BMS INSTITUTE OF TECHNOLOGY & MGMT.

Yelahanka, Bangalore-64

Department of Electrical & Electronics Engineering

VI SEMESTER

10EEL68 –CONTROL SYSTEM LAB

LABORATORY MANUAL

NAME OF THE STUDENT : ....

BRANCH : ....

UNIVERSITY SEAT NO. : ....

SEMESTER & SECTION : ....

BATCH : ....

Vision of the Department

To emerge as one of the finest Electrical & Electronics Engineering Departments facilitating the development of competent professionals, contributing to the betterment of society.

Mission of the Department

Create a motivating environment for learning Electrical Sciences through teaching, research, effective use of state of the art facilities and outreach activities.

Program Educational Objectives

Graduates of the program will,

PEO1	Have successful professional careers in Electrical Sciences, and IT enabled areas and be able to pursue higher education.
PEO2	Demonstrate ability to work in multidisciplinary teams and engage in lifelong learning.
PEO3	Exhibit concern for environment and sustainable development.

Program Outcomes:

After the successful completion of the course, the graduate will be able to

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

2. **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.

3. **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.

4. **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.

5. **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.

6. **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.

7. **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.

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

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

10. **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.

11. **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.

12. 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.

COURSE OUTCOMES:

After the successful completion of the course, the student will be able to

1. Execute time response analysis of a second order control system using MATLAB
2. Analyze and interpret stability of the system through Root Locus, Bode plot and Nyquist plot.
3. Design Lag, Lead, Lead-Lag compensators and verify experimental results using MATLAB.
4. Analyze toque- speed characteristics of DC and AC servomotors.
5. Analyze the effect of P, PI, PD and PID controllers on a control system.

CO – PO Mapping:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	3	1	2	3				2	1		
CO2	3	3	1	2	3				2	1		
CO3	3	3	3	2	3				2	1		
CO4	3	3		2					2	1		
CO5	3	3	3	2	3				2	1		

3- Strongly Related 2- Moderately Related 1-Weakly Related

SYLLABUS

Subject Code: 10EEL68 **IA Marks: 25**
No. of Practical Hrs/ Week: 03 **Exam Hours: 03**
Total No. of Practical Hrs: 42 **Exam Marks: 50**

1. Using MATLAB/SCILAB
a) Simulation of a typical second order system and determination of step response and evaluation of time domain specifications
b) Evaluation of the effect of additional poles and zeroes 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

2. (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 its frequency response.
(b) To determine experimentally the transfer function of the lead compensating network.

3. (a) To design RC lag compensating network for the given specifications., viz., the maximum phase lag and the frequency at which it occurs, and to obtain its frequency response.
(b) To determine experimentally the transfer function of the lag compensating network.

4. Experiment to draw the frequency response characteristic of a given lag- lead compensating network.

5. To study the effect of P, PI, PD and PID controller on step response of a feedback control system (Using control engineering trainer/process control simulator).Verify the same by simulation.

6. a) Experiment to draw the speed – torque characteristic of a two - phase A.C. servomotor.
b) Experiment to draw speed torque characteristic of a D.C. servomotor.

7. To determine experimentally the frequency response of a second -order system and evaluation of frequency domain specifications.

8. Using MATLAB/SCILAB
a) Simulate a D. C. position control system and obtain its step response
b) To verify the effect of the input wave form, loop gain system type on steady state errors.
c) To perform a trade-off study for lead compensation
d) To design a PI controller and study its effect on steady state error

9. Using MATLAB/SCILAB
a) To examine the relationships between open-loop frequency response and stability , open loop frequency and closed loop transient response
b) To study the effect of addition closed loop poles and zeroes on closed loop transient response

10. Using MATLAB/SCILAB
a) Effect of open loop and zeroes on root locus contour
b) To estimate effect of open loop gain on the transient response of closed loop system by using Root locus
c) Comparative study of Bode, Nyquist and Root locus with respect to Stability.

11. Experiment to draw to syncro pair characteristics.

DO'S AND DON'TS IN THE LABORATORY

DO'S:

1. All students must wear uniform compulsory.
2. Must follow the schedule time, late comers will not be permitted.
3. Personal belongings should be placed in the specified place
4. Silence & tidiness should be maintained in the Lab.
5. Cycle of experiments should be followed.
6. Students are expected to come prepared for experiments &VIVA.
7. Handle all the equipments with care & strictly follow the instructions.
8. Check the circuit connections properly & get it checked, verified by staff in-charge before switch it ON.
9. Equipments should be switched OFF and chairs should be placed back in position before leaving the lab.
10. Separate Lab observation book should be maintained. Details regarding observation & relevant information about the experiments should be maintained.
11. Get the observation book signed from the staff-in-charge before leaving the lab.
12. Switch OFF & remove all connections, return instruments before leaving the lab.
13. Practical records should be submitted regularly with complete information (circuit diagram, theory… etc).

DON'TS:

1. Don't come late to the lab.
2. Don't enter into the lab with golden rings, bracelets and bangles.
3. Don't make or remove the connections with power ON.
4. Don't switch ON the supply without verifying by the staff member.
5. Don't switch OFF the machine with load.
6. Don't leave the Lab without the permission of the staff in-charge.

CONTENTS

Experiment No: 01

TIME RESPONSE OF SECOND ORDER SYSTEM

Aim: To obtain time response of a second order system in case of under damped, over damped and critically damped systems.

Theory:

The time response of control system consists of two parts. Transient response and steady state response. C (t) = $C_{tr}(t) + C_{ss}(t)$. Most of the control systems use time as its independent variable. Analysis of response means to see the variation of output with respect to time. The output of the system takes some finite time to reach to its final value. Every system has a tendency to oppose the oscillatory behavior of the system which is called damping. The damping is measured by a factor called damping ratio of the system. If the damping is very high then there will not be any oscillations in the output. The output is purely exponential. Such system is called an over damped system.

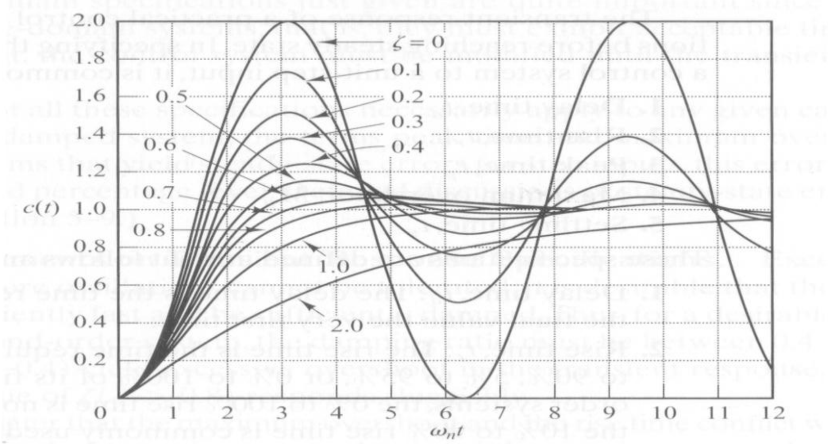
If the damping is less compared to over damped case then the system is called a critically damped system. If the damping is very less then the system is called under damped system. With no damping system is undamped.

$1<\xi<\infty$ --- Over damped system.

$\xi=1$ --- Critically damped system.

$0<\xi<1$ --- Under damped system.

$\xi=0$ --- Undamped system.



Time domain specifications: Delay time $T_d = (1 + 0.7\xi)/ w_n$

Rise Time $T_r = (\Pi - \theta)/ w_d$

Peak overshoot time = $T_p = \Pi/ w_d$

$\% M_p = \exp(- \Pi\xi/\text{sqrt}(1-\xi^2))$

Settling Time $T_s = 4/\xi w_n$ (2% tolerance)

Apparatus Required: PC loaded with MATLAB

Procedure:

Open the MATLAB command window.

1) Click on file-new-M file to open the MATLAB editor window.
2) In the given MATLAB editor window enter the program to obtain the step response.

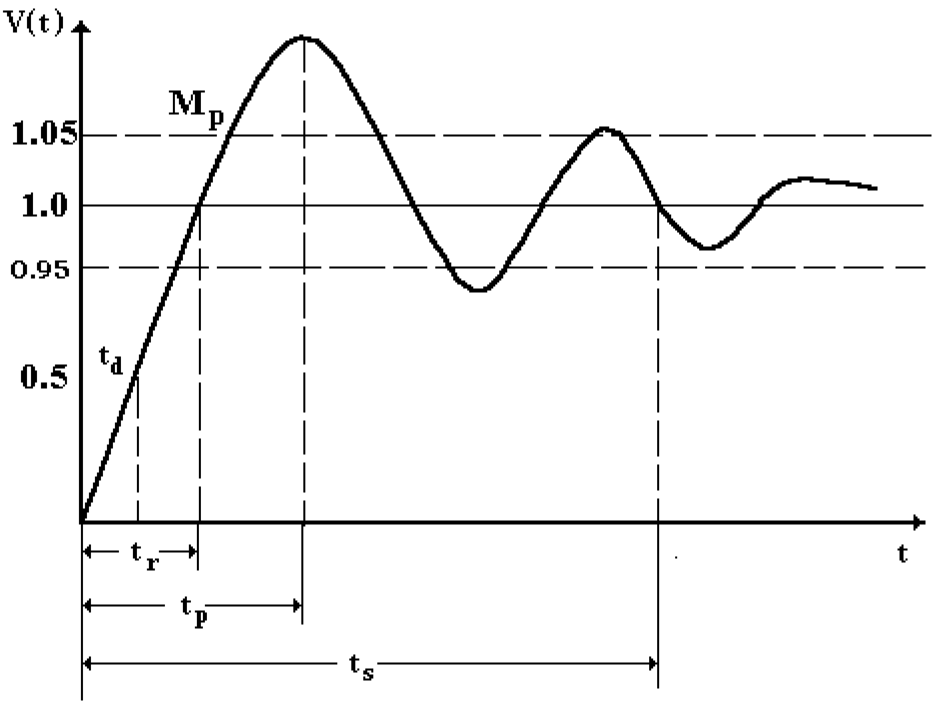
```
% step response of a second order system
ωn = input('enter the natural frequency');
ξ = input('enter damping ratio');
num = [ωn*ωn];
den = [1  2*ξ*ωn  ωn*ωn];
sys = tf (num, den)
```

step(sys);

3) Save the file in work directory.
4) Run the program and enter the respective value for natural frequency, damping ratio and time
5) The graphs displayed are according to the above values

6) The values of wd, td, theta, tr, ts, Mp can be obtained by
   a) Right click on the figure window and select grid to get grids on the curve.
   b) Right click on the figure window and select characteristics and enable peak response, settling time & rise settling
   c) Repeat the steps 5,6,7 for different values of ξ.

Graph:



Tabular Columns :

Time Domain Specifications	From MATLAB	By Calculation
Rise Time		
Peak Time		
Settling Time		
Max. Overshoot		

1b) Evaluation of the effect of additional poles and zeros on time response of second order system.

MATLAB program to evaluate the effect of additional poles and zeros on time response of second order system. This program uses the command zpk.
For the second order system the poles are -10+30i and -10-30i

The program given below gives the time response of 2nd order system

```
Z=[];
P=[-10+30i -10-30i];
K=1000;
sys=zpk(z,p,k)
t=[0:0.001:1];
step(sys,t);
grid
```

For the second order system, if we add a pole it changes to third order.

To study the effect of additional poles,

Location of poles	Effect on time response
-1	
-10	
-100	

To study the effect of additional zeros,

Location of zeros	Effect on time response
-1	
-10	
-100	

1c) Effect of loop gain of a negative feedback system on stability

The following program is used to study the effect of loop gain of a negative feedback system on stability. The value of gain k is varied and different step responses are obtained.

```
clc
z=[]
p=[-0.5+i -0.5-i -1];
k1=1;
k2=2;
k3=3;
sys1=zpk(z,p,k1)
sys2=zpk(z,p,k2)
sys3=zpk(z,p,k3)
t=[0:0.01:20];
[y1,t]=step(sys1,t)
[y2,t]=step(sys2,t)
[y3,t]=step(sys3,t)
plot(t,y1,t,y2,t,y3)
legend('k=1', 'k=2', 'k=3')
grid
```

Result:

Viva questions:

1. What is meant by time response of a system?
2. What do you mean by damping factor?

Experiment No.2

RC LEAD COMPENSATING NETWORK

Aim: To design a passive RC lead compensating network for the given specifications and to obtain its frequency response.

Apparatus Required: Resistors, capacitors, wires, multimeter, and phase- frequency meter.

Theory:

If a sinusoidal input is applied to the input of a network and steady state output has a phase lead, then network is called lead compensator/network. Lead compensator has a zero at s = 1/T and a pole at s = 1/ αT with zero closer to the origin than pole. This compensator speeds up the transient response and increases the margin of stability of a system. It also helps to increase the system error constant through to a limited extent. These compensators are used when fast dynamic response is required.

Effect of Phase Lead Compensation

1. The velocity constant K_v increases.
2. The slope of the magnitude plot reduces at the gain crossover frequency so that relative stability improves & error decrease due to error is directly proportional to the slope.
3. Phase margin increases.
4. Response become faster.

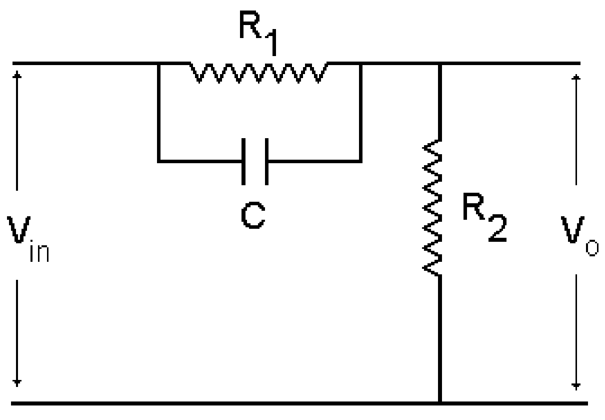
Advantages of Phase Lead Compensation

1. Due to the presence of phase lead network the speed of the system increases because it shifts gain crossover frequency to a higher value.
2. Due to the presence of phase lead compensation maximum overshoot of the system decreases.

