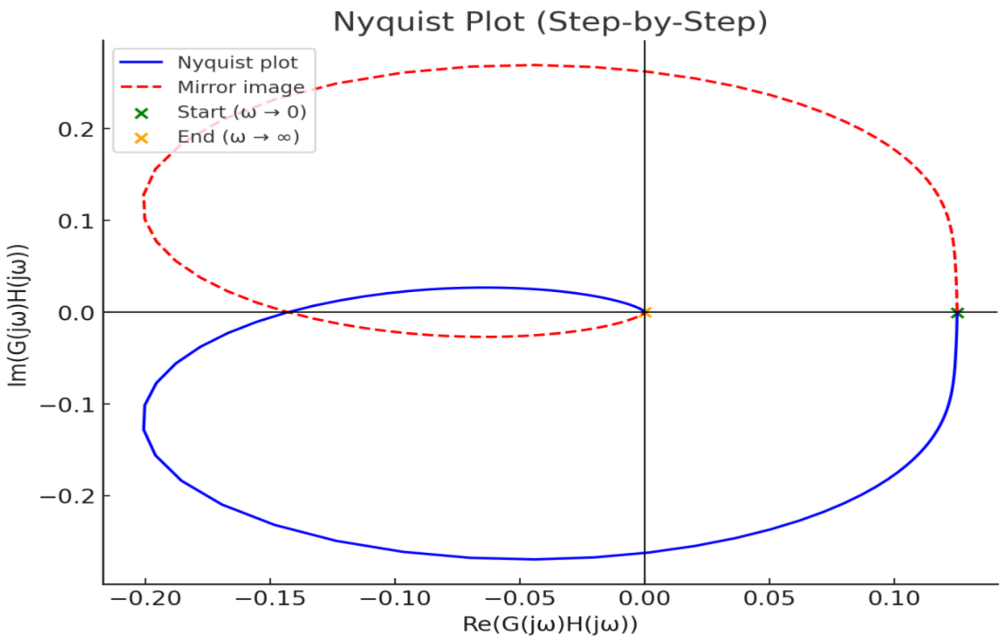
NUM = [K]

DEN = [1 2 5 8]

SYS = TF (NUM, DEN)

NQUIST (SYS)

Plots Obtained:



Result: The nyquist plot for a given transfer function has been plotted using MATLAB

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

EXPERIMENT-10

STATE SPACE MODEL FOR CLASSICAL TRANSFER FUNCTION USING MATLAB

Aim:

To find State Space Model for a given transfer function and vice versa using MATLAB and verify the same theoretically.

Apparatus Required:

1. PC compatible with MATLAB software
2. Control System Toolbox.

Theory:

Modern control design and analysis required a lot of linear algebra (matrix multiplication, inversion, calculation of eigen values and eigenvectors, etc.), which is not very easy to perform manually. The repetitive linear algebraic operations required in modern control design and analysis is, however, easily implemented on a computer with the use of standard programming techniques. A useful high – level programming language available for such talks is the MATLAB, which not only provides the tools for carrying out the matrix operations, but also contains several other features, such as the time – step integration of linear or nonlinear governing differential equations, which are invaluable in modern control analysis and design. Nowadays, personal computer versions of MATLAB are commonly applied to practical problems across the board, including control of aerospace vehicles, magnetically levitated trains and even stock – market applications.

For solving many problems in control systems, Control System Toolbox for MATLAB is very useful. It contains a set of MATLAB M-files of numerical procedures that are commonly used to design and analyze modern control systems. The Control System Toolbox is available with the MATLAB.

Theoretical Calculations:

$$\frac{Y(S)}{U(S)} = \frac{1}{S^3 + 10S^2 + 9S + 10}$$

There are many possible state space representations for this system.
One possible state space representation is

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -10 & -9 & -10 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} U$$

$$Y = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + [\,0\,]\ U$$

Transformation from state –space transfer function:

To obtain the transfer function from state space equations, we use the following command

[num, den] = SS2tf [A, B, C, D, in]

in must be specified for systems with more than one input. If the system has only one i/p then either,

[num, den] = SS2tf [A, B, C, D]

(or)

[num, den] = SS2tf [A, B, C, D, 1]

