ATME COLLEGE OF ENGINEERING

13th Km Stone, Bannur Road, Mysore - 570028

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

(ACADEMIC YEAR 2024-25)

LABORATORY MANUAL

CONTROL SYSTEM LABORATORY-BEEL606

Prepared By	Verified By	Approved by
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Vision of the Institute

Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

Mission of the Institute

- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torch-bearers of tomorrow's society.
- To strive to attain ever-higher benchmarks of educational excellence

Vision of the Department

To create Electrical and Electronics Engineers who excel to be technically competent and fulfill the cultural and social aspirations of the society.

Mission of the Department

- To provide knowledge to students that builds a strong foundation in the basic principles of electrical engineering, problem solving abilities, analytical skills, soft skills and communication skills for their overall development.
- To offer outcome based technical education.
- To encourage faculty in training & development and to offer consultancy through research & industry interaction.

Program Outcomes (PO's)

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 lifelong learning in the broadest context of technological change.

Program Specific Outcomes (PSO's)

PSO1: Apply the concepts of Electrical & Electronics Engineering to evaluate the performance of power systems and also to control industrial drives using power electronics.

PSO2: Demonstrate the concepts of process control for Industrial Automation, design models for environmental and social concerns and also exhibit continuous self- learning.

Program Educational Objectives (PEO's)

PEO1: To produce competent and ethical Electrical and Electronics Engineers who will exhibit the necessary technical and managerial skills to perform their duties in society.

PEO2: To make graduates continuously acquire and enhance their technical and socioeconomic skills**.**

PEO3: To aspire graduates on R&D activities leading to offering solutions and excel in various career paths.

PEO4: To produce quality engineers who have the capability to work in teams and contribute to real time projects.

Control System Laboratory			
Course Code	BEEL606	IA Marks	50
Number of Practical Hours/Week	03	Exam Hours	03
RBT Levels	L1,L2,L3,L4, L5	Exam Marks	50
Credits - 02			

Course objectives:

- To draw the speed torque characteristics of AC and DC servo motor.
- To determine the time and frequency reposes of a given second order system using
- discrete components.
- To design and analyze Lead, Lag and Lag – Lead compensators for given specifications.
- To study the feedback control system and to study the effect of P, PI, PD and PID controller and Lead compensator on the step response of the system.
- To simulate and write a script files to plot root locus, bode plot, to study the stability of the system

Sl. No	Experiments
01	Experiment to draw the speed torque characteristics of (i) AC servo motor (ii) DC servo motor
02	Experiment to draw synchro pair characteristics
03	Experiment to determine frequency response of a second order system
04	A. To design a passive RC lead compensating network for the given specifications, viz, the maximum phase lead and the frequency at which it occurs and to obtain the frequency response. B. To determine experimentally the transfer function of the lead compensating network.
05	A. To design a passive RC lag compensating network for the given specifications, viz, the maximum phase lag and the frequency at which it occurs and to obtain the frequency response B. To determine experimentally the transfer function of the lag compensating network
06	Experiment to draw the frequency response characteristics of the lag – lead compensator network and determination of its transfer function.
Experiments 7 to 11 must be done using MATLAB/SCILAB/OCTAVE only.	
07	A. To simulate a typical second order system and determine step response and evaluate time response specifications. B. To evaluate the effect of additional poles and zeros on time response of second order system. C. To evaluate the effect of pole location on stability. D. To evaluate the effect of loop gain of a negative feedback system on stability.
08	To simulate a second order system and study the effect of (a) P, (b) PI, (c) PD and (d) PID controller onthe step response.
09	A. To simulate a D.C. Position control system and obtain its step response. B. To verify the effect of input waveform, loop gain and system type on steady state errors. C. To perform trade-off study for lead compensator. D. To design PI controller and study its effect on steady state error.
10	A. To examine the relationship between open-loop frequency response and stability, open-loop frequency and closed loop transient response. B. To study the effect of open loop gain on transient response of closed loop system using root locus.
11	A. To study the effect of open loop poles and zeros on root locus contour. B. Comparative study of Bode, Nyquist and root locus with respect to stability

Revised Bloom's Taxonomy Level:	**L_1 – Remembering; L_2 – Understanding; L_3 – Applying;**

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

1. **Determine** the performance characteristics of AC servomotor, DC servomotors and sychro-transmitter receiver pair. [L3]
2. **Analyse** the time response and frequency response of a second order system using software package and discrete components**. [**L4**]**
3. Design and **Analyse** the Lead, Lag and Lag-Lead compensators for the given specifications. [L4]
4. **Analyse** the effect of P, PI, PD, PID and DC position controllers on the step response of the second order system. [L4]
5. **Evaluate** the stability of the system using root locus, bode plot. And Nyquist plot.[L4]

List of Text Books

1. **Control Systems Engineering,** I. J. Nagarath and M.Gopal, New Age International (P) Limited, 4th Edition – 2005

2. **Modern Control Engineering,** K. Ogata, PHI, 5th Edition, 2010.
List of URLs, Text Books, Notes, Multimedia Content, etc
• http://nptel.ac.in/courses/108101037/ • https://www.youtube.com/watch?v=iyRWW-5OmBA • https://www.youtube.com/watch?v=FSAfFw_dqgA • https://www.youtube.com/watch?v=xLhvil5sDcU

Cycle of Experiments

Cycle 1:

Exp. No.	Experiment Title	COs
1	Experiment to draw the Speed Torque Characteristics of (i) AC servo motor (ii) DC servo motor.	CO1
2	Experiment to draw synchro-pair characteristics	CO1
3	Experiment to determine frequency response of a second order system.	CO2
4	a. To simulate a typical second order system and determine step response and evaluate time response specifications. b. To evaluate the effect of additional poles and zeros on time response of second order system. c. To evaluate the effect of pole location on stability d. To evaluate the effect of loop gain of a negative feedback system on stability.	CO2
5	To simulate a second order system and study the effect of (a) P, (b) PI, (c) PD and (d) PID controller on the step response.	CO4

Cycle 2:

Exp. No.	Experiment Title	COs
6	a. To design a passive RC lead compensating network for the given specifications, viz, the maximum phase lead and the frequency at which it occurs and to obtain the frequency response. b. To determine experimentally the transfer function of the lead compensating network.	CO3
7	a. To design a passive RC lag compensating network for the given specifications, viz, the maximum phase lag and the frequency at which it occurs and to obtain the frequency response. b. To determine experimentally the transfer function of the lag compensating network	CO3
8	Experiment to draw the frequency response characteristics of the lag – lead compensator network and determination of its transfer function.	CO3
9	a. To simulate a D.C. Position control system and obtain its step response. b. To verify the effect of input waveform, loop gain and system type on steady state errors. c. To perform trade-off study for lead compensator. **d.** To design PI controller and study its effect on steady state error.	CO4
10	a. To examine the relationship between open-loop frequency response and stability, open-loop frequency and closed loop transient response. b. To study the effect of open loop gain on transient response of closed loop system using root locus.	CO5
11	a. To study the effect of open loop poles and zeros on root locus contour b. Comparative study of Bode, Nyquist and root locus with respect to stability	CO5

Experiment No: 01 **Date:**

A. Experiment to Draw the Speed Torque Characteristics of AC Servo Motor

Aim: To obtain speed – torque characteristics of AC servo motor

Objective: The students will learn about the characteristics of AC Servo Motor.

Apparatus:

- AC servo motor kit
- Patch cards
- Ammeter

Panel diagram:

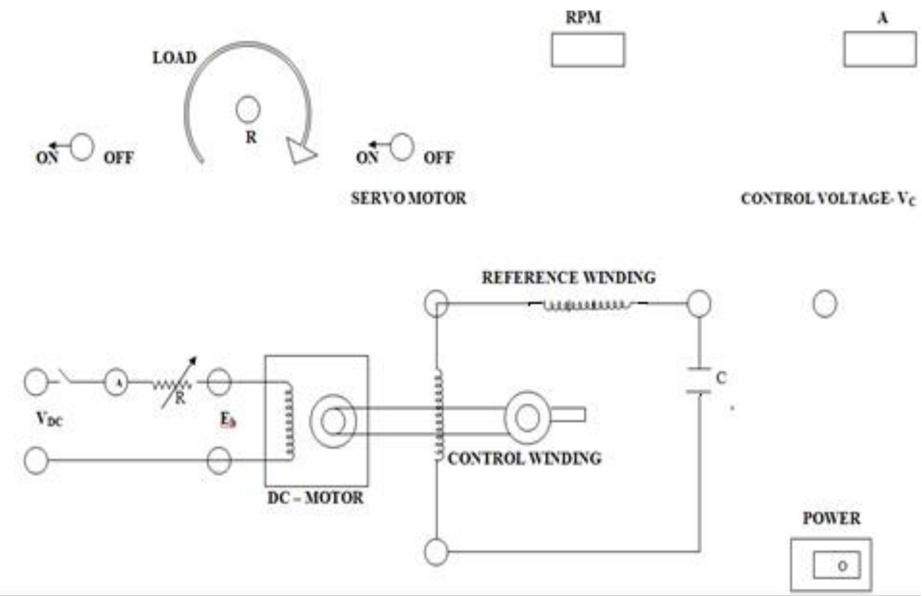

Fig.1.1: AC – Servo Motor speed – torque characteristics study unit

Procedure:

To plot Speed vs. Torque characteristics

1. Study all the controls carefully on the front panel.
2. Initially keep the load control switch at OFF position, keep servomotor supply switch also at OFF position.
3. Keep load potentiometer and control voltage auto transformer at minimum positions.
4. Switch ON main supply to the unit and also AC servomotor supply switch.
5. Set control winding voltage of 180V and reference winding voltage of 240V by varying the autotransformer.
6. With load switch in OFF position, note down the no load speed and back EMF of the DC motor.
7. Switch ON the load switch and vary the load by varying the load potentiometer in steps and note down the corresponding Speed, Back EMF and armature current(I_a) in the tabular column.
8. Repeat the above experiment for control winding Voltage 200V and 180V.
9. Plot the graph of speed Vs torque for the different control winding voltages in a single graph.

To plot Speed vs. Back EMF

1. Initially keep load control switch at OFF position, keep servomotor supply switch also at OFF position.
2. Keep load potentiometer and control voltage auto transformer at minimum positions.
3. Now switch ON main supply to the unit and also AC servomotor supply switch.
4. With load switch in OFF position, vary the speed of the AC servomotor by varying the control voltage and note down back EMF generated by the dc motor in the tabular column.
5. Plot the graph of speed vs. Back EMF.

Tabular Column:

Table 1.1:Speed torque characteristics Readings of AC Servo Motor (Load Test)

Sl. No.	I_a (A)	N (rpm)	E_b (V)	P (W)	T (g-cm)
Case1:________V					
Case2:________V					
Case3: ________V					

The Torque is given by,

$$T = \frac{P * k * 60}{2\pi N}$$

Where, $P = E_b * I_a$

$k = 1.019*10^4$

Table 1.2: Speed vs. Back EMF Curve (Under No Load Condition):

Sl. No.	N (rpm)	E_b (V)

Typical Graphs:

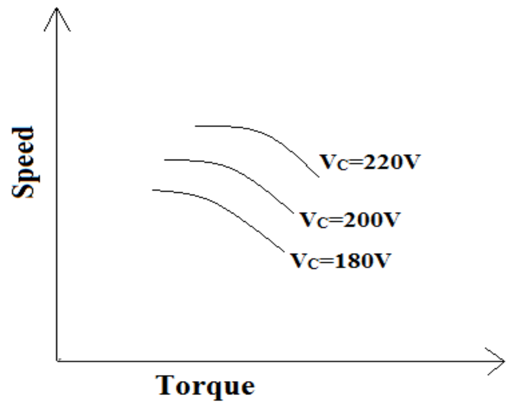

Fig 1.2: Typical graph of Speed vs. Torque Characteristics

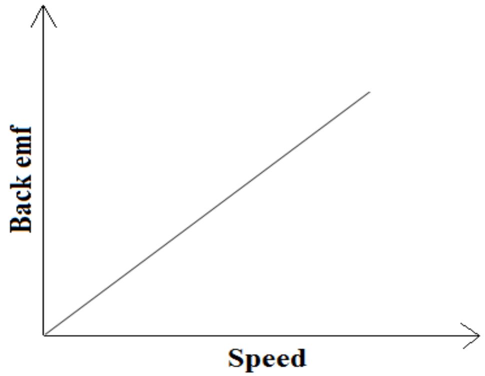

Fig 1.3: Typical graph of Speed vs. Back EMF Characteristics

Free Space for rough work:

Conclusion:

Outcomes: At the end of the experiment

1. The students will acquire the knowledge on the AC servo motor.
2. The students will be able to plot the Speed-Torque Characteristics of AC Servo Motor.

B. Experiment to Draw the Speed Torque Characteristics of DC Servo Motor

Aim: To obtain speed – torque characteristics of DC servo motor.