Disadvantages of Phase Lead Compensation

1. Steady state error is not improved.

Circuit Diagram:



Lead Network

Derivation of transfer function:

Write the above circuit in Laplace form.

Vi(s) = $(Z_1+Z_2)*I(s)$ (Where I(s) is the current in the circuit and $Z_1= (R_1//C)$ and $Z_2 = R_2$)

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

Vo(s)/Vi(s) = $Z_2/(Z_1+Z_2)$

After simplification,

$$G_C(S) = \frac{(S+1/T)}{(S+1/\alpha T)}$$ where $T = R_1 C$ and , $\alpha = R_2/(R_1 + R_2)$

Design Equations:

Specifications for the design: Φ_m =…………. at fm = …………...

1. $\sin \Phi_m = \frac{(1-\alpha)}{(1+\alpha)}$ $\alpha<1$
2. $\alpha = R_2/(R_1 + R_2)$
3. $\omega_m = \frac{1}{T\sqrt{\alpha}}$
4. $T = R_1 C$

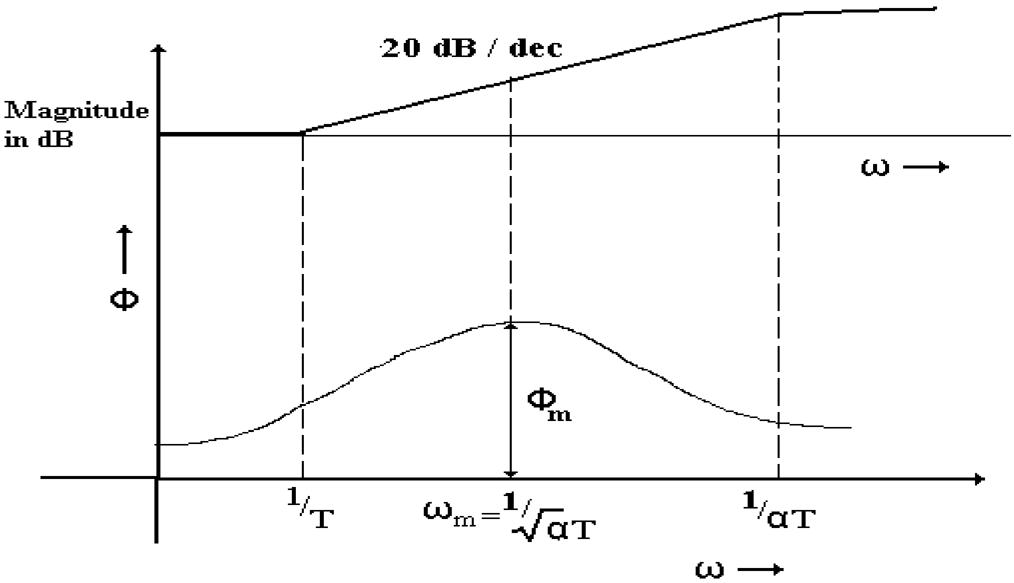
Procedure:

1. Derive the transfer function for the Lead network given above.
2. For the given specification, ie for given Φ_m at given F_m , calculations of R1, R_2 and C. are done.
3. Connections are made as per the Lead circuit diagram by the selecting the values found in the above step.
4. Switch ON the mains supply and apply sinusoidal wave by selecting suitable amplitude.
5. The frequency of the signal is varied in steps and at each step note down the corresponding magnitude of output and phase angle.
6. Draw the frequency response plot and hence find the transfer function & compare it with the design.

Tabular Column:

Input voltage V_S = ……….V(volts)			
Frequency (Hz)	output V_O (volts)	Ø(degree) indicated	Gain (dB)

Typical Lead Characteristics:



Result:

Viva questions:

1. What is lag compensation? Write the frequency response of it.
2. What is the importance of lag network?

Experiment No.3

RC LAG COMPENSATING NETWORK

Aim: To design a passive RC lag compensating network for the given specifications and to obtain its frequency response.

Apparatus Required: Resistors, capacitors, wires, multimeter, and phase- frequency meter.

Theory: If a sinusoidal input is applied to the input of a network and steady state output has a phase lag, then network is called lag compensator/network. Lag compensator has a pole at $s = 1/\beta T$ and a pole at $s = 1/T$ with pole closer to the origin than zero. This compensator improves the steady state behavior of the system while nearly preserving its transient response. These compensators are used when low steady state error is required.

Effect of Phase Lag Compensation

1. Gain crossover frequency increases.
2. Bandwidth decreases.
3. Phase margin will be increase.
4. Response will be slower before due to decreasing bandwidth, the rise time and the settling time become larger.

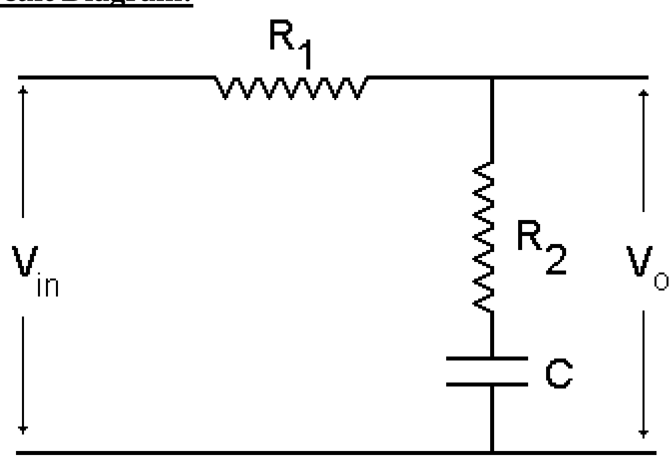
Advantages of Phase Lag Compensation

1. Phase lag network allows low frequencies and high frequencies are attenuated.
2. Due to the presence of phase lag compensation the steady state accuracy increases.

Disadvantages of Phase Lag Compensation

1. Due to the presence of phase lag compensation the speed of the system decreases.

Circuit Diagram:



Lag Network

Derivation of transfer function:

Write the above circuit in Laplace form.

$Vi(s) = (Z_1+Z_2)*I(s)$ (where I(s) is the current in the circuit and $Z_1= R_1$ and $Z_2=(R_2+1/CS)$

$Vo(s) = Z_2*I(s)$
$Vo(s)/Vi(s) = Z_2 / (Z_1+Z_2)$

After simplification,

$$G_C(S) = \frac{(S+ 1/ T)}{(S+ 1/ \beta T)} \quad \text{where } \beta = (R_1 + R_2) / R_2 \text{ and } T = R_2 C$$

Design Equations:

Specifications for the design: Φ_m =…………. at fm = …………...

To find maximum lag angle:

1. $\sin \Phi_m = \dfrac{(\beta -1)}{(\beta +1)}$ $\beta>1$
2. $\beta = (R_1 + R_2) / R_2$
3. $\omega_m = \dfrac{1}{T\sqrt{\beta}}$
4. $T = R_2 C$

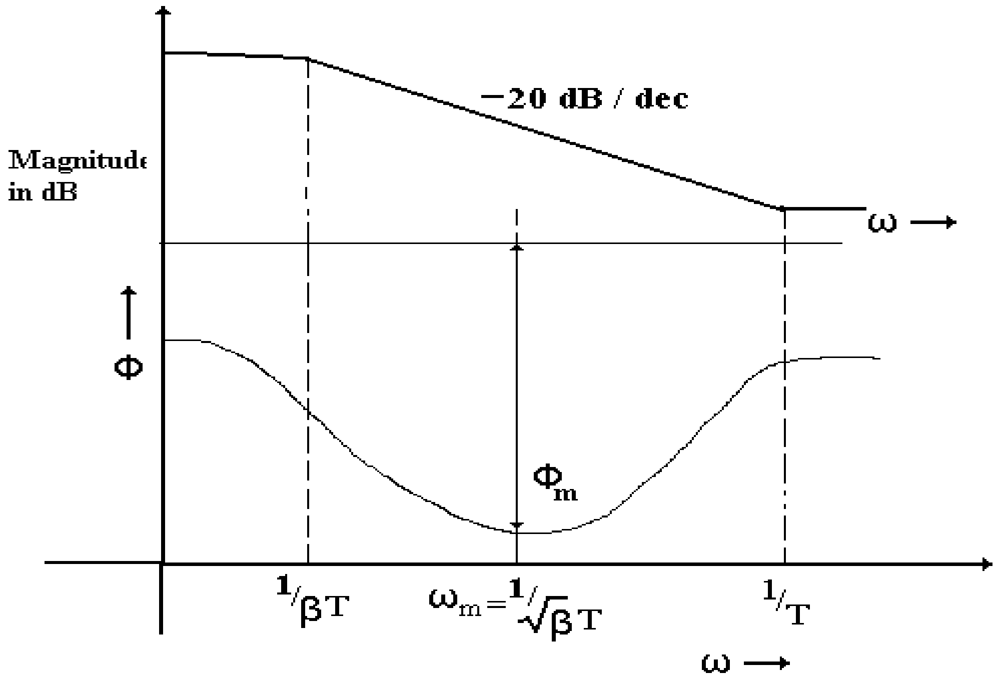
Procedure:

1. Derive the transfer function for the Lag network given above.
2. For the given specifications, ie for given Φ_m at given f_m , calculations of R1, R_2 and C. are done.
3. Connections are made as per the Lag circuit diagram by the selecting the values found in the above step.
4. Switch ON the mains supply and apply sinusoidal wave by selecting suitable amplitude.
5. The frequency of the signal is varied in steps and at each step note down the corresponding magnitude of output and phase angle.
6. Draw the frequency response plot and hence find the transfer function & compare it with the design.

Tabular Column:

Input voltage V_S = ……… V(volts)			
Frequency (Hz)	$V_{O(volts)}$ (rms)	Ø(degree) indicated	Gain(dB) 20 log(Vo/Vs)

Typical Lag Characteristics:



Result:

Viva questions:

1. What is the need for compensation?
2. What is meant by compensation?
3. What is lag compensation? Write the frequency response of it.
4. What is the importance of lag network?

Experiment No.4

LAG -LEAD NETWORKS

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

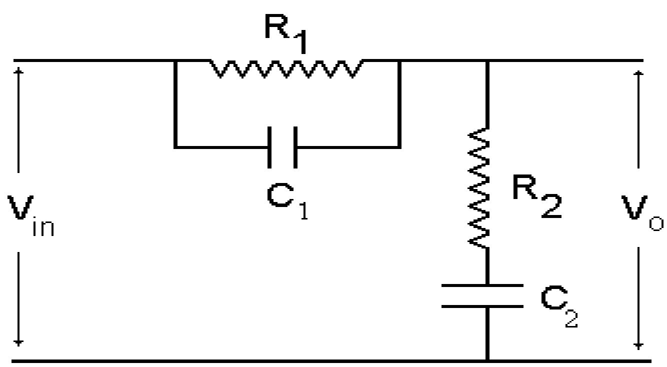
Apparatus Required: Resistors – 10k – 2 nos, capacitors – 0.1µF – 2nos, wires, multimeter, and phase- frequency meter.

Theory: Lag lead compensator is a combination of a lag compensator and lead compensator. The lag section has one real pole and one real zero with pole to the right of zero. The lead section also has one real pole and one zero but zero is to the right of the pole. When both steady state and transient response require improvement, a lag lead compensator is required.

Advantages of Phase Lag-Lead Compensation

1. Due to the presence of phase lag-lead network the speed of the system increases because it shifts gain crossover frequency to a higher value.
2. Due to the presence of phase lag-lead network accuracy is improved.

Circuit Diagram:



Lag-Lead 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.

$Vi(s) = (Z_1+Z_2)*I(s)$ (Where I(s) is the current in the circuit and $Z_1= (R_1//C_1S)$ and

$Z_2 = (R_2 + 1/C_2S)$

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

$Vo(s)/Vi(s) = Z_2 /(Z_1+Z_2)$

After simplification,

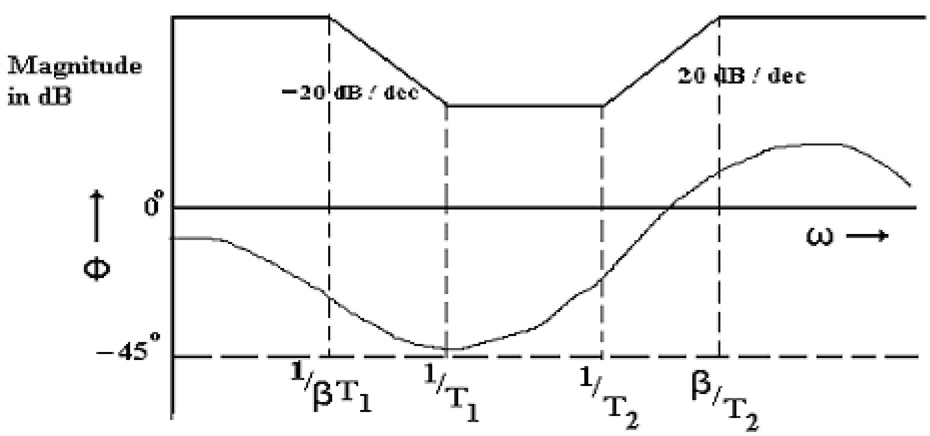
$$G_C(S) = \frac{(S + 1/T_1)\,(S + 1/T_2)}{(S + 1/\beta T_2)(S + \beta/T_1)}$$

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_S =………… V(volts)			
Frequency (Hz)	V_O (rms)	Ø(degree) indicated	Gain(dB) 20 log(Vo/Vs)

Typical Characteristics:



Result:

Viva questions:

1. What is lag lead Compensation? Write the frequency response of it.
2. What is the importance of lag lead network?

Experiment No.5

STUDY OF P, P-I, P-I-D CONTROLLERS

Aim: To study the effect of P, PI, PD and PID controller on the step response of a feedback control system.