A. The given transfer function

$$\frac{Y(S)}{U(S)} = \frac{1}{S^3 + 10S^2 + 9S + 10}$$

$$S^3\ Y(S) + 10S^2\ Y(S) + 9S\ Y(S) + 10\ Y(S) = U(S)$$

Taking laplane transform on both sides,

$$\frac{d^3x}{dt^3} + \frac{10d^2x}{dt^2} + \frac{9dx}{dt} + 10x = U$$

Choosing state variation as $Y = x_1$, $\dot{x} = x_2$, $\ddot{x} = x_3$

$$\dot{x}_1 = x_2 \ ; \ \ddot{x}_2 = x_3$$

$$\dot{x}_3 = U - 10x_1 - 9x_2 - 10x_3$$

This system

One possible state space representation is

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -10 & -9 & -10 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} U$$

$$Y = x_1$$

$$Y = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + [\,0\,]\,U$$

B. From the state model, the following matrices are obtained.

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -10 & -9 & -10 \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \qquad D = [\,0\,]$$

$$SI - A = \begin{bmatrix} S & 0 & 0 \\ 0 & S & 0 \\ 0 & 0 & S \end{bmatrix} - \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -10 & -9 & -10 \end{bmatrix}$$

$$= \begin{bmatrix} S & -1 & 0 \\ 0 & S & -1 \\ 10 & 9 & S+10 \end{bmatrix}$$

$$(SI - A)^{-1} = S\,[S^2 + 10S + 9\,] + 10$$

$$= S^3 + 10S^2 + 9S + 10$$

$$\frac{1}{S^3 + 10S^2 + 9S + 10} \begin{bmatrix} S^2 + 10S + 9 & S + 10 & 1 \\ -10 & S^2 + 10S & S \\ -10S & -(9S + 10) & S^2 \end{bmatrix}$$

$$C(SI - A)^{-1} = \frac{1}{S^3 + 10S^2 + 9S + 10} \begin{bmatrix} S^2 + 10S + 9 & S + 10 & 1 \end{bmatrix}$$

$$C(SI - A)^{-1}B + D = \frac{1}{S^3 + 10S^2 + 9S + 10} \begin{bmatrix} S^2 + 10S + 9 & S + 10 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + [\,0\,]$$

$$T.F = \frac{1}{S^3 + 10S^2 + 9S + 10}$$

Program:

```
n = input ( 'enter 1 for converting tf to SS and 2 for converting ss to tf');

    Switch  n

  Care 1
        num = input ( 'enter the num of tf');
        den = input  ('enter the den of tf') ;
        disp  ('the tf is') ;
        t = tf ( num, den)
        [ a, b, c, d ] = tf 2 SS (num,  den)
  Care  2
```

```
a = input ('enter the system matrix A');
b =input ( 'enter the i/p matrix B') ;
c = input ('enter the o/p matrix C') ;
d = input  ('enter the transmission matrix D') ;
[num,  den ] = ss2 tf  ( a, b, c, d )
tf (num,  den)
otherwise
disp  ('the choice is invalid') ;
end.
```

OUTPUT

Enter 1 for converting tf 2 SS and 2 for SS to tf

Enter the num [1]

Enter the den $[1 \quad 10 \quad 9 \quad 10]$

Then tf is $\dfrac{1}{S^3 + 10S^2 + 9S + 10}$

$$a = \begin{bmatrix} -10 & -9 & -10 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

$$b = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \qquad c = [0 \quad 0 \quad 1] \qquad \mathrm{d} = [\,0\,]$$

enter 1 for converting tf 2 SS and = for SS to tf

enter the system matrix $\mathrm{A} = [0 \quad 1 \quad 0\ ;\ 0 \quad 0 \quad 1\ ;\ -10 \quad -9 \quad -10]$

enter i/p matrix B =[0 ; 0 ; 1]

enter o/p matrix $\mathrm{C} = [1 \quad 0 \quad 0]$

enter the transmission matrix D [0]

num = $[0 \quad 0.000 \quad -0.000 \quad 1.000]$

den = $[1.000 \quad 10.000 \quad 9.000 \quad 10.000]$

The transfer function is = $\dfrac{1}{S^3 + 10S^2 + 9S + 10}$

Procedure:

1. Open the MATLAB Command window by clicking on the MATLAB.exe icon.
2. Enter the given transfer function in the command window by using the syntax-

SYS = TF(NUM, DEN) where ‘num’ is the matrix containing the elements of numerator and ‘den’ is the matrix containing the elements of denominator.

3. To convert the given transfer function into state space enter the following syntax in the command window [A, B, C, D] = TF2SS (NUM, DEN)
4. Note the values of the matrices A, B, C and D and represent the state space model.
5. Type EXIT at the command window to close the MATLAB.