Objective: The students will learn about the characteristics of DC Servo Motor

Apparatus:

1. DC servo motor Kit
2. Patch cards
3. Ammeter (mA)

DC Servomotor specifications:

1. Type: Permanent magnet type
2. Voltage: 24V D.C
3. Torque: 400 gm-cm
4. Speed: 4400 RPM

Panel Diagram:

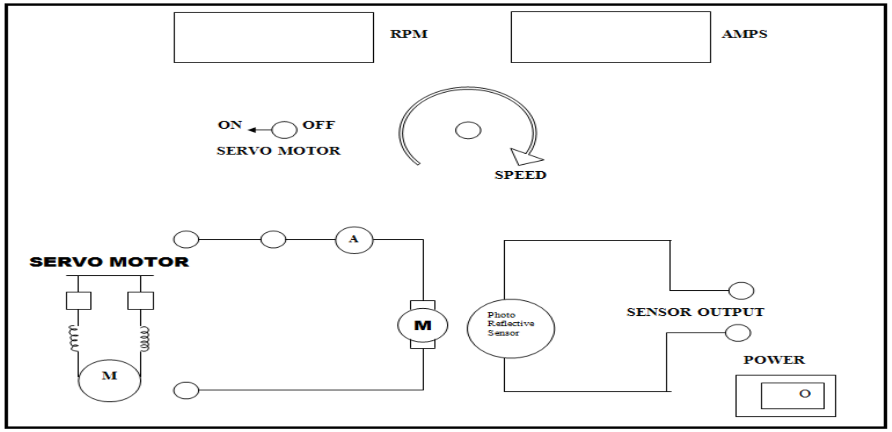

Fig. 1.4: DC– Servo Motor Speed – Torque characteristics study unit

Front panel details:

1. MAINS: Mains ON/OFF switch to the unit with built-in indicator.
2. LCD DISPLAY: LCD display to display the speed in RPM
3. AMMETER(A): Ammeter to measure the DC motor current.
4. SERVOMOTOR ON: AC supply ON/OFF switch to the servomotor.
5. LOAD- ON/OFF: ON/OFF Switch to load the motor.
6. R: Potentiometer to vary the Load-500 Ohms/25 Watts.
7. V_{dc}: 12 V unregulated DC supply to DC motor.
8. (M) : PMDC motor terminals to measure the Back EMF.
9. CONTROL WINDING: Control winding terminals of AC Servomotor.
10. REFERENCE WINDING: Reference winding of AC servo motor.
11. CONTROL VOLTAGE: Auto transformer to vary the AC supply to the Control winding.

Procedure:

1. Study all the controls carefully on the front panel.
2. Keep the load at no load condition. Switch On the mains supply to the unit.
3. Switch on the servomotor.
4. Set the rated DC voltage to 24V across the servo motor.
5. Note down the no load current and no load speed.
6. Increase the load in steps till the load current reaches 0.8 Amps(do not exceed 0.8 amps).
7. At each load note down the speed, current and spring balance readings.
8. Calculate the corresponding torque and plot the speed-torque characteristics.
9. Repeat the procedure for 60% and 40% of the rated voltage.

Tabular column:

Table 1.2: Speed torque characteristics Readings of DC Servo Motor (Load Test)

Sl. No.	I_a (A)	N (rpm)	Weight-W_1 (g)	Weight-W_2 (g)	Total Weight $W = W_1 - W_2$ (g)	Torque T = W* R (g-cm)
Set voltage V_1 = _________V						
Set voltage V_1 = _________V						
Set voltage V_1 = _________V						

The Torque is given by,

$T = k*W*r$ (g-cm)

Let k= 1; constant

Where, 'r' is the radius of the pulley in cm and it is obtained from the circumference (2πr).

Typical graph:

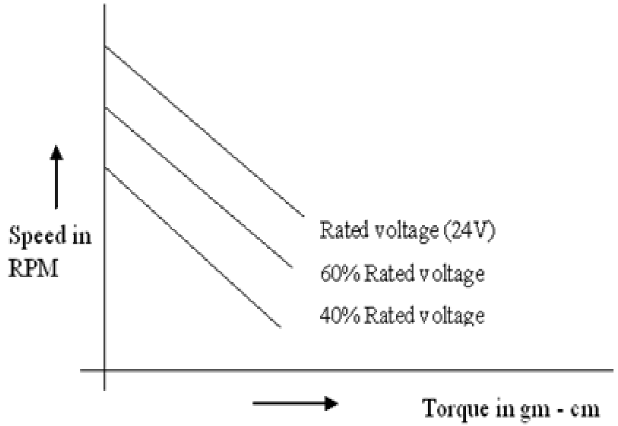

Fig.1.5: Typical Graph of Speed-Torque Characteristics of DC Servo Motor

Conclusion:

Outcomes: At the end of the experiment,

1. The students will acquire the knowledge on the of DC servo motor.
2. The students will be able to plot the Speed-Torque Characteristics of DC Servo Motor.

Viva Questions:

1. Give the comparison between AC Servo Motor and DC Servo Motor.
2. Mention the applications of AC Servo Motor and DC Servo Motor.
3. Define the working principle of Servo Motor.

Free Space for rough work:

Preparation	Conduction	Calculation/Result Analysis	Total

Signature of Faculty Member

Experiment No: 02 **Date:**

Experiment to Draw SynchroPair Characteristics

Aim: To study the operations of syncro transmitter and receiver pair.

Objective: The students will get knowledge regarding synchro transmitter and receiver and their operations.

Apparatus:

1. Synchro transmitter and receiver set.
2. Patch cards.

Front panel details:

1. POWER:Power ON/OFF switch to the unit with builtin indicator.
2. TRANSMITTER:Synchro Transmitter.
3. SWITCH:Switch for transmitter rotor supply.
4. ROTOR - R1, R2:Synchro Transmitter rotor terminals.
5. S1, S2, S3:Synchro Transmitter stator terminals.
6. RECEIVER:Synchro Receiver
7. SWITCH:ON/OFF Switch for rotor supply.
8. S1', S2', S3':Synchro Receiver stator terminals.
9. ROTOR- R1', R2': Synchro Receiver
10. VOLTMETER:AC Voltmeter to measure stator and rotor voltages.

Internal connection diagram:

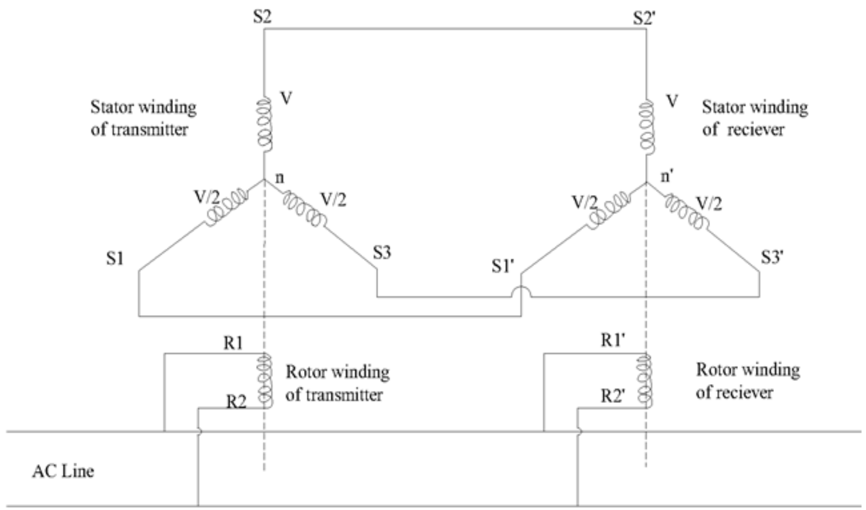

Fig.2.1: Internal connection diagram of Transmitter and Receiver Pair

Procedure:

1. Connect mains supply cable.
2. Connect the stator terminals of transmitter S1, S2 and S3 with stator terminals of receiver S1′, S2′ and S3′ with the help of patch cords respectively.
3. Now at zero angular position of rotor of transmitter, note down that of receiver and tabulate them.
4. Vary the angular positions of rotor of synchro transmitter in steps by 30° and note down the corresponding angular positions of rotor of synchro receiver.
5. It is observed that whenever the rotor of the synchro transmitter is rotated, the rotor of the synchro receiver follows it both directions of rotations and its positions are linear with the initial error.
6. Switch off the mains supply of the kit after bringing back the rotor of the transmitter at 0°.

7. Plot a graph between angular positions of rotor of transmitter and angular positions of rotor of receiver

Tabular Column:

Table.2.1: Synchro Transmitter Rotor Position vs. Stator Voltages for Three Phases (V_{S3S1}, V_{S1S2}, V_{S2S3})

Sl. No.	Rotor position in degrees	V_{S3S1}	V_{S1S2}	V_{S2S3}
1	0			
2	30			
3	60			
4	90			
5	120			
6	150			
7	180			
8	210			
9	240			
10	270			
11	300			
12	330			

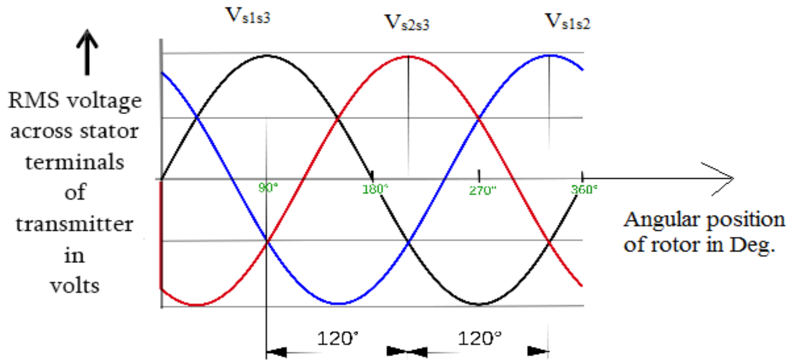

Fig.2.2: Model graph of rotor position vs.stator voltages for three phases

Tabular Column:

Table.2.2: Transmitter angular position and receiver angular position

Sl. No.	Transmitter angular position in degrees	Receiver angular position in degrees
1	0	
2	30	
3	60	
4	90	
5	120	
6	150	
7	180	
8	210	
9	240	
10	270	
11	300	
12	330	

Typical Graph:

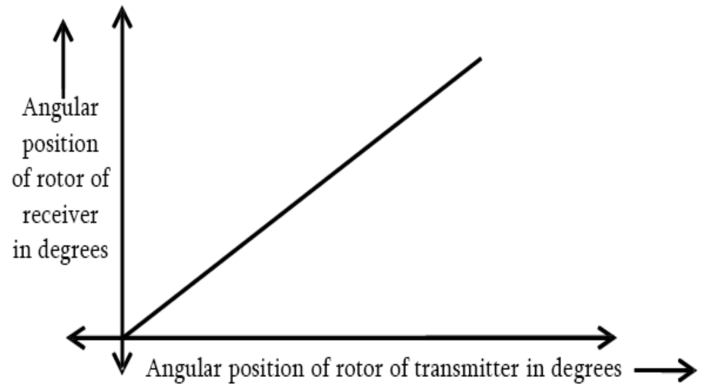

Fig.2.3: Angular position of rotor of receiver vs. angular position of rotor of transmitter

Conclusion:

Outcome: At the end of the experiment,

1. The students will get the knowledge on the synchro transmitter receiver pair

Viva Questions:

1. Define synchro transmitter and synchro receiver.
2. Give the comparison between transmitter and receiver.
3. Mention applications of synchro transmitter and synchro receiver.

Preparation	Conduction	Calculation/Result Analysis	Total

Signature of Faculty Member

Free Space for rough work:

Experiment No: 03 **Date:**

Experiment to Determine Frequency Response of a Second Order System

Aim: To plot the frequency response of second order system and determine frequency domain specifications.

Objective: The students will learn regarding second order system and to determine frequency response for those systems.

Apparatus:
1. DRB, DIB and DCB
2. CRO
3. Patch cards
4. Signal Generator
5. Probes

This Frequency response characteristics unit consists of the following sub units:
1. Sine wave source: 0 to 3.5 Volts, 100Hz to 2000Hz frequency range
2. Digital phase angle / frequency meter
3. Digital voltmeter.
4. RLC Network.

Circuit Diagram:

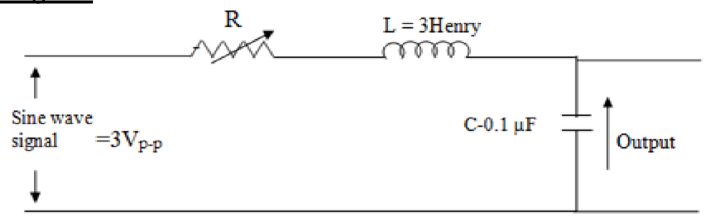

Fig.3.1: Circuit Diagram

Design:

Let C = 0.1µF and L=3H

$$\omega = \frac{1}{\sqrt{LC}} = 1825.7\ rad/s$$

$$f = \frac{\omega}{2\pi} = 290Hz$$

$$R = 2\xi\sqrt{L/C}$$

For $\xi = 0.5$, R = 5.5 kΩ (Under damped)

$\xi = 1$, R = 11 kΩ (Critically damped)

$\xi = 1.2$, R = 16.5 kΩ (Over damped)

Procedure:

1. Connect the circuit as shown in the connection diagram.
2. Switch ON the Mains supply to the unit.
3. Connect sine wave output to networks input.
4. Set the amplitude of sine wave to some value 3V peak.
5. Vary the input frequency of the sine wave from 100 Hz to 2Hz in steps and tabulate the corresponding output voltage and phase angles.
6. Plot the graph of phase angle vs. frequency and gain v/s frequency for various values of damping factor on a single semi log sheet. Determine the frequency domain specifications from the plots.