Theory:

PID controllers are commercially successful and widely used controllers in Industries. For example, in a typical paper mill there may be about 1500 Controllers and out of these 90% would be PID controllers. The PID controller consists of proportional controller, integral controller and derivative controller. Depending upon the application on or more combinations of the controllers are used.(ex: in a liquid control system where we want zero steady state error, a PI controller can be used and in a temperature control system where we do not want zero steady state error, a simple P controller can be used.

The equation of the PID controller in time domain is given by,

$m(t) = K_P e(t) + K_i/T_i \int e(t)\, dt + K_d T_d\, de(t)/dt$

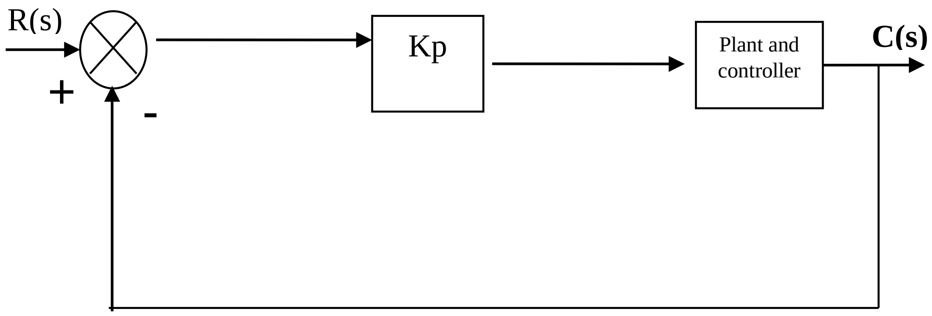
where K_P is a proportional gain T_i is the integral reset time and T_d is the derivative time of the PID controller, m(t) is the output of the controller and e(t) is the error signal given by e(t) = r(t) – c(t).

The characteristics of P, I, and D controllers

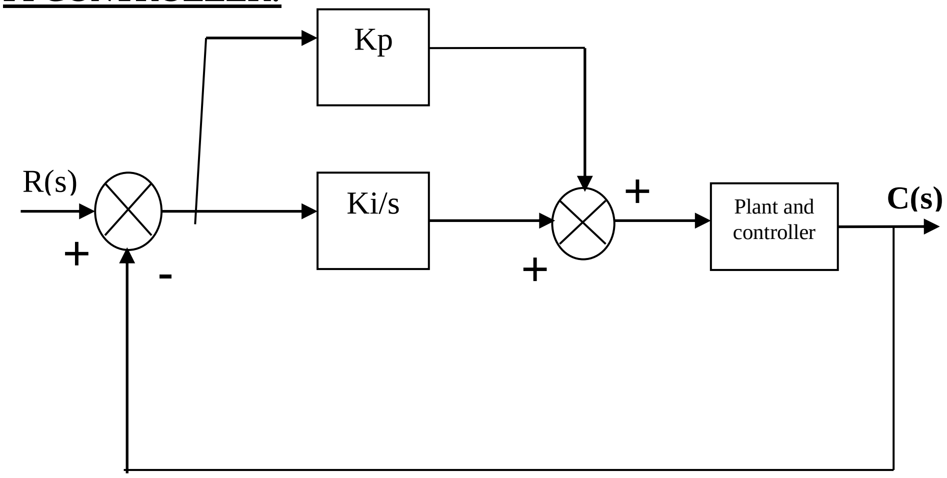
A proportional controller (Kp) will have the effect of reducing the rise time and will reduce ,but never eliminate, the steady-state error. An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers Kp, Kd, and Ki on a closed-loop system are summarized in the table shown below.

Parameter	Rise time	Overshoot	Settling time	Steady-state error	Stability[14]
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor change	Decrease	Decrease	No effect	Improve if K_d small

PROPORTIONAL (P) CONTROLLER:



PI CONTROLLER:

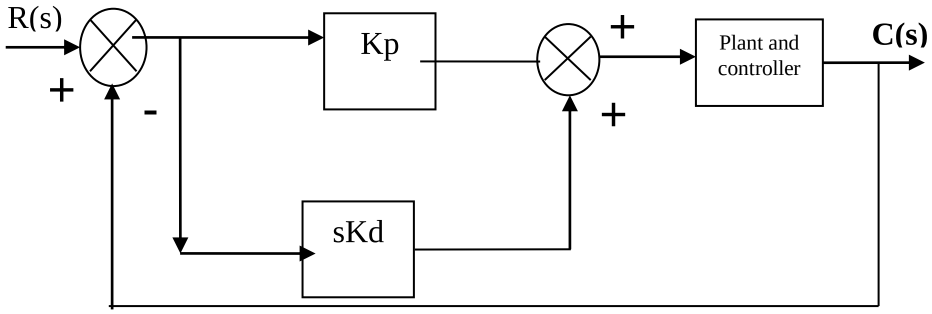


From the block diagram

$C(s)/R(s)=(s+Ki)\ \omega n^2/s^3 + 2\xi\ \omega ns^2+ \omega n^2 s+Ki\ \omega n^2$

The characteristic equation is third order, so system also becomes third order reducing SS error to zero

PD CONTROLLER:

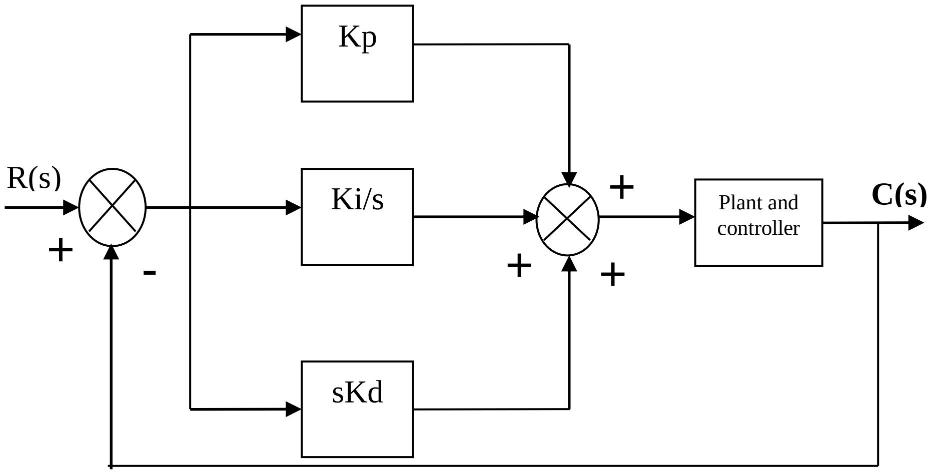


From the block diagram

$C(s)/R(s) = \omega n^2\ (1+sTd)/S^2 + (2\xi\ \omega n+ \omega n^2 Td)S+ \omega n^2$

Comparing with $S^2 + 2\xi\ \omega nS+ \omega n^{2,}$ damping ratio increases reducing the peak overshoot in the response

PID CONTROLLER



In PID controller, the error signal is given by
Ea(s)= Kp E(s)+ sTd E(s) + Ki/s E(s)

Procedure:
1. The connections are made as in the diagrams.
2. DC supply from the kit is given.
3. The values of kp, Kd, Ki are adjusted and the waveforms are observed on the CRO.

Result:

Viva questions:

1. What is P-I control?
2. What is P-D control?
3. What is P-I-D control?
4. Why differential control is not used alone?
5. What is the problem with proportional control?

Experiment No.6 (a)

AC SERVO MOTOR

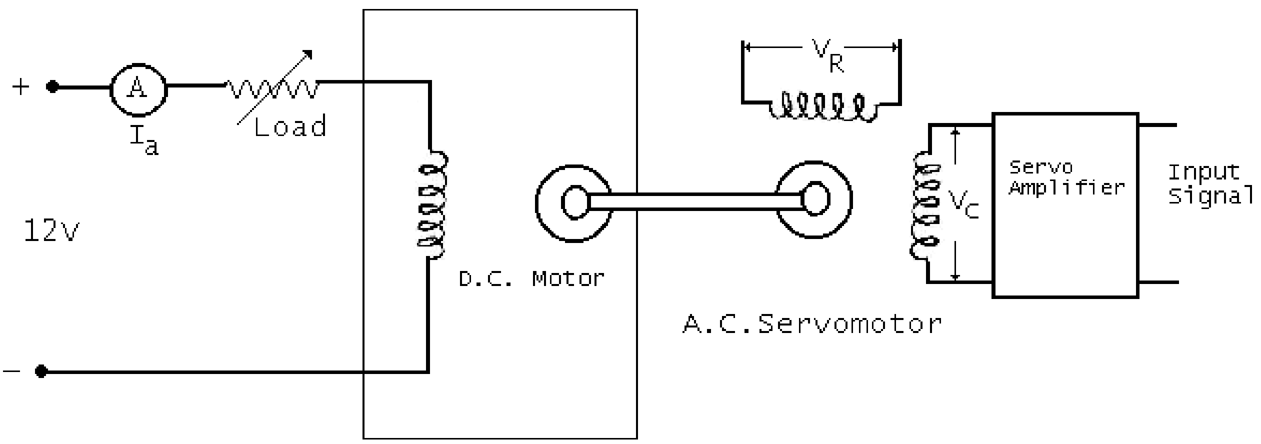
Aim: To obtain torque speed characteristics of AC servo motor.

Theory:

An AC servomotor is basically a two phase induction motor except for certain special design features. The motor of the servo motor is built with high resistance so that its X/R ratio is small and the toque speed characteristics is linear. For low resistance, the characteristics is nonlinear. Such a characteristics is unacceptable in control systems. The motor construction is usually squirrel cage or drag cup type. The diameter of rotor is kept small in order to reduce inertia to obtain good accelerating characteristics. In servo applications the voltage applied to the two stator windings are seldom balanced. One of the phases known as the reference phase is excited by constant voltage and the other phase is known as the control phase is excited by a voltage of variable magnitude from a servo amplifier and polarity with respect to the voltage supplied to the reference winding. For low power applications AC servo motors are preferred because they are light weight, rugged construction.

Apparatus Required: AC servo motor speed torque unit, multimeter.

Circuit Diagram:



AC servomotor specifications:

Reference winding voltage: 230v AC
Control winding voltage: 230v AC
Rated power = 50 watts
Moment of Inertia (J) = 0.7gm/cm^2
Friction co efficient B = 0.021
Speed: 2000rpm

Procedure:

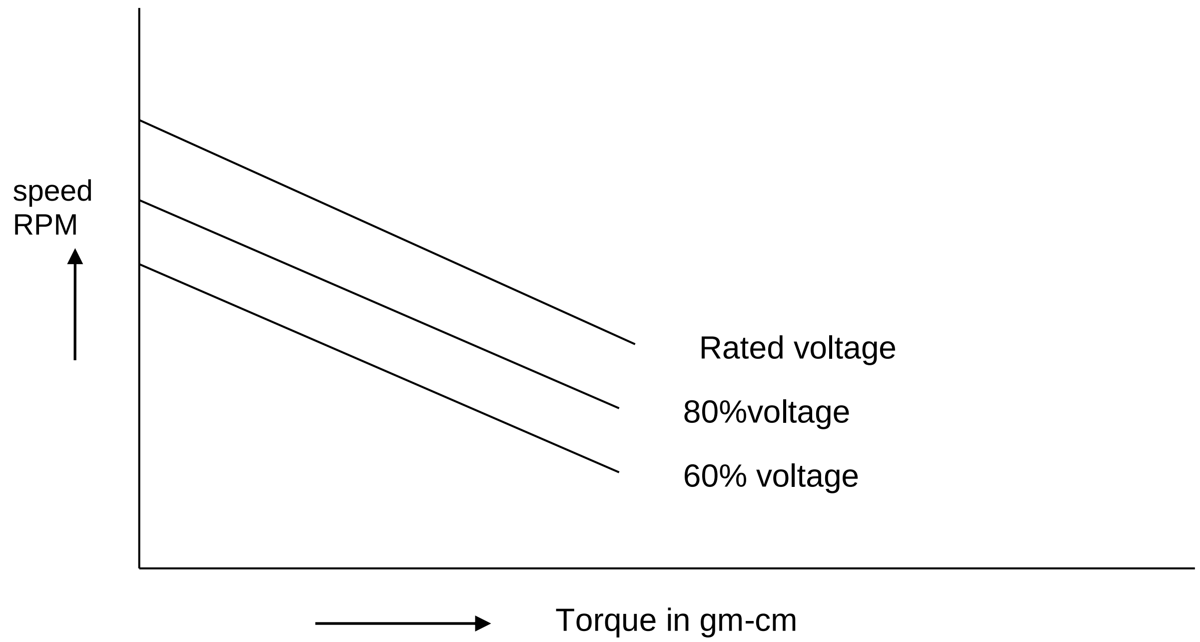
1. Connections are made as per circuit diagram.
2. The load switch is in OFF position, so that DC machine is not connected to auxiliary power supply (12V). AC servomotor switch is in OFF position.
3. Ensure speed control and load control pot is in minimum position.

4. Switch ON the mains and also AC servomotor. The AC servomotor starts rotating and speed will be indicated by meter in front panel.
5. The reference winding voltage can be measured.
6. Now switch ON the load control switch and start loading the servomotor.
7. Note down corresponding values of Ia & Ep (& speed).
8. Now new control winding voltage is set by varying position of speed control switch. Again the machine is loaded & Ia,Ep are noted down.
9. Speed –Torque characteristics are plotted.