Result: The State Space Model for a given transfer function has been obtained using MATLAB

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

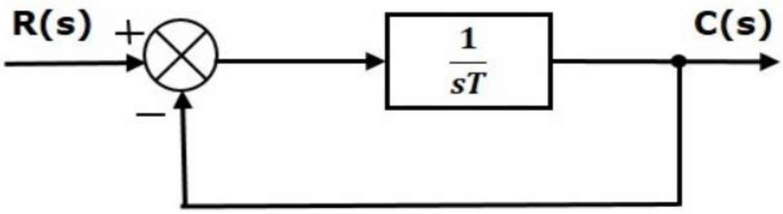
EXPERIMENT-11

TIME RESPONSE OF FIRST ORDER CONTROL SYSTEM

Aim: To obtain the time response plot of first order system

Apparatus: RLC Kit or MATLAB software package

Theory:



We know that the transfer function of the closed loop control system has unity negative feedback as,

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

Substitute, $G(s) = \frac{1}{sT}$ in the above equation.

$$\frac{C(s)}{R(s)} = \frac{\frac{1}{sT}}{1+\frac{1}{sT}} = \frac{1}{sT+1}$$

The power of s is one in the denominator term. Hence, the above transfer function is of the first order and the system is said to be the **first order system**.

We can re-write the above equation as

$$C(s) = \left(\frac{1}{sT+1}\right)R(s)$$

Substitute, $R(s) = \frac{1}{s}$ in the above equation.

$$C(s) = \left(\frac{1}{sT+1}\right)\left(\frac{1}{s}\right) = \frac{1}{s\,(sT+1)}$$

Do partial fractions of C(s).

$$C(s) = \frac{1}{s\,(sT+1)} = \frac{A}{s} + \frac{B}{sT+1}$$

Substitute, A = 1 and B = −T in partial fraction expansion of $C(s)$.

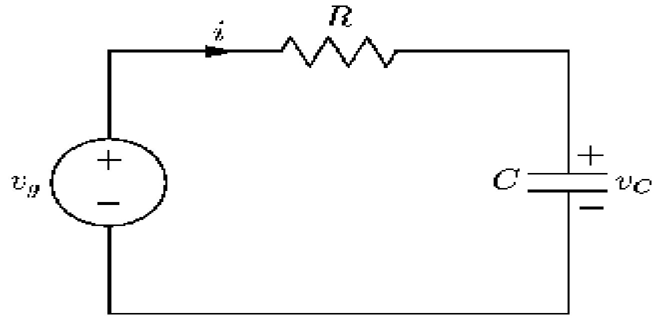
$$C(s) = \frac{1}{s} - \frac{T}{sT+1} = \frac{1}{s} - \frac{T}{T\,(s+\frac{1}{T})}$$

$$\Rightarrow C(s) = \frac{1}{s} - \frac{1}{s+\frac{1}{T}}$$

Apply inverse Laplace transform on both the sides.

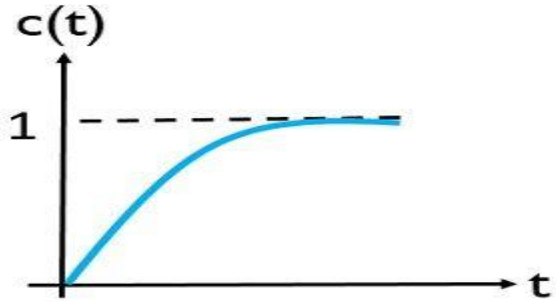
$$c(t) = \left(1 - e^{-\left(\frac{t}{T}\right)}\right)u(t)$$

Circuit Diagram:

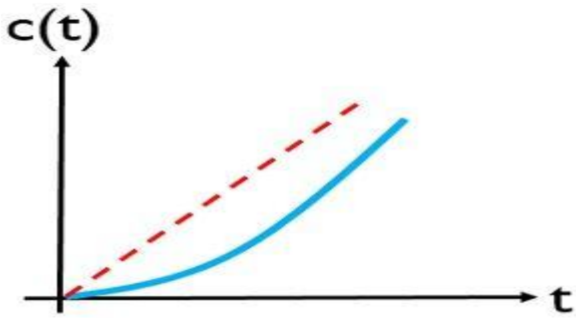


Model Graph:-

Step response of first order system:



Ram response of first order system:



Procedure:

1. Connections are made as per the circuit diagram.
2. Switch on the main supply to the unit. Observe the source o/p by selecting square wave and by varying amplitude using function generator.
3. First select square wave signal with a required time constant. Draw input square wave.
4. Connect signal output to first order system input using RC.
5. Draw the graph for the respective output.