Tabular Column:

1. **Under damped. ξ =**

Sl.No.	f(Hz)	Vi (V)	ω in (rad)	Vo (V)	Phase φ	Gain (Vo/Vi)	Gain in dB 20log(Vo/Vi)

2. **Critically damped, ξ =**

Sl.No.	f(Hz)	Vi (V)	ω in (rad)	Vo (V)	Phase φ	Gain (Vo/Vi)	Gain in dB 20log(Vo/Vi)

3. **Over damped, ξ =**

Sl.No.	f(Hz)	Vi (V)	ω in (rad)	Vo (V)	Phase φ	Gain (Vo/Vi)	Gain in dB 20log(Vo/Vi)

Typical Frequency response curve:

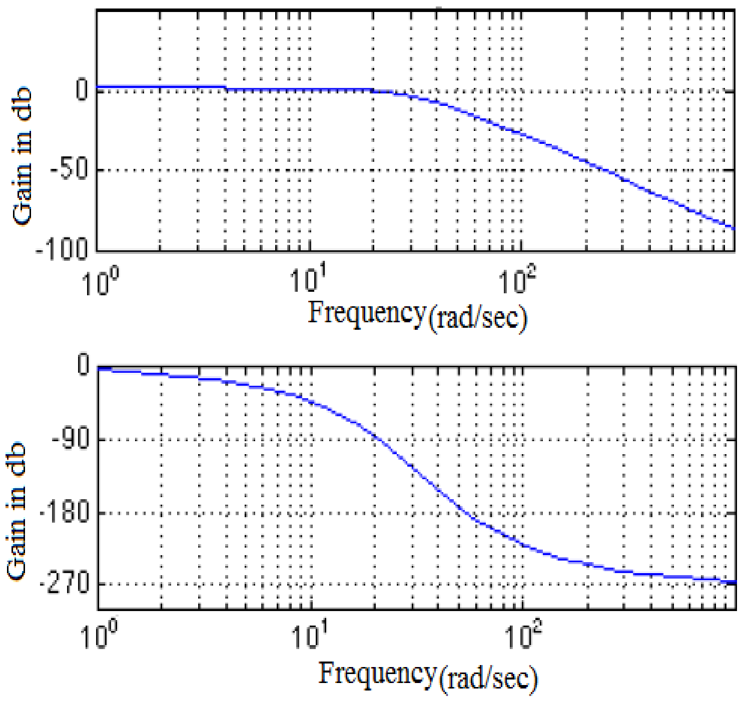

Fig.3.2: Typical frequency response curve

Conclusion:

Outcomes: At the end of the experiment,

1. The students will be able to design the RLC circuits for various damping ratios.
2. The students will acquire the knowledge on frequency response of a second order system and find its frequency domains.

Viva Questions:

1. Define damping ratio.
2. Give the comparison between under damped, critically damped and over damped.
3. Mention the advantages of second order system.
4. Mention the differences between first order system and second order system.

Preparation	Conduction	Calculation/Result Analysis	Total

Free Space for rough work:

Signature of Faculty Member

Experiment No: 04 **Date:**

A. **To design a passive RC Lead compensating network for the given specifications, viz., the maximum phase lead and the frequency at which it occurs and to obtain the frequency response.**
B. **To determine experimentally the transfer function of the lead compensating network.**

Aim:

- To design a passive RC lead compensating network for the given specifications,
- To obtain its frequency response curve.
- To determine experimentally the transfer function of the given lead compensating network.

Objectives:

1. The students will get knowledge regarding lead compensating network and its design.
2. The students will learn about frequency response curve and determination of transfer function for the lead network.

Apparatus required:

1. Function generator
2. DRB and DCB
3. Phase angle detector
4. voltmeter

Circuit diagram:

Basic lead Compensator:

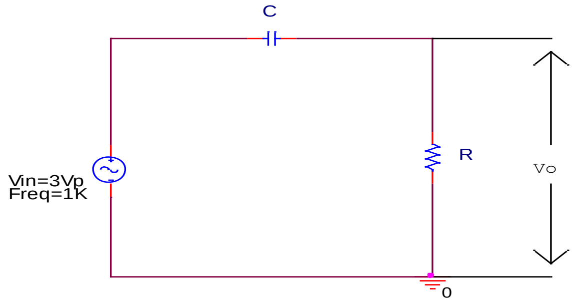

Fig.4.1: Basic Lead Compensator Circuit

Limited lead Compensator:

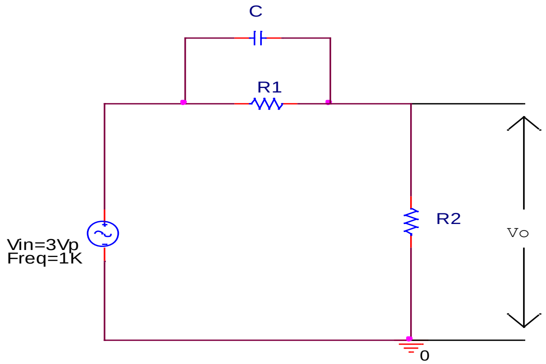

Fig.4.2: Limited Lead Compensator Circuit

Design:

Basic Lead Compensator:

Design lead compensator for a phase angle of 58° at 1 kHz

Phase angle φ of a basic lead circuit shown in Fig.4.1 is given by

$$\varphi = \tan^{-1}\left(\frac{1}{\omega RC}\right)$$

Assuming the value of C, Value of R is calculated.

Limited Lead Compensator:

Design a limited lead compensator for a phase angle of 40° at 500 Hz

Transfer function of limited lag compensator shown in Fig.4.2 is given by,

$$G(s) = \frac{\alpha(1+sT)}{1+sT\alpha}, \quad \alpha < 1 \quad \text{.................}1$$

$$\text{Where, } \alpha = \frac{R_1}{R_1 + R_2} \text{ ,..............................}2$$

$$T = R_1C\text{..}3$$

Maximum possible Phase angle of lag network depends on the value of β and is given by

$$\varphi_m = \tan^{-1}\left(\frac{1-\alpha}{2\sqrt{\alpha}}\right), \text{ ....}4$$

Lower the value of α, we get higher lead angle.

Frequency at which max phase angle occurs is given by,

$$\omega_m = \frac{1}{T\sqrt{\alpha}}\text{...............................}5$$

Lead angle is given by,

$$\varphi = \tan^{-1}(\omega T) - \tan^{-1}(\omega\alpha T)\text{..........}6$$

Simplifying above equation, we get

$$\tan(\varphi) = \frac{\omega T(1-\alpha)}{1+\alpha(\omega T)^2}\text{....................}7$$

- For the given phase angle φ, value of α is correctly chosen using the equation-4 and value of T is found using equation-7.
- By assuming the value of C, value of R_1 is found using equation-3.
- Value of R_2 is found using equation-2.

Procedure:

To Plot Frequency response Curve

1. A passive RC lead compensating network is designed for the given specifications.
2. Connections are made as per the circuit diagram.
3. The output voltage of sine generator is set to 3 V (peak) and is supplied as input to the RC lead compensator.
4. The input frequency of the circuit is varied in steps and the corresponding output voltage, frequency and Phase angle between input and output signal is tabulated.
5. The plots of gain in dB Vs frequency and phase angle vs. frequency are plotted in semi log sheet.

To Determine the Transfer function of the compensator experimentally

1. From the plot of phase angle vs. frequency, obtain the maximum phase lag φ_m in degrees and the frequency at which this maximum phase lag occur *f* in Hz.
2. Using the formula ω*m*= 2 ∗ π ∗*f*, compute the maximum frequency in rad/s.
3. Using the formula, $\beta = \frac{1+\sin\varphi_m}{1-\sin\varphi_m}$, compute the constant factor β.
4. Using the formula, $\omega_m = \frac{1}{T\sqrt{\beta}}$, compute the time constant T in sec.
5. Transfer function of Lag Compensation is determined using the formula, $G(s) = \frac{\alpha(1+sT)}{1+sT\alpha}$
6. Verify the same, as follows.

Verification:

1. From the given RC phase lag compensator network, collect the values of the components R_1, R_2 and C.

2. With the help of the formula $\alpha = \frac{R_1}{R_1 + R_2}$ Compute the value of α.
3. With the help of the formula, T = $R_1 * C$ obtain the value of time constant T in sec.
4. Theoretical transfer function of Lag Compensation is determined using the formula $G(s) = \frac{\alpha(1+sT)}{1+sT\alpha}$.

Tabular Column:

Input Voltage, V_i = 3V

Sl.No.	f (Hz)	V_O (V)	Phase angle Φ in degrees	Gain = (V_O/V_i)	Gain in dB 20log(V_o/V_i)

Typical Graph:

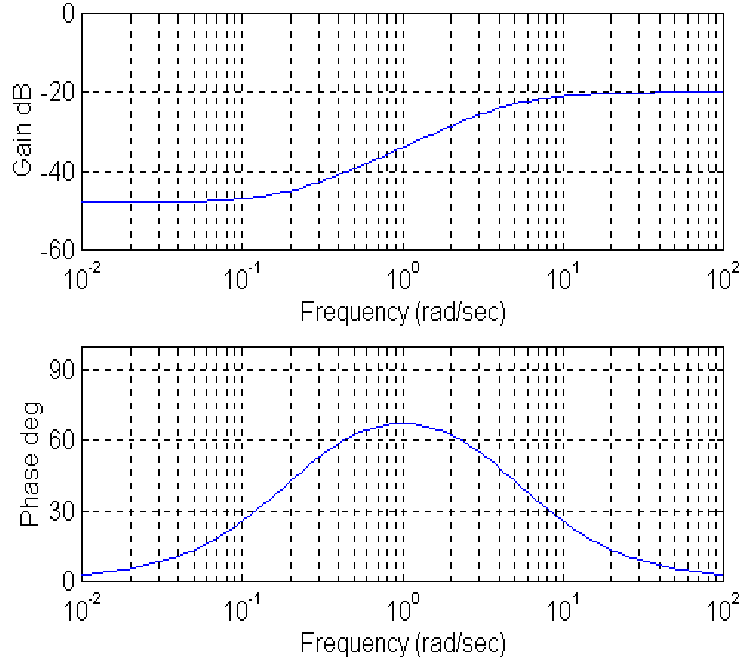

Fig.4.3: Typical Frequency Response Curve of Lead Compensator

Conclusion:

Outcomes: At the end of the experiment,

1. The students will be able to design lead compensator circuit for a given phase angle.
2. The students will acquire the knowledge on the applications of lead compensator circuit.

Viva Questions:

1. Mention the advantages of lead compensator.
2. Give the differences between lead compensator and lag compensator.
3. Mention the effects of phase lead compensation.

Preparation	Conduction	Calculation/Result Analysis	Total

Free Space for rough work:

Signature of Faculty Member

Experiment No: 05 **Date:**

A. To design a passive RC Lag compensating network for the given specifications, viz., the maximum phase lag and the frequency at which it occurs and to obtain the frequency response.

B. To determine experimentally the transfer function of the lag compensating network.

Aim:

- To design a passive RC lag compensating network for the given specifications,
- To obtain its frequency response curve.
- To determine experimentally the transfer function of the given lag compensating network.

Objectives:

1. The students will get knowledge regarding lead compensating network and its design.
2. The students will learn about frequency response curve and determination of transfer function for the lead network

Apparatus required:

- Function generator
- DRB and DCB
- Phase angle detector
- voltmeter

Circuit diagram:

Basic Lag Compensator:

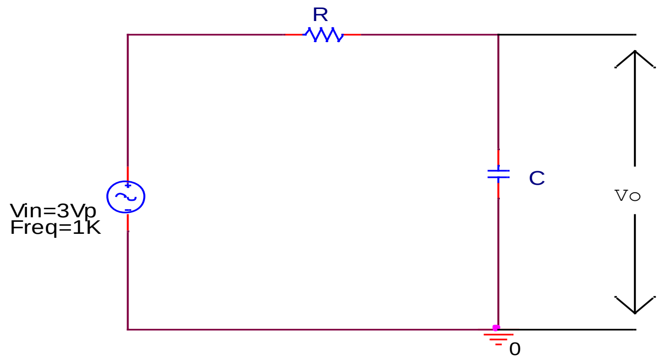

Fig.5.1: Basic Lag Compensator Circuit

Limited Lag Compensator:

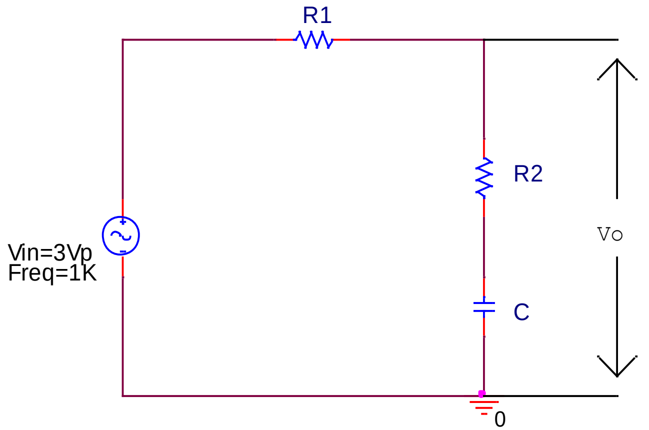

Fig.5.2: Limited Lag Compensator Circuit

Design:

Basic Lag Compensator:

Design a lag compensator for a phase angle of 81° at 1 kHz

Phase angle φ of a basic lag circuit shown in Fig.5.1 is given by,

$$\varphi = \tan^{-1}(\frac{1}{\omega RC})$$

Assuming the value of C, Value of R is calculated.

Limited Lag Compensator:

Design a limited lag compensator for a phase angle of 50° at 1 kHz

Transfer function of limited lag compensator shown in Fig. 2 is given by,

$$G(s) = \frac{1+sT}{1+sT\beta}, \quad \beta > 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots..1$$

$$\text{Where, } \beta = \frac{R_1 + R_2}{R_2} \quad ,\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2$$

$$T = R_2C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3$$

Maximum possible Phase angle of lag network depends on the value of β and is given by

$$\varphi_m = \tan^{-1}(\frac{1-\beta)}{2\sqrt{\beta}}), \ldots\ldots\ldots\ldots\ldots\ldots4$$

As the value of β increases, we get higher lag angle.

Frequency at which max phase angle occurs is given by,

$$\omega_m = \frac{1}{T\sqrt{\beta}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.5$$

Lag angle is given by,

$$\varphi = \tan^{-1}(\omega T) - \tan^{-1}(\omega\beta T) \ldots\ldots.6$$

Simplifying above equation, we get

$$\tan(\varphi) = \frac{\omega T(1-\beta)}{1 + \beta(\omega T)^2} \ldots\ldots\ldots\ldots\ldots\ldots7$$

- For the given phase angle φ, value of β is correctly chosen using the equation-4 and value of T is found using equation-7.
- By assuming the value of C, value of R_2 is found using equation-3.
- Value of R_1 is found using equation-2.