Tabular column:

Current(mA)	**E_b(v)**	**Speed (rpm)**	**Power(watts)**	**Torque(gm-cm)**

Graph:



Calculation:

Power = $E_b \times I_a$ Watts

Torque = $(E_b \times I_a \times 60 \times 1.0196 \times 10^5) / 2 \Pi \times N$ gm-cm

Viva questions:

1. What are the applications of AC servo motor?
2. How is AC servo motor different from normal AC motor?
3. What is the working principle of AC servo motor?

Experiment No.6 (b)

DC SERVO MOTOR

Aim: To plot Torque -Speed characteristics of a DC servomotor.

Theory :

The mechanism in which the control variable is adjusted by the error served by comparing output and input is called servomechanism. Any quantity e.g. voltage, speed, temperature, position, torque be controlled by providing appropriate feedback. The motor which respond to the error signal abruptly and actuate the load quickly are called servo motors. These are specifically designed and built primarily for use in feedback control systems as output actuators. The power rating can vary from a fraction of a watt up to a few hundred watts. They have high speed response which requires low rotor inertia. These motors are therefore smaller in diameter and longer in length. DC servo motors are used in high power applications. Some DC motors with relatively small power rating are used in instruments and computer related instruments. Other applications are CNC machines, robot systems, radars, machine tools, etc. Most important among the characteristics of the DC servo motor is the maximum acceleration obtainable. The operation of this motor is same as normal DC motor.

Apparatus Required: DC servo motor speed torque unit, multimeter.

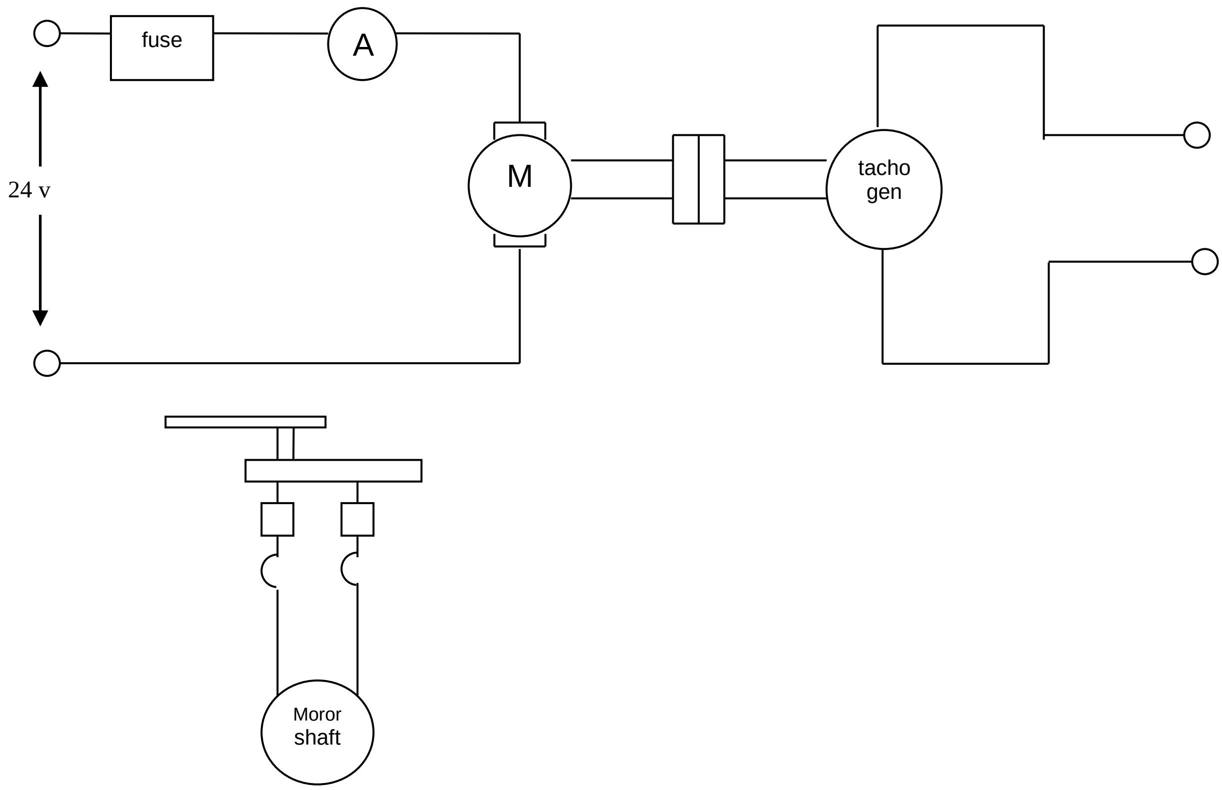
DC servomotor specifications:

Type : permanent magnet type
Voltage : 24v DC
Torque : 400gm-cm
Speed : 4400 RPM

Procedure:

1. The connections are made as per circuit diagram.
2. All the front panel controls are carefully studied. Adjust zero reading in both the balances.
3. Keep the servomotor switch at off position, spring balances at minimum position.
4. Switch on the mains supply to the unit and both the r.p.m meter and ammeter shows zero reading.
5. Switch on DC servomotor. The motor starts rotating and the speed is indicated by r.p.m meter. Now vary the speed potentiometer to maximum position and check the DC voltage and it will be around 24V.
6. At this voltage note down speed and current.
7. Slowly the motor is loaded by adjusting the wheel and note down current, speed, w1 and w2 spring balance readings for every 25 gms or 50 gms of load. Enter the reading in tabular column. The motor is loaded upto 200 gms, since the torque is 400 gms and radius of brake drum is 2 cms.
8. Now release the load and repeat for different percentage of rated voltage.
9. The readings are tabulated and speed Vs torque is plotted.

Circuit Diagram:



Tabular Column:

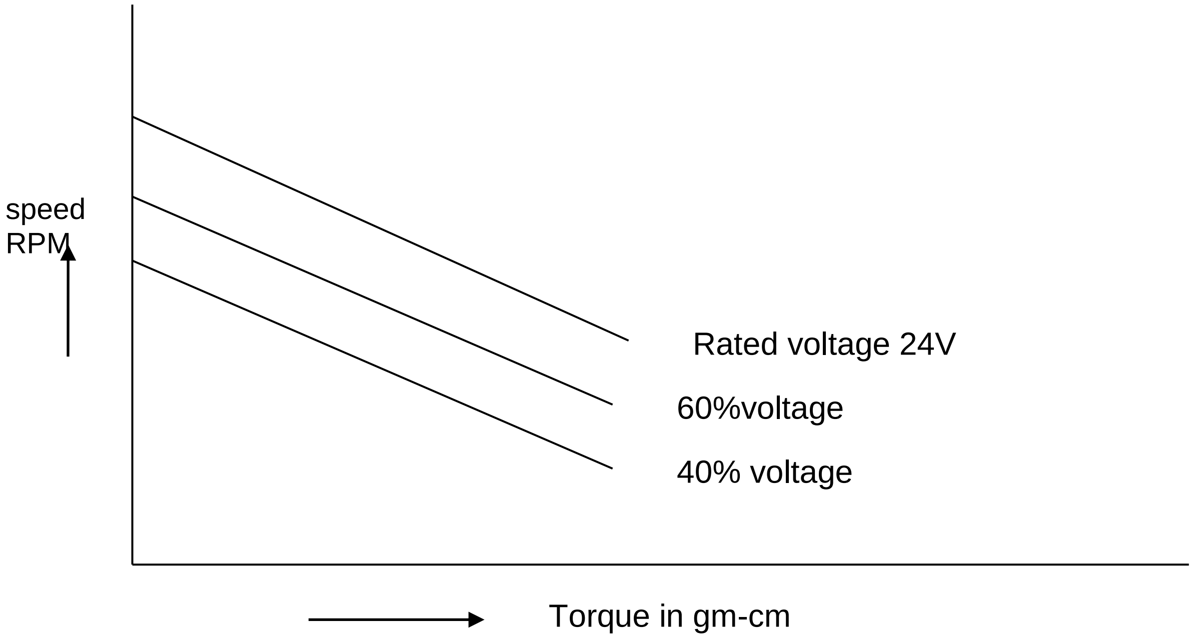
At Rated voltage = 24V

Speed(rpm)	W_1 gm	W_2 gm	W=(W_1 - W_2) gm	Torque gm-cm

Calculation:

Torque =W X R gm-cms and R=radius of the shaft, W=W1-W2.

Graph:



Result:

Viva questions:

1. What is meant by servomechanism?
2. How servomotor is different from ordinary DC motor?
3. What is meant by speed control?
4. What are the applications of DC Servo motor?

Experiment No.7

FREQUENCY RESPONSE OF A SECOND ORDER SYSTEM

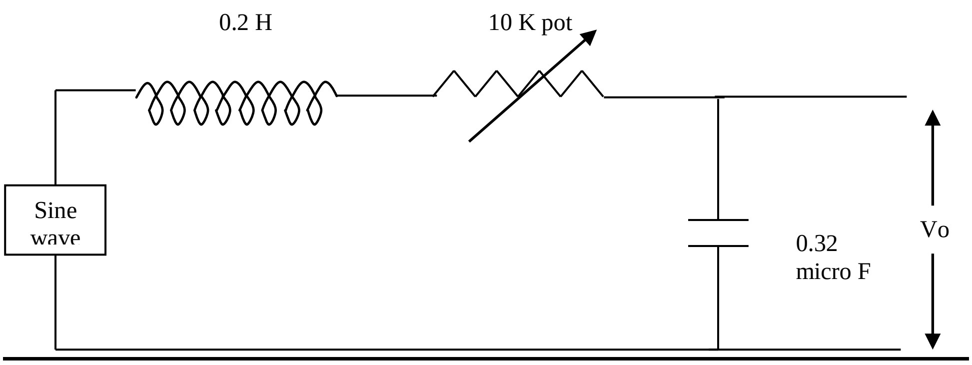
Aim: To determine frequency response of a second order system and evaluation of Frequency domain specifications.

Theory:

The frequency response of a system or a component is normally performed by keeping the amplitude A fixed and determining B and Φ for a suitable range of frequencies where steady state output may be represented as c(t) = B sin(wt + Φ) The ease and Accuracy of measurements are some of the advantages of the frequency response method. Without the knowledge of transfer function, the frequency response of stable open loop system can be obtained experimentally or the systems with very large time constants, the frequency response test is cumbersome to perform. We can use the data obtained from measurements on the physical system without deriving its mathematical model. Nyquist, bode, Nichols etc are some of the frequency response methods. For difficult cases, such as conditionally stable systems, Nyquist Plot is probably the only method to analyse stability.

Apparatus Required: Second order system study unit. Function generator, wires multimeter, CRO

Circuit Diagram:



Procedure:

1. Connections are made as per the circuit diagram.
2. A sinusoidal signal with amplitude of 1V is applied to the circuit.
3. The frequency is varied in steps and at each step frequency, phase angle, output is noted down.
4. A frequency response characteristic is plotted.
5. From the graph note down M_R, ω_R , ω_C .

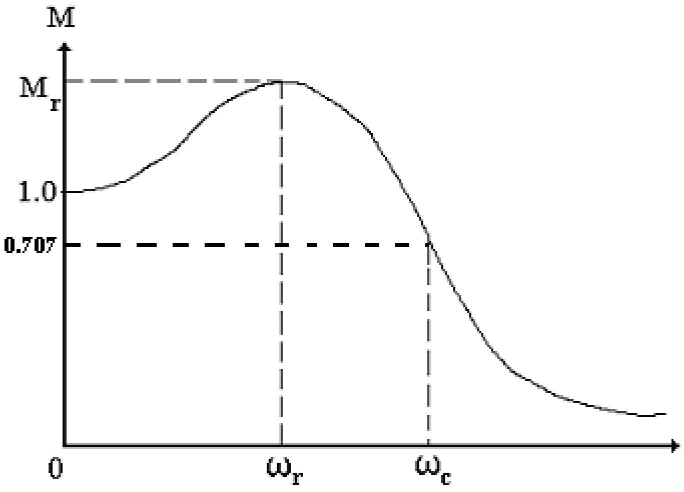
Frequency domain specifications:

$\omega_r = \omega_n \sqrt{(1- 2\zeta^2)}$

$M_R = 1/2\zeta \sqrt{(1- \zeta^2)}$

$\acute{\omega}_d = \omega_n \sqrt{(1- \zeta^2)}$

Graph:



Result:

Viva questions:

1. State the advantages and limitations of frequency domain approach.
2. Define bandwidth.

Experiment No.8

DC POSITION CONTROL

Aim: To simulate a DC position control system and hence to find the step response using MATLAB.

Theory:
DC position control system which we study here is used control the position of shaft, by use of potentiometer error detector. The error is to be amplified by the amplifier and must be given to the armature controlled motor whose shaft position will get controlled as per the control signal. The motor shaft is coupled to the load through gearing arrangement with ratio N1/N2. Position control systems have innumerable applications namely machine tool position Control, constant tension control of sheet rolls in paper mills, control of sheet metal thickness in hot rolling mills, radar tracking system, missile guidance systems, inertial guidance, In armature controlled DC servomotor the excitation of the field winding is kept constant and torque is varied by varying the applied voltage connected to the armature. Here the servo system is used to position the load shaft in which the driving motor is geared to the load to be varied.

Apparatus required: PC loaded with MATLAB

Formation of mathematical model:

K_p = gain of the potentiometer of error detector.
K_a = gain of the amplifier.
K_b = back emf constant.
K_t = torque constant.
J = equivalent moment of inertia of motor and load referred to motor.
B = equivalent viscous friction of motor and load referred to motor

For potentiometer error detector

$E(s) = K_p[R(s) – C(s)]$

For amplifier,
$E_a(s) = K_a E(s)$

For armature controlled DC motor,

i_f = constant as flux Φ is constant.
$T = K_t i_a$.
$e_b \alpha \theta$ (angular displacement of the DC motor shaft)
$e_b = K_b d\theta/dt$

For the armature circuit,
$e_b = e_b + L_a di_a/dt + i_a R_a$

Taking Laplace transforms,
$E_b(s) = K_b s\theta(s)$
$E_a(s) = E_b(s) + I_a(s) [R_a+sL_a]$
$T = k_t I_a(s)$

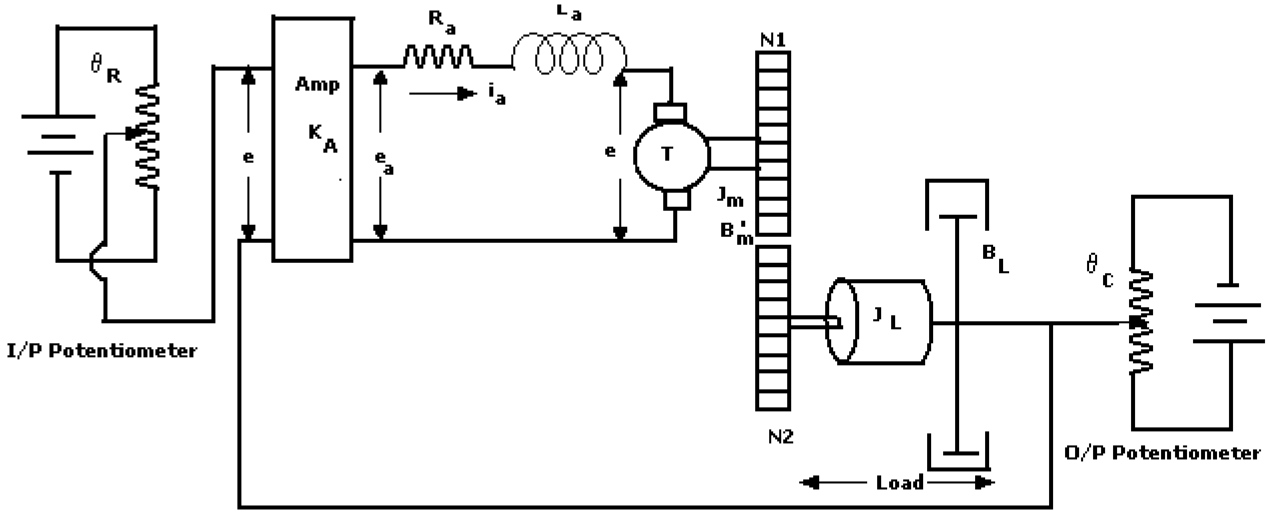
Now, torque is utilized to drive load = shaft of motor.

$T = k_t I_a(s) = J\, d^2\theta/dt^2 + f\, d\theta/dt$

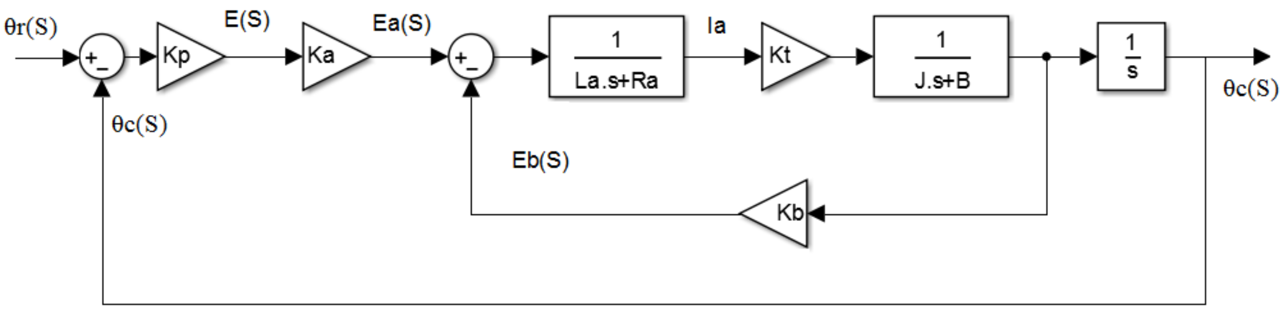
After simplification,

$$\theta(s)/E_a(s) = \frac{K_t}{s[J_s+f][R_a+sL_a]+K_tK_bs}$$

Circuit Diagram:



Block Diagram:

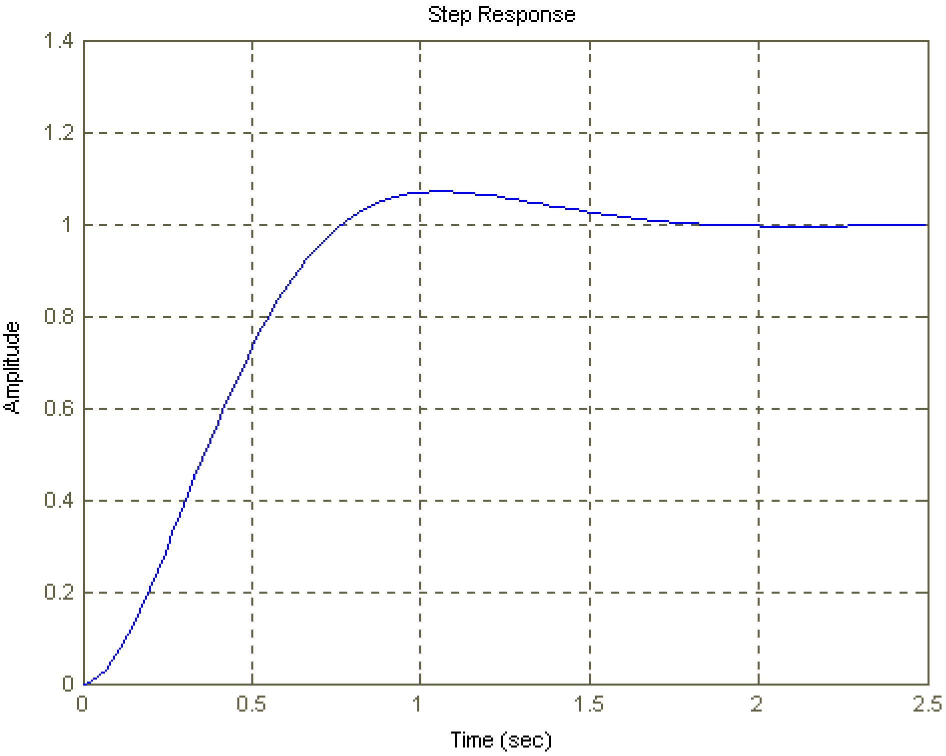


Procedure:

1. Develop the complete block diagram of the given schematic diagram of position control servomechanism using simulink.
2. Kp is the variable and set it to some suitable value to simulate over, under damped conditions of the system.
3. From the response curve obtained determine the time domain specifications.

Typical example:

k_P = (24/pi), k_A = 10, $k_T = 6*10^{-5}$ Nm/amps, J = 5. $4*10^{-5}$ kg-m^2, $B=4*10^{-4}$ Nm rad/sec
R_a=0.1 ohms, L_a= 0.001 H.



Result:

Viva questions:

1. What do you mean by DC position control?
2. What are the applications of DC servo mechanism

Experiment No.9

BODE PLOT

AIM: Obtain the phase margin and gain margin for a given transfer function by drawing bode plots and verify the same using MATLAB.

Theory:
One of the most useful representation of transfer function is a logarithmic plot which consists of two graphs, one giving the logarithm of [G (jw)] and the other phase angle of G(jw) both plotted against frequency in logarithmic scale. These plots are called bode plots. The main advantage of using bode diagram is that the multiplication of magnitudes can be converted into addition. Bode plots are a good alterative to the Nyquist plots.

Frequency response specifications:

1. Gain cross over frequency w_{gc} = It is the frequency at which magnitude of G (jw) H (jw) is unity ie 1.
2. Phase cross over frequency w_{pc} = It is the frequency at which phase angle of G(jw) H(jw) is -180^o
3. Gain margin G.M = It is defined as the margin in gain allowable by which gain can be increased till system reaches on the verge of instability. Mathematically it is defined as the reciprocal of the magnitude of the G(jw) H(jw) measured at phase cross over frequency.
4. Phase margin P.M = Amount of additional phase lag which can be introduced in the system till system reaches on the verge of instability. Mathematically it can be defined as

   $P.M = 180^o + \angle G(jw)H(jw)_{\text{at } w=wgc}$

Procedure:
1) Open the MATLAB command window.
2) Click on file/new/M file to open the MATLAB editor window. In MATLAB editor window enter the program
3) Save the program as .M file.
4) Execute the program by selecting run.
5) Note down the gain crossover, Phase crossover frequencies, gain margin and phase margin from the plot.
6) Also copy the plot.

Typical Problem

Transfer fuction : 36 / ($s^3+6s^2+11s+6$) .

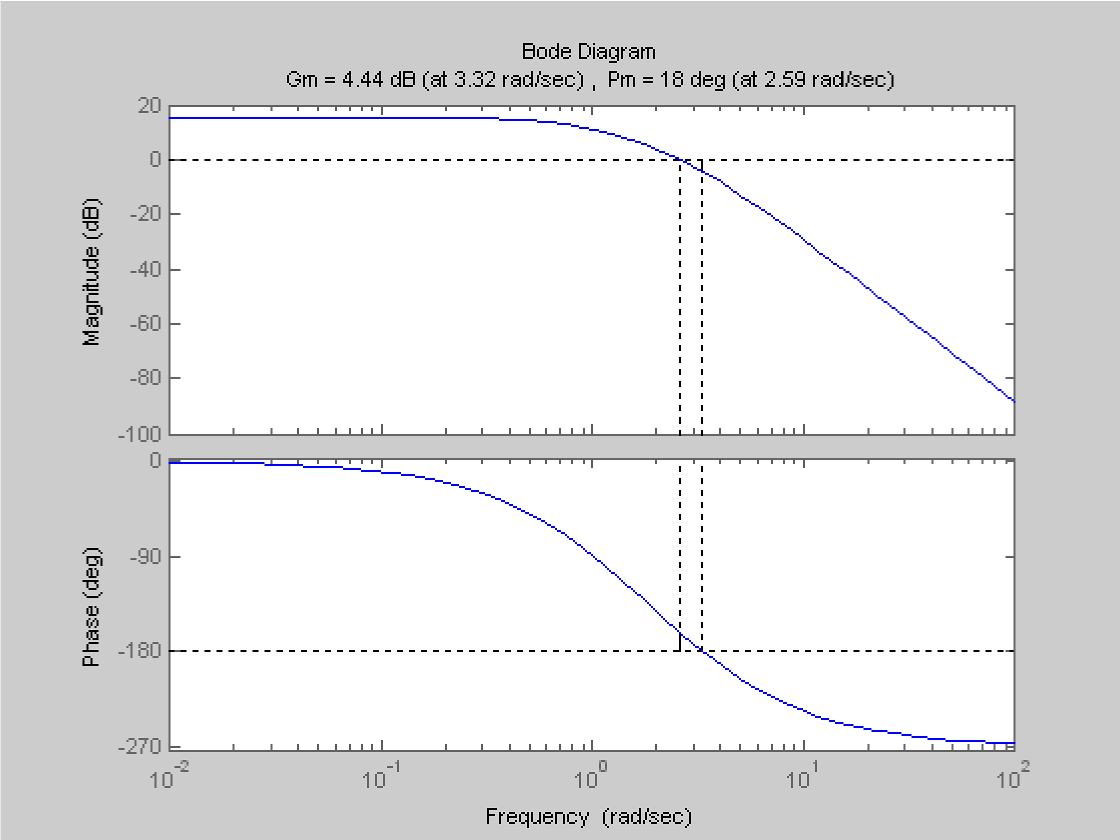
```
num = [36];
den = [1 6 11 6];
sys =   tf (num , den)
bode (sys)
margin(sys)
```

Examlples

Find gain Margin and Phase Margin:

a) TF = $\dfrac{0.5}{S(S+1)(S+0.5)}$.

b) TF = $\dfrac{10}{(S+2)(S+3)(S+4)}$.



Result:

Viva questions:

1. write MATLAB program to find the value of k for a given phase margin
2. write MATLAB program to find the value of k for a given gain margin

Experiment No.10 (a)

ROOT LOCUS DIAGRAM

a)AIM: To obtain Root locus of a given T. F. and hence finding breakaway point, intersection point on imaginary axis and to draw the Nyquist plot for the given transfer function using MATLAB.

Theory:

Root locus technique is used to find the roots of the characteristics equation. This technique provides a graphical method of plotting the locus of the roots in the s plane as a given parameter usually gain is varied over the complete range of values. This method brings in to focus the complete dynamic response of the system. By using root locus method the designer can predict the effects location of closed loop poles by varying the gain value or adding open loop poles and/or open loop zeroes. The closed loop poles are the roots of the characteristic equation.

Various terms related to root locus technique that we will use frequently in this article.

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

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

5. Asymptotes of Root Loci: Asymptote originates from the centre of gravity or centroid and goes to infinity at definite some angle. Asymptotes provide direction to the root locus when they depart break away points.
6. Angle of Asymptotes: Asymptotes makes some angle with the real axis and this angle can be calculated from the given formula, Where p = 0, 1, 2 .... (N-M-1)

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

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

Program Procedure:

1) Open the MATLAB command window.
2) Click on file/new/M file to open the MATLAB editor window. In MATLAB editor window enter the program
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:

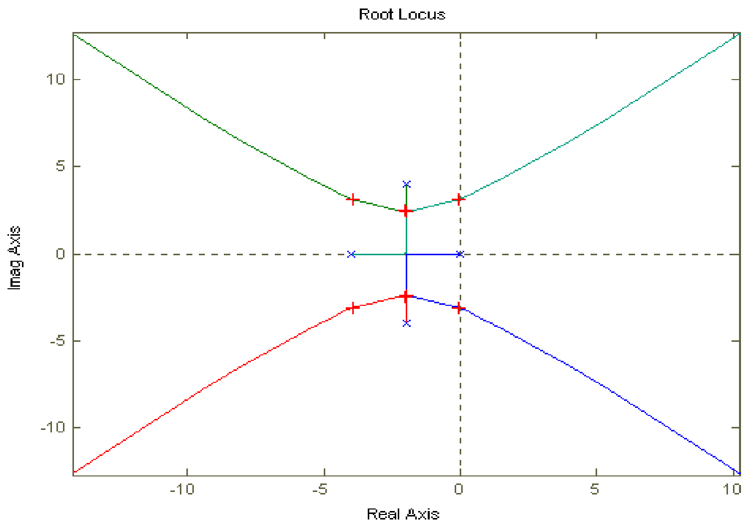
Given ; G(s)H(s) = $10/S^4 + 8S^3 + 36\ S^2 + 80\ S$

Program:

```
p  = [ 0   0   0    0    10 ];
q = [ 1   8   36  80  0 ];
sys = tf(p,q)
Zpk(sys)
rlocus(sys)
```

Output in the command window:

```
Transfer function:
        36
----------------------
s^3 + 6 s^2 + 11 s + 6
```



Result:

Viva questions:

1. What is the significance of root locus method?
2. What are the rules of construction of root locus?
3. What are the disadvantages of Root Locus Method?
4. What are the advantages of root-locus method?
5. What is meant by Asymptotes and when it comes into picture in root-locus method?
6. What is meant by angle of arrival and angle of departure?
7. What you mean by breakaway and break-in points?
8. When do you expect a breaking point in a root-locus?

Experiment No.10 (b)

NYQUIST PLOT

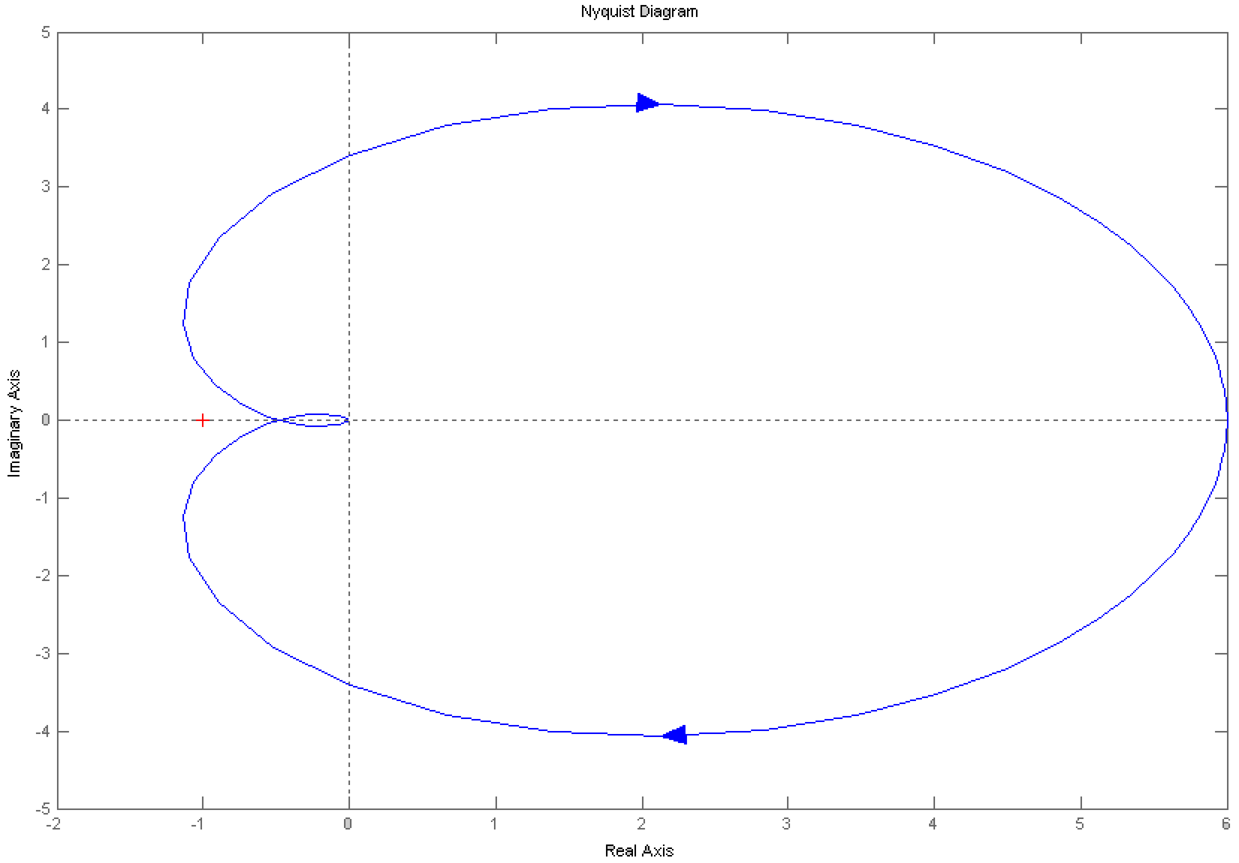
Program for Nyquist plot:

Given the T.F=60/(s+1)(s+2)(s+5)

Programme:
P=[60]
Q=[1 8 17 10]

Sys=tf(P,Q)
Nyquist(sys)

Result:



Examples

Draw the Nyquist plot for following T.F

1) T.F=1/s(1+2s)(1+s)
2) T.F=(1+4s)/s^2(1+s)(1+2s)

Experiment No.11

CHARACTERSTICS OF SYNCHROS

A. STUDY OF SYNCHRO TRANSMITTER

AIM: To study about synchro transmitter and also about the transformation of angular position of its rotor into unique set of stator voltages.

APPARATUS REQUIRED:

Sl. No.	NAME OF THE APPARATUS	TYPE	QUANTITY
1.	Synchro transmitter- receiver pair kit		1
2	Connecting wires	Patch cords	As required

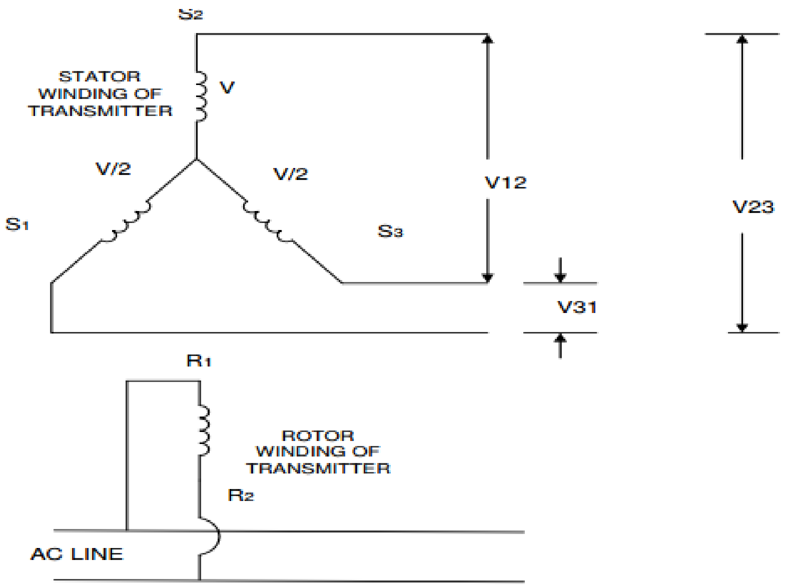
Theory:

The term synchro is a generic name for a family of inductive devices which works on the principle of a rotating transformer (Induction motor). Basically they are electro mechanical devices or electromagnetic transducer which produces an output voltage depending upon angular position of the rotor. A Synchro system is formed by interconnection of the devices called the synchro transmitter and the synchro control transformer. They are also called as synchro pair. The synchro pair measures and compares two angular displacements and its output voltage is approximately linear with angular difference of the axis of both the shafts. They can be used in the following two ways.

i. To control the angular position of load from a remote place / long distance.

ii. For automatic correction of changes due to disturbance in the angular position of the load.

CIRCUIT DIAGRAM:



TORQUE TRANSMISSION USING SYNCHRO TRANMITTER

PRECAUTIONS:

1. Keep the angular positions of rotors of transmitter and receiver at zero position before starting the experiment.
2. Handle the angle pointers for both the rotors in a gentle manner.
3. Do not attempt to pull out the angle pointers.
4. Do not short rotor or stator terminals.

PROCEDURE:

1. Connect the mains supply to the synchro Transmitter- receiver system with the help of the given mains cord.
2. Connect 110V AC supply to the rotor terminals (R1 and R2) of the transmitter only and switch on the mains supply.
3. Now at zero angular position of rotor of transmitter, note down the voltage between stator winding terminals i.e., V_{S1S2}, V_{S2S3} and V_{S3S1} with the help of given patch cords and tabulate them.
4. Vary the angular positions of rotor of the transmitter in steps by 30 and note down the corresponding voltages between stator winding terminals in a tabular column.
5. The zero position of rotor and stator coincide with voltage V_{S1S2} equal to zero. Do not disturb this condition.
6. Switch off the mains supply of the kit after bringing back the rotor at zero.
7. Plot a graph between angular positions of rotor of transmitter and stator voltages for all three phases.

TABULAR COLUMN:

Sl. No.	**Rotor position in degrees**	**RMS voltages between stator terminals**		
		V_{S1S2}	**V_{S2S3}**	**V_{S3S1}**
1	0			
2	30			
3	60			
4	90			
5	120			
6	150			
7	180			
8	210			
9	240			
10	270			
11	300			
12	330			
13	360			

GRAPH: - Plot a graph of angular position VS voltage for all the three phases.

RESULT: -The synchro Transmitter was studied and waveform of stator winding voltages was plotted on graph .

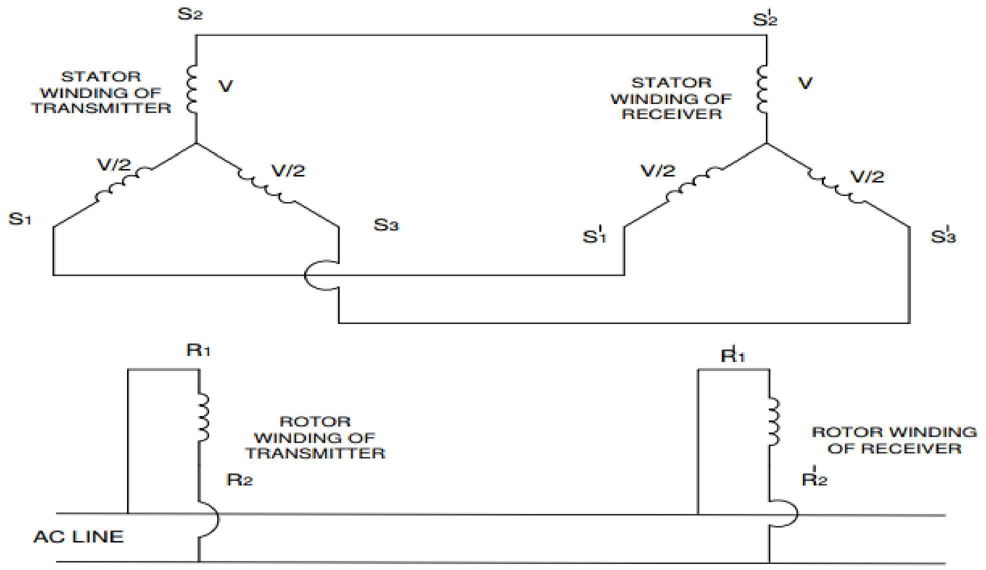
B. STUDY OF SYNCHRO TRANSMITTER-RECEIVER PAIR

AIM: To study about synchro transmitter – receiver pair.

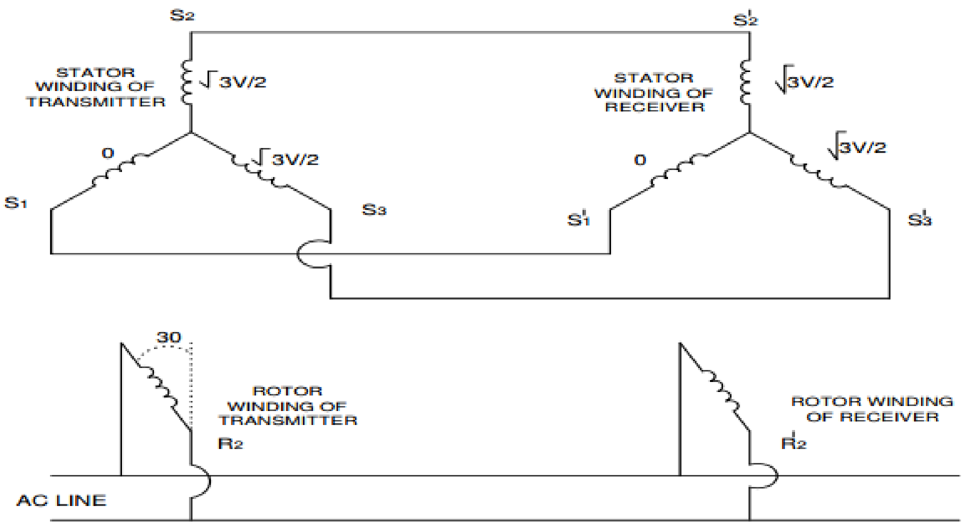
APPARATUS REQUIRED:

Sl. No.	NAME OF THE APPARATUS	TYPE	QUANTITY
1.	Synchro transmitter- receiver pair kit		1
2	Connecting wires	Patch cords	As required

CIRCUIT DIAGRAM:



TORQUE TRANSMISSION USING SYNCHRO TRANMITTER



TORQUE TRANSMISSION USING SYNCHRO TRANMITTER AND RECEIVER AS PAIR

PRECAUTIONS:

1. Keep the angular positions of rotors of transmitter and receiver at zero position before starting the experiment.
2. Handle the angle pointers for both the rotors in a gentle manner.
3. Do not attempt to pull out the angle pointers.
4. Do not short rotor or stator terminals.

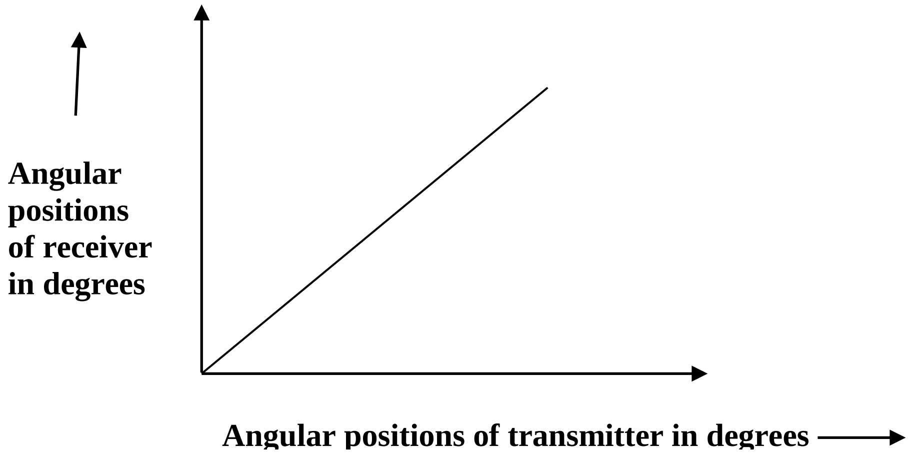
PROCEDURE:

1. Connect the mains supply to the synchro Transmitter- receiver system with the help of the given mains cord.
2. Connect the stator terminals of transmitter S_1, S_2, and S_3 with stator terminals of receiver S_1, S_2, and S_3 with the help of patch cords respectively.
3. Connect 110V AC supply to the rotor terminals (R1 and R2) of both transmitter and receiver, and then switch on the mains supply.
4. Now at zero angular position of rotor of transmitter, note down that of receiver and tabulate them.
5. Vary the angular positions of rotor of the transmitter in steps by 30 and note down the corresponding angular positions of rotor of synchro receiver.
6. 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.
7. Switch off the mains supply of the kit after bringing back the rotor of the transmitter at zero.
8. Plot a graph between angular positions of rotor of transmitter and angular positions of rotor of receiver.

TABULAR COLUMN:

Sl. No.	Angular positions of transmitter	Angular positions of receiver
1	0	
2	30	
3	60	
4	90	
5	120	
6	150	
7	180	
8	210	
9	240	
10	270	
11	300	
12	330	
13	360	

MODEL GRAPH:



RESULT:
Thus the characteristics of synchro transmitter receiver pair were studied.

<u>Viva questions:</u>

1. What is meant by synchro-transmitter receiver pair?
2. Give the application of synchro-transmitter receiver pair?

Add on Experiment 1:

DIGITAL SIMULATION OF LINEAR SYSTEMS

AIM: To digitally simulate the time response characteristics of Linear SISO systems using state variable formulation.

APPARATU REQUIRED:A PC with MATLAB package.

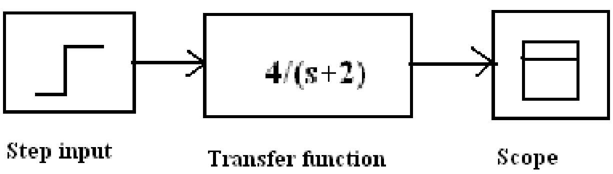
THEORY:
State Variable approach is a more general mathematical representation of a system, which, along with the output, yields information about the state of the system variables at some predetermined points along the flow of signals. It is a direct time-domain approach, which provides a basis for modern control theory and system optimization. SISO (single input single output) linear systems can be easily defined with transfer function analysis. The transfer function approach can be linked easily with the state variable approach.

The state model of a linear-time invariant system is given by the following equations:
$\dot{X}(t) = A\,X(t) + B\,U(t)$ **State equation**
$Y(t) = C\,X(t) + D\,U(t)$ **Output equation**
Where A = n x n system matrix,
B = n x m input matrix,
C= p x n output matrix and
D = p x m transmission matrix,

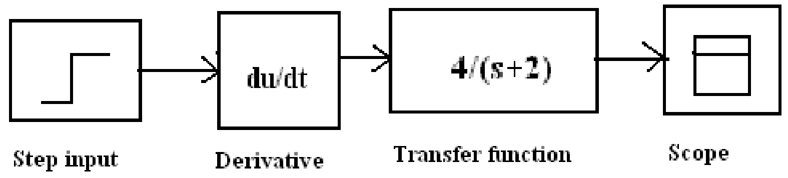
PROGRAMME:
OPEN LOOP RESPONSE (FIRST ORDER SYSTEM)
T.F=4/(s+2)
Response of system to Step and Impulse input

```
n=[4];              n=[4];
d=[1 2];            d=[1 2];
sys=tf(n,d);          sys=tf(n,d);
step(sys)           impulse(sys)
```

SIMULINK
Step Input Open Loop –I Order



Impulse Input Open Loop –I Order

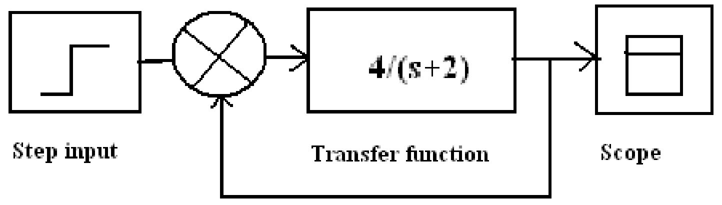


Close Loop Response

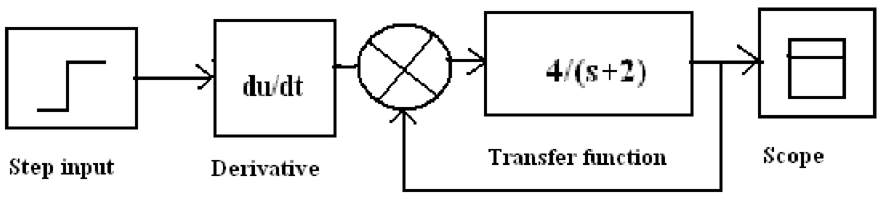
```
n=[4];
d=[1 2];
sys=tf(n,d);
sys=feedback(sys,1,-1)
step(sys)
impulse(sys)
```

SIMULINK

Step Input Close Loop –I Order



Impulse Input Close Loop –I Order



SECOND ORDER SYSTEM

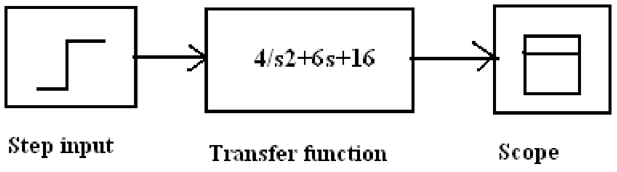
TF= $4/s^2+6s+16$

Open Loop Response

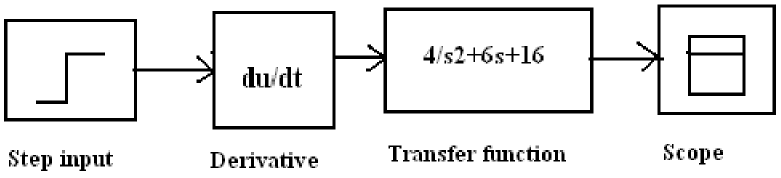
```
n=[4];
d=[1 6 16];
sys=tf(n,d);
step(sys)
impulse(sys)
```

SIMULINK

Step Input Open Loop –II Order



Impulse Input Open Loop –II Order

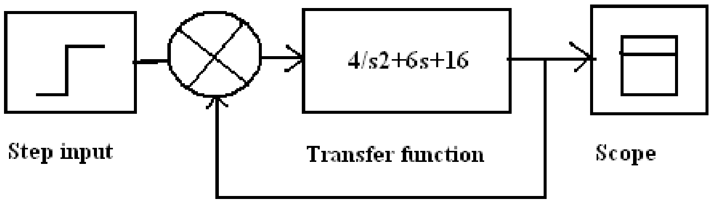


Close Loop Response

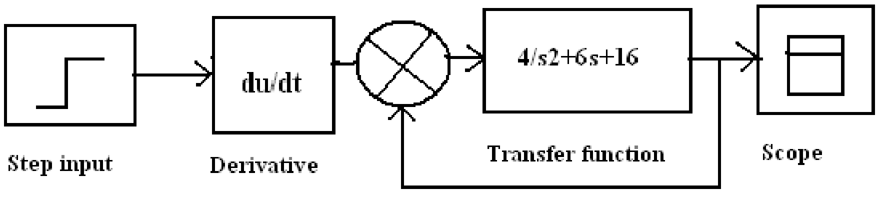
```
n=[4];
d=[1 6 16];
sys=tf(n,d);
sys=feedback(sys,1,-1)
step(sys)
impulse(sys)
```

SIMULINK

Step Input Close Loop –I Order



Impulse Input Close Loop –II Order



STATE SPACE EQUATION

```
A=[-6 -16; 1 0];
B=[1; 0];
C=[ 0 4];
D=[0];
Sys=ss(A,B,C,D);
step(sys)
impulse(sys)
```

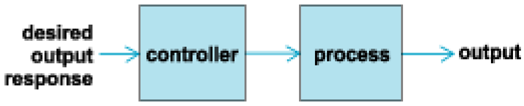
RESULT:

APPENDIX-A

CONTROL SYSTEM FUNDAMENTALS

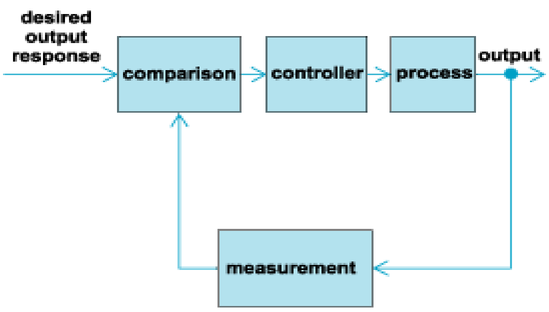
Definition: Control system is an interconnection of components forming system configurations which will provide a desired system response as time progresses. The steering of an automobile is a familiar example. The driver observes the position of the car relative to the desired location and makes corrections by turning the steering wheel. The car responds by changing direction and the driver attempts to decrease the error between the desired and Actual course of travel. In this case, the controlled output is the automobile's direction of travel, and the control system includes the driver, the automobile, and the road surface. The control engineer attempts to design a steering control mechanism which will provide a desired response for the automobile's direction control. Different steering designs and automobile designs result in rapid responses, as in the case of sports cars, or relatively slow and comfortable responses, as in the case of large autos with power steering.

Open loop control: The basis for analysis of a control system is the foundation provided by linear system theory, which assumes a cause-effect relationship for the components of a system. A component or process to be controlled can be represented by a block. Each block possesses an input (cause) and output (effect). The input-output relation represents the cause-and-effect relationship of the process, which in turn represents a processing of the input signal to provide an output signal variable, often with power amplification. An open-loop control system utilizes a controller or control Actuator in order to obtain the desired response



Open-loop control system.

Closed loop control: In contrast to an open-loop control system, a closed-loop control system utilizes an additional measure of the Actual output in order to compare the Actual output with the desired output response. A standard definition of a feedback control system is a control system which tends to maintain a prescribed relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control. In the case of the driver steering an automobile, the driver uses his or her sight to visually measure and compare the Actual location of the car with the desired location. The driver then serves as the controller, turning the steering wheel. The process represents the dynamics of the steering mechanism and the automobile response.



Closed-loop control system.

A feedback control system often uses a function of a prescribed relationship between the output and reference input to control the process. Often, the difference between the output of the process under control and the reference input is amplified and used to control the process so that the difference is continually reduced. The feedback concept has been the foundation for control system analysis and design.

Applications for feedback systems

Familiar control systems have the basic closed-loop configuration.

1. A refrigerator has a temperature setting for desired temperature,

2. A thermostat to measure the Actual temperature and the error, and a compressor motor for

3. Other examples in the home are the oven, furnace, and water heater.

4. In industry, there are controls for speed, process temperature and pressure, position, thickness, composition, and quality, among many others.

5. Feedback control concepts have also been applied to mass transportation, electric power systems, automatic warehousing and inventory control, automatic control of agricultural systems, biomedical experimentation and biological control systems, and social, economic, and political systems.

Advantages of feedback control

The addition of feedback to a control system results in several important advantages. A process, whatever its nature, is subject to a changing environment, aging, ignorance of the exact values of the process parameters, and other natural factors which affect a control process. In the open-loop system, all these errors and changes result in a changing and inaccurate output. However, a closed-loop system senses the change in the output due to the process changes and attempts to correct the output. The sensitivity of a control system to parameter variations is of prime importance. A primary advantage of a closed-loop feedback control system is its ability to reduce the system's sensitivity.

One of the most important characteristics of control systems is their transient response which often must be adjusted until it is satisfactory. If an open-loop control system does not provide a satisfactory response, then the process must be replaced or modified. By contrast, a closed-loop

system can often be adjusted to yield the desired response by adjusting the feedback loop parameters.

A second important effect of feedback in a control system is the control and partial elimination of the effect of disturbance signals. Many control systems are subject to extraneous disturbance signals which cause the system to provide an inaccurate output. Feedback systems have the beneficial aspect that the effect of distortion noise and unwanted disturbances can be effectively reduced.

Costs of feedback control

While the addition of feedback to a control system results in the advantages outlined above, it is natural that these advantages have an attendant cost. The cost of feedback is first manifested in the increased number of components and the complexity of the system. The second cost of feedback is the loss of gain. Usually, there is open-loop gain to spare, and one is more than willing to trade it for increased control of the system response. Finally, a cost of feedback is the introduction of the possibility of instability. While the open-loop system is stable, the closed-loop system may not be always stable.

Stability of closed-loop systems

The transient response of a feedback control system is of primary interest and must be investigated. A very important characteristic of the transient performance of a system is the stability of the system. A stable system is defined as a system with a bounded system response. That is, if the system is subjected to a bounded input or disturbance and the response is bounded in magnitude, the system is said to be stable.

The concept of stability can be illustrated by considering a right circular cone placed on a plane horizontal surface. If the cone is resting on its base and is tipped slightly, it returns to its original equilibrium position. This position and response is said to be stable. If the cone rests on its side and is displaced slightly, it rolls with no tendency to leave the position on its side. This position is designated as neutral stability. On the other hand, if the cone is placed on its tip and released, it falls onto its side. This position is said to be unstable.

Design

A feedback control system that provides an optimum performance without any necessary adjustments is rare indeed. Usually one finds it necessary to compromise among the many conflicting and demanding specifications and to adjust the system parameters to provide a suitable and acceptable performance when it is not possible to obtain all the desired optimum specifications.

It is often possible to adjust the system parameters in order to provide the desired system response. However, it is often not possible to simply adjust a system parameter and thus obtain the desired performance. Rather, the scheme or plan of the system must be reexamined, and a new design or plan must be obtained which results in a suitable system. Thus, the design of a control system is concerned with the arrangement, or the plan, of the system structure and the selection of suitable components and parameters. For example, if one desires a set of performance measures to be less than some specified values, one often encounters a conflicting set of requirements. If these two performance requirements cannot be relaxed, the system must be altered in some way. The alteration or adjustment of a control system, in order to make up for deficiencies and inadequacies and provide a suitable performance, is called compensation.

Compensating Networks:

Control systems are designed to perform specific tasks. The requirements imposed on the control system are usually the performance specifications. The specifications may be given in terms of transient response or steady state requirements. Setting the gain is the first step in adjusting the system for satisfactory operation. In many practical cases, however the adjustment of the gain alone may not provide sufficient alteration of the system behavior to meet the given specifications. Increasing the gain value will improve the steady state behavior but will result in poor stability. It is then necessary to redesign the system. Such a redesign or addition of a suitable device is called compensation.

A device inserted in to the system for the purpose of satisfying the specifications of the system is called compensator. Commonly used compensators are lead, lag, lead-lag and PID compensators. The compensators used may be and electrical, mechanical, hydraulic, pneumatic etc. Usually electric network serves compensators for many control systems.

APPENDIX-B

MATLAB BASICS

MATLAB, which stands for MATrix LABoratory, is a state-of-the-art mathematical software package, which is used extensively in both academia and industry. It is an interactive program for numerical computation and data visualization, which along with its programming capabilities provides a very useful tool for almost all areas of science and engineering. Unlike other mathematical packages, such as MAPLE or MATHEMATICA, MATLAB cannot perform symbolic manipulations without the use of additional Toolboxes. It remains however, one of the leading software packages for numerical computation.

As you might guess from its name, MATLAB deals mainly with matrices. A scalar is a 1-by-1 matrix and a row vector of length say 5, is a 1-by-5 matrix. One of the many advantages of MATLAB is the natural notation used. It looks a lot like the notation that you encounter in a linear algebra. This makes the use of the program especially easy and it is what makes MATLAB a natural choice for numerical computations. The purpose of this experiment is to familiarize MATLAB, by introducing the basic features and commands of the program.

MATLAB is case-sensitive, which means that `a + B` is not the same as `a + b`.
The MATLAB prompt (») in command window is where the commands are entered.

Matrices :

row matrix: Elements in a row are separated either by using white spaces or commas
eg: a=[1 2 4 5]
column matrix: Elements which differ by a column are seperated by enter or semicolumn
eg: b=[1; 2; 3]

Looking into matrix:

a(row,column) allows to look the particular element in the matrix “a”

Vectors:

d= [0:7]
”d” is a vector or row matrix with first element as 0 and last element as 7 and increment is by default 1. The default increment can be changed (to 0.1) by using increment field in between as e= [0:0.1:7].
d(1:2) allows to look into vector with increment 1
e(1:2:4) look with increment

Operators:

1. + addition
2. - subtraction
3. * multiplication
4. ^ power
5. ' transpose
6. \ left division

7. / right division

Remember that the multiplication, power and division operators can be used in conjunction with a period to specify an element-wise operation.

Typical commands:

1. whos
2. who
3. clear
4. quit
5. save filename – filename.mat
6. load filename - retrive
7. dairy filename - b4 and after ascii text file
8. help

Built in Functions:

1. Scalar Functions:

Certain MATLAB functions are essentially used on scalars, but operate element-wise when applied to a matrix (or vector). They are summarized below.

1. sin - trigonometric sine
2. cos - trigonometric cosine
3. tan - trigonometric tangent
4. asin - trigonometric inverse sine (arcsine)
5. acos - trigonometric inverse cosine (arccosine)
6. atan - trigonometric inverse tangent (arctangent)
7. exp - exponential
8. log - natural logarithm
9. abs - absolute value
10. sqrt - square root
11. rem - remainder
12. round - round towards nearest integer
13. floor - round towards negative infinity
14. ceil - round towards positive infinity

2. Vector Functions:

Other MATLAB functions operate essentially on vectors returning a scalar value. Some of these functions are given below.

1. max largest component : get the row in which the maximum element lies
2. min smallest component
3. length length of a vector
4. sort sort in ascending order
5. sum sum of elements
6. prod product of elements
7. median median value
8. mean mean value std standard deviation

3. Matrix Functions:

Much of MATLAB‟ s power comes from its matrix functions. These can be further separated into two sub-categories.

The first one consists of convenient matrix building functions, some of which are given below.

1. eye - identity matrix
2. zeros - matrix of zeros
3. ones - matrix of ones
4. diag - extract diagonal of a matrix or create diagonal matrices
5. triu - upper triangular part of a matrix
6. tril - lower triangular part of a matrix
7. rand - randomly generated matrix

eg: diag([0.9092;0.5163;0.2661])

ans =

0.9092 0 0

0 0.5163 0

0 0 0.2661

commands in the second sub-category of matrix functions are

1. size size of a matrix
2. det determinant of a square matrix
3. inv inverse of a matrix
4. rank rank of a matrix
5. rref reduced row echelon form
6. eig eigenvalues and eigenvectors
7. poly characteristic polynomial
8. norm norm of matrix (1-norm, 2-norm, ∞ -norm)
9. cond condition number in the 2-norm
10. lu LU factorization
11. qr QR factorization
12. chol Cholesky decomposition
13. svd singular value decomposition

Operations on matrices:

1. Transpose (single quote „)

a= [1 2 3];

b=a‟ ;

2. extraction of submatrices

a=[1,2;3,4;5,6];

b=a(1:2,2:1;1:1;2:2);

c=a(:,2) ; second column of matrix "a" is sub- matrix "c"

d=a(1,:) ; first row of matrix "a" is sub-matrix "d"

3. Determinant and Inverse of a matrix

eg: A = [9,7,0;0,8,6;7,1,-6];

size(A), det(A), inv(A)

We can check our result by verifying that AA–1 = I and A–1A = I .

A*inv(A), inv(A)*A

The eigenvalues and eigenvectors of A (i.e. the numbers λ and vectors x that satisfy

Ax = λx) can be obtained through the eig command.
eig(A)
produces a column vector with the eigenvalues
[X,D]=eig(A)
produces a diagonal matrix D with the eigen values on the main diagonal, and a full matrix X whose columns are the corresponding eigenvectors.

PLOTTING COMMANDS:

If *x* and *y* are two vectors of the same length then `plot(x,y)` plots *x* versus *y*.

For example, to obtain the graph of *y* = cos(*x*) from – ∧ to ∧ , we can first define the vector *x*

with components equally spaced numbers between – ∧ and ∧ , with increment, say 0.01.

```
» x=-pi:0.01:pi;
```

We placed a semicolon at the end of the input line to avoid seeing the (long) output.
Note that the smallest the increment, the “smoother” the curve will be.
Next, we define the vector *y*

```
» y=cos(x);
```

(using a semicolon again) and we ask for the plot

```
» plot(x,y)
```

It is good practice to label the axis on a graph and if applicable indicate what each axis represents. This can be done with the `xlabel` and `ylabel` commands.

```
» xlabel('x')
» ylabel('y=cos(x)')
```

Inside parentheses, and enclosed within single quotes, we type the text that we wish to be displayed along the *x* and *y* axis, respectively. We could even put a title on top using

```
» title('Graph of cosine from -pi to pi')
```

Various line types, plot symbols and colors can be used. If these are not specified (as in the case above) MATLAB will assign (and cycle through) the default ones as given in the table below.

```
y yellow   . point
m magenta  o circle
c cyan     x x-mark
r red      + plus
g green    - solid
b blue     * star
w white    : dotted
k black    -. dashdot
           -- dashed
```

So, to obtain the same graph but in *green*, we type

```
» plot(x,y,’g’)
```

where the third argument indicating the color, appears within single quotes. We could get a *dashed* line instead of a *solid* one by typing

```
» plot(x,y,’--’)
```

or even a combination of line type and color, say a *blue dotted* line by typing

```
» plot(x,y,’b:’)
```

Multiple curves can appear on the same graph. If for example we define another vector

```
» z = sin(x);
```

we can get both graphs on the same axis, distinguished by their line type, using

```
» plot(x,y,'r--',x,z,'b:')
```

When multiple curves appear on the same axis, it is a good idea to create a *legend* to label and distinguish them. The command `legend` does exactly this.

```
» legend('cos(x)','sin(x)')
```

The text that appears within single quotes as input to this command, represents the legend labels. We must be consistent with the ordering of the two curves, so since in the `plot` command we asked for *cosine* to be plotted before *sine*, we must do the same here.

At any point during a MATLAB session, you can obtain a hard copy of the current plot by either issuing the command `print` at the MATLAB prompt, or by using the command menus on the plot window. In addition, MATLAB plots can by *copied* and *pasted* (as pictures) in your favorite word processor (such as Microsoft Word). This can be achieved using the Edit menu on the figure window. Another nice feature that can be used in conjunction with `plot` is the command `grid`, which places grid lines to the current axis

(just like you have on graphing paper). Type `help grid` for more information. Other commands for data visualization that exist in MATLAB include `subplot` create an array of (tiled) plots in the same window `loglog` plot using log-log scales `semilogx` plot using log scale on the *x*-axis `semilogy` plot using log scale on the *y*-axis.

APPENDIX-C

TRANSFER FUNCTION CONVERSION

A transfer function is also known as the network function is a mathematical representation, in terms of spatial or temporal frequency, of the relation between the input and output of a (linear time invariant) system. The transfer function is the ratio of the output Laplace Transform to the input Laplace Transform assuming zero initial conditions. Many important characteristics of dynamic or control systems can be determined from the transfer function.

The transfer function is commonly used in the analysis of single-input single-output electronic system, for instance. It is mainly used in signal processing, communication theory, and control theory. The term is often used exclusively to refer to linear time-invariant systems (LTI). In its simplest form for continuous time input signal x(t) and output y(t), the transfer function is the linear mapping of the Laplace transform of the input, X(s), to the output Y(s).

Zeros are the value(s) for z where the numerator of the transfer function equals zero. The complex frequencies that make the overall gain of the filter transfer function zero. Poles are the value(s) for z where the denominator of the transfer function equals zero. The complex frequencies that make the overall gain of the filter transfer function infinite.

The general procedure to find the transfer function of a linear differential equation from input to output is to take the Laplace Transforms of both sides assuming zero conditions, and to solve for the ratio of the output Laplace over the input Laplace.

TRANSFER FUNCTION FROM ZEROS AND POLES

MATLAB PROGRAM:

```
z=input('enter zeroes')
p=input('enter poles')
k=input('enter gain')
[num,den]=zp2tf(z,p,k)
tf(num,den)
```

EXAMPLE:

Given poles are -3.2+j7.8,-3.2-j7.8,-4.1+j5.9,-4.1-j5.9,-8 and the zeroes are -0.8+j0.43,-0.8-j0.43,-0.6 with a gain of 0.5

ZEROS AND POLES FROM TRANSFER FUNCTION

MATLAB PROGRAM:

```
num = input('enter the numerator of the transfer function')
den = input('enter the denominator of the transfer function')
[z,p,k] = tf2zp(num,den)
```

EXAMPLE:

Obtain the poles and zeros of the transfer function given below:

$C(S)/R(S)= (S^2+4S+3)/(S^3+3S^2+7S+5)$

TRANSFER FUNCTION FROM STATE MODEL

The transfer function is defined as the ratio of Laplace transform of output to Laplace transform of input. The transfer function of a given state model is given by:

T.F= $C[SI-A]^{-1}B$

A state space representation is a mathematical model of a physical system as a set of input, output and state variables related by first-order differential equations. The state space representation (also known as the "time-domain approach") provides a convenient and compact way to model and analyze systems with multiple inputs and outputs.

Unlike the frequency domain approach, the use of the state space representation is not limited to systems with linear components and zero initial conditions. "State space" refers to the space whose axes are the state variables. The state of the system can be represented as a vector within that space.

The input state equation is given by,

$\dot{X}=AX+BU$

$Y=CX+DU$

The output equation is written as,

MATLAB PROGRAM:

```
A =input('enter the matrix A')
B= input('enter the matrix B')
C = input('enter the matrix C')
D= input('enter the matrix D')
Sys =ss2tf(A,B,C,D)
```

EXAMPLE:

Obtain the transfer function from the State Model given below:

A = [0 1; -25 -4]

B = [1 1; 0 1]

C = [1 1; 1 1]

D = [0 0; 0 0]