Procedure: **(Simulation Method)**

1. Open the MATLAB software.
2. Open file and click new option.
3. Click on the model option.
4. Design the block diagram of given unity feedback controller system by using proper modules that are available in the SIMULINK LIBRARY in the model file.
5. Run the simulink model by clicking on RUN symbol available on the window and Double click on the scope to observe response.

Procedure: **(Program Method)**

1. Open the MATLAB software.
2. Open file and click new M-file option.
3. Enter the below program

```
clc
clear
num=[       ];
den= [             ];
sys= tf(num, den)
step(sys, 20)
```

4. Click on Run symbol available on the window and observe response in command window.

Result: The time response plot of first order system is verified for unit step and ramp inputs.

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2

EXPERIMENT-12

KALMAN'S TEST OF CONTROLLABILITY AND OBSERVABILITY USING MATLAB.

Aim:

To find the transfer function of the given system, controllability, observability and System stability.

Apparatus: MATLAB software package

X= AX + BU

Y= CX + DU

$$A=\begin{pmatrix} -1 & 1 & 0 \\ 0 & -4 & 2 \\ 0 & 0 & -10 \end{pmatrix}$$

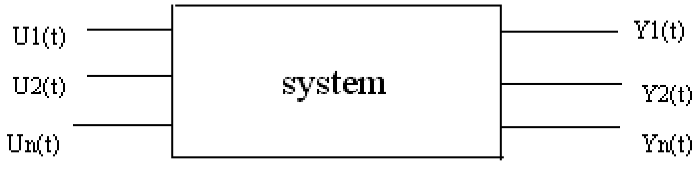
$$B = \begin{pmatrix} 1 \\ 0 \\ 1 \end{pmatrix} \qquad C = \begin{pmatrix} 1 & 0 & 1 \end{pmatrix} \qquad D=(0)$$

Theory:

State: Minimum amount of information required to estimate the future of the system.
State variable: The minimal set of these variables which describe the state of the system. Suppose n state variables are represented as 'n' components of a state then the vector is known as state vector.

$$X(t) = \begin{pmatrix} x_1(t) \\ x_2(t) \\ x_{n}(t) \end{pmatrix}_{n \times 1}$$

State – Space model representation



State-equation X(t) = AX(t) + BU(t)

Output equation Y(t) = Cx(t) + DU(t)

Transfer function matrix, T.F = $C(SI – A)^{-1}$ B+D.

A system is said to be completely state controllable if it is possible to find an input u(t) that will transfer a system from any initial state to any final state over a specified time interval.

Controllable matrix S= [B AB A^2 B ……..A^{n-1}B]

If rank of the matrix is n, then the system is state controllable.

Rank (S) = n. [|B| ≠ 0]

A system is said to be state observability the state of the system can be determined from the knowledge of input U(t) & o/p y(t) over a finite interval of time. The representation is W = [C^T A^T C^T $(A^T)^2$ C^T…….$(A^T)^{n-1}$ C^T]

Rank (W) = n [observable]

Calculations:

Program-1

```
A= [-1  1  0 ; 0   -4   2 ; 0   0   -10]
B= [1   0  -1];
C= [1   0  1];
D= [0]
[num, den]=ss2tf [A, B, C, D];
T=tf(num, den)
```

Program-2

```
A= [-1  0  0, 0  -4  2, 0  0  -10];
B= [1   0  -1];
C= [1   0  1];
D= [0]
S=ctrb(A, B);
n=det(s);
if abs(n)<eps
disp('system is not controllable');
else
disp('system is controllable');
end
```

Program-3

```
A= [-1  0  0, 0  -4  2, 0  0  -10];
B= [1   0  -1];
C= [1   0  1];
D= [0]
W=obsv(A,C);
n=det(W);
if abs(n)<eps
disp('system is not observability');
else
disp('system is observability');
end.
```

Result:

Hence, the transfer function of the given system, controllability, observability and system stability are found.

Outcomes: PO1,PO2,PO3,PO4,PO5,PO6,PO7,PO8,PO9,PO10,PO11,PO12,PSO1,PSO2