Procedure:

To Plot Frequency response Curve

1. A passive RC lag compensating network is designed and for the given specifications.
2. Connections are made as per the circuit diagram.
3. The output voltage of sine generator is set to 3V (peak) and is supplied as input to the RC lag compensator.
4. The input frequency of the circuit is varied in steps and the corresponding output voltage, frequency and Phase angle between input and output signal is tabulated.
5. The plots of gain in dB Vs frequency and phase angle vs. frequency are plotted in semi log sheet.

To Determine the Transfer function of the compensator experimentally

1. From the plot of phase angle vs. frequency, obtain the maximum phase lag φ_m in degrees and the frequency at which this maximum phase lag occurs *f* in Hz
2. Using the formula $\omega_m = 2 * \pi * f$, compute the maximum frequency in rad/s.
3. Using the formula, $\beta = \frac{1+\sin\varphi_m}{1-\sin\varphi_m}$ compute the constant factor β.
4. Using the formula $\omega_m = \frac{1}{T\sqrt{\beta}}$, compute the time constant T in sec.
5. Transfer function of Lag Compensation is determined using the formula $G(s) = \frac{1+sT}{1+sT\beta}$
6. Step 6: Verify the same, as follows.

Verification:

1. From the given RC phase lag compensator network, collect the values of the components R_3, R_2 and C.
2. With the help of the formula, $\beta = \frac{R_1 + R_2}{R_2}$ compute the value of β.
3. With the help of the formula, T = R2 ∗C, obtain the value of time constant T in sec.
4. Theoretical transfer function of Lag Compensation is determined using the formula $G(s) = \frac{1+sT}{1+sT\beta}$.

Tabular Column:

Input Voltage V_i= 3V

Sl.No.	f (Hz)	V_O (V)	Phase angle Φ in degrees	Gain = (V_O/V_i)	Gain in dB 20log(V_o/V_i)

Typical Graphs:

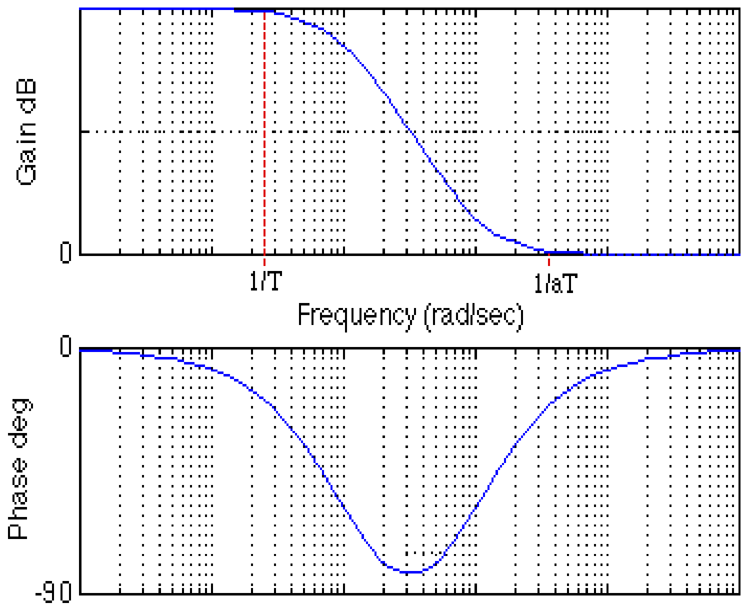

Fig.5.3: Model Frequency Response Curve of Lag Compensator

Conclusion:

Outcomes: At the end of the experiment,

1. The students will be able to design lag compensator circuit for a given phase angle.
2. The students will acquire the knowledge on the applications of lead compensator circuit.

Viva Questions:

1. Mention the applications of lag compensator.
2. Give the advantages and disadvantages of lag compensator.
3. Mention the effects of phase lag control.

Preparation	Conduction	Calculation/Result Analysis	Total

Free Space for rough work:

Signature of Faculty Member

Experiment No: 06 **Date:**

Experiment to draw the frequency response characteristics of the Lag –lead compensator network and determination of its transfer function

Aim: Experiment to draw the frequency response of a given lead-lag compensating network.

Objective: The students will learn regarding frequency response characteristics of the lag – lead compensator network and also to determine the transfer function.

Apparatus Required:

1. Resistors – 10k – 2 Nos
2. Capacitors – 0.1μF – 2 Nos
3. Wires
4. Multimeter
5. Phase- frequency meter.

Circuit Diagram:

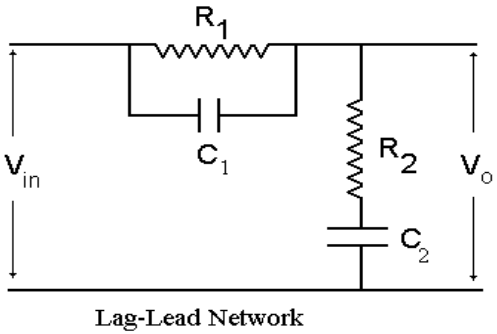

Fig.6.1: Circuit diagram Lag-Lead Compensator Network

Procedure:

1. Derive the transfer function for the lag lead network given above.
2. Connections are made as per the Lag lead circuit diagram by the selecting the proper values.
3. Switch ON the mains supply and apply sinusoidal wave by selecting suitable amplitude.
4. The frequency of the signal is varied in steps and at each step note down the corresponding magnitude of output and phase angle.
5. Draw the frequency response plot and hence find the transfer function & compare it with the design.

Derivation of transfer function:

Write the above circuit in Laplace form.

$V_i(s) = (Z_1+Z_2)*I(s)$, Where I(s) is the current in the circuit.

$Z_1= (R_1//C_1S)$ and $Z_2 = (R_2 + 1/C_2S)$

$V_O(s) = Z_2*I(s)$

$V_o(s)/V_i(s) = Z_2 /(Z_1+Z_2)$

After simplification, $GC(S) = \frac{(S+ 1/ T_1)(S+ 1/ T_2)}{(S+ 1/ \beta T2)(S+ \beta/ T1)}$

Where, $T_1 = R_1C_1$, $T_2 = R_2C_2$, $R_1C_1+ R_2C_2 + R_1C_2 = 1/ \beta T_2 + \beta/ T_1$

Tabular Column:

V_i =………… V			
Sl. No.	**V_O, RMS (V)**	**Φ in degrees**	**Gain in dB = 20 log (V_O/V_i)**

Typical Graph:

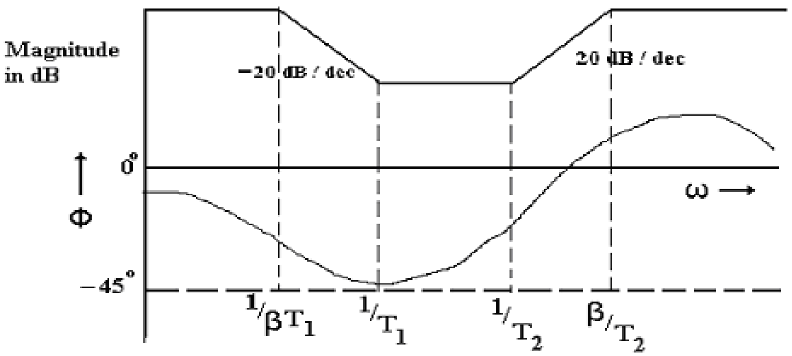

Fig.6.2: Typical response of Lag-lead compensator

Conclusion:

Outcome: At the end of the experiment,

1. The students will acquire the knowledge of the effect of lag-lead circuit on any system.

Viva Questions:

1. Mention the advantages and disadvantages of lag-lead compensator.
2. Give the differences between lag-lead and lead compensator.
3. Mention the applications of lag-lead compensator.

Preparation	Conduction	Calculation/Result Analysis	Total

Signature of Faculty Member

Free Space for rough work:

Experiment No: 07 **Date:**

A. **Simulation of a typical second order system using MATLAB and determination of step response and evaluation of time domain specifications.**
B. **Evaluation of effect of additional poles and zeros on time response of second order system.**
C. **Evaluation of effect of pole location on Stability.**
D. **Effect of loop gain of a negative feedback system on stability.**

Aim: To determine the step response of second order system and study the effect of adding poles and zeros on the response of the system.

Objective: The students will learn about program to determine step response of second order system and evaluate the time domain specifications.

Procedure:

Case I: To simulate a typical second order system and determine step response and evaluate time response specifications.

Standard form of transfer function of a second order system is

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2} ------(1)$$

The dynamic behavior of a second order system can be described in terms of ξ and ω_n

If, $0 < \xi < 1$, the closed loop poles are complex conjugate and lie in the left half of the s-plane. The system is then under damped and the transient response is oscillatory.

If, $\xi = 1$, the system is called critically damped.

If, $\xi > 1$, the system is called over damped.

If, $\xi = 0$, the system is undamped and the transient response does not die out; but oscillation continues indefinitely

Time Response Characteristics:

Rise Time (T_R): Rise time is defined as the time required for the response to rise from 10% to 90% of the final value for an under damped system.

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

Settling Time (T_S): Settling time is defined as the time required for the response to decrease and stay within the specified percentage (2% to 5%) of its final value.

$$t_s(5\%) = 3\tau = \frac{3}{\xi\omega_n} ---------(3)$$

$$t_s(2\%) = 4\tau = \frac{4}{\xi\omega_n} ---------(4)$$

Peak Overshoot (M_P): Peak overshoot is defined as the maximum response of the system measured from the final value.

$$M_P = e^{-\pi\xi\sqrt{1-\xi^2}} ---------- (5)$$

Peak Time (T_P): The time required to reach the first peak overshoot is defined as peak time.

$$t_p = \frac{\pi}{\omega_n\sqrt{1-\xi^2}} ---------- (6)$$

1. Consider an example for the second order system with an open loop transfer function as $G(S) = \frac{5}{S(S+1)}$ and unity feedback system H(s) = 1.
2. The closed loop transfer function is determined by using the equation, $TF = \frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)H(s)} -------- (7)$
3. By substituting the values of G(s) and H(s) in above equation we get, $TF = \frac{C(s)}{R(s)} = \frac{5}{s^2+s+5} ----------(8)$
4. Comparing Equation (1) and (8), we get ω_n= 2.236 and ξ= 0.224. Since ξ < 1, the given system is under damped.
5. Write the programusing GNU OCTAVE to simulate step response of the givensystem and save the file and load the control package.
6. Evaluate time domain specifications :
   a. Run the program. Step response appears on the screen.
   b. By using pointer read the time domain specifications.

Program:

Program to obtain step response of second order system

```
clc
% prg c(t)
num = [5];
den = [1 1 5];
G = tf(num, den)
kp=dcgain(G)
ess=1/(1+kp)
w = sqrt (den(3))
zeta = den(2) / (2*w)
TD=(1+0.7*zeta)/w
TS = 4/ (zeta*w)
TP = pi/ (w*sqrt(1-zeta^2))
TR=(pi-atan((sqrt(1-zeta^2))/zeta))/(w*sqrt(1-zeta^2))
Percentovershoot= exp(-zeta*pi/ sqrt(1-zeta^2))*100
step(G)
title('Step response of c(t)')
figure
pzmap(G)
title('pole zero map of c(t)')
figure
```

Output Response:

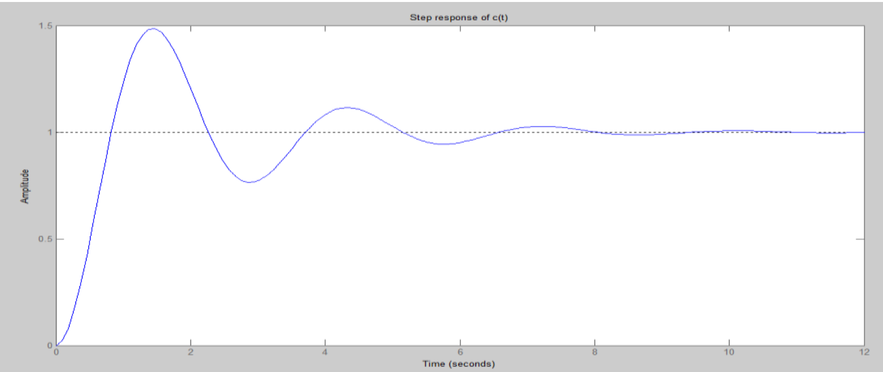

Fig.7.1: Step Response Curve

Results:

Particulars	Theoretical Value	Simulated Value
Delay Time		
Rise Time		
Peak Time		
Settling Time		
Peak Overshoot		

Case – II: Evaluation of the effect of additional poles and zeroes on time response of second order system.

Effect of adding pole to the transfer function:

1. If pole is added at -2 for the open loop transfer function.

$$G(S) = \frac{5}{S(S+1)}.$$

The transfer function gets modified as,

$$G(s) = \frac{5}{s(s+1)(s+2)}$$

2. The closed loop transfer function for the given system is obtained as,

$$TF = \frac{5}{s^3 + 3s^2 + 2s + 5}$$

3. Effect of adding pole to transfer function results in
   a. Increases the order of the system.
   b. Increases the overshoot.
   c. Reduces the stability.
   d. Increases the Rise time of the step response.

Program:

```
clc
% prg c(t)
num = [5];
den = [1 32 5];
G = tf(num, den)
step(G)
```

```
title('Step response of c(t)')
figure
pzmap(G)
title('pole zero map of c(t)')
figure
```

Output Response:

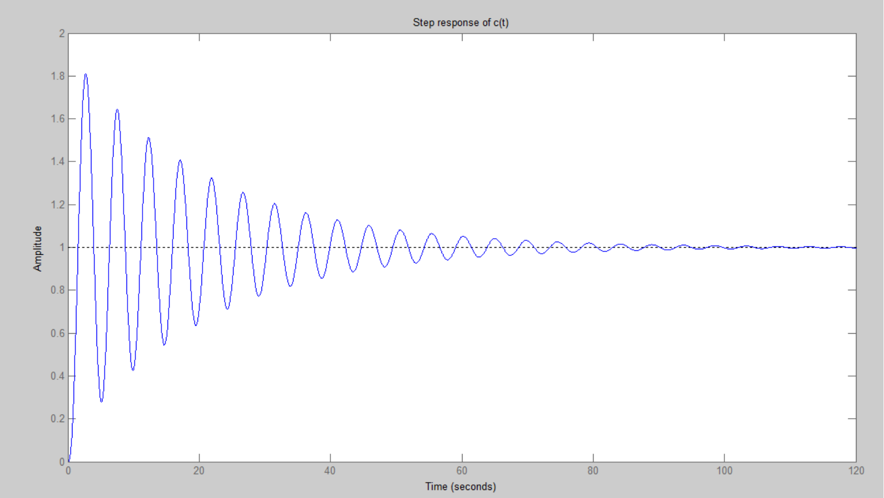

Fig.7.2: Step response after adding pole to the transfer function

Results:

Particulars	Simulated Value
Delay Time	
Rise Time	
Peak Time	
Settling Time	
Peak Overshoot	

Effect of adding zero to the transfer function:

1. If zero is added at -2 for the open loop transfer function.
   $G(S) = \frac{5}{S(S+1)}$.
   The transfer function gets modified as,
   $$G(s) = \frac{5(s+2)}{s(s+1)}$$
2. The closed loop transfer function for the given system is obtained as,
   $$TF = \frac{5s+10}{s^2+6s+10}$$
3. Comparison of location for zeroes with respect to overshoot and damping parameters.

Time response parameters	Location of Zeros		
	Far away from the imaginary axis	Zero moving towards right	Zero moves closer to origin
Overshoot	Large	Reduced	Almost nil
Damping	Very poor	Improved	Improves

Program:

```
clc
% prg c(t)
num = [5 10];
den = [1 6 10];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Output Response:

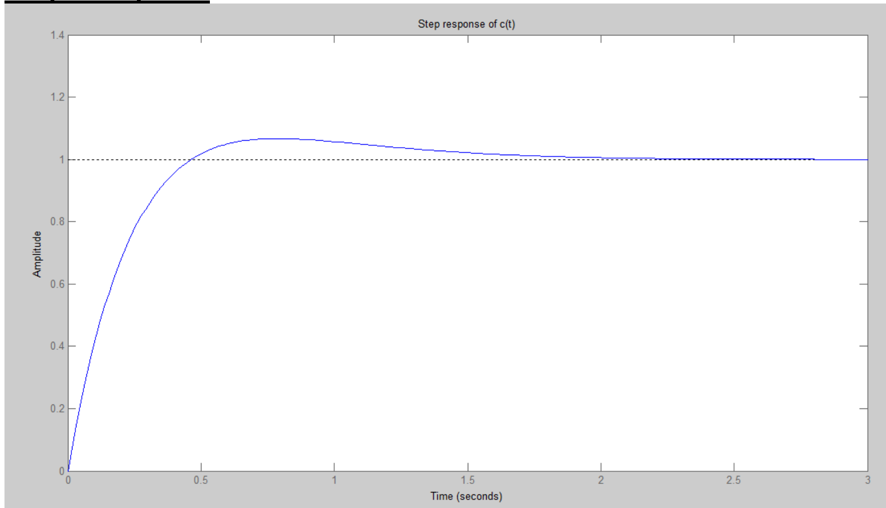

Fig.7.3: Step response after adding zeros to the transfer function

Results:

Particulars	Simulated Value
Delay Time	
Rise Time	
Peak Time	
Settling Time	
Peak Overshoot	

Case – III: Evaluation of effect of pole location on Stability:

1. The stability of a feedback system is directly related to the location of the roots of the characteristic equation of the system transfer function.
2. "A linear system will be stable if and only if all the poles of the transfer function are located on the left half of the 'S' plane".
3. Consider the below examples to study the effect of location of pole on stability of the system.

Example 1(a): $\frac{C(S)}{R(S)} = \frac{1}{S+5}$ i.e. Pole at s = -5

Program:

```
clc
% prg c(t)
num = [1];
den = [1 5];
G = tf(num, den)
impulse(G)
title('Step response of c(t)')
figure
```

Output Response:

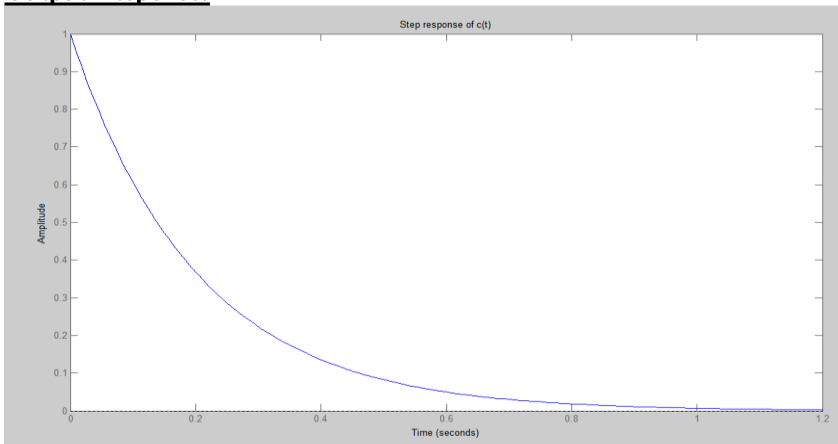

Fig.7.4: Time response for $\frac{C(S)}{R(S)} = \frac{1}{S+5}$

Example 1(b): $\frac{C(S)}{R(S)} = \frac{1}{S-5}$ i.e. Pole at s = 5

Program:

```
clc
% prg c(t)
num = [1];
den = [1 -5];
G = tf(num, den)
impulse(G)
title('Step response of c(t)')
figure
```

Output Response:

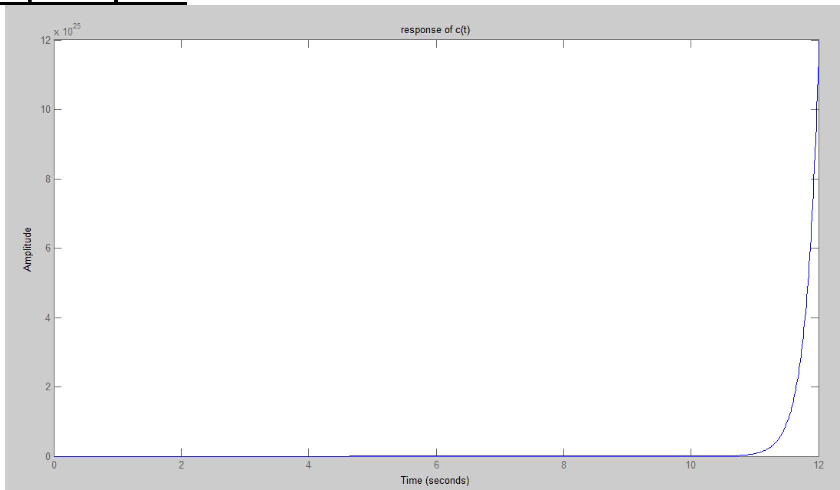

Fig.7.5: Time response for $\frac{C(S)}{R(S)} = \frac{1}{S-5}$

Example 2(a): $\frac{C(S)}{R(S)} = \frac{1}{S^2+5S+29}$ i.e. Pole at s = -2.5$\pm j4.77$

Program:

```
clc
% prg c(t)
num = [1];
den = [1 5 29];
G = tf(num, den)
impulse(G)
title('Step response of c(t)')
figure
```

Output Response:

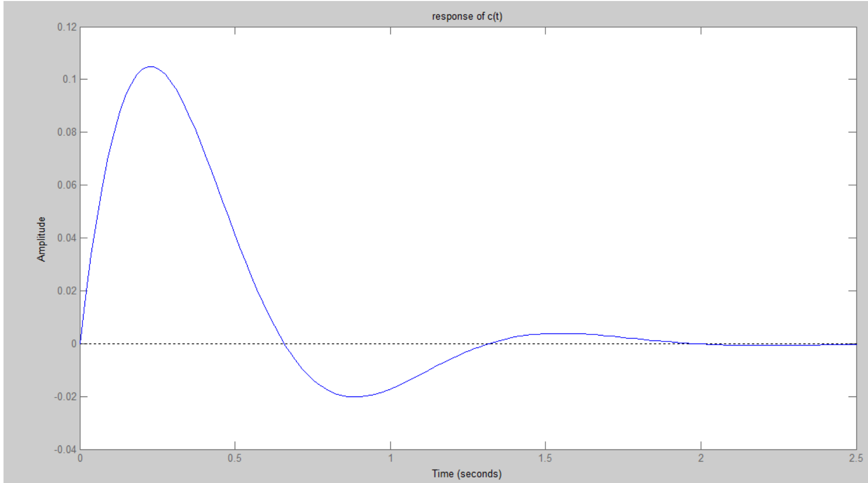

Fig.7.6: Time response for $\frac{C(S)}{R(S)} = \frac{1}{S^2+5S+29}$

Example 2(b): $\frac{C(S)}{R(S)} = \frac{1}{S^2-5S+29}$ i.e. Pole at s = 2.5$\pm j4.77$

Program:

```
clc
% prg c(t)
num = [1];
den = [1 -5 29];
G = tf(num, den)
impulse(G)
title('Step response of c(t)')
figure
```

Output Response:

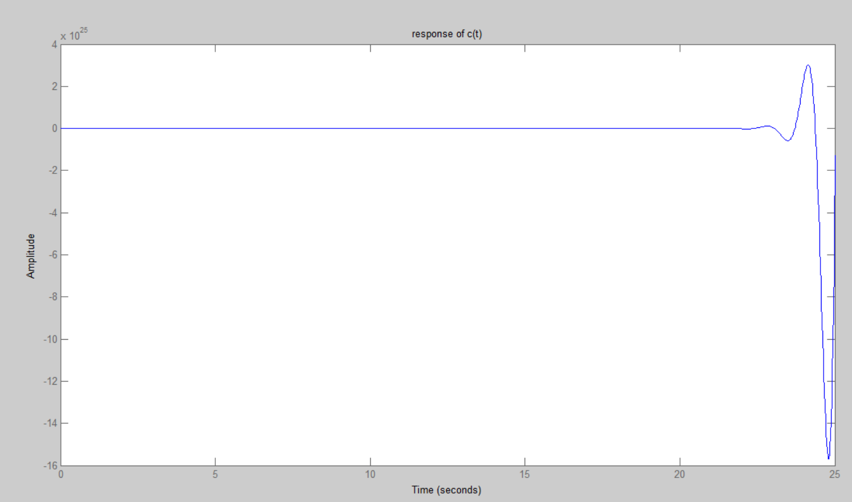

Fig.7.7: Time response for $\frac{C(S)}{R(S)} = \frac{1}{S^2-5S+29}$

Case – IV: Effect of loop gain of a negative feedback system on stability

1. Effect of loop gain of a negative feedback system on stability of a system can be identified by knowing characteristic equation of the system and applying "Routh's Stability Criterion".
2. Consider an open loop transfer function of a system as,

$$G(s)H(s) = \frac{K}{s(s^2+4s+20)(s+4)}$$

3. Determine the value of 'K' loop gain for which the system is stable. Consider the system with unity feedback H(s) = 1.
4. The closed loop transfer function is obtained as,

$$TF = \frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)H(s)} = \frac{K}{s^4+8s^3+36s^2+80s+K}$$

5. From closed loop TF, Determine characteristic equation

i.e. $S^4 + 8S^3 + 36S^2 + 80S + K = 0$

6. Form Routh's stability array,

S^4	1	36	K
S^3	8	80	$\div by\ 8$
S^3	1	10	
S^2	26	K	
S^1	(260-K)/26	0	
S^0	K		

For a system to be stable, it is necessary and sufficient that each term of first column of Routh array of its characteristic equation be positive. If this condition is not met, the system is unstable and number of sign changes of the terms of the first column of the Routh array corresponds to the number of roots of the characteristic equation in the right half of the s-plane.

7. For stability all the coefficients in the first column of the array must be positive, therefore

$$K > 0 \text{ and } (260-K)/26 > 0$$

By rearranging the terms the range of K for which the system is stable is $0 < K < 260$. When K =260, the system gives sustained oscillations.

Program:

```
clc
% prg c(t)
num = [1];
den = [1 8 36 80 0];
G = tf(num, den)
[r,k]=rlocus(G,[240:10:280])
title('response of c(t)')
figure
```

Results:

r = (Pole location)				
-3.9061+ 3.1037i	-3.9542 + 3.13i	-4.0000 + 3.1623i	-4.0436 + 3.1900i	-4.0853+3.2169i
-3.9061 - 3.1037i	-3.9542 - 3.135i	-4.0000 - 3.1623i	-4.0436 - 3.1900i	-4.0853 - 3.2169i
-0.0939 + 3.103i	-0.0458 + 3.13i	0.0000 + 3.1623i	0.0436 + 3.1900i	0.0853 + 3.2169i
-0.0939 - 3.1037i	-0.0458 - 3.133i	0.0000 - 3.1623i	0.0436 - 3.1900i	0.0853 - 3.2169i
k = (value of loop gain)				
240	250	260	270	280

By seeing the above table, we can tell at

a. K < 260 system is stable because all the 4 poles are in left half of s-plane
b. K = 260 system is marginally stable because 2 poles are on the imaginary axis
c. K > 260 system is unstable because 2 poles are located on right half of s-plane.

Conclusion:

Outcomes: At the end of the experiment,

1. Students will be able to find Delay Time, Rise Time, Peak Time, Settling Time and Peak Overshoot from OCTAVE simulation.
2. The students will know about the effect of adding poles and zeros to the second order system.
3. Effect pole location and loop gain on stability of the system.

Viva Questions:

1. Mention the time response specifications and define them.
2. Define steady state error and mention error constants.
3. Define static position error constant and static velocity error constant.

Preparation	Conduction	Calculation/Result Analysis	Total

Free Space for rough work:

Signature of Faculty Member

Experiment No: 08 **Date:**

To simulate a second order system and study the effect of (a) P, (b) PI, (c) PD and (d) PID controller on the step response

Aim: To study the effect of different controllers on the step response of second order system.

Objective: The students will learn regarding different controllers and their effects on step response of second order system.

Procedure:

1. Consider an open loop transfer function $G(S) = \frac{1}{s^2+10s+20}$ with unity feedback system as shown in block diagram.
2. Obtain the closed loop transfer function and write the program using GNU OCTAVE to simulate step response of the given system and save the file and load the control package.
3. Evaluate time domain specifications :
    e. Run the program. Step response appears on the screen.
    f. By using pointer read the time domain specifications and also determine the steady state error.

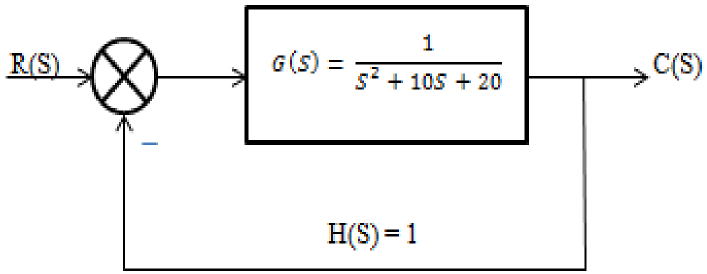

Fig.8.1: Closed loop system

Closed Loop Transfer Function $\frac{C(S)}{R(S)} = \frac{G(S)}{1+G(S)H(S)}$

$$\frac{C(S)}{R(S)} = \frac{1}{S^2 + 10S + 21}$$

Program:

```
clc
% prg c(t)
num = [1];
den = [1 10 21];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Tabular Column:

Time domain specification parameter	Simulated values
Delay Time	
Rise Time	
Peak Time	
Settling Time	
Peak Overshoot	
Steady State Error	

Proportional (P) Controller:

1. In Proportional Controller the actuating signal is proportional to the error signal. The error signal is the difference between reference input signal and feedback signal obtained from output.
2. Analyse the above system by including proportional controller as shown in block diagram.
3. Obtain the closed loop transfer function and write the program using GNU OCTAVE to simulate step response of the given system and save the file and load the control package
4. The proportional controller reduces the rise times and steady state error and increases the peak overshoot. For different values of K_P obtain the time specifications and steady state error.

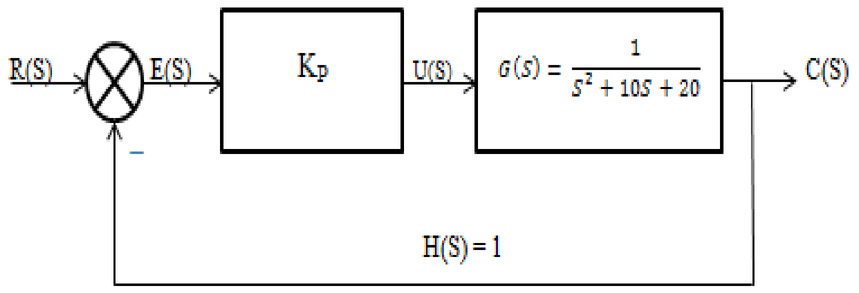

Fig.8.2: Block diagram of Second order system with Proportional Controller

Closed Loop Transfer Function

$$\frac{C(S)}{R(S)} = \frac{K_P}{S^2 + 10S + 20 + K_P}$$

Program:

```
clc
% prg c(t)
num = [10];
den = [1 10 30];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Tabular Column:

Time domain specification parameter	Simulated values			
K_P	**10**	**100**	**300**	**500**
Delay Time				
Rise Time				
Peak Time				
Settling Time				
Peak Overshoot				
Steady State Error				

Proportional Integral (PI) Controller:

1. In PI controller the actuating signal consists of proportional-error signal along with the integral of the error signal.
2. Analyse the given second order system by including proportional Integral (PI) controller as shown in block diagram.
3. Obtain the closed loop transfer function and write the program using GNU OCTAVE to simulate step response of the given system and save the file and load the control package.
4. The proportional Integral controller reduces the steady state error and improves the transient response but it also increases the system settling

time. For different values of $K_I$keeping $K_P$constant obtain the time specifications and steady state error.

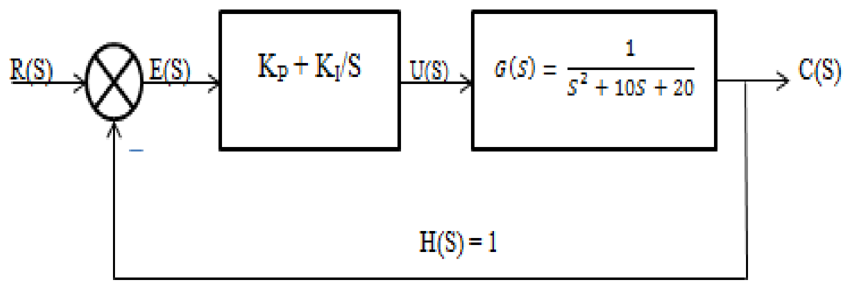

Fig.8.3: Block diagram of Second order system with Proportional Integral Controller

Closed Loop Transfer Function

$$\frac{C(S)}{R(S)} = \frac{SK_P + K_I}{S^3 + 10S^2 + (20 + K_P)S + K_I}$$

Program:

```
clc
% prg c(t)
num = [30 50];
den = [1 10 50 50];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Tabular Column:

Time domain specification parameter	Simulated values		
	$K_P = 30$, $K_I = 50$	$K_P = 30$, $K_I = 70$	$K_P = 30$, $K_I = 100$
Delay Time			
Rise Time			
Peak Time			
Settling Time			
Peak Overshoot			
Steady State Error			

Proportional Derivative (PD) Controller:

1. In PD controller the actuating signal consists of proportional error signal and also the derivative of error signal.
2. Analyse the given second order system by including proportional Derivative (PD) controller as shown in block diagram.
3. Obtain the closed loop transfer function and write the program using GNU OCTAVE to simulate step response of the given system and save the file and load the control package
4. The derivative controller reduces both the overshoot and the settling time and had a small effect on rise time and steady state error.
5. To control the steady state error the derivative gain K_D must be high.
6. The PD controller reduces the response times of the system and can make it susceptible to noise.

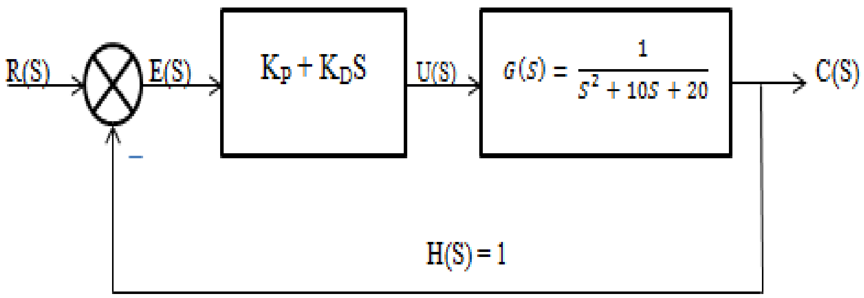

Fig.8.4: Block diagram of Second order system with Proportional Derivative Controller

Closed Loop Transfer Function

$$\frac{C(S)}{R(S)} = \frac{K_P + K_D S}{S^2 + (10 + K_D)S + 20 + K_P}$$

Program:

```
clc
% prg c(t)
num = [10 500];
den = [1 20 520];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Tabular Column:

Time domain specification parameter	Simulated values	
	K_P = 500, K_D = 10	K_P = 500, K_D = 50
Delay Time		
Rise Time		
Peak Time		
Settling Time		
Peak Overshoot		
Steady State Error		

Proportional Integral Derivative Controller (PID) Controller:

1. For PID controller, the actuating signal consists of proportional error signal and also the derivative and integral of error signal.
2. Analyse the given second order system by including proportional Integral Derivative (PD) controller as shown in block diagram.
3. Obtain the closed loop transfer function and write the program using GNU OCTAVE to simulate step response of the given system and save the file and load the control package.
4. The PID controller removes the steady state error and reduces the settling time while maintaining reasonable transient response.

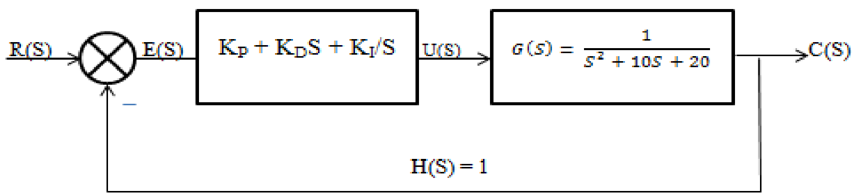

Fig.8.5: Block diagram of Second order system with PID Controller

Closed Loop Transfer Function

$$\frac{C(S)}{R(S)} = \frac{S^2K_D + SK_P + K_I}{S^3 + (10 + K_D)S^2 + (20 + K_P)S + K_I}$$

Program:

```
clc
% prg c(t)
num = [10 500];
den = [1 20 520];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Tabular Column:

Time domain specification parameter	Simulated values
	K_P = 500, K_D = 50, K_I = 400
Delay Time	
Rise Time	
Peak Time	
Settling Time	
Peak Overshoot	
Steady State Error	

Conclusion:

Outcomes: At the end of the experiment,

1. The students have knowledge on PI, PD and PID controller.
2. The students will be able to design PI, PD and PID controller.

Viva Questions:

1. Define PI, PD and PID Controllers
2. Give the comparison between PI and PD Controller.
3. Why differential control is not used alone?
4. Mention the applications of PID Controller.

Preparation	Conduction	Calculation/Result Analysis	Total

Free Space for rough work:

Signature of Faculty Member

Experiment No: 09 **Date:**

A. To simulate a DC Position control system and obtain its step response.
B. To verify the effect of the input wave form, system type on steady state errors.
C. To perform a trade-off study for lead compensation.

Case A:

Aim: To study the DC position control system of DC motor and obtain its step response.

Objective: The students will learn regarding DC position control system of DC motor.

Circuit Diagram:

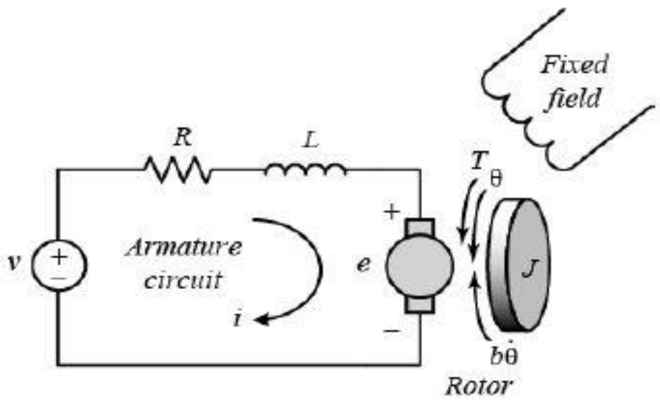

Fig.9.1: Armature controlled DC motor

Design:

The closed loop transfer function of the system is given by

$$\frac{\theta(S)}{V(S)} = K_T/s[(Js + b)(Ls + R) + K_T K_B]$$

Where,

J = Moment of inertia of the rotor = 3.228 * 10^{-6} kgm^2

B = Motor viscous friction constant = 3.5077 * 10^{-6} Nms

K_B = Electromotive force constant = 0.0274 V/rad/sec

K_T = Motor torque constant = 0.0274 Nm/A

R = Electric Resistance = 4Ω

L = Electric Inductance = 2.75 * 10^{-6} H

Program:

```
clc
% prg c(t)
num = [];
den = [];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Procedure:

1. Obtain the closed loop transfer function for the system given by substituting the given values.
2. Write the program in GNU Octave after entering the coefficients of numerator and denominator.
3. Obtain the step response of the given system and determine different time specifications and steady state error.

4. Tabulate the results.

Tabular Column:

Time domain specification parameter	Simulated Values
Delay Time	
Rise Time	
Peak Time	
Settling Time	
Peak Overshoot	
Steady State Error	

Case B: To verify the effect of the input wave form, system type on steady state errors.

The open loop transfer function of a unity feedback system can be written in pole zero form as given below.

$$G(s) = \frac{K(s+Z_1)(s+Z_2)\dots\dots}{s^n(s+P_1)(s+P_2)\dots\dots}$$

The above equation involves S^n in denominator which corresponds to number of integrations in the system. As S tends to zero, this term dominates in determining steady state error. Control systems are therefore classified in accordance with number of integrations in open loop transfer function G(S) as Type 0, Type 1 and Type 2 systems for n=0,1,2 respectively.

Example-1: Consider a type 0 system whose transfer function is given by

$$\frac{C(s)}{R(s)} = \frac{(s+1)}{(s^2+2s+6)}$$

Step response of the system can be simulated as given in the program below.

Program:

```
clc
% prg c(t)
num = [1 1];
den = [1 2 6];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Output Response:

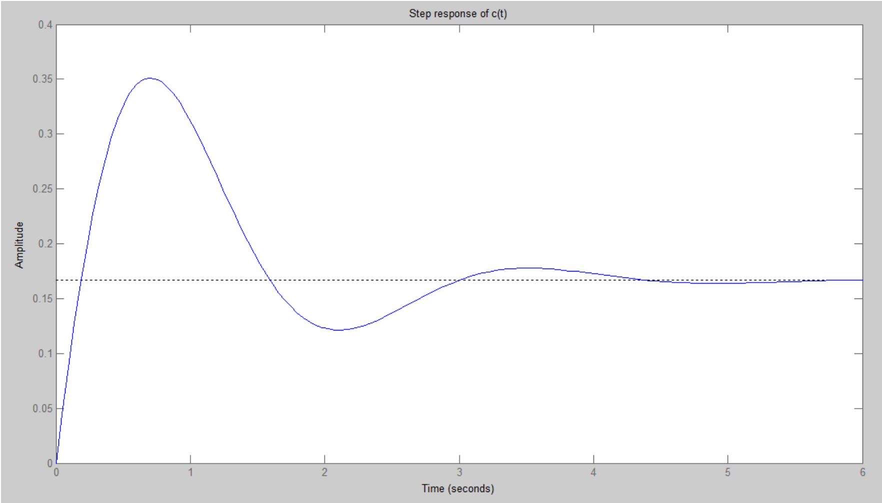

Fig 9.2: Step Response of Type 0 System

Example-2: Consider a type 1 system given by transfer function

$$\frac{C(s)}{R(s)} = \frac{(s+1)}{s(s^2+2s+6)}$$

Step response of the system can be simulated as given in the program below.

Program:

```
clc
% prg c(t)
num = [1 1];
den = [1 2 6 0];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Output Response:

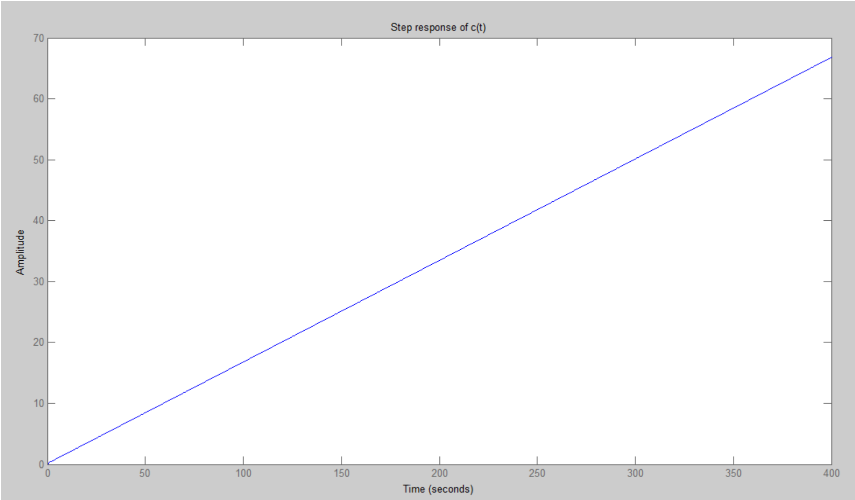

Fig 9.3: Step Response of Type 1 System

Example-3: Consider a type 2 system given by transfer function

$$\frac{C(s)}{R(s)} = \frac{(s+1)}{s^2(s^2+2s+6)}$$

Step response of the system can be simulated as given in the program below.

Program:

```
clc
% prg c(t)
num = [1 1];
den = [1 2 6 0 0];
G = tf(num, den)
step(G)
title('Step response of c(t)')
figure
```

Output Response:

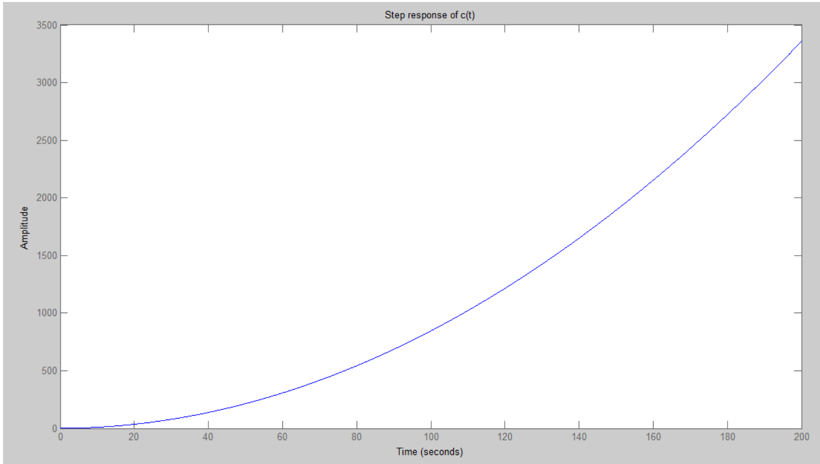

Fig 9.4: Step Response of Type 2 System

Observation:

System Type	Steady state error for unit step input
Type 0	$1/1+K_p$
Type 1	∞
Type 2	∞

Example-4: Consider the type 0, type 1 and type 2 systems given in examples 1, 2 and 3. The effect on steady state errors for these systems for a ramp input can be simulated by the program given below.

Program:

```
sys1=tf([1 1],[1 2 6 ]);
sys2=tf([1 1],[1 2 6 0]);
sys3=tf([1 1],[1 2 6 0 0]);
t=0:0.1:10;
u1=t;
lsim(sys1,'r', sys2,'m', sys3,'g', u1,t)
```

Output Response:

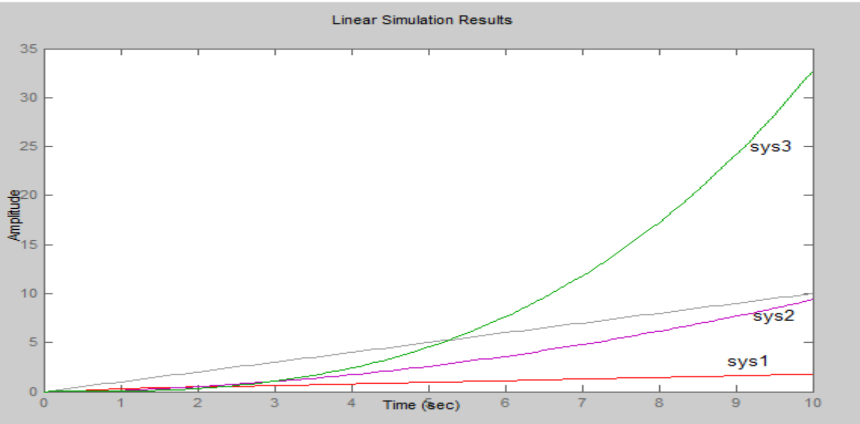

Fig.9.5: Effect of ramp input on steady state errors of type 0(sys1), type 1(sys2) and type 2(sys3) systems

Observation:

System Type	Steady state error for ramp input
Type 0	∞
Type 1	$1/K_v$
Type 2	0

Example-5: Consider the type 0, type 1 and type 2 systems given in examples 1, 2 and 3. The effect on steady state errors for these systems for a parabolic input can be simulated by the program given below.

Program:

```
sys1=tf([1 1],[1 2 6 ]);
sys2=tf([1 1],[1 2 6 0]);
sys3=tf([1 1],[1 2 6 0 0]);
t=0:0.1:10;
u1=t.*t;
lsim(sys1,'r', sys2,'m', sys3,'g', u1,t)
```

Output Response:

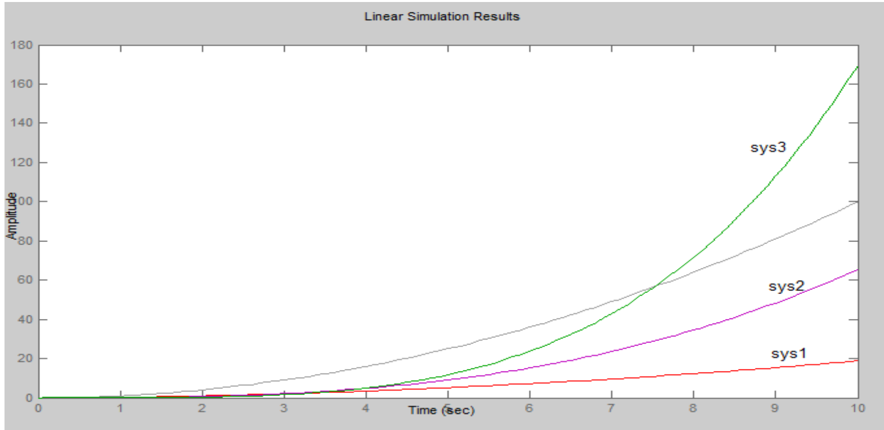

Fig 9.6: Effect of parabolic input on steady state errors of type 0(sys1), type 1(sys2) and type 2(sys3) systems

Observation:

System Type	Steady state error for Parabolic input
Type 0	0
Type 1	0
Type 2	$1/K_a$

Case C: To perform a trade-off study for lead compensation

The lead compensation on bode plots proceeds by adjusting the system error constant to a desired value.

The phase margin of the uncompensated system is then checked. Iffound satisfactory, the lead compensation is designed to meet the specified phase margin.With lead compensation introduced in the system, following observations are made.

- Phase margin is increased.
- Bandwidth increases.
- Peak resonance is reduced.
- Resonance frequency is increased.

Thus in general, the effect of lead compensator increases the margin of stability and speed of response.

Example: Consider a type 1 unity feedback system with an open loop transfer function.

$$G_f(s) = \frac{12}{S(S+1)}.$$

The bode plot of the given system is obtained by the program given below.

Program:

```
num = [12];
den = [1 1 0];
sys = tf (num , den)
bode (sys)
margin(sys)
```

Output Response:

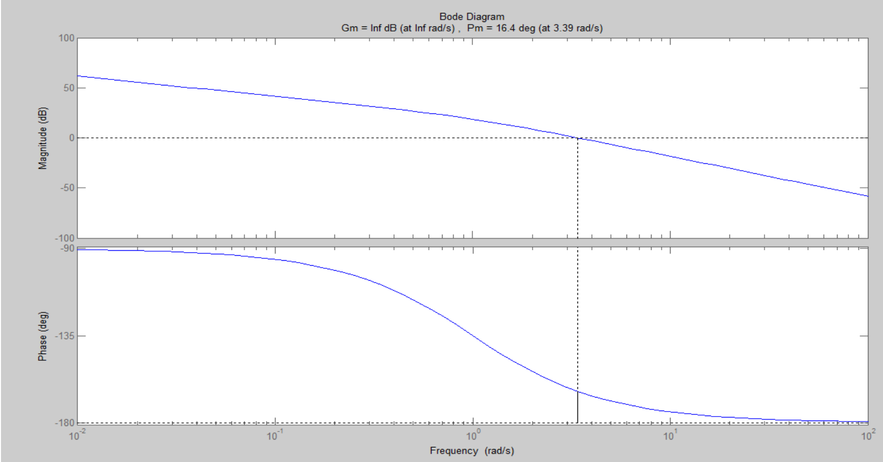

Fig 9.7 Bode plot of a type 1 system without compensation

Consider a lead compensator whose transfer function is given by;

$$G_c(s) = \frac{0.377s+1}{0.128s+1}$$

The open loop transfer function of the compensated system is now given by;

$$G_c(s) = \frac{12(0.377s+1)}{S(S+1)(0.128s+1)}$$

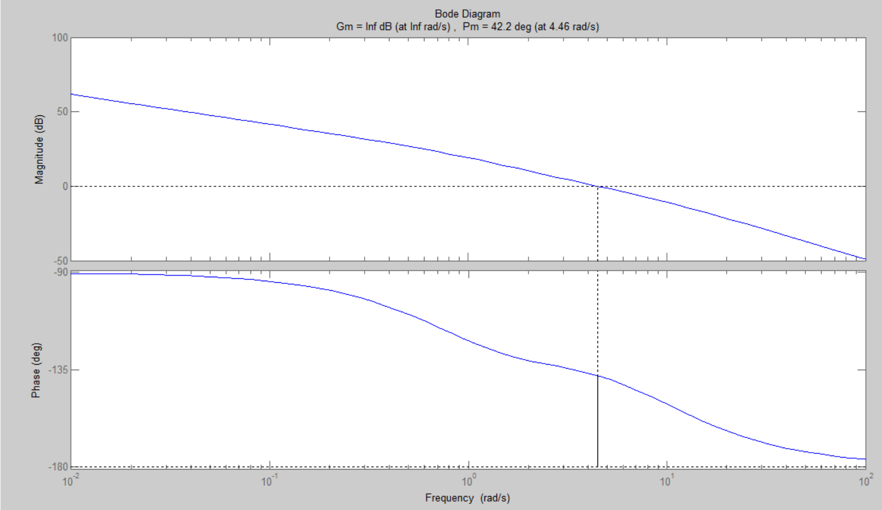

Fig 9.8: Bode plot of a compensated system

Observation:

System	Phase margin
Uncompensated system	16.4 degrees at 3.3 rad/sec
Compensated system	42.2 degrees at 4.46 rad/sec

Conclusion:

Outcome: At the end of experiment,

The students will have knowledge of DC position control of DC motor and also effect of type of system and input waveform on steady state error.

Viva Questions:

1. Define DC position of a system.
2. Differentiate between armature controlled and field controlled DC motor.
3. Define steady state error and mention different error coefficients.

Preparation	Conduction	Calculation/Result Analysis	Total

Free Space for rough work:

Signature of Faculty Member

Experiment No: 10 **Date:**

To examine the relationships between open-loop frequency response and stability, open loop frequency and closed loop transient response

Aim: To study the relationship between open loop frequency response and stability, open loop frequency and closed loop transient response.

Objective: The students will learn regarding open loop frequency response, stability and closed loop transient response.

Stability of a system can be accessed by determining the gain margin and phase margin. These gain and phase margins can be found by drawing the frequency response plots. **Polar plots, Bode plots, Nyquist plots** are the examples of frequency response plots.

Gain margin (GM): This is the factor by which the magnitude of G(jω)H(jω) at the phase cross over frequency is to be multiplied to make it unity. If the phase cross over frequency is ω_p, this is the frequency at which the phase plot of G(jω)H(jω) is crossing the -180° line (phase angle = -180°).

Therefore $|G(j\ \omega p)H(j\omega p)|GM = 1$ or

20log $|G(j\ \omega p)H(j\omega p)|$ + 20log (GM) = 0

Hence gain margin in db is the value by which the log magnitude plot is shifted to make 0db at the phase cross over frequency.

To determine the gain margin, find the phase cross over frequency from the phase plot and then find the gain at this frequency.

Therefore GM = 0 – gain in db at the phase cross over frequency.

Phase margin (PM): The phase margin is the amount of phase to be added to the phase angle at the gain cross over frequency to make the phase angle = -180°. If ω_g is the gain cross over frequency. This is the frequency at which the magnitude of G(jω)H(jω) is unity or 0db.

To determine the phase margin, find the gain cross over frequency from the magnitude plot and then find the phase angle at this frequency.

PM = phase angle at the gain cross over frequency + 180°

Condition for stability through PM and GM: For a system to be stable both gain margin and phase margins must be positive. Also $\omega_{p>}\omega_g$.

Construct the Bode plot and find gain margin and phase margin and comment on stability for the given transfer function.

$$G(s) = \frac{50}{s(1+0.5s)(1+0.05s)}$$

Program:

```
num = 50;
den =[0.025 0.55 1 0];
sys = tf(num,den);
bode(sys);
margin(sys);
```

From the plot note down the gain margin (GM), phase margin (PM) and the corresponding cross over frequencies. For unstable systems, GM and PM will not be displayed correctly but can be obtained by clicking on the plot at suitable points.

a. Click on the phase angle curve and find the frequency at which the curve crosses the 180^0 line. This gives the phase cross over frequency ω_p.
b. Click on the magnitude curve and find the magnitude at $\omega=\omega_p$. The gain margin is calculated as, GM = 0 - magnitude at phase cross over frequency.
c. Click on the magnitude curve and find the frequency at which the curve crosses 0dB line. This will give the gain cross over frequency ω_g.
d. Click on the phase angle curve and find the phase angle at $\omega=\omega_g$. The phase margin is calculated as PM = phase angle at the gain cross over frequency + 180° at $\omega=\omega_g$.

The GM, PM and the cross over frequencies can also be obtained using the following function.

[GM PM WCF WCG] = margin (sys);

Where GM = gain margin in abs unit (20logGM is the GM in db)

PM = Phase margin
WCF = phase cross over frequency
WCG = Gain cross over frequency.
These parameters will be displayed in the command window.

Check for the stability of the system.For a system to be stable both gain margin and phase margins must be positive. Also $\omega_{p>}\omega_g$ .If this condition is satisfied then the system is stable or otherwise the system is unstable.

Output Response:

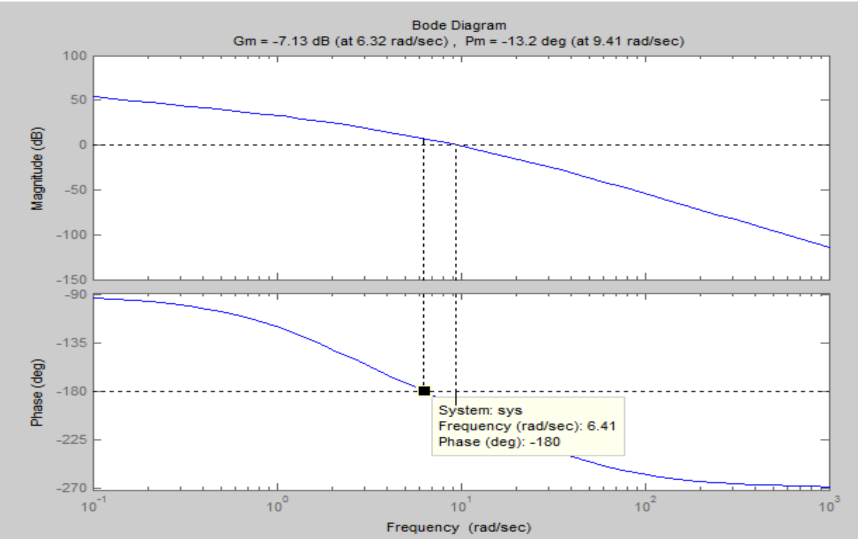

Fig.10.1: Frequency response of the system

Conclusion:

Outcome: At the end of experiment,

The students will have knowledge of obtaining the stability analysis of the system by using the Bode plot and the relationship between the open loop frequency and the stability.

Viva Questions:

1. Define phase margin?
2. Define gain margin?
3. Define phase cross over frequency?
4. Define gain cross over frequency?

Preparation	Conduction	Calculation/Result Analysis	Total

Free Space for rough work:

Signature of Faculty Member

Experiment No: 11 **Date:**

To study the effect of open loop poles and zeros on root locus contour and Comparative study of bode, Nyquist and root locus with respect to stability.

Aim: To obtain Root locus of a given T. F. and hence finding breakaway point, intersection point on imaginary axis and analysis complementary information of linear control system stability by applying graphical methods: Bode plot, Nyquist Plot and Root locus method for common transfer function.

Objectives:

1. The students will learn about procedure for drawing root locus diagram and also obtaining the same by using simulation.
2. The students will knowledge about the breakaway point and intersection point.
3. The students will compare complementary information of linear control system stability by applying different graphical methods Bode plot, Nyquist Plot and Root locus and how each method complements the other.

Procedure:

1. Open the GNU OCTAVE command window.
2. Click on file/new/M file to open the editor window. In editor window enter theprogram
3. Save the program as .M file.
4. Execute the program by selecting run.
5. Copy the plot obtained, note down the breaking point, intersection point.

Program for root locus:

Given $G(s)H(s)=\dfrac{K}{s(s+1)(s+2)(s+3)}$

Program:

```
num=[1 ];
den=[1 6  11 6 0];
sys=tf(num,den);
printsys(num,den);
[r,k]=rlocus(sys)
rlocus(sys)
```

Typical Graph:

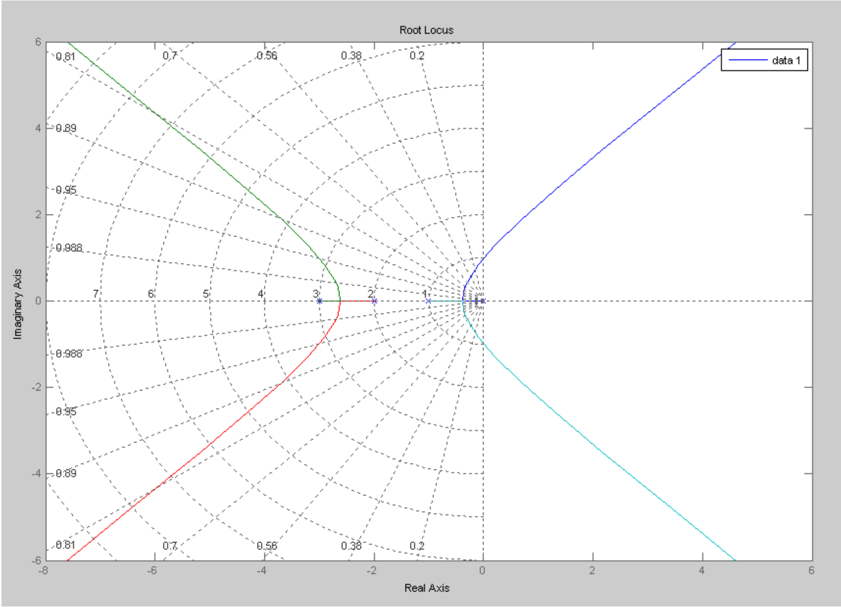

Fig.11.1: Root locus curve

Tabular Column:

	Theoretical Values	Simulated Values
Poles		
Breakaway Point		
Gain		
Imaginary Axis Crossover		

Effect of adding a zero on root locus plot

1. The root locus shifts towards left half of S-plane.
2. Relative stability of system is improved.

Consider a zero to be added to the given transfer function as given by $G(s)H(s) = \frac{K(s+1)}{s(s+1)(s+2)(s+3)}$

The program is modified as

```
num=[1 1 ];
den=[1 6  11 6 0];
sys=tf(num,den);
printsys(num,den);
[r,k]=rlocus(sys)
rlocus(sys)
```

Typical Graph:

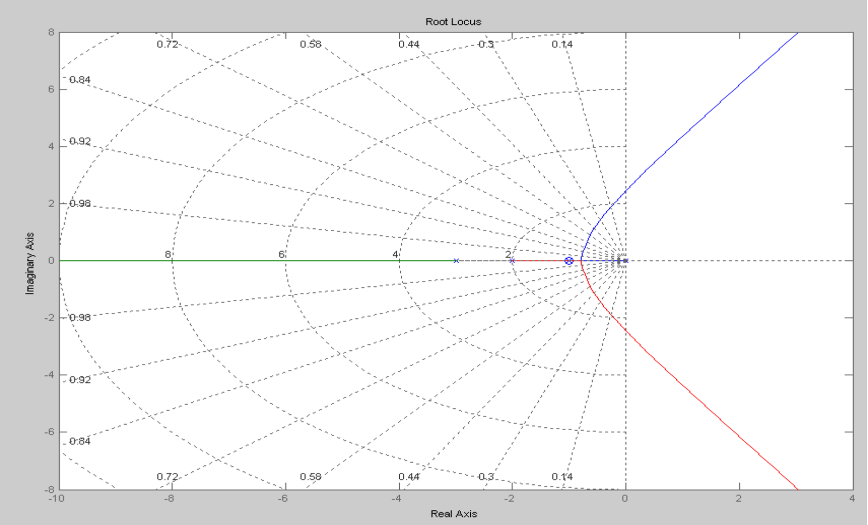

Fig.11.2: Root locus curve

Effect of adding a pole on root locus plot

a. Root locus shifts towards the right half of S-plane.
b. Angles of asymptotes reduce.
c. Relative stability of the system is decreased.

Consider a pole to be added to the given transfer function as given by $G(s)H(s) = \frac{K}{s(s+1)(s+2)(s+3)(s+4)}$

The program is modified as

```
num=[1 ];
den=[1 10 35 50 24  0];
sys=tf(num,den);
printsys(num,den);
[r,k]=rlocus(sys)
rlocus(sys)
```

Typical Graph:

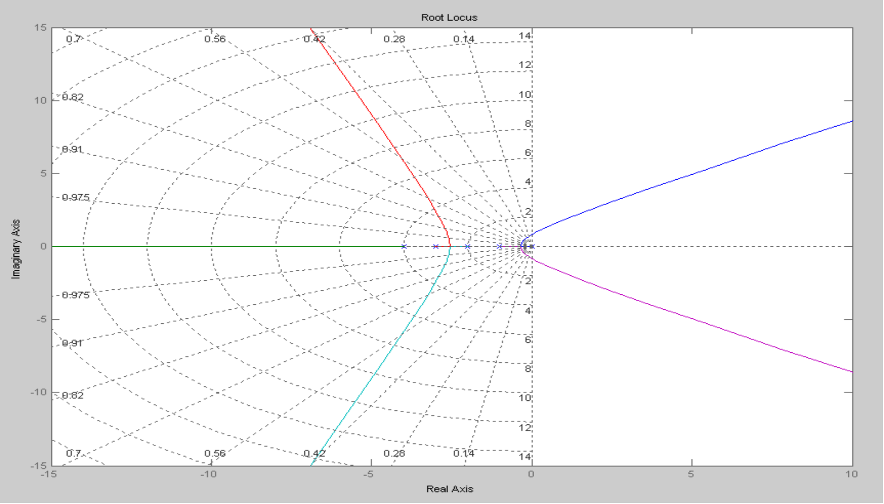

Fig.11.3: Root locus curve

B. Comparative study of bode, Nyquist and root locus with respect to stability

Example 1

Given $G(s)H(s) = \frac{80}{s(s+2)(s+20)}$

$$G(s) = \frac{80}{s(s+2)(s+20)} = \frac{80}{s^3 + 22s^2 + 40s}$$

Program for root locus:

Program:

```
num = [80];
den = [1 22 40 0];
sys=tf(num,den);
printsys(num,den);
[r,k]=rlocus(sys)
rlocus(sys)
```

Program for Bode Plots:

Given $G(s)H(s) = \frac{80}{s(s+2)(s+20)}$

Program:

```
num = [80];
den = [1 22 40 0];
G = tf(num, den);
[gm, pm, wep, weg] = margin(G)
bode(G), grid
```

```
num = [80];
den = [1 22 40 0];
G = tf(num, den);
margin(G)
%grid
```

Program for Nyquist Plots:

$G(s)H(s) = \frac{80}{s(s+2)(s+20)}$

Program:

```
clc
num = [80];
den = [1 22 40 0];
sys=tf(num, den);
nyquist(sys)
[re, im, w] =nyquist(sys)
```

Example 2

Given $G(s)H(s) = \frac{K}{s(s+4)(s+5)}$

Program for root locus:

Program:

```
num = [1];
den = [1 5 4 20 0];
sys=tf(num,den);
printsys(num,den);
[r,k]=rlocus(sys)
 rlocus(sys)
```

Program for Bode Plots:

Given $G(s)H(s) = \frac{K}{s(s+4)(s+5)}$

Program:

```
num = [1];
den = [1 5 4 20 0];
G = tf(num, den);
[gm, pm, wep, weg] = margin(G)
bode(G), grid
```

```
num = [1];
den = [1 5 4 20 0];
G = tf(num, den);
margin(G)
%grid
```

Program for Nyquist Plots:

Given $G(s)H(s) = \frac{K}{s(s+4)(s+5)}$

Program:

```
clc
num = [1];
den = [1 5 4 20 0];
sys=tf(num, den);
nyquist(sys)
[re, im, w] =nyquist(sys)
```

Conclusion:

Outcomes: At the end of the experiment,

1. The students will be able to plot root loci using root locus.
2. The students will be able to Bode plot and determine its specifications.
3. The students will be able to Nyquist plot and determine its specifications.
4. The students will able to determine stability of a system.
5. The students will be able to Evaluate complementary information of linear control system stability by applying graphical methods method for a common transfer function and how each method complements the other.

Viva Questions:

1. What is the significance of root locus method?
2. What are the rules of construction of root locus?
3. Mention the advantages and disadvantages of root locus method.
4. What is meant by Asymptotes?
5. Define phase margin?
6. Define gain margin?
7. Define phase cross over frequency?
8. Define gain cross over frequency?
9. Define Nyquist criterion.

Preparation	Conduction	Calculation/Result Analysis	Total

Signature of Faculty Member

Free Space for rough work: