CONTROL SYSTEMS LAB MANUAL

Subject: Control Systems Lab

Subject Code: ELPC552

B.Tech V Semester

Department of Electrical Engineering
J.C. Bose University of Science and Technology,
YMCA, Faridabad-121006

DEPARTMENT OF ELECTRICAL ENGINEERING

VISION OF THE DEPARTMENT

Electrical Engineering Department congregates the challenges of new technological advancements to provide comprehensively trained, career-focused, morally strong accomplished graduates, cutting-edge researchers by experimental learning which contribute to ever-changing global society and serve as competent engineers.

MISSION OF THE DEPARTMENT

- To commit excellence in imparting knowledge through incubation and execution of high-quality innovative educational programs.
- To develop the Research-oriented culture to build national capabilities for excellent power management.
- To inculcate and harvest the moral values and ethical behavior in the students through exposure of self -discipline and personal integrity.
- To develop a Centre of Research and Education generating knowledge and technologies which lay ground work in shaping the future in the field of electrical engineering.

PROGRAM OUTCOMES (POs)

Graduates of the Electrical Engineering program at JCBUST, YMCA will be able to:

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

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

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

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

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

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

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

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

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

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

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

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

PROGRAM SPECIFIC OUTCOMES (PSOs)

PSO1. To apply state-of-the-art knowledge in analysis design and complex problem solving with effective implementation in the multidisciplinary area of Electrical Engineering with due regard to environmental and social concerns.

PSO2. To prepare graduates for continuous self-learning to apply technical knowledge and pursue research in advanced areas in the field of Electrical Engineering for a successful professional career to serve society ethically.

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

PEO1. To produce competent electrical engineering graduates with a strong foundation design, analytics and problem solving skills for successful professional careers in industry, research and public service.

PEO2. To provide a stimulating research environment so as to motivate the students for higher studies and innovation in the specific and allied domains of electrical engineering.

PEO3. To encourage the graduates to practice the profession following ethical codes, social responsibility and accountability.

PEO4. To train students to communicate effectively in multidisciplinary environment.

PEO5. To imbibe an attitude in the graduates for life-long learning process.

Syllabus

Control Systems Lab (ELPC-552)

L-T-P **Internal Marks-15**
0-0-2 **ExternalMarks-35**
Total-50

LIST OF EXPERIMENTS

MATLAB EXPERIMENTS:

1. To plot poles and zeros locations of a first order and second order transfer functions. Also simulate them to different inputs using Matlab.
2. To find the closed loop transfer function of multi-loop feedback block diagram via block diagram reduction method using Matlab.To plot Root Locus using Matlab.
3. To plot Root Locus and identify stability of a system using Matlab.
4. To plot Nyquist plot and identify stability of a system using Matlab.
5. To plot Bode plot and identify stability of a system using Matlab.
6. To design Proportional-Integral-Derivative (PID) Controller using Matlab.

HARDWARE EXPERIMENTS:

7. To study DC potentiometer as error detector.
8. To study synchro transmitter/receiver.
9. To study PID controller.
10. To study linear system simulator.
11. To study DC position control system.
12. To study temperature control system.
13. To study lag-lead compensators.
14. To study speed-torque characteristic of AC servo motor.
15. To study stepper-motor control system.

Note: Any 08-10 of above experiments are to be conducted.

COURSE OBJECTIVES & OUTCOMES

Course objectives:

1. **To enhance the learning experience** of the students in topics encountered in Control Systems using Matlab software.
2. **To get hands-on experience** in using the control system kits which are developed to learn the fundamental concepts of control systems and control system components.

Course outcomes: After completion of this lab, students will be able to:

CO1. Use Matlab software to learn control systems.

CO2. Examine the response of control system by measuring relevant parameters under different disturbances.

CO3. Demonstrate the impact of PID controllers on linear system.

CO4. Understand the design compensators.

Mapping of Course Outcomes (COs) with POs and PSOs

COs	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	3	3	3	2	3	1	2	1	3	2	2	3	3	3
CO2	3	3	3	2	2	1	2	1	3	2	2	3	3	3
CO3	3	3	3	2	2	1	2	1	3	2	2	3	3	3
CO4	3	3	3	2	2	1	2	1	3	2	2	3	3	3

Justification:

1. **CO1** aligns strongly with fundamental knowledge, PO5. Modern tool usage, and experimentation (PO1-PO3, PO5, PO9, and PO12), while it moderately aligns with PO4, PO6, PO7-PO8, PO10, and PO11). It supports PSO1, PSO2 significantly through hands-on analysis, testing, and problem-solving.
2. **CO2** linked mainly to PO1-PO3, PO9, and PO12 and moderately to (PO4-PO5, PO7, PO10, and PO11). The practical experience and performance analysis contribute to PSO1 and PSO2, reflecting real-world skills.
3. **CO3** involves both practical and theoretical knowledge contributing significantly to all relevant POs, especially in experimentation and design (PO1-PO3, PO9, and PO12) and advanced problem-solving learning throughout the life (PSO1, PSO2).

4. **CO4** emphasizes design, analysis, characteristics and aligns closely with research and experimentation (PO1-PO3), along with its application to individual/team work and Life-long learning (PO9, PO12). The course outcome also encourages continuous learning (PSO2, PO12).

||General Instructions||

1. Students should come well-prepared for the experiment they will be conducting.
2. Usage of mobile phones in the laboratory is strictly prohibited.
3. In the lab, wear shoes and avoid loose-fitting clothes.
4. Read and understand the experiment manual thoroughly before starting the experiment. Know the objectives, procedures, and safety precautions.
5. Before starting the experiment, check the condition of the equipment, wiring, and connections. Report any damaged or malfunctioning equipment to the lab instructor immediately.
6. Ensure all connections are made as per the circuit diagram. Double-check all connections before powering the equipment.
7. Do not switch on the power supply until the instructor has approved your setup. Always start with the minimum voltage/current required and gradually increase as needed.
8. Familiarize yourself with the lab's emergency shutdown procedures, including the location of emergency switches and fire extinguishers.
9. Do not bring food or drinks into the lab to avoid accidental spills, which can lead to electrical hazards.
10. Stay attentive during the experiment. Avoid distractions like mobile phones, and do not engage in unnecessary conversation during lab work.
11. Accurately record all measurements and observations during the experiment. Ensure that all data is properly noted in your lab report.
12. If you are unsure about any procedure or face difficulties during the experiment, do not hesitate to ask the lab instructor for guidance.
13. After completing the experiment, switch off the power supply, disconnect the setup, and return all equipment to its proper place. Ensure the workspace is clean and organized.

Control Systems Lab
(ELPC-552)

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Experiment No. 1

Aim: To plot poles and zeros locations of a first order and second order transfer functions. Also simulate them to different inputs using Matlab.

Facilities Required to do the Experiment: Matlab/Simulink installed computer system

Theory and Results:

A second order transfer function can be written in Matlab as:

```
num = [4 4];

den = [1 2 5];

sys = tf(num, den);
```

Result:

Transfer function:

```
  4 s + 4

-------------

s^2 + 2 s + 5
```

OR

```
sys = tf([4 4],[1 2 5]);
```

Result:

Transfer function:

```
  4 s + 4

-------------

s^2 + 2 s + 5
```

OR

```
s=tf('s');
sys= (4*s + 4)/(s^2 + 2*s + 5);
```

Result:

Transfer function:

```
  4 s + 4
-------------
s^2 + 2 s + 5
```

Poles and zeros can be obtained and plotted as:

```
pole(sys);
zero(sys);

ans =
  -1.0000 + 2.0000i
  -1.0000 - 2.0000i
ans =
    -1
```

OR

```
[p,z]=pzmap(sys);

p =
  -1.0000 + 2.0000i
  -1.0000 - 2.0000i
z =
    -1
pzmap(sys); %Plot pole zero map in s plane
```

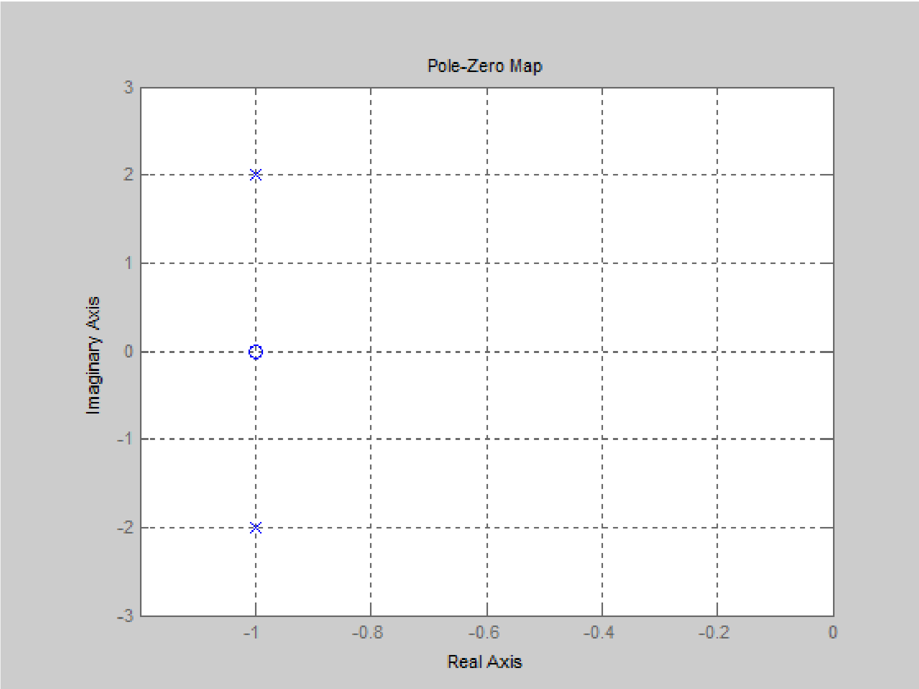


Fig. 1 Pole-zero plot.

Impulse Response is found out as:

```
impulse(sys); %Plot impulse response of the system
```

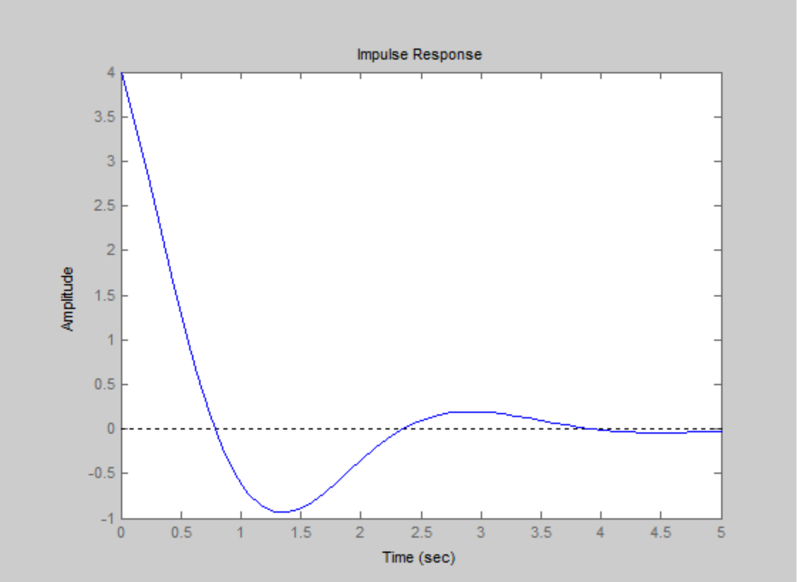


Fig. 2 Impulse response of 2nd order system.

The same response is obtained using Simulink diagram shown in Fig. 2.

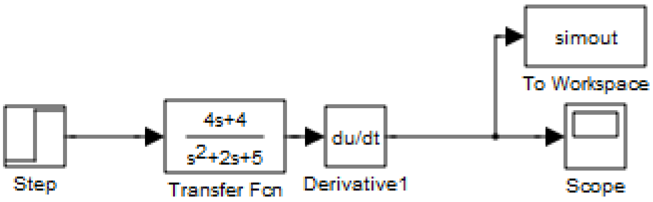


Fig. 3 Simulink diagram for impulse response of 2nd order system.

Step Response is found out as:

step(sys); %Plot step response of the system

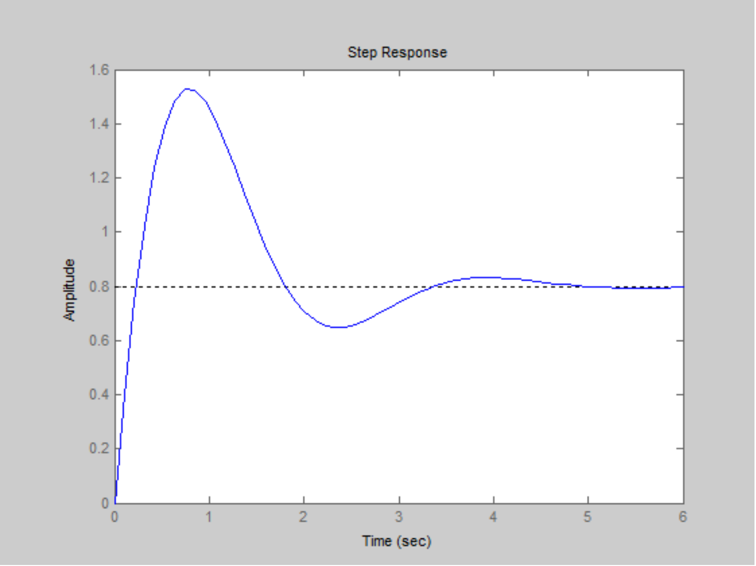


Fig. 4 Step response of 2nd order system.

The same response is obtained using Simulink diagram shown in Fig. 4.

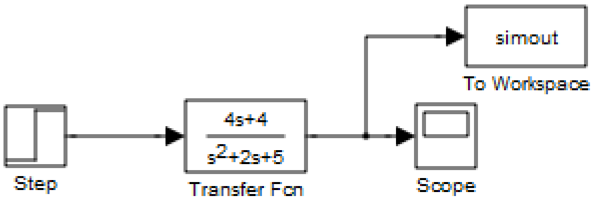


Fig. 5 Simulink diagram for step response of 2nd order system.

Ramp Response is found out as:

step(sys/s); %Plot ramp response of the system

OR

```
t=0:500:1500
alpha=1
ramp=alpha*t        % Your input signal
[y,t]=lsim(sys,ramp,t)
plot(t,y)
```

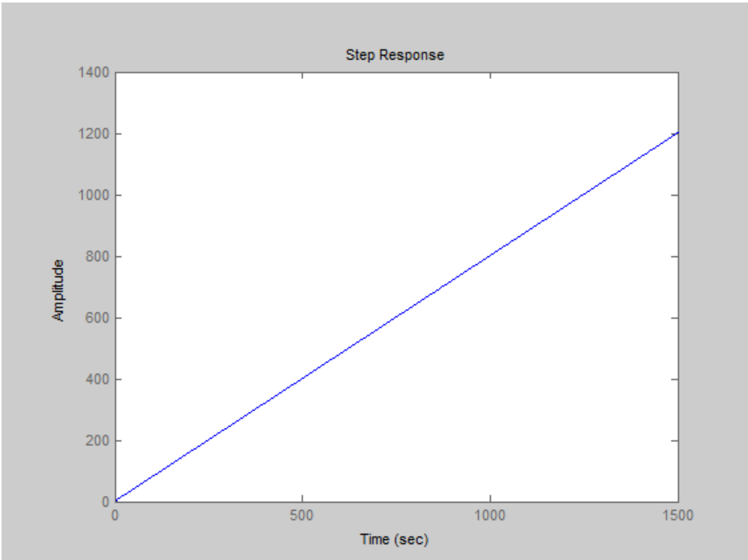


Fig. 6 Ramp response of 2nd order system.

The same response is obtained using Simulink diagram shown in Fig. 6.

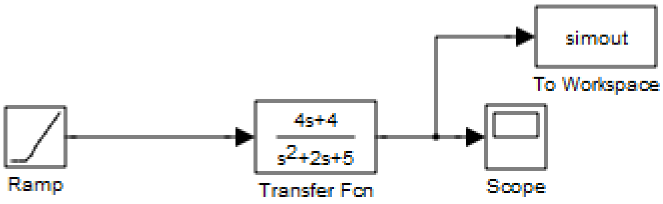


Fig. 7 Simulink diagram for ramp response of 2nd order system.

Repeat with 1st order system.

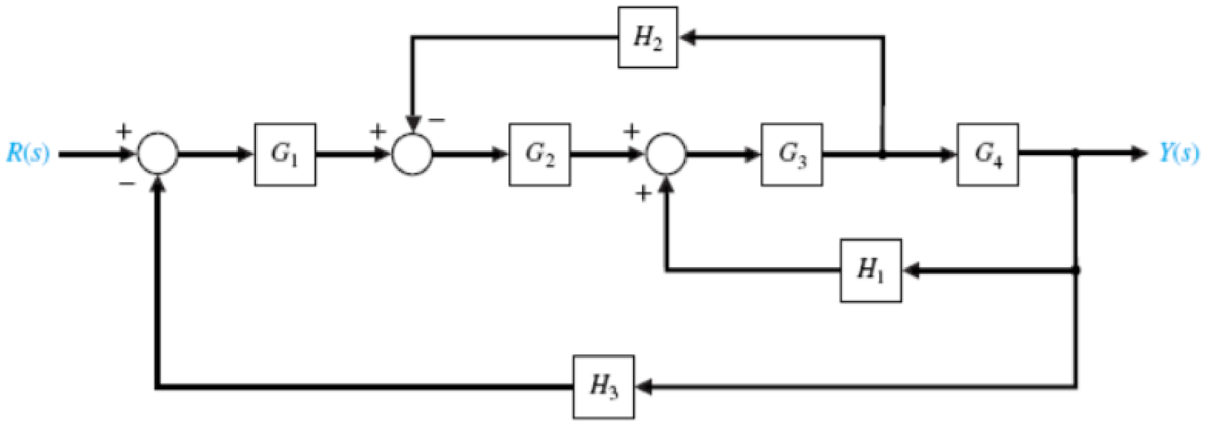
Result: Transfer can be represented using different methods in Matlab. Poles and zeros first order and second order transfer functions are plotted and simulated using impulse, step and ramp inputs in Matlab and Simulink.

Experiment No. 2

Aim: To find the closed loop transfer function of multi-loop feedback block diagram via block diagram reduction method using Matlab.

Facilities Required to do the Experiment: Matlab installed computer system

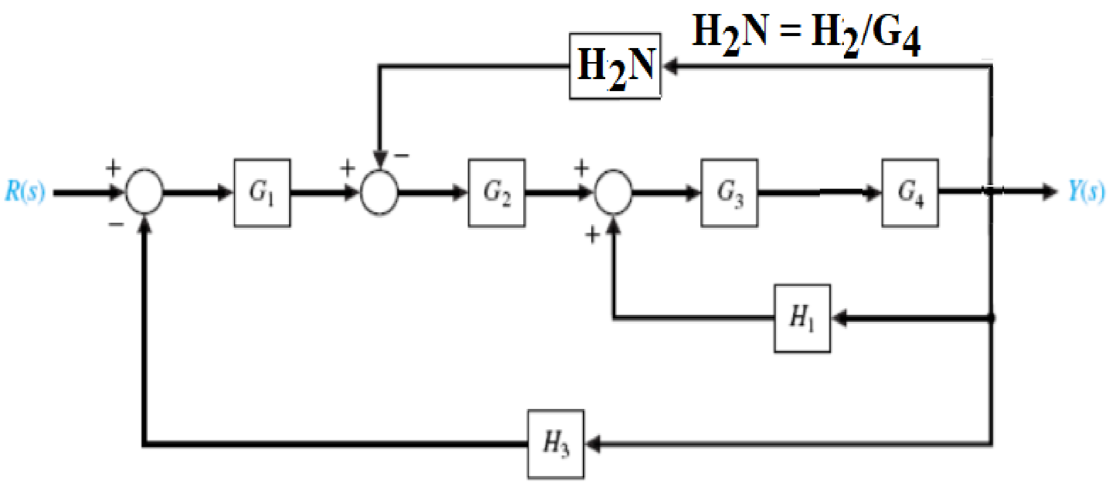
Method: The considered block diagram is given as:



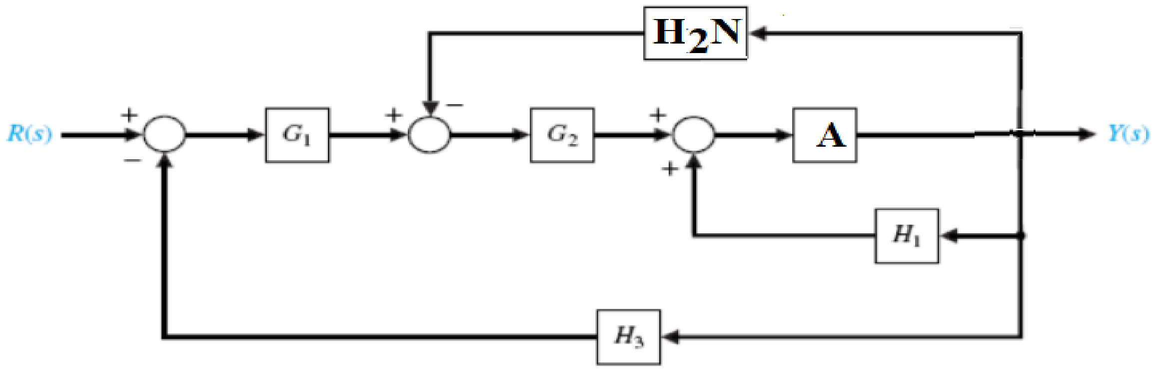
$$G_1=\frac{1}{s+10} \qquad G_2=\frac{1}{s+1} \qquad G_3=\frac{s^2+1}{s^2+4s+4} \qquad G_4=\frac{s+1}{s+6}$$

$$H_1=\frac{s+1}{s+2} \qquad H_2=2 \qquad H_3=1$$

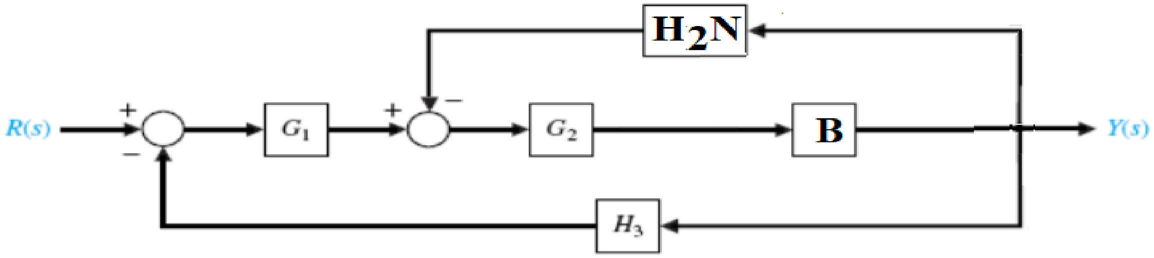
Step-1



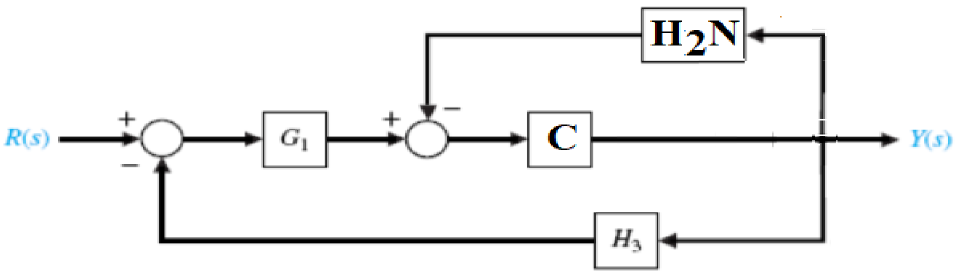
Step-2



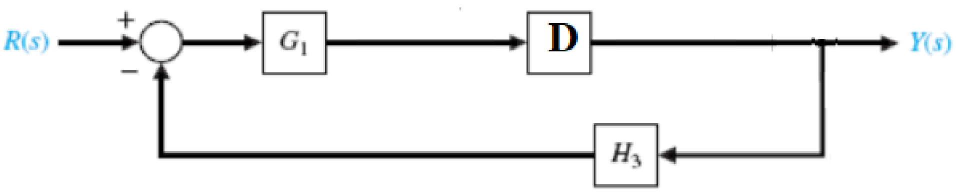
Step-3



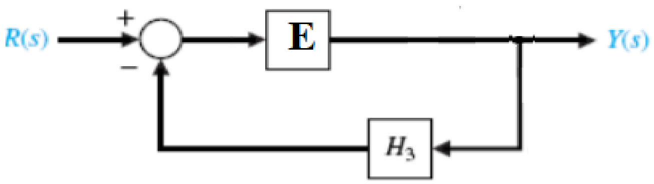
Step-4



Step-5



Step-6



Step-7

Matlab solution:

```
G1 = tf(1,[1 10]);
G2 = tf(1,[1 1]);
G3 = tf([1 0 1],[1 4 4]);
G4 = tf([1 1],[1 6]);
H1 = tf([1 1],[1 2]);
H2 = 2;
H3 = 1;
H2N = H2/G4;
A=series(G3,G4);
B=feedback(A,H1,+1);
C=series(G2,B);
D=feedback(C,H2N,-1);
E=series(G1,D);
F=feedback(E,H3,-1)
```

```
Transfer function:
          s^5 + 4 s^4 + 6 s^3 + 6 s^2 + 5 s + 2
-------------------------------------------------------------
12 s^6 + 205 s^5 + 1066 s^4 + 2517 s^3 + 3128 s^2 + 2196 s + 712
```

Repeat the process for some other block diagram.

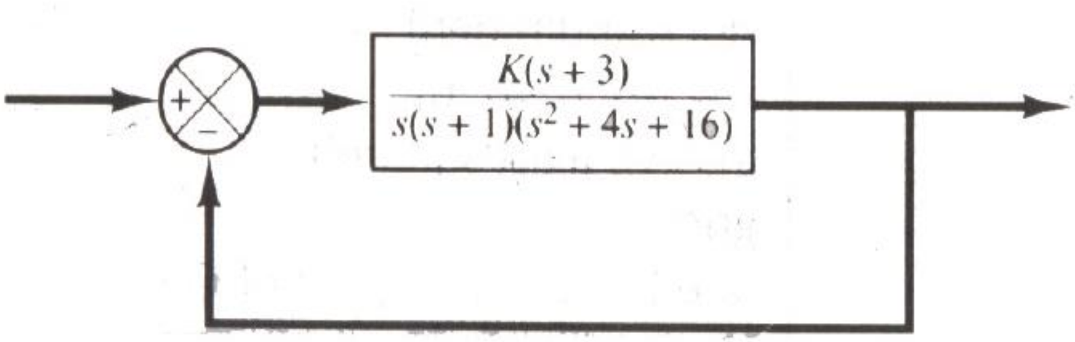
Result: The overall transfer function of a complex block diagram can be obtained using series, parallel, and feedback Matlab commands.

Experiment No. 3

Aim: To plot Root Locus and identify stability of a system using Matlab.

Facilities required to do the Experiment: Matlab installed computer system.

Method: Consider the system shown in figure.



Open loop transfer function of the system:

$$G(s)H(s) = \frac{K(s+3)}{s(s+1)(s^2+4s+16)}$$

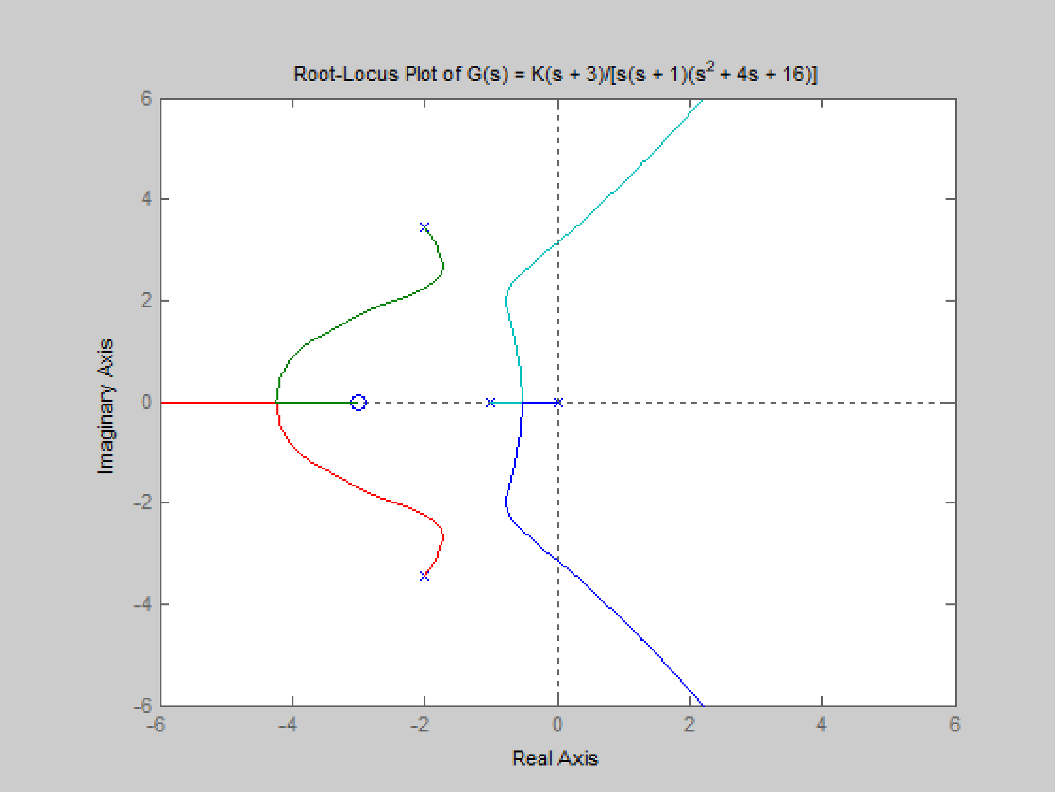
Open loop zeros = –3 (Z = 1)

Open loop poles = 0, –1, –2 ± 3.4641i (P = 4)

No of asymptotes or root loci = P – Z = 3

Matlab solution:

```
num = [1 3];
den = [1 5 20 16 0];
rlocus (num, den);
title ('Root-Locus Plot of G(s) = K(s + 3)/[s(s + 1)(s^2 + 4s + 16)]');
R = roots(den)
R =
        0
  -2.0000 + 3.4641i
  -2.0000 - 3.4641i
  -1.0000
```



Note: Also find root locus of the above system manually using various steps and compare the Matlab and manual responses.

Result: The root locus of the given unity feedback closed system is obtained mathematically and also using Matlab. Both Matlab and manually obtained responses are observed same.

Experiment No. 4

Aim: To plot Nyquist plot and identify stability of a system using Matlab.

Facilities required to do the Experiment: Matlab installed computer system

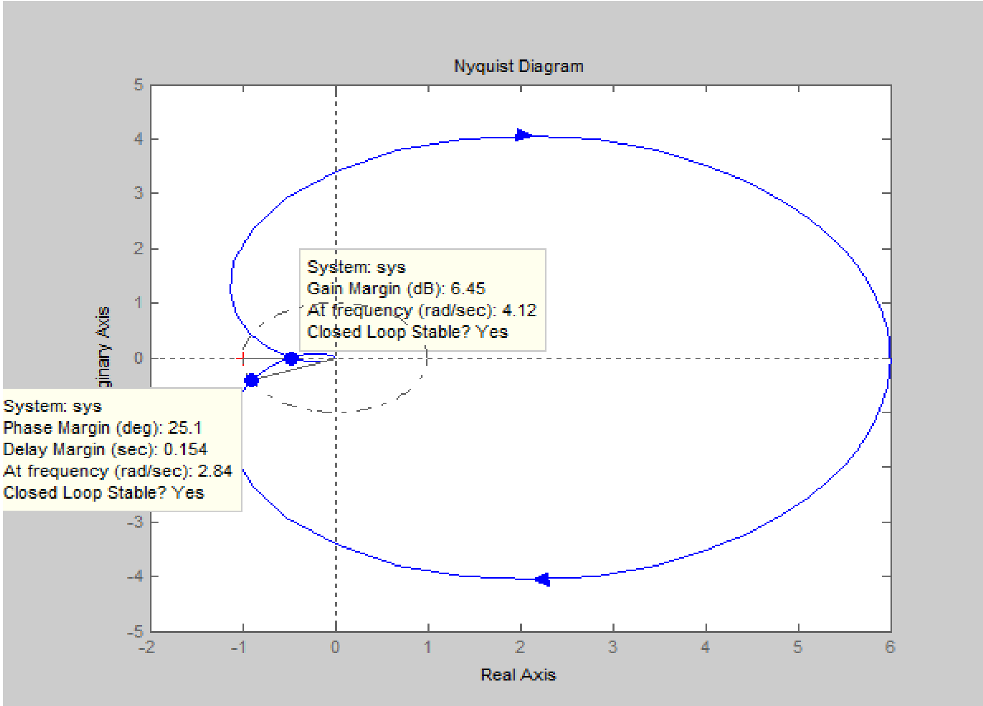
Method: Consider the Open loop transfer function of the system:

$$G(s) = \frac{60}{(s+1)(s+2)(s+5)}$$

Matlab solution:

```
num = 60;

den = conv([1 1],conv([1 2],[1 5]));

sys=tf(num,den);

nyquist(sys)

[GM, PM, wpc, wgc] = margin(sys);

GMdB=20*log10(GM);

GMdB, PM, wpc, wgc]
```

```
ans =
   6.4523   25.0512    4.1248    2.8361
```



From given OL transfer function:
P = 0, OL poles in RH of s-plane
From the Nyquist plot:

N = 0, clockwise encirclement of –1+jo point

N = Z–P,

Hence, Z = 0

Roots of the characteristic equation [D(s) = 1+G(s)H(s) = 0] in RH of s-plane are equal to zero. Which is the mandatory condition of stability of closed loop system.

Hence, System is stable.

Note: Also draw Nyquist plot of the above system manually and compare the Matlab and manual responses.

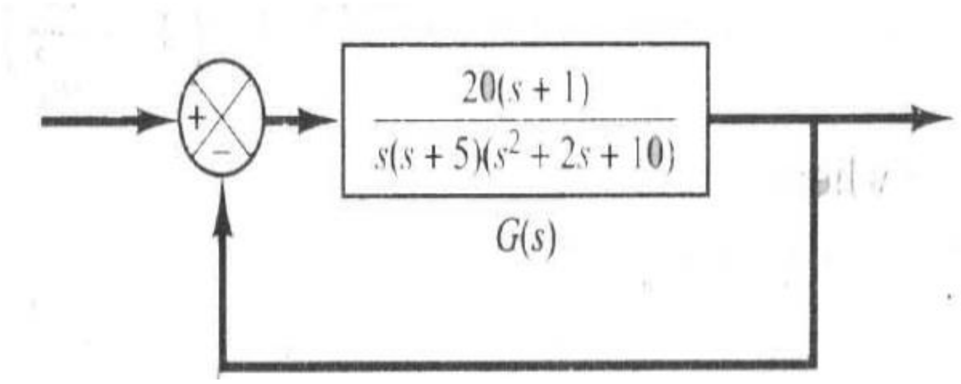
Result: The Nyquist plot of the given unity feedback closed system is obtained mathematically and also using Matlab. Both Matlab and manually obtained diagrams are observed same. Both GM (in dB) and PM are positive, so the system is stable. Additionally, for a stable system, condition of $\omega_{pc} > \omega_{gc}$ also satisfied.

Experiment No. 5

Aim: To plot Bode plot and identify stability of a system using Matlab.

Facilities required to do the Experiment: Matlab installed computer system

Method: Consider the system shown in figure.



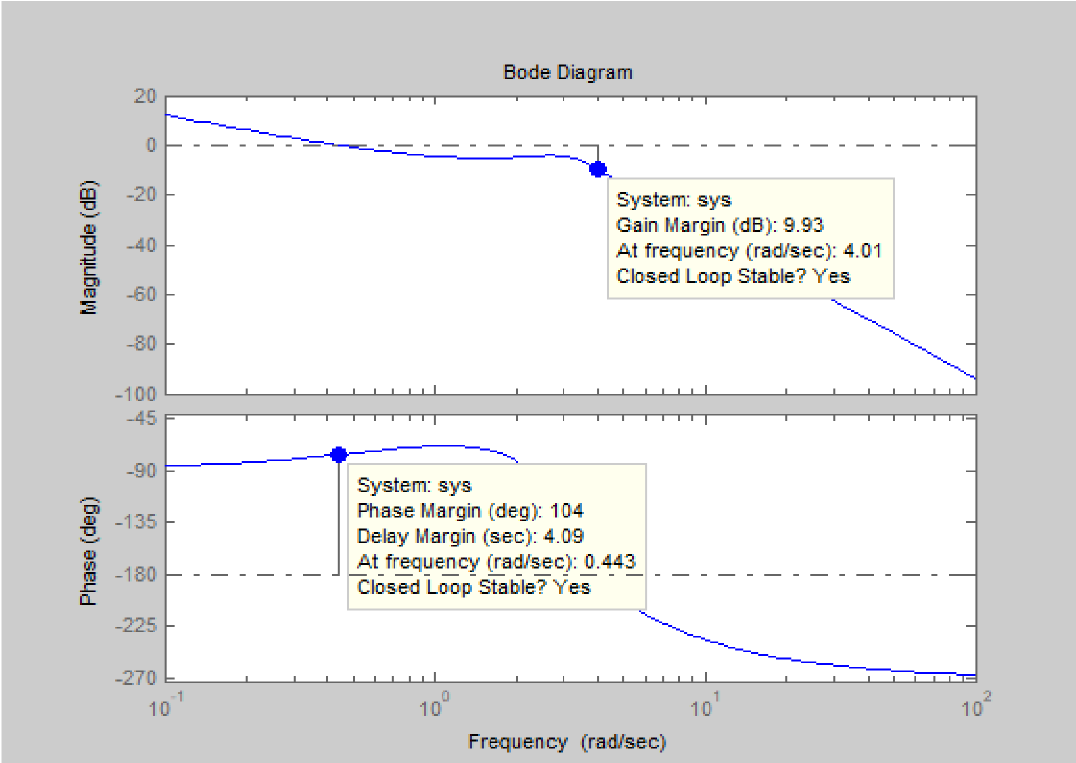
Open loop transfer function of the system:

$$G(s) = \frac{20(s+1)}{s(s+5)(s^2+2s+10)}$$

$$= \frac{20s+20}{(s^2+5s)(s^2+2s+10)}$$

Matlab solution:

```
num = [20 20];
den = conv([1 5 0],[1 2 10]);
sys=tf(num,den);
w=logspace(-1,2,100);
bode(sys,w)
[GM, PM, wpc, wgc] = margin(sys);
GMdB=20*log10(GM);
[GMdB, PM, wpc, wgc]
ans =

    9.9301  103.6573    4.0132    0.4426
```



Note: Also draw bode diagram of the above system manually using log graph paper and compare the Matlab and manual responses.

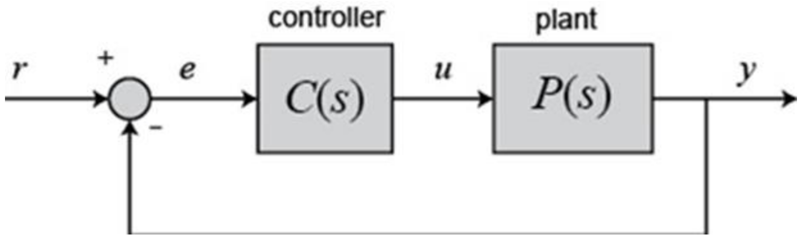
Result: The bode diagram of the given unity feedback closed system is obtained mathematically and also using Matlab. Both Matlab and manually obtained diagrams are observed same. Both GM (in Db) and PM are positive, so the system is stable. Additionally, for a stable system, condition of $\omega_{pc} > \omega_{gc}$ also satisfied.

Experiment No. 6

Aim: To design proportional-integral-derivative (PID) Controller using Matlab.

Key MATLAB commands: tf, step, pid, feedback

Theory and Results: Consider the following unity feedback system:



The transfer function of a PID controller is found as:

$$K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s}$$

K_p = Proportional gain,

K_i = Integral gain,

K_d = Derivative gain

We can define a PID controller in MATLAB using the transfer function directly, for example:

```
Kp = 1;
Ki = 1;
Kd = 1;
s = tf('s');

C = Kp + Ki/s + Kd*s

s^2 + s + 1
--------------
        s
```

Alternatively, we may use Matlab's PID controller command.

```
C =
                  1
Kp + Ki * --- + Kd * s
                  s
with Kp = 1, Ki = 1, Kd = 1
```

The control signal (u) to the plant is equal to the proportional gain (Kp) times the magnitude ofthe error plus the integral gain (Ki) times the integral of the error plus the derivative gain (Kd) times the derivative of the error.
This control signal (u) is sent to the plant, and the new output (y) is obtained. The new output (y)is then fed back and compared to the reference to find the new error signal (e). The controller takes this new error signal and produces new control signal (u).

The Characteristics of P, I, and D Controllers

A proportional controller (Kp) will have the effect of reducing the rise time and will reduce butnever eliminate the **steady-state error**. An integral control (Ki) will have the effect of eliminating the steady-state error for a constant or step input, but it may make the transient response slower. A derivative control (Kd) will have the effect of increasing the stability of thesystem, reducing the overshoot, and improving the transient response.
The effects of each of controller parameters, Kp, Ki and Kd on a closed loop system are summarized in the table below:

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
K_p	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small Change	Decrease	Decrease	No Change

Note that these correlations may not be exactly accurate, because Kp, Ki, and Kd are dependent on each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for Kp, Ki, and Kd.

Example Problem

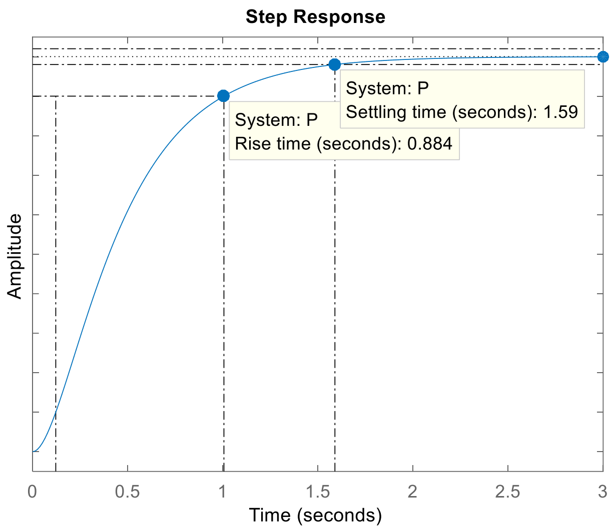
$$\frac{X(s)}{F(s)} = \frac{1}{s^2 + 10s + 20}$$

The goal of this problem is to show you how each of Kp, Ki, and Kd contributes to obtain, Fast rise time, Minimum overshoot and No steady-state error.

Open-Loop Step Response

Let’s first view the open-loop step response. Create a new m-file and run the following code:

```
s = tf('s');
P = 1/(s^2 + 10*s + 20);
step(P)
```



The DC gain of the plant transfer function is 1/20, so 0.05 is the final value of the output to aunit step input. This corresponds to the steady-state error of 0.95 (1-0.05), quite large indeed. Furthermore, the rise time is about one second, and the settling time is about 1.5 seconds.

Let's design a controller that will reduce the rise time, reduce the settling time, and eliminate the steady-state error.

Proportional Control

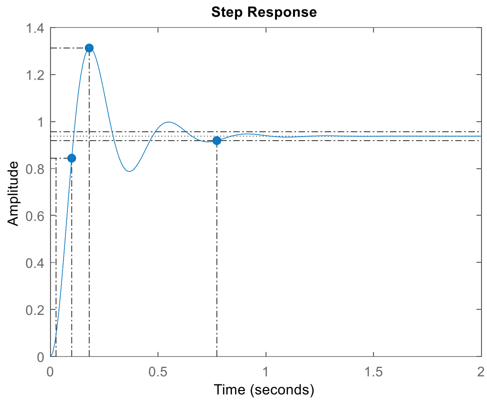
From the table shown above, we see that the proportional controller (Kp) reduces the rise time, increases the overshoot, and reduces the steady-state error.

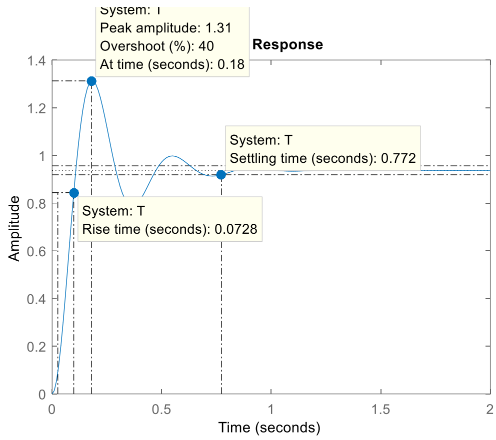
The closed-loop transfer function of the above system with a proportional controller is:

$$\frac{X(s)}{F(s)} = \frac{K_p}{s^2 + 10s + (20 + K_p)}$$

Let the proportional gain (Kp) equal 300 and change the m-file to the following:

```
s = tf('s');
P = 1/(s^2 + 10*s + 20);
Kp = 300;
Ki = 0;
Kd = 0;
C = pid(Kp,Ki,Kd);
T = feedback(C*P,1);
t = 0:0.01:2;
step(T,t);
```





The above plot shows that the proportional controller reduced both the rise time and the steady-state error, increased the overshoot, and decreased the settling time by small amount

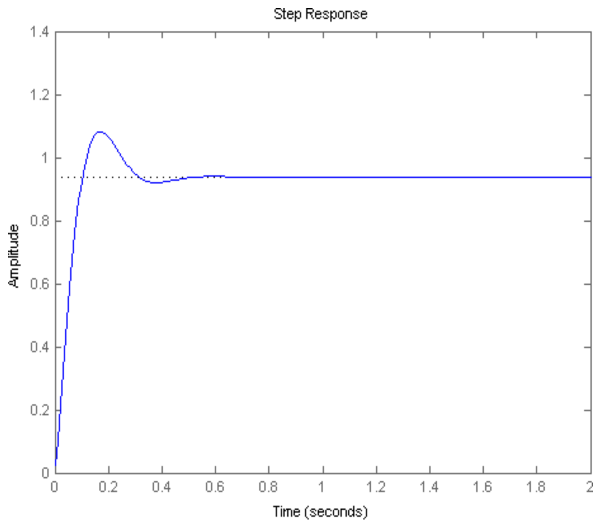
Proportional-Derivative Control

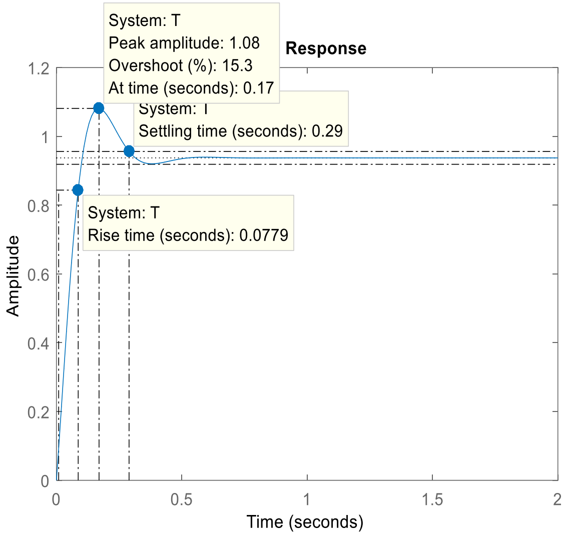
Now, let's take a look at a PD control. From the table shown above, we see that the derivativecontroller (Kd) reduces both the overshoot and the settling time. The closed-loop transfer function of the given system with a PD controller is:

$$\frac{X(s)}{F(s)} = \frac{K_d s + K_p}{s^2 + (10 + K_d)s + (20 + K_p)}$$

Let Kp equal 300 as before and let Kd equal 10. Enter the following commands into an m-file andrun it in the MATLAB command window.

```
s = tf('s');

P = 1/(s^2 + 10*s + 20);

Kp = 300;
Ki = 0;
Kd = 10;
C = pid(Kp,Ki,Kd);
T = feedback(C*P,1);
t = 0:0.01:2;
step(T,t)
```





This plot shows that the derivative controller reduced both the overshoot and the settling time,and had a small effect on the rise time and the steady-state error.

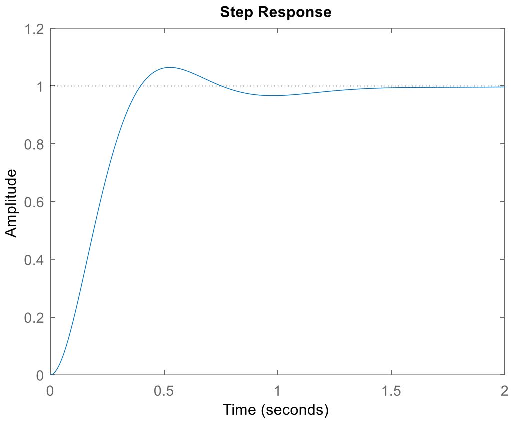
Proportional-Integral Control

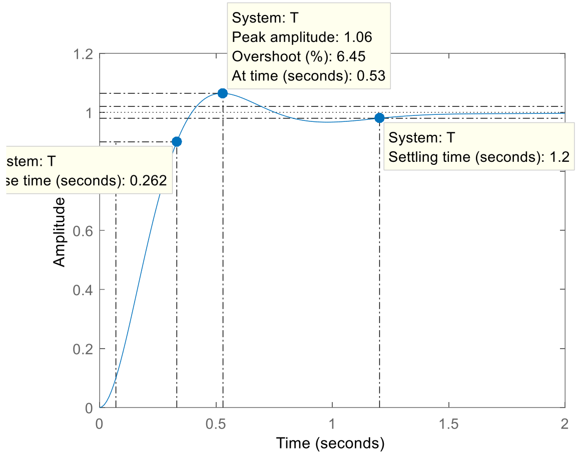
Before going into a PID control, let's take a look at a PI control. From the table, we see that an integral controller (Ki) decreases the rise time, increases both the overshoot and the settling time, and eliminates the steady-state error. For the given system, the closed-loop transfer function witha PI control is:

$$\frac{X(s)}{F(s)} = \frac{K_p s + K_i}{s^3 + 10s^2 + (20 + K_p)s + K_i}$$

Let's reduce the Kp to 50, and let Ki equal 100. Create a new m-file and enter the following commands:

```
s = tf('s');

P = 1/(s^2 + 10*s + 20);
Kp = 50;

Ki = 100;

Kd = 0;

C = pid(Kp,Ki,Kd);

T = feedback(C*P,1);

t = 0:0.01:2;

step(T,t)
```





With PI, the steady state error is observed zero.

Proportional-Integral-Derivative Control:

$$\frac{X(s)}{F(s)} = \frac{K_d s^2 + K_p s + K_i}{s^3 + (10 + K_d)s^2 + (20 + K_p)s + K_i}$$

s = tf('s');

P = 1/(s^2 + 10*s + 20);

Kp = 50;

Ki = 100;

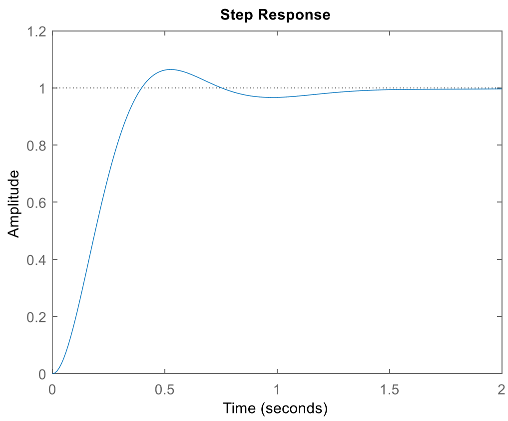
Kd = 2;

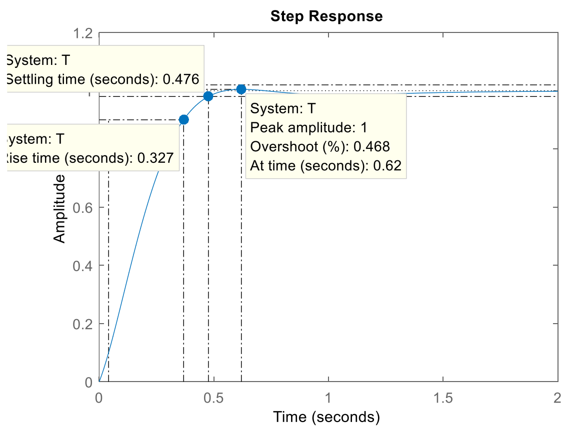
C = pid(Kp,Ki,Kd);

T = feedback(C*P,1);

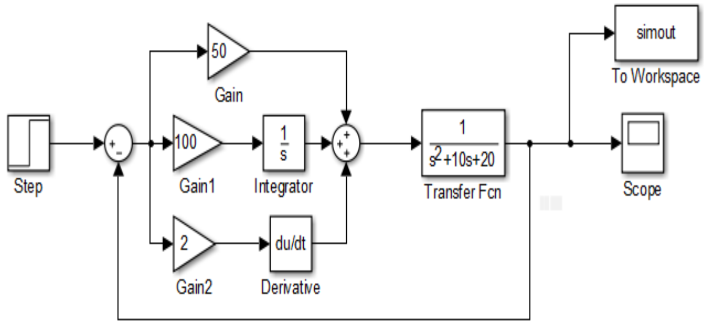
t = 0:0.01:2;

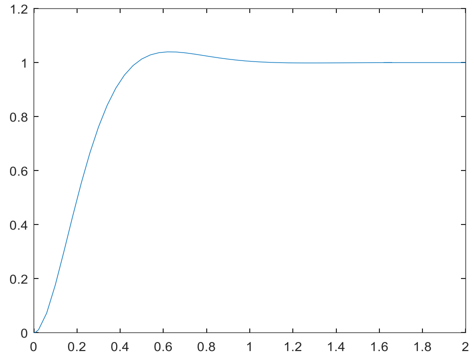
step(T,t)





With PID, the steady state error is observed zero. The settling time and Peak Overshoot reduced compared to PI. However, rise time increased.





Conclusion:

P controller will always show steady state error. Steady state error is zero with I, PI or PID controller. Better responses are obtained with PID controller. Responses of Matlab and Simulink are same for same PID controller. It is advised to use some optimization technique to decide the gains of P, PI or PID controllers.

Experiment No. 7

Aim: To study DC potentiometer as error detector.

Facilities required to do the Experiment: Experimental kit, wire and electric supply. system

Theory:

All feedback control systems operate from the error signal which is generated by a comparison of the reference and the output. Error detectors perform the crucial task of comparing the reference and output signals. In a purely electrical system where the reference and output are voltages, the error detector is a simple comparator. In some other systems with non-electrical outputs, the output signal is converted into electrical form through a measurement or transducer block, and then error detection is performed on the electrical signals. A position control system, with both input and output variables as mechanical positions (linear or angular), may however consist of two potentiometers – reference and output, which function as an error detector. The Potentiometer Error Detector consists of two identical potentiometers electrically connected in parallel and supplied by a voltage source as shown in figure 1a.

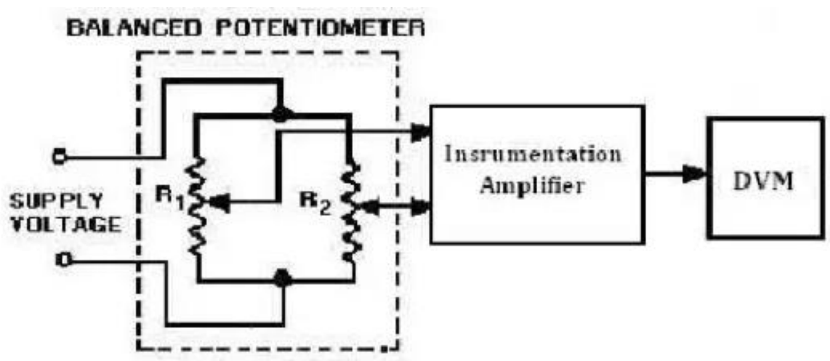


Fig.1a Basic Circuit Diagram

The symbolic circuit representation of a potentiometer error detector is shown in figure 1b below.

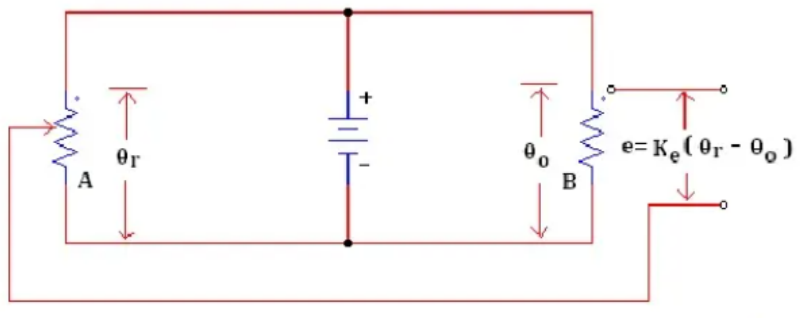


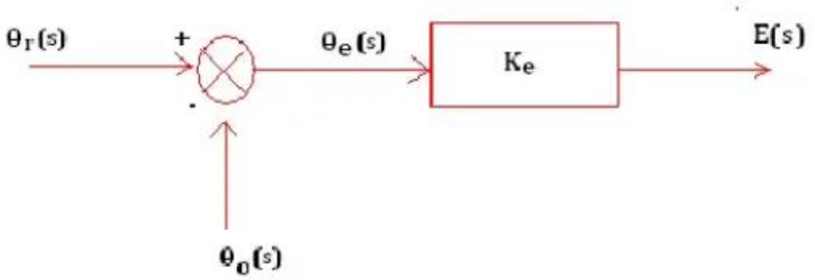
Fig.1b Circuit Diagram of Potentiometer Error Detector

The input shaft is coupled to the potentiometer marked A, and is held fixed at the desired angular position say θ_r while the output shaft is coupled to the potentiometer marked B and the position is indicated as θ_0. The potential difference between the variable points of potentiometers A and B is proportional to the angular difference ($\theta_r - \theta_0$). Therefore, the error is given by,

$e \propto \theta_r - \theta_0$ or $e = K_e (\theta_r - \theta_0)$

$E(s) = K_e (\theta_r(s) - \theta_0(s))$ or $E(s) = K_e \theta_e(s)$

Where K_e is gain of error detector.

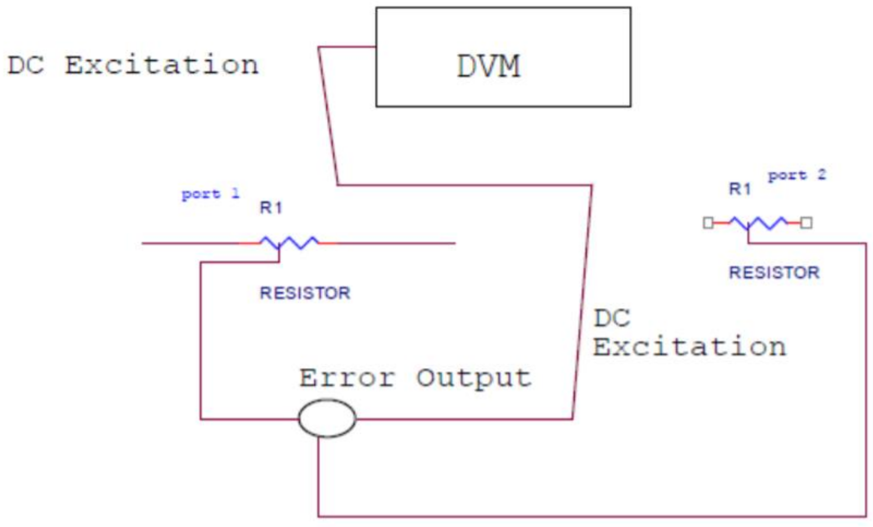


Block Diagram of Potentiometer error detector

Transfer function is

$$\frac{E(s)}{\theta_e(s)} = K_e$$

Circuit diagram:

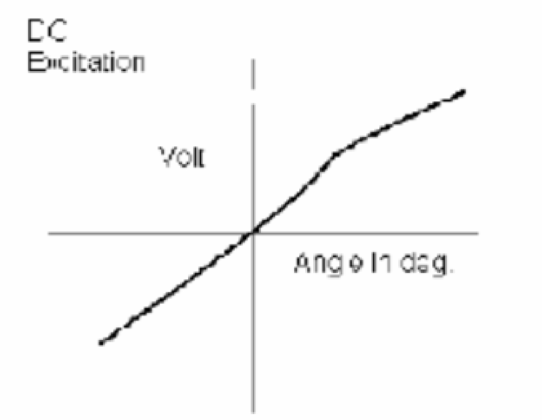


Procedure:

1. Connect the power and select the excitation switch to DC. Keep port-2 to centre = 180^0.
2. Connect DVM to error output.
3. Turn port-1 from 0^0 to 360^0 in steps of 30^0.
4. Note displacement $\theta_e = \theta_2 - \theta_1$ and output error voltage V_e.
5. Plot graph between θ_e and V_e.

Observation Table:

S.No.	Port-1 position θ_1	$\theta_e = \theta_2 - \theta_1$ or $\theta_e = 180^0 - \theta_1$	V_e
1	0^0	180^0	
2	30^0	150^0	
3	60^0	120^0	
4	90^0	90^0	
5	120^0	60^0	
6	150^0	30^0	
7	180^0	0^0	
8	210^0	-30^0	
9	240^0	-60^0	
10	270^0	-90^0	
11	300^0	-120^0	
12	330^0	-150^0	
13	360^0	-180^0	



Result:

The graph is plotted between error displacement angle and output error voltage. The output error voltage increase linearly with positive displacement error angle and decrease with negative displacement error angle. Hence, DC potentiometer can be used as an error detector.

Experiment No. 8

Aim: To study synchro transmitter/receiver.

Introduction:

The synchro transmitter / receiver demonstrator unit is designed to study of remote transmission of position in AC servo mechanisms. These are also called as torque transmitter - receiver. The unit has one pair of transmitter receiver synchro motors, powered by an isolated ac inbuilt supply. Sockets are brought upon the panel to make connections with attenuated compensated output in ratio of 1:10 for waveform observation. The synchro pair is well mounted inside steel cabinate and dials printed in degrees with resolution of 2^0 provided to study phase / displacement errors. The control knobs are factory adjusted for electrical zero and procedure is given in last page if recorrection required due to transportation. Complete unit is 220 V AC main operable.

The Synchros:

In remote control system sometimes it is required to transmit angular position of a shaft following the motion of other shaft located in distance. Electromechanical systems are very useful for the purpose in which shaft angular position is converted into electrical signals, transmitted through cable and received at the monitor end by similar system. The synchro transmitter / receiver is used in feedback system in servo systems for acknowledgment.

Synchros are small motors having structure of wound rotor and wound stator. The windings are mutual coupled in such way that it gives substantially sinusoidal variation as a function of shaft angular position. The synchro transmitter / receiver, rotor has dumb ball shaped magnetic structure having primary winding, which is connected with the reference voltage Vr, through set of slip rings and brushes. The secondary windings are wound in slotted stator and are distributed around its periphery 120^0 apart. In schematics the windings are shown as three phase configuration but only single phase voltage appears across them. The magnitude and polarity of these voltages / phase depends upon the angular position of the rotor.

In Fig. 1, when rotor and winding S2 are in such position that magnetic meridians are in parallel axis, flux developed in S2 is in phase, and out of phase in S1 and S3. The phase angle between S2 and other windings is out of phase. The effect of it that voltage developed in S2/S1, S2/S3 has maximum amplitude while S1/S3 will be minimum. This condition called electrical zero. Let Vs1n, Vs2n and Vs3n represent the voltages induced in stator coils S1, S2 and S3 respectively with respect to neutral than

$$Vs1n = KVr \sin \omega ct \cos (\theta + 240^0) \qquad ..1$$

$$Vs2n = KVr \sin \omega ct \cos (\theta^0) \qquad ..2$$

$$Vs3n = KVr \sin \omega ct \cos (\theta + 120^0) \qquad ..3$$

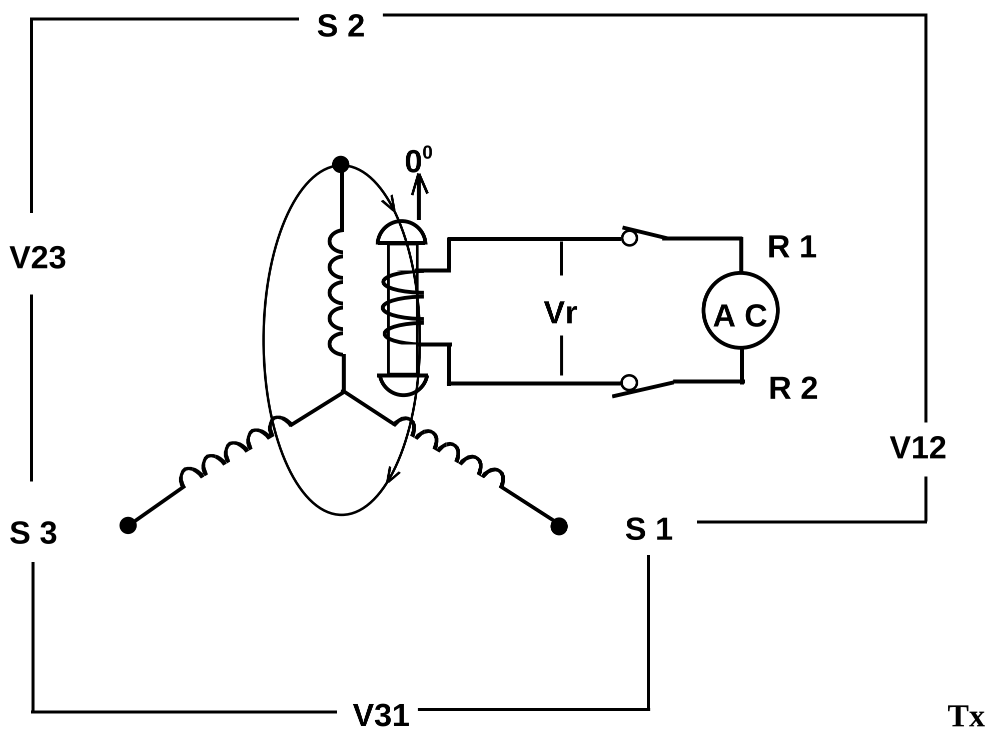


Fig. 1. The angular position and winding operation of synchro. Fig shows in phase of S2 with rotor, in 0^0 and S1, S3 out of phase i.e., 180^0 w.r.t input AC.

The terminal voltages across the stator coils are

$$V23 = \sqrt{3}\, KVr \sin(\theta + 240^0) \sin \omega ct \qquad ..4$$

$$V31 = \sqrt{3}\, KVr \sin(\theta^0 + 0^0) \sin \omega ct \qquad ..5$$

$$V12 = \sqrt{3}\, KVr \sin(\theta + 120^0) \sin \omega ct \qquad ..6$$

Where, Vr sin ωct, is the input reference voltage θ is the respected angle in degree, V31 = Vs3n - Vs1n, V23 = Vs2n - Vs3n and V12 = Vs1n - Vs2n, K is a constant. In Fig. 2a, a transmitting angle is drawn showing different phase angles between different windings in reference of rotor phase and voltage magnitude and its corresponding angle. In Fig. 2b, the computed graph shown.

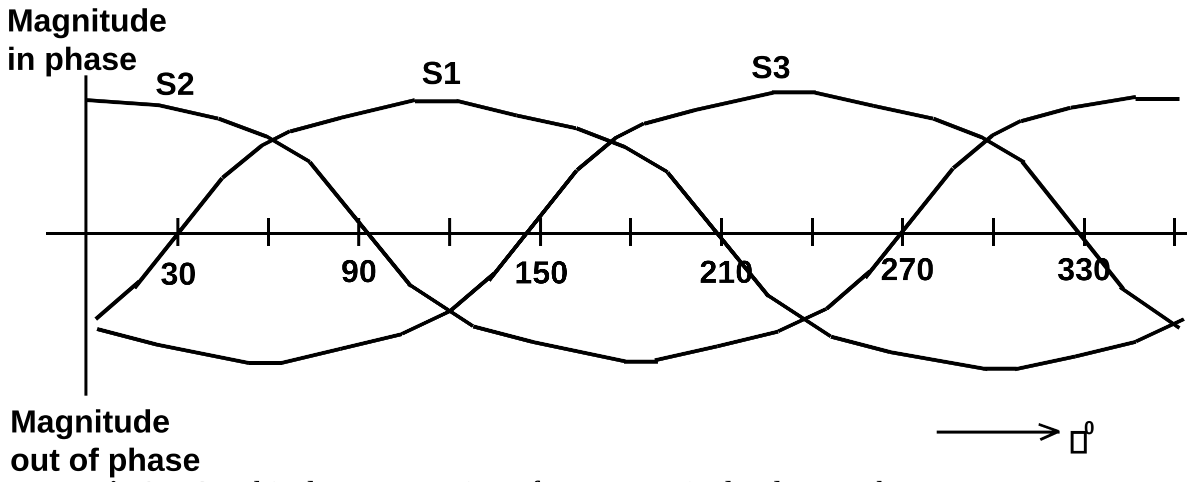


Fig 2a. Graphical representation of stator terminal voltage / phase w.r.t Vr.

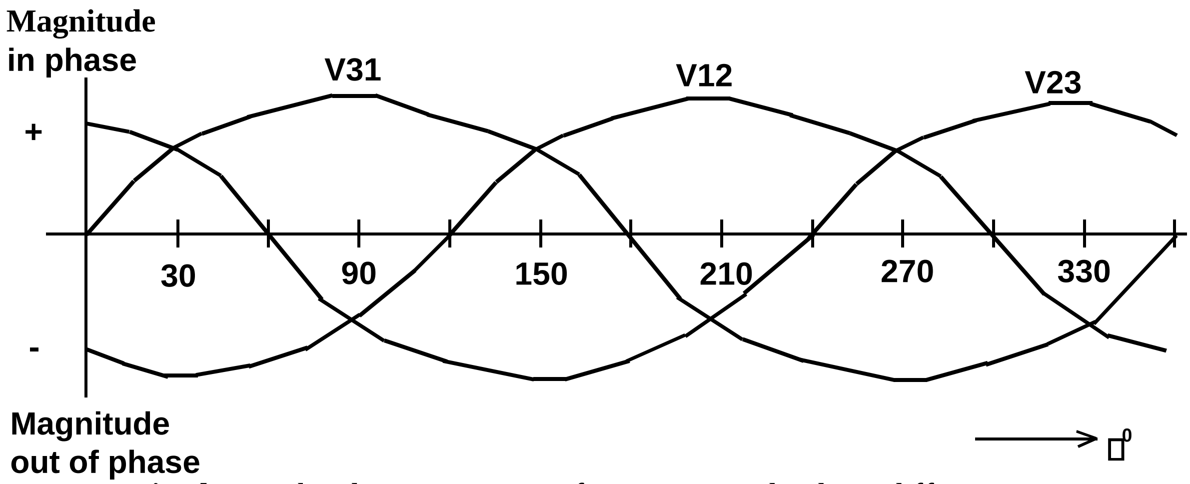


Fig 2b. Graphical representation of stator terminal voltage difference.

The transmitter / receiver system:

In Fig 3, connection between transmitter and receiver is shown. The rotor of transmitter is excited with the ac line and similar is feed to the receiver rotor. The stators of both are connected in synchronism, S1 with S1, S2 with S2 and S3 with S3. In this configuration the rotor of receiver follows the position of the transmitter rotor angular position. Neglecting tolerance and losses, if transmitter rotor is moved to 90^0 clockwise, position than receiver rotor also rotate to similar degree with similar direction. It can be understood as, let transmitter may be generator G, and receiver may be motor M. The generated voltages / phase which are related to rotor angular position is coupled electrically with the M in similar phase. It develops proportional torque which forces M rotor to make equilibrium with the generator rotor position. In this condition no current flows in stator windings. When the Tx rotor moved to other position, this voltage distribution is disturbed. The imbalance in voltage develop a torque that tends to move receiver rotor to follow new position such as Tx, the current is nulled again. In this way the Tx - Rx pair serve to transmit the information of angular position of Tx to remotely situated Rx.

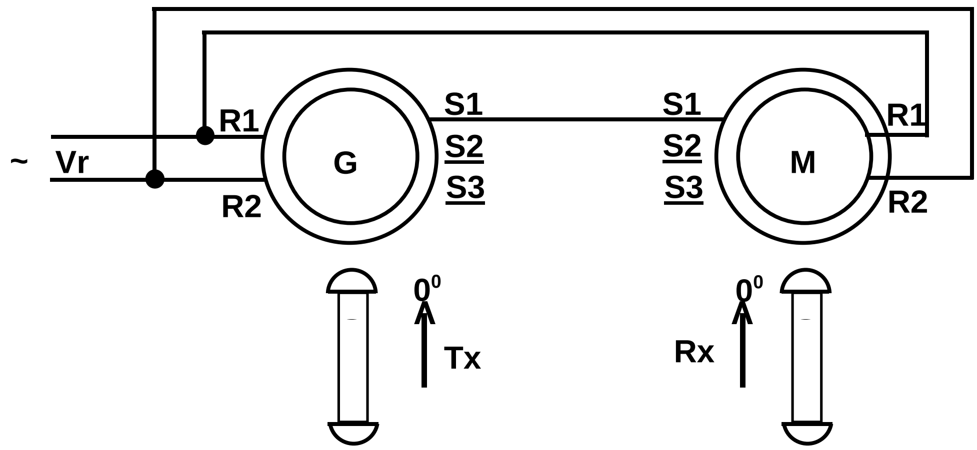


Fig 3. The angular position and connection diagram of synchro. Fig shows both rotors, are in phase^0.

Experiment procedure

Other apparatus required: A dual trace CRO/DSO and multi-meter.

Exp a. To study of synchro transmitter in term of position^0 v/s phase and voltage magnitude with respect to rotor voltage magnitude / phase.

1. Connect the CRO one channel with the provided sockets COM and REF in observation block, as shown in Fig 4. The ground of CRO should be connected with COM. The reference socket as attenuated 1 : 10, voltage of Tx, R2 with respect to R1.

2. Connect CRO other channel, say B channel with outputs of S1, S2 andS3 alternately given in observation block, while kept Tx dial to certain position say 0^0. Note the output in Vpp and its phase angle with respect to REF output waveform. The S1, S2 and S3 sockets are also 1 : 10 attenuated.

3. Measure the voltage difference between stator sockets S1, S2 and S3 directly (meter range 200 VAC) such V12 between S1 and S2, V31 between S3 and S1, V23 between S2 and S3.

3. Rotate Tx dial in 30^0 incremental steps and note voltage magnitude and phase w.r.t. input at REF.

4. Prepare a table as given in reference from observations.

Table 1 For observation on CRO.

Angular position in degree	Magnitude/ phase S1	Magnitude/ phase S2	Magnitude/ phase S3
0	$V/180^0$	$V/0^0$	$V/180^0$
30	0	$V/0^0$	$V/180^0$
60	$V/0^0$	$V/0^0$	$V/180^0$
90	$V/0^0$	0	$V/180^0$
120	$V/0^0$	$V/180^0$	$V/180^0$
150	$V/0^0$	$V/180^0$	0
180	$V/0^0$	$V/180^0$	$V/0^0$
210	0	$V/180^0$	$V/0^0$
240	$V/180^0$	$V/180^0$	$V/0^0$
270	$V/180^0$	0	$V/0^0$
300	$V/180^0$	$V/0^0$	$V/0^0$
330	$V/180^0$	$V/0^0$	0

V reference: .... Vpp

The voltage/ phase is Vpp measured on CRO with respect to input magnitude and polarity. 0^0 means in phase with input.

Table 2 For observation on multi-meter.

Angular position in degree	Magnitude/ phase V12	Magnitude/ phase V31	Magnitude/ phase V23
0	..Vac	..Vac	..Vac
30	...	...	...
60	...	...	...
90	...	...	...
120	...	...	...
150	...	...	...
180	...	...	...
210	...	...	...
240	...	...	...
270	...	...	...
300	...	...	...
330	...	...	...

V reference: .... V (across R1 - R2)

The voltages should be measured on multi-meter (200V AC range) with respect to S1 - S2, S3 - S1 and S2 - S3.

5. From Table 1, plot graphical curves between the voltage / phase of stator terminal (see Fig. 3a).

6. Plot another graphical representation between the voltage difference measured in Table 2, v/s displacement in θ^0. Note the -ve number show the out of phase voltage.

Exp b: To study of remote position indication system using synchro transmitter / receiver.

1. Connect the circuit as shown in Fig. 5. Keep Tx dial at 0^0 position. Watch the Rx dial position. If there is an error than try it to remove gently positioning the Rx dial.
2. Increase the Tx dial position to 30^0 and note the Rx dial position.
3. Proceed with same incremental and note Rx dial position each time. Tabulate the observations. Find out the tracking difference between two. In practice with tolrence of $\pm$1%, the error rate should be within $\pm 3.6^0$.

For correction of dial remove top cover and slightly unscrew the motor holder ring fastened by two screw. Rotate motor to coincide the angle and tight the screws.

Be careful not to touch the connection tags.

Table 3 For observation on Tx – Rx, Tolrence + 3.6^0

Angular position in degree Tx	Angular position in degree Rx	Difference θ^0 Tx - θ^0 Rx
0	..deg	..deg
30	...	...
60	...	...
90	...	...
120	...	...
150	...	...
180	...	...
210	...	...
240	...	...
270	...	...
300	...	...
330	...	...

Synchro Tx - Rx p -11.

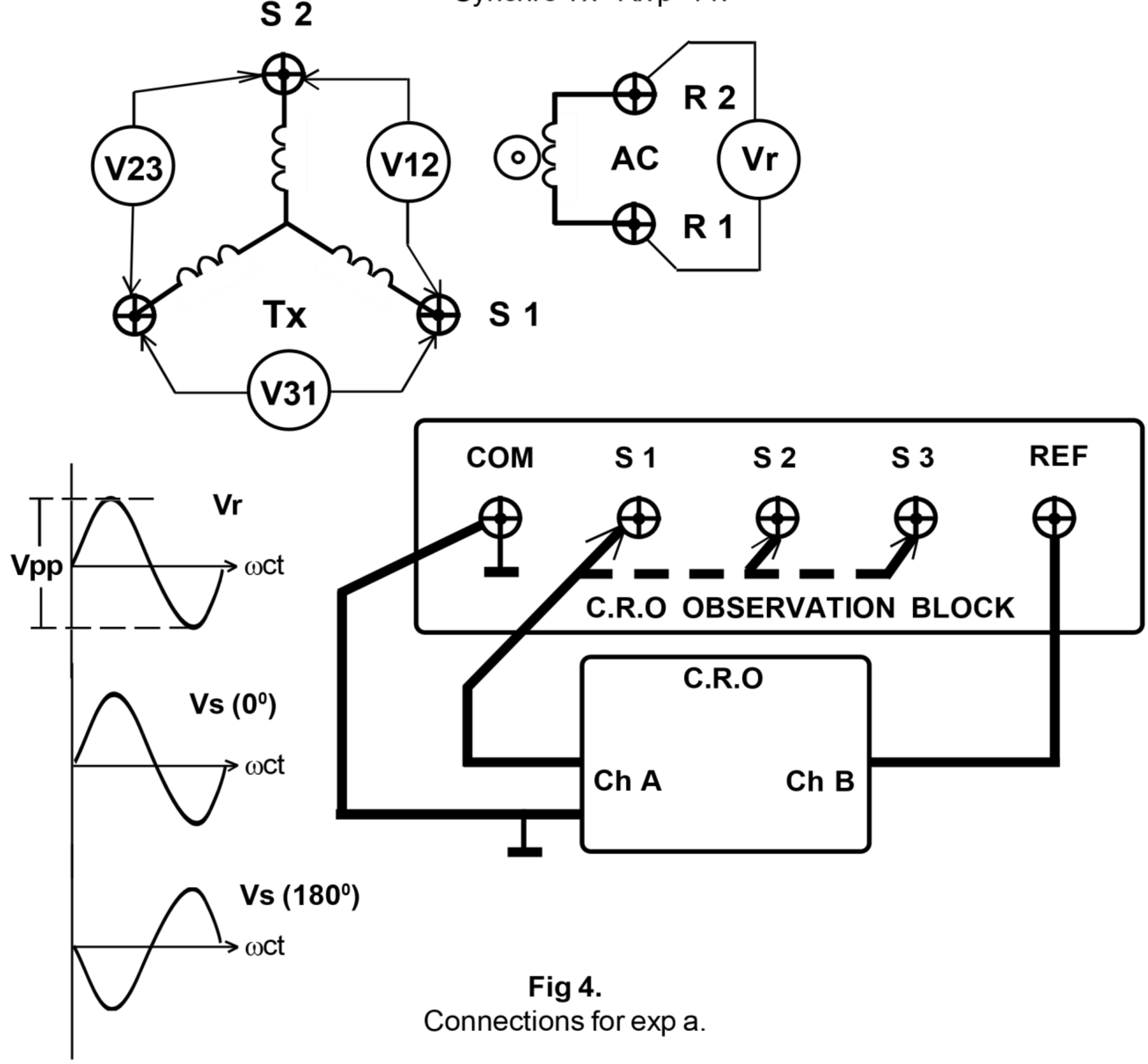
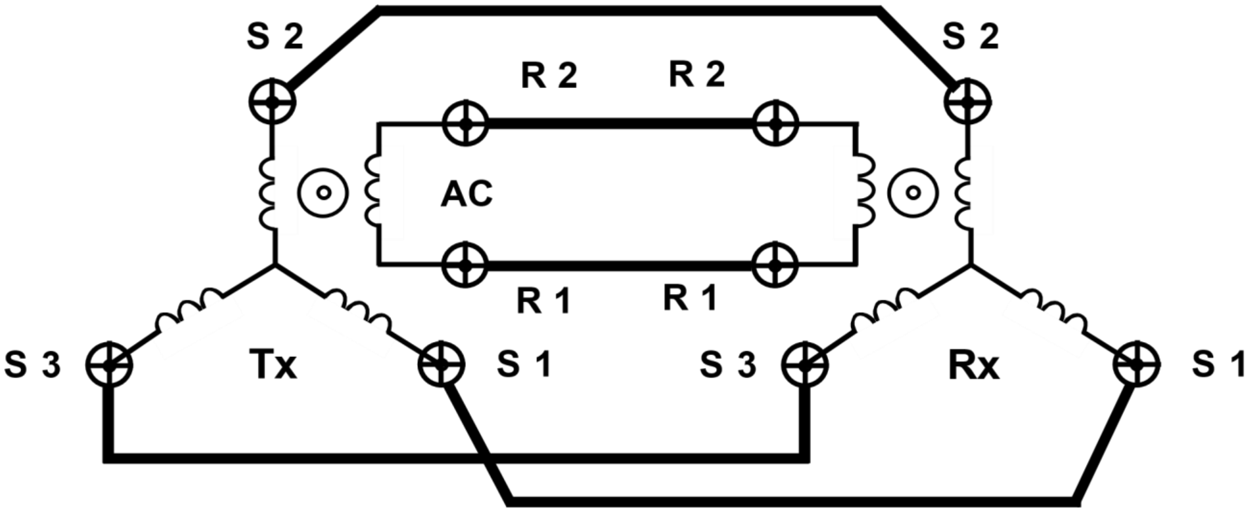


Fig 4.
Connections for exp a.



S 3

Fig 5. Connections for Exp. b.

Experiment No. 9

Aim: To study PID controller.

Introduction:

This set up is designed to study performance of analog PID controller with simulated process. The board has built in signal source, building blocks for simulated process and PID controller with built in regulated dc supply to operate the system.

The PID controller:

The PID controller has three adjustable parameters, as P, I, D, each has 10 turn potentiometers with dial knobs which are subdivided for 0.02 resolution. Three sockets are provided to add or out any of desired control P, I or D. At input of PID controller an adder is provided which sums the reference and feedback signals. The input and output of PID control has no phase shift.

The process or plant:

These are analog simulated systems as basic building blocks.

(a) Time constants, which are two identical units having transfer function of 1 / (1 + 0.01s) app. There is no phase shift between input output.

(b) Integrator, having approximately transfer function of K/s. It has a phase difference of 180^0 between its input output, thus it must be connected with feedback loop via an (inverting) uncommitted amplifier, designated as (AMP) on the board.

(c) Time delay, a pure time delay of about 1.3 msec generated by multiple pole approximation. There is no phase shift between input - output.

(d) The uncommitted amp (AMP): it is an op amp configured as phase inverter, usually recommended for integer out to connect with the feedback loop of PID input, its gain constant is = -1

The input or output to process blocks are indicated by arrows, an incoming arrow for input and outgoing for output.

3. ***The source:*** There are two signal sources,

Square wave which is adjustable in frequency (10 to 40 Hz) and amplitude (0 to 2 Vpp app), and other signal source in shape of triangular wave to sweep cathode ray oscilloscope in x - direction. Both signals are synchronized but un-calibrated for frequency and amplitude.

The ground sockets, two in Nos. are common to all points.

The controller:

The PID controller provided in the board have three separate control knobs for each parameter, P for proportional gain, I for integral gain and D for derivative gain. The three controls are continuously variable 10 turn potentiometers, with knobs, which are divided in 10 x 50 parts. In other words, the one turn is divided in 10 parts from 0 to --> 9.99(0) by dial scale and such 10 parts divided in further 5 divisions thus gives a resolution of 1/ 50 = 0.02(least count). A revolution of knob is designated to 1 count in minor scale corresponding to movement of 0.1. E.G. if full scale value of a parameter is 20 (in case of Kp), then revolution of knob from 0 to 1, in minor scale, corresponding to 0.01 x 20 = 0.2, or simply if the knob revolute to one full turn than the gain will be 0.1 x 20 = 2. In similar manner the derivative (D) control is also divided in same parts. The integral control is similar divided in same parts. Three sockets are provided for signal outputs designated as PID.

PID controller structure:

The familiar equation for a PID controller is,

$$m(t) = K_p\, e(t) + K_i/s\ \ e(t) + K_d\, de(t)/dt$$

In Laplace domain the above equation is written as,

$$m(s) = K_p\, E(s) + K_i/s\, E(s) + sK_d\, E(s)$$

Which is represented as in Fig. 2.

The transfer function of the PID controller can be written as,

(G) PID = m(s)/E(s) = $[Kds^2 + Kps + Ki]/s$

Exp. a. *To observe Open loop performance of building blocks:*

a1. The process blocks: Feed square wave 1 Vpp 20 Hz signal to the input of time constant block. Connect dual trace CRO as shown in Fig. 3. Find out the time constant from the appearing wave shape.

a2. Feed similar signal to the input of integrator input and measure output signal. The integrating capacitor charges on a constant rate of 0.5 / R, hence the triangular wave output is, $Vpp = 0.5/R\ (\tau/2C) = \tau/4(1/RC) = Ki$.

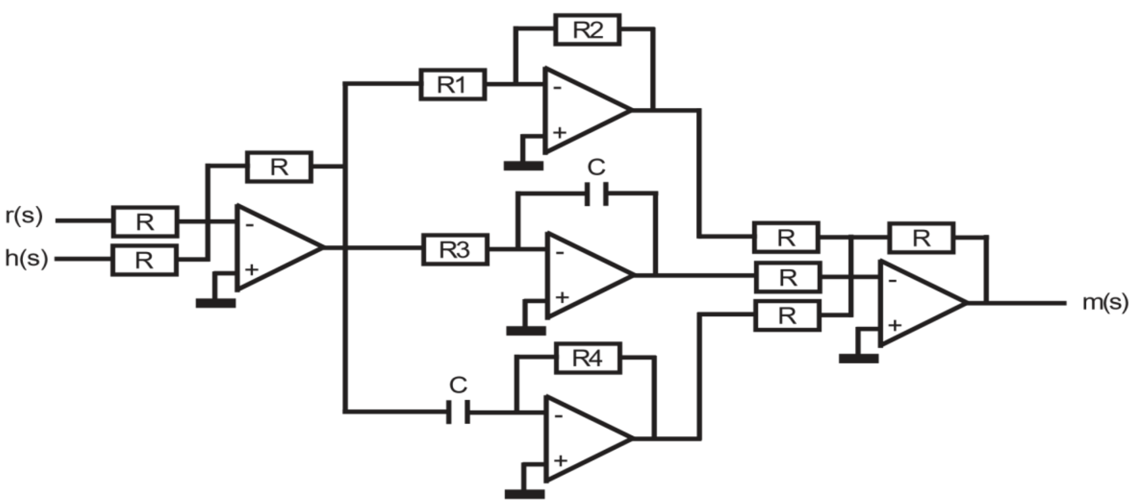


Fig 1. The PID controller structure.

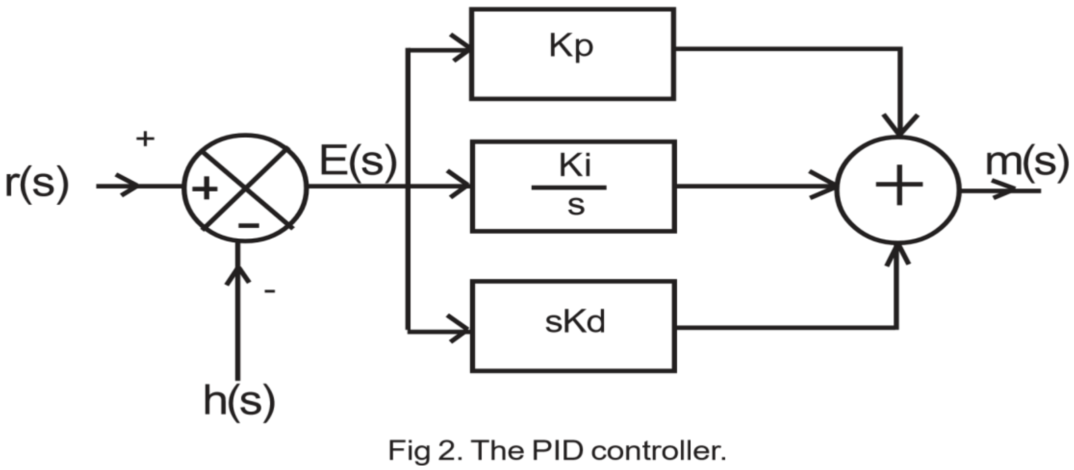
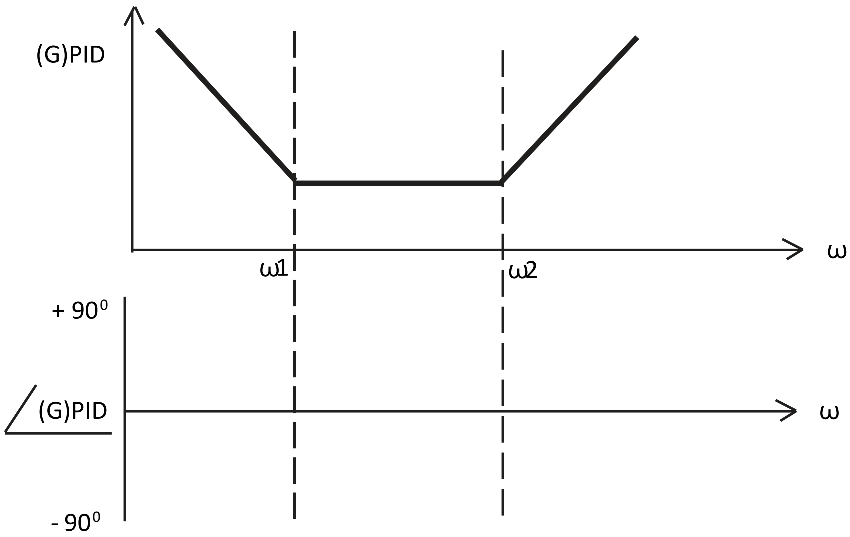


Fig 2. The PID controller.



Bode plot of PID controller showing poles and zeros.

... = 4 Vpp/τ (Vin). Where, τ is the input signal time period.

a3. Feed similar signal to the input of delay block. Find out the delay time L, and time constant T.

a4. Feed similar signal to the input of uncommitted amplifier input and observe the output for gain and phase.

a5. Feed similar signal to each input of adder block alternately and observe the output.

Write down the transfer function of each block.

Exp b. *Calibration of PID controls:*

Before commencing the experiment, it is advised to calibrate, the control positions. To calibrate the controls, the procedure given below should be adopted.

b.1. To calibrate the P control: Adjust P control knob to maximum (10 on major scale) Connect CRO at P socket w.r.t ground. Apply a square wave signal at error input of 50 mSec duration with an amplitude of 200 mVpp. The maximum gain value obtains at screen of CRO connected at PID output as,

Kp (max) = pp square wave output/ pp square wave input

b.2. To calibrate I control set I control to maximum (10 on major scale) CRO to I socket and ground. Apply 200mVpp square wave signal of 50 mS, at input of error amp and note the output on CRO. The maximum value of Ki, from step a2, will be,

Ki (max) = 4 x f x triangular wave in volts pp / pp square wave input

b.3. To calibrate the D control set D control to maximum and CRO with D socket. Apply a triangular pulse of 1.0 Vpp (50 mSec = 20 Hz) at input of error amplifier and note the pp output of square wave at output as,

Kd (max) = pp square wave output / 4 x f x triangular wave input pp

** Although we do our best but still there are some possibilities of error. The given tables should be taken for example only.*

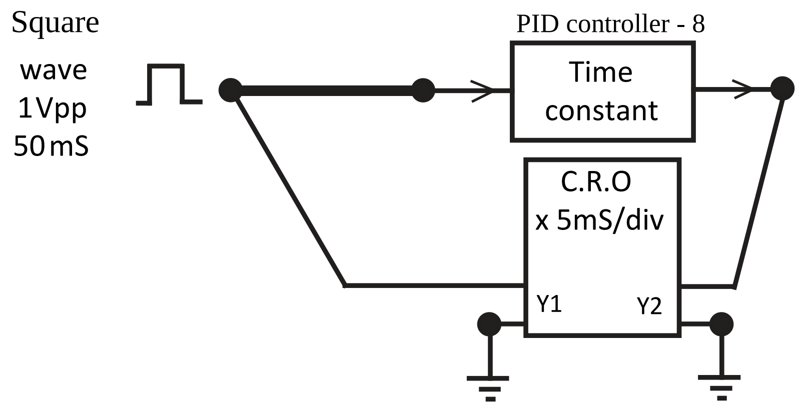
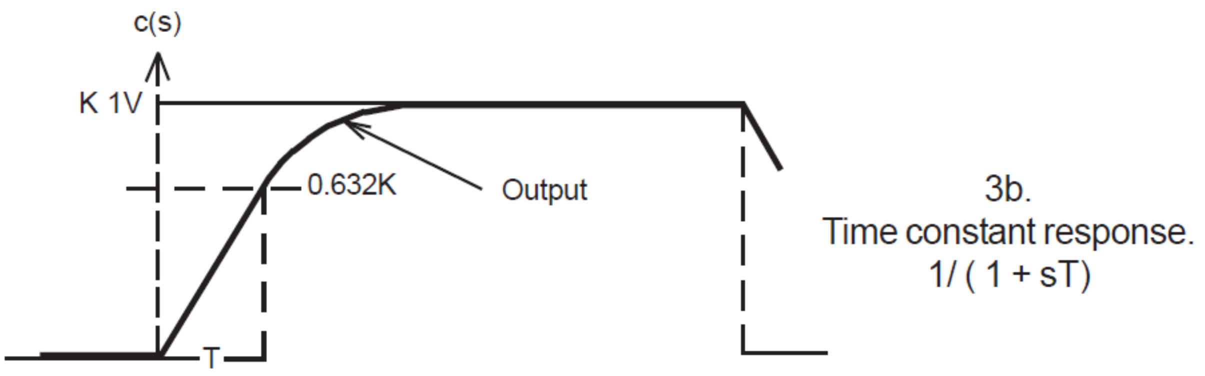
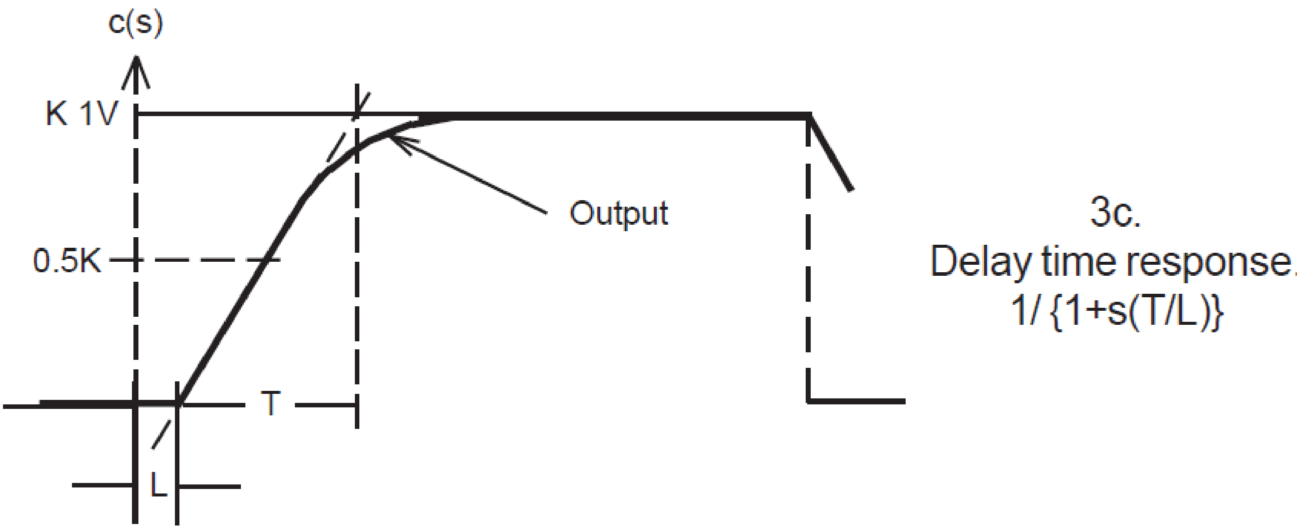
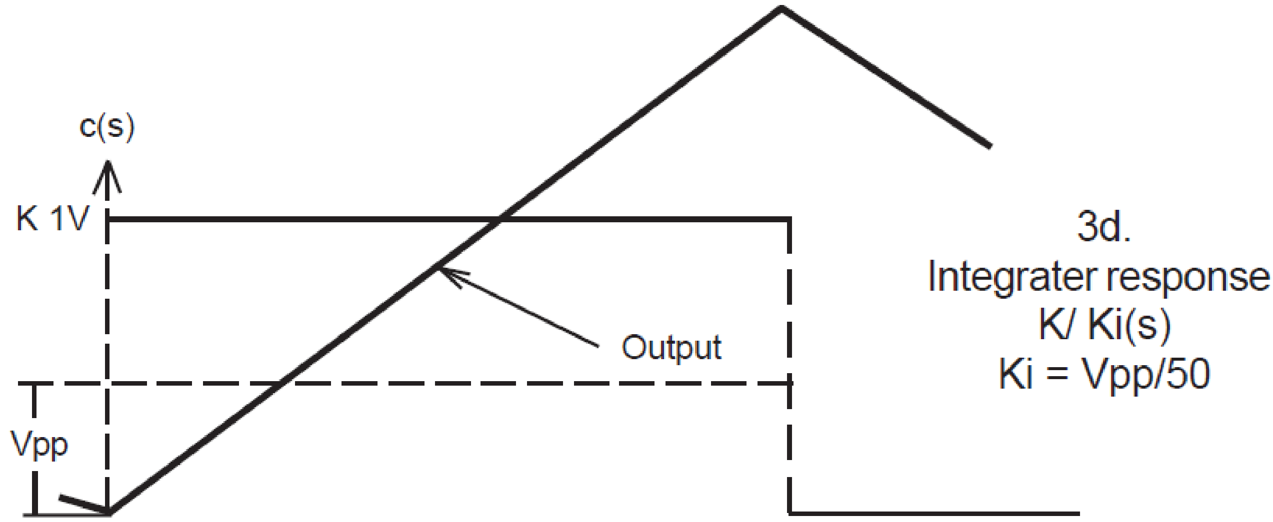


Fig. 3a. The open loop measurement. Diagram show the time constant block under measurement. Trigger CRO with Y1 channel.

Similar connections are made to measure the other process blocks.

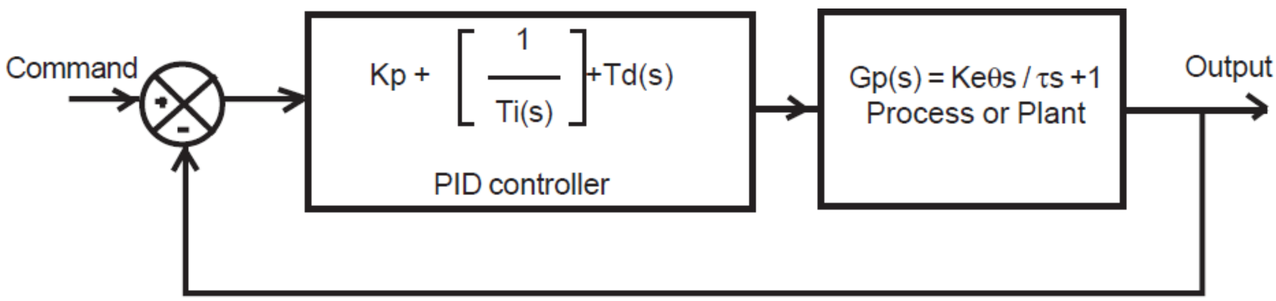






Tuning of PID controllers:

Although the PID controllers are adjusted at sites, but there are classical tuning methods are purposed in literatures. The fig below shows a PID controller with process or plant.



PID control and process for robust control

Ziegler - Nichols rules for tuning PID controllers: Already given in text books, there are two methods proposed for determining values of proportional gain Kp, integral time Ti and derivative time Td. In the first method called 'process reaction curve' in which plant response to step input is evaluated. However, it should be assured that the plant should not involve neither integrator(s) nor dominant conjugate poles. The step response should be looked like a  (S), shaped curve as shown in Fig. 3c.

The S shaped curve may be characterized by two constants, delay time L and time constant T. These are determined by drawing tangent line at the inflection point of the curve and determining the intersections of the tangent line with time axis X and line K. Ziegler - Nichols suggest to set the values of Kp, Ti and Td according to formula as given below in Table 1.

Table 1. Tuning rules.

Type of controller-1	Kp	Ti	Td
P	T / L	Inf	0
PI	0.9. T / L	L / 0.33	0
PID	1.2. T / L	2L	0.5L

In second' continuous cycling method' in first step Ti = inf and Td = 0. Using proportional control action sustained oscillation is made. This method is applied only when the output has sustained oscillations. At proportional gain where the oscillations are maintained the value of Kp = Kct, the critical gain value. Than Kp is adjusted for half of critical value Kct. The time period of oscillation determined (in sustained mode) and it is equal to Pct. The values of Kp, Ti and Td are shown in Table 2.

Table 2. Tuning rules.

Type of controller -2	Kp	Ti	Td
P	0.5Kct	inf	0
PI	0.45Kct	.833Pct	0
PID	0.6Kct	0.5Pct	0.125Pct

Ziegler - Nichols tuning rules widely used but sometime plant dynamics are not known in that cases trial and error methods adopted. Overshoot up to 25% is reduced in these cases.

Exp. c. *The P controller with 1st order type 0 system with delay.*

c.1. Connect the circuit as shown in Fig 4a. Feed 1Vpp square wave input 20 Hz (50 mSec). Trigger CRO with the input signal. Kept CRO in CAL mode.

c.2. Trace the process reaction curve upon paper, in regard with input as shown in Fig. 4b. Find out the terms T and L.

c.3. Now close the loop, as shown in Fig. 5. Switchover CRO for XY mode. Adjust P control as given in Table 3, and note the X and Y values.

c.4. Find out the value of Kp at where the response observed oscillatory. It is the critical gain Kct. (Start P control from zero).

c.5. Increase the Kp more thus the system generates oscillations.

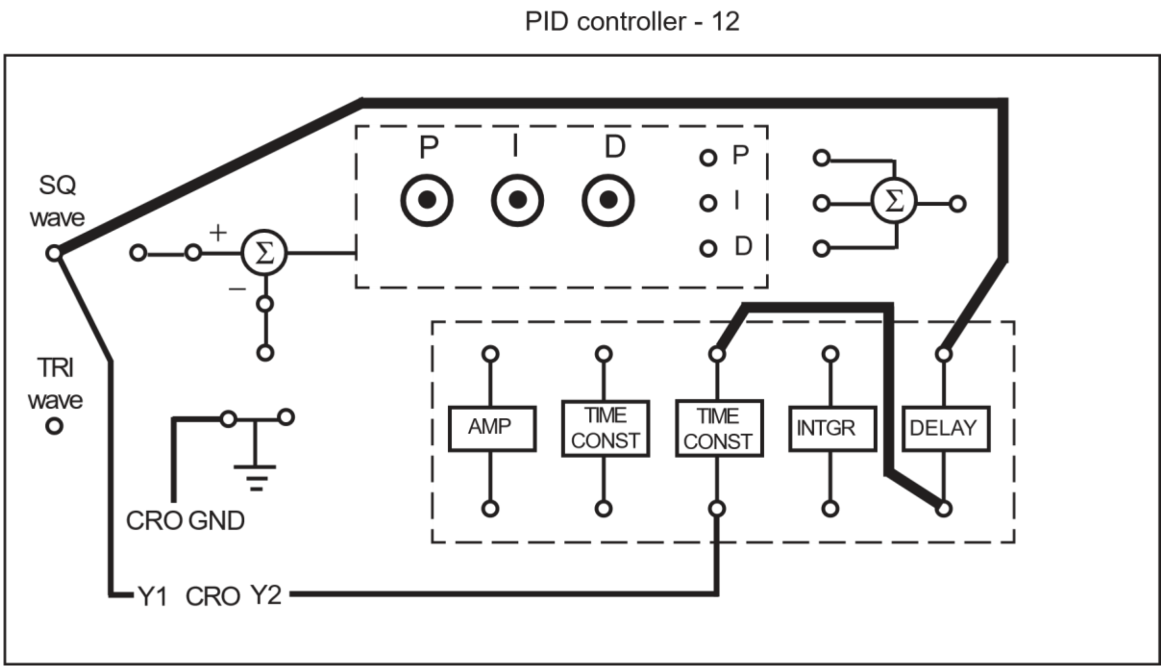
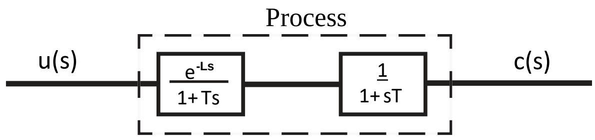
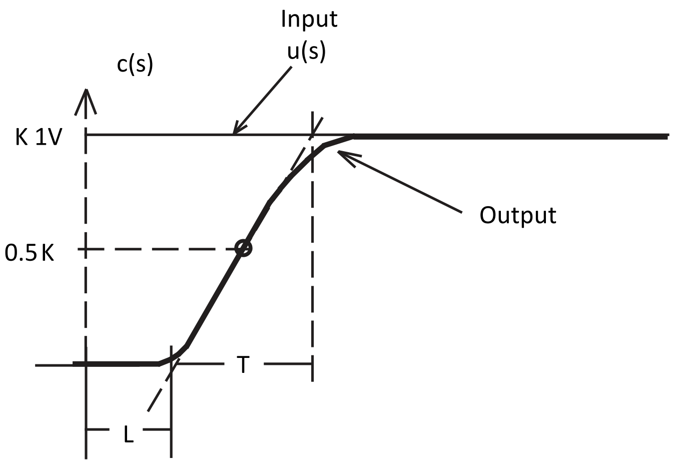


Fig. 4a. Connection diagram for Process reaction curve. CRO 2 mS/div.



4b.

First order type 0 system with transportation lag.



4c.

Transfer function curve

$$\frac{c(s)}{u(s)} = \frac{K.e^{-Ls}}{Ts + 1}$$

CRO to normal mode and measure the time period of oscillations as Pct.

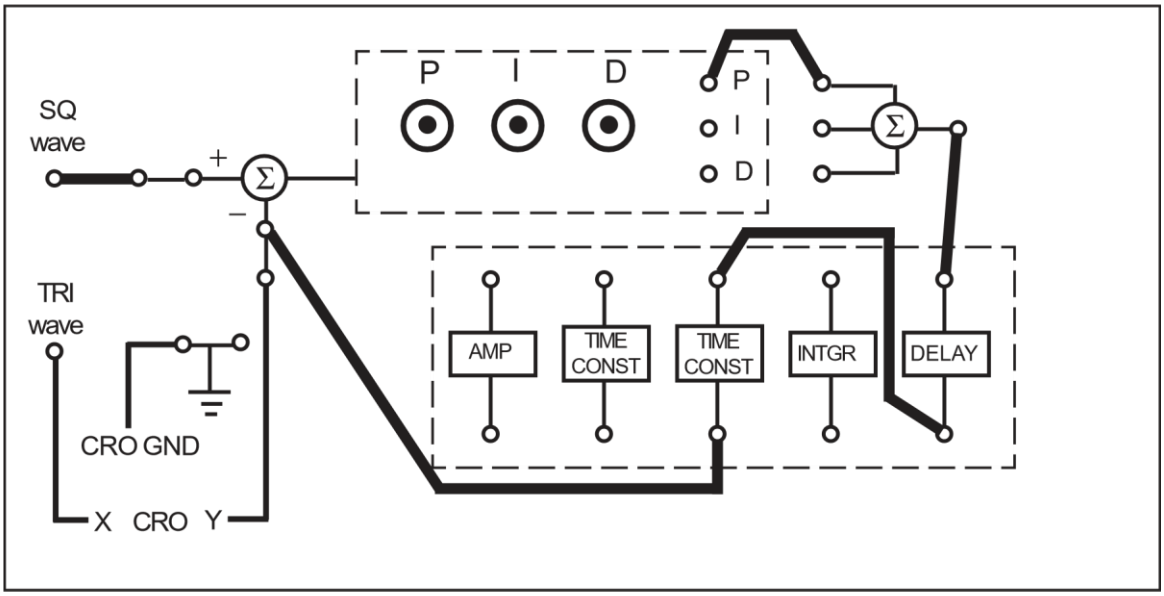
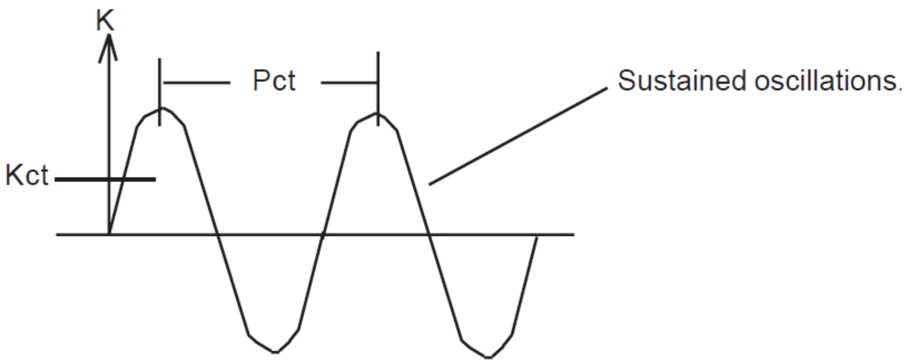
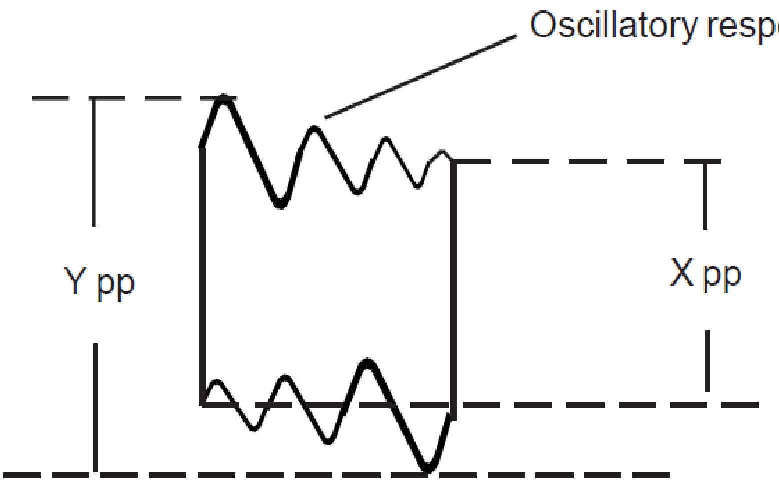


Fig. 5a. Connection diagram for P controller. D is = 0 and I = inf.



5b. Measurement of Pct (CRO in trigger mode).



5c. Measurement of Kct (CRO in XY mode). Width of the loop depends upon triangle wave amplitude.

Table 3. The P controller with type 0 system.

Kp	Xpp	Ypp	overshoot	e_{ss}
1.00	...	..	...	...
2.00				
3.00				
3.50				
4.00				
4.50				
5.00				

Oscillatory response at kp = ... = Kct. Sustained oscillation time Pct = ... Switchover in CRO trigger mode and find out the period of oscillation as Pct. (time base must be in CAL mode).

c.6. Switchover again in XY mode and adjust P control to value shown in table 2, (0.5 Kct). Find out the %os and steady state error.

c.7. Adjust P control to the value shown in table 1. The L and T are obtained from open loop studies step c.2. Find out the %os and ess.

The %overshoot = Ypp - Xpp /2.

The steady state error ess = Square wave amplitude - Xpp.

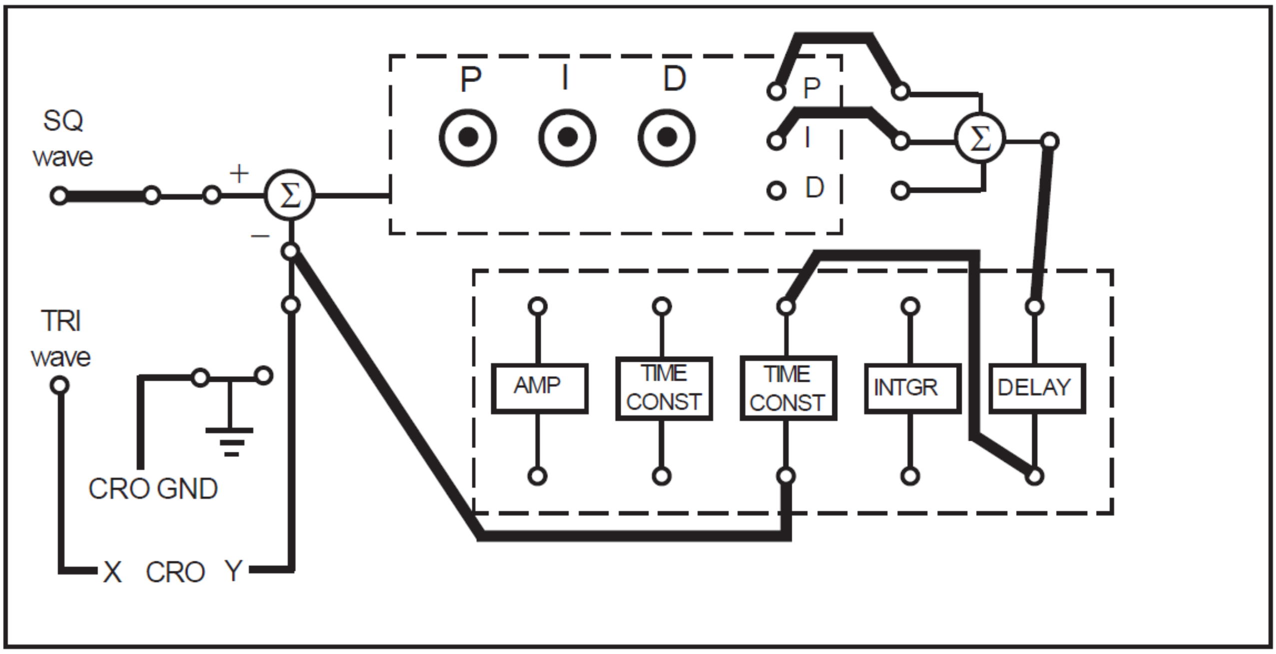


Fig 6. Connection diagram for PI controller. D is = 0.

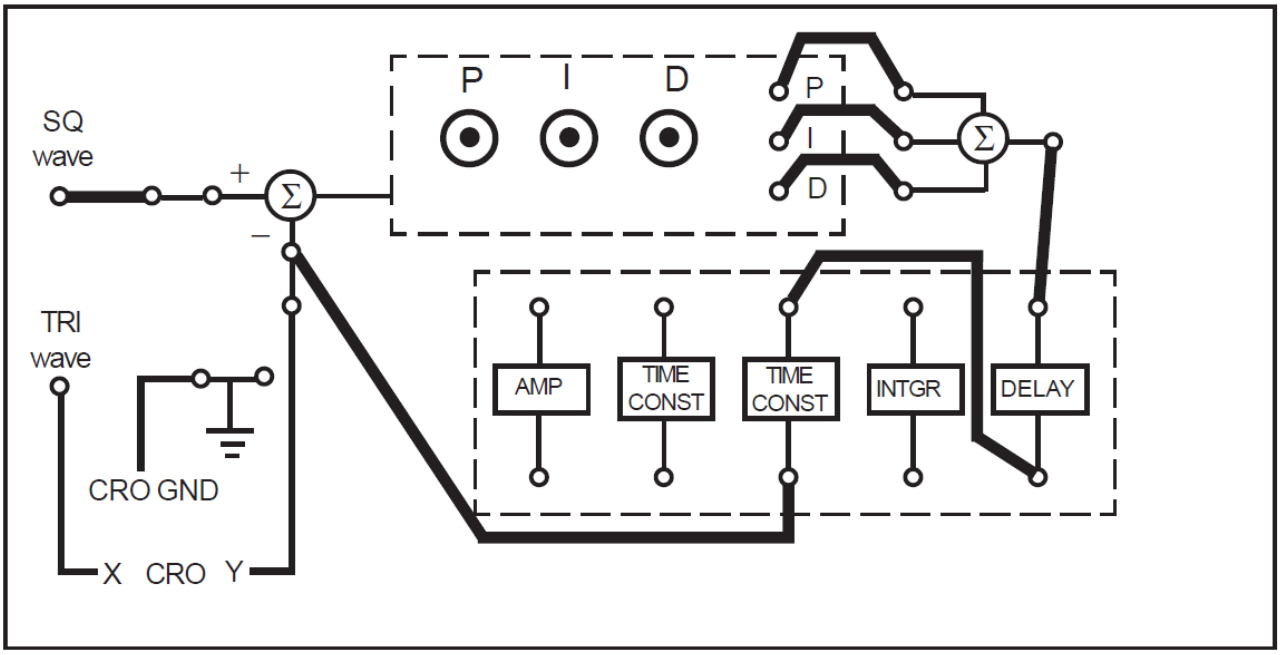
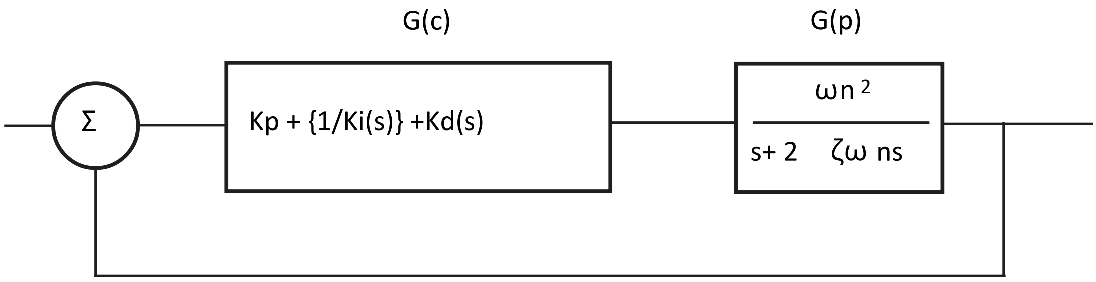


Fig 7. Connection diagram for PID controller.



Exp d. *PI controller with type 0 system with delay.* Circuit as Fig. 6.

d.1. From table 2, the Kp is set for 0.45 Kct, and Ki adjusted for different values as shown in table 4.

The steps are similar to exp c. CRO in XY mode.

Table 4. PI controller with type 0 system. Kp = 0.45 Kct = ...

Idial	Ki,s^{-1}	Xpp	Ypp	Overshoot	e_{ss}
8.00	...	..	...	...	...
8.50	...				
9.00	...				

d.2. Adjust I control to value shown in table 2, (0.833 Pct). Find out the %os and steady state error.

d.3. Adjust P control to the value shown in table 1. Adjust I control to given value in table 1. Find out the %os and ess.

The %overshoot = Ypp - Xpp /2.

The steady state error ess = Square wave amplitude - Xpp.

Exp e. The PID controller with type 0 system with delay.

e.1. Connect the circuit as fig 7. Set P control for 0.6 Kct and I control 0.5 Pct. Select XY mode for CRO.

e.2. Proceed with D control adjusted as Table 5.

Table 5. PID controller with type 0 system. Kp = 0.6 Kct , Ki = 0.5Pct.

D dial	**Kds^{-1}**	**Xpp**	**Ypp**	**overshoot**	**ess**
0.00	0.00	..	...	...	...
0.20	....				
0.40					

0.60

0.80

1.00

1.20

1.40 ....

e.3. Adjust D control to value shown in Table 2, (0.125 Pct). Find out the %os and steady state error.

Exp f. The P controller with type 1 system. Fig. 8.

The steps are similar to steps taken in experiment c. tabulate the results as shown in Table 3.

Exp g. The PI controller with type 1 system. Fig. 9.

Set Kp = 7.5. Adjust Ki from dial setting at 5.00, to 8.00 and tabulate the %os and ess.

Exp h. The PID controller with type 1 system. Fig. 10.

Set Kp = 7.5 and Ki = 7.00 (dial), Adjust Kd from dial setting at 1.00, to 5.00 and tabulate the %os and ess.

Disconnect the integral and derivative control leads. The system is only with P controller. Select CRO for trigger mode (normal mode). Measure the tp, and Mp from the response curve.

Compute the transfer function of the system from the observation. Now put the values of I and D from PID table prepared from Exp. h. Write the transfer function.

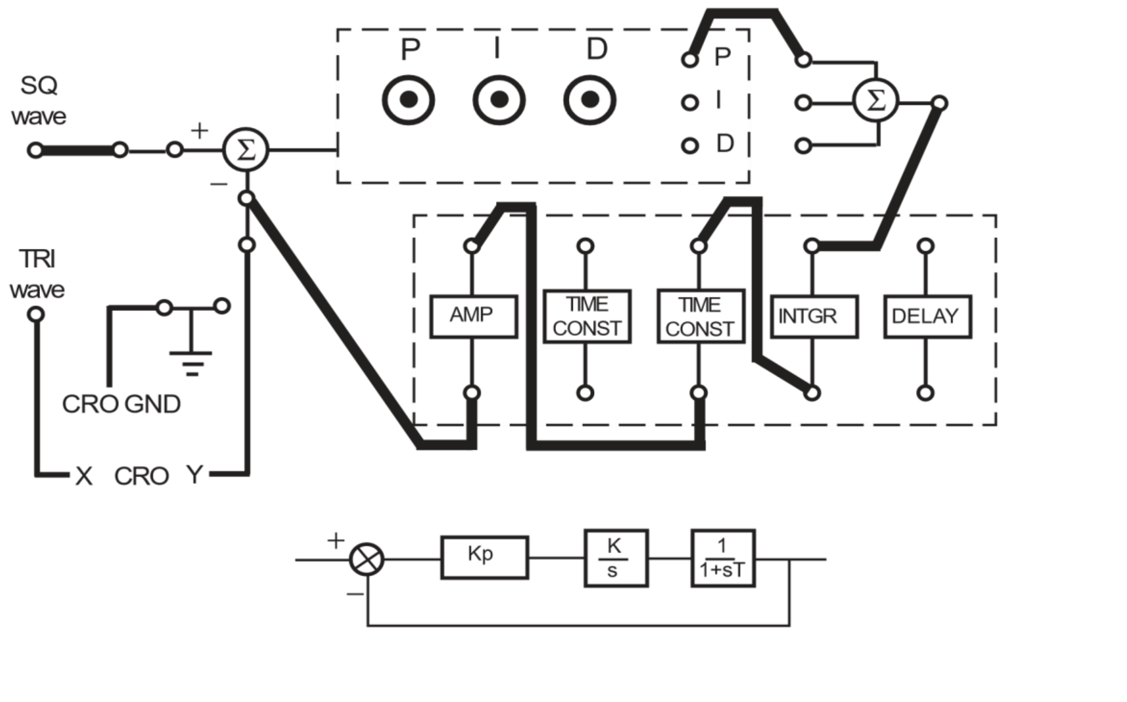


Fig 8.
Connection diagram for P controller . D is = 0 and I = inf, system type 1

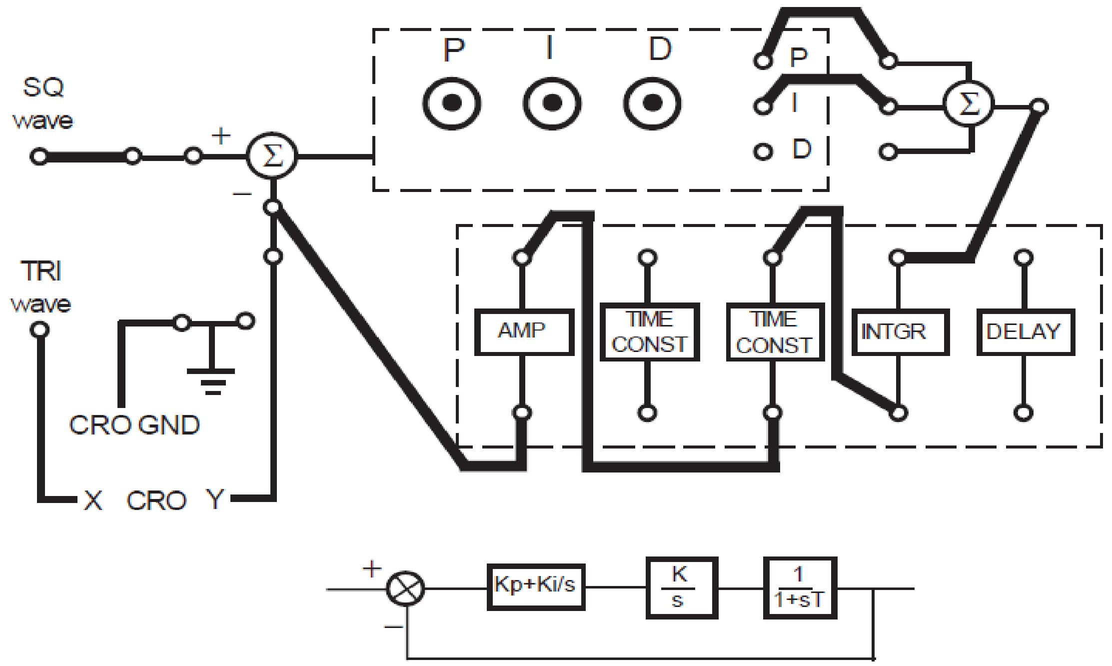


Fig 9.
Connection diagram for PI controller . D is = 0 , system type 2

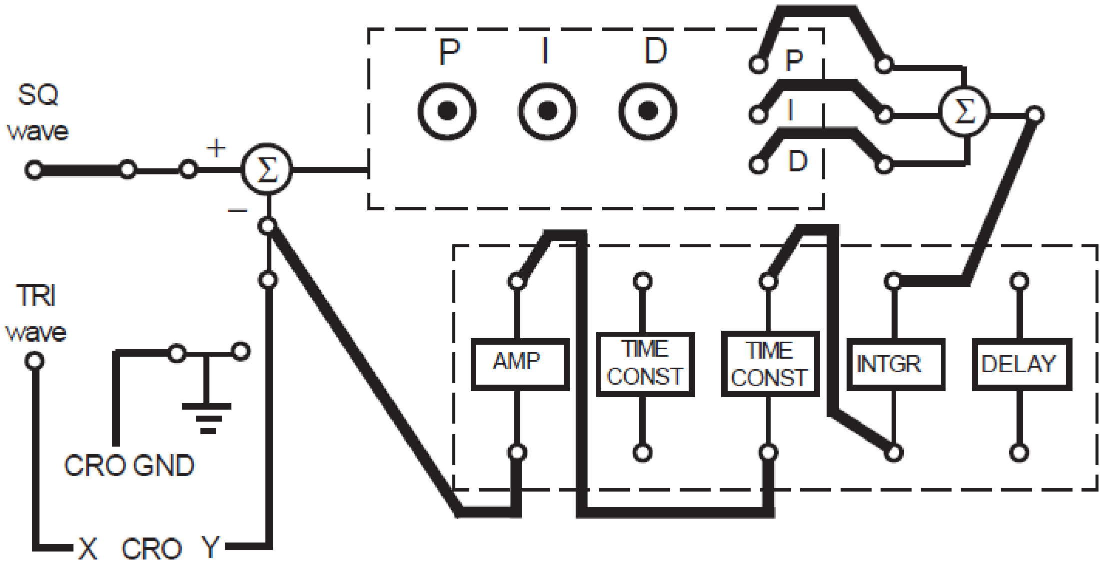


Fig 10.
Connection diagram for PID controller .System type 2

Before commencing experiment, the calibration of three parameters should be done. Than experiments should be start from simple pole (time constants). The tables given below are experimentally found during tests*.

P - Control:

A square wave signal of 0.2Vpp of time period 50 msec is applied at error amplifier input and CRO is connected across the PID output, socket P. Keeping P control maximum 10 digit on main dial, the output was 4Vpp. Thus a gain factor is 4 / 0.2 = 20. As the P control knob has linear dividing thus setting of 1, at main dial and 0.6 at vernier dial gives a gain factor Kp = 1.6 x 2 = 3.2. As main dial is divided into 10 parts thus one part of it is = full scale gain 20 / 10 = 2 and its least count is .04 since resolution is = .02

I - control:

A square wave signal of 0.2Vpp of 50 mSec = 1 / T = 20 Hz, applied at the input of error amplifier. CRO connected with the output of PID, at I. A triangular wave of Vpp is obtained at I control set for maximum. The main dial readings for different settings is obtained. As stated earlier the integral constant is

$K_I / _S$ = 4x 20(1.24) / 0.2 = 992 $x10^{-3}$ /sec

D control:

Applying a triangular wave of 1.0Vpp of 50 mSec = 20 Hz, at input of error amplifier with D control at maximum, CRO at D output socket, a 0. Vpp square wave obtained at CRO connected at PID output. The value of Kd max = 0. 9 / 4 x 20 x 1.0 = 0.01125 = 1.125 x 10^{-3} sec

Thus each subdividing number on vernier dial gives .0.1125 on digit 1.00.

The time constants transfer function is measured as (1 / 1 + 1 $x10^{-3}$s)

For integrator it is (1/12.5s)

For delay ($1x10^{-3}$) seconds.

* The results may vary with test instruments.

The results carried out at works (for example only).

P control: Refer to Fig. 5.

Input: 1 Vpp sq wave of 20 Hz, constant throughout the experiment. CRO in XY mode, connected at error - input and ground.

Sr No.	Dial set	K_P	Ypp	Xpp	%O.S	ess
01	0.50	1.00				
02	1.00	2.00				
03	1.50	3.00				
04	1.75	3.50				
05	2.50	5.00				

Kct =   (dial set at   ), Pct =   x 10^{-3} sec.

PI control:

KP = 0.45Kct =   . Dial set for   Ki adjust for I control as below.

Sr No.	Dial set	K_I./sec^{-1}	Ypp	Xpp	%O.S	ess
01	5.00					
02	6.00					
03	7.00					
04	8.00					
05	8.50					
06	9.00					

PID control:

K_P = 0.6Kct =   dial   , K_I = 0.5Pct = x 10^{-3} / sec,   dial

Sr No.	Dial set	$K_{D\ app}$	Ypp	Xpp	%O.S	ess
01	0.20	0.00				
02	0.40					
03	0.60					
04	0.80					
05	1.00					
06	1.20					
07	1.40					

Comparing with Table 1, value found (T = $x10^{-3}$ s and L = $x\ 10^{-3}$ s)

P = (dial at), I = $x10^{-3}$ s (dial at) and D = $x\ 10^{-3}$ (dial set at) for maximum overshoot within % with minimum ess within 0.01.

From Table 2, value found (Kct = and Pct = $x10^{-3}$ s)

P = (dial), I = $x10^{-3}$ (dial =) and D = $x10^{-3}$ (dial)

The transfer function of PID controller is

$G_C(s) = K_p + 1/T_i s + T_D s$

Put the experimental results and calculate transfer function.

Experiment No. 10

Aim: To study linear system simulator.

Introduction: - This set up is designed to study the time response of simulated linear systems. The present set up has straightforward building blocks of simulated process & signal sources. A cathode ray oscilloscope (dual trace is best option) is the only other apparatus required to carried out the most experiments. The set up consists following features:

Basic building blocks: - There are some basic building blocks are given upon the panel. A dynamic system can be configured connecting them in suitable manners. All blocks have input / output sockets with arrowhead mark and common of them is connected internally with common ground.

1. *Error detector with gain:* - This block has three inputs marked as Disturbance, reference and feedback. It has one output shown by arrowhead mark. The input error signals referred as e1, e2, e3 are added and the output could be written as: {e o = K (e 1 + e 2 + e 3)}

No - sign indicate the output has same phase with the inputs.

K is the gain factor (0 - 10) which can be adjusted with calibrated 10 turn potentiometer provided upon the panel.

2. ***Integrators:*** - *These blocks have a pole at the origin and simulates type - 1, system. It has a transfer function in form of {-K / s}, - means introduce a phase shift between input / output.*
3. ***Time constants:*** - *Next to integrate these blocks simulates type 0, system and its transfer function is in the form of {-K1 / (sT + 1)}. The next time constant block is similar to the first except it has one other input* x10, which results in 10 times higher gains necessary to form second order system simulating. Its transfer function is in the form of {- K2 / (sT + 1)}.
4. ***The disturbance adder:*** - It is an inverting two input and one output adder. The inputs can be written as e 1, e 2 and the output can be defined as:

{eo = -e1 + e2} (The gain factor of this block is 1).

5. ***Amplifier: -*** It is a unity gain inverting amplifier and used to invert the phase of input signal, which is necessary for negative feedback applied to form close loop configuration. Its transfer function is, {eo = -ein}

The signal sources: - The setup has necessary built in signal sources to conduct the experiments. The only other external source required in the form of low frequency sine wave oscillator as a disturbance signal. The provided signal sources are as below.

1. ***Square wave:*** It has variable frequency which can be adjusted from frequency control provided upon the panel. The output amplitude is also variable and can be controlled independently with the help of control provided just under the output socket.
2. ***Triangular wave:*** It has same frequency as square wave with independent amplitude control situated just below the output socket.
3. ***Sine (par) wave:*** To observe the time respond signal an integrated triangle wave of fixed amplitude is provided. Its amplitude is 1 - 3Vpp (frequency depended) and it is also frequency related with other two signals.
4. ***Trigger:*** A constant amplitude (1Vpp) signal provided to trigger CRO in external mode.

The frequency of all four signals is controlled with the help of frequency control simultaneously has range from < 20 Hz to > 50 Hz. The amplitudes of square and triangular wave are variable between 0 to 2 Vpp while trigger output has constant 1V and integrated triangle wave 1 - 3Vpp (freq depend). All the basic building blocks and signal sources based upon op - amps, has powered from internal dc symmetrical regulated power supply.

Some basics

a. First order systems: The first order systems are characterized by one pole and (or)a zero. An integrator with time constant have transfer functions in the form of {K / s} and {K / (sT + 1)}, respectively are common. The input / output characteristics of such systems for unit step input can be written for Fig. 1, if

$$\frac{C(s)}{R(s)} = \frac{K}{(sT + 1)} \qquad \text{subsituting} \qquad R(s) = \frac{1}{s}$$

by expending partial fraction

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

Taking inverse Laplace transform

$$C(s) = (1 - e^{-t/T}) \qquad \text{for } t = 0$$

$$\& \qquad c(t) = \{K / (1 - e^{-t/T})$$

The time constant of the system is defined in above Eq. is equal to t = T, which gives an exponential rising curve c(t), then for Fig. 1b, $T = (1 - e^{-1}) = 0.632K$ where K is final value. The smaller the time constant T, the faster will be response of the system.

For Fig. 2

$$\frac{C(s)}{R(s)} = \frac{K}{(s)}, \quad \text{subsituting} \quad R(s) = \frac{1}{s}, \quad \& \quad C(s) = \frac{K}{(1/s^2)}$$

Then $c(t) = Kt$

The output is a linear ramp with constant K/s. Higher the value of it lower the steady state error.

b. Second order systems: The second order systems are characterized by two poles and up to two zeros. In view of study transient response, the zeros are not considered for simplification and since they do not affect the results. The transfer function of such system as shown in Fig. 3 can be written as:

$$G(s) = \frac{\omega^2_n}{s2 + 2 \zeta \omega_n s + \omega^2 n}$$

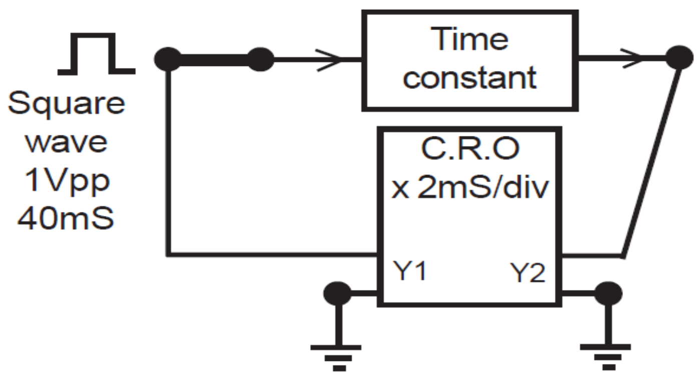


Fig 1a.
Connection for evaluation
Time constant response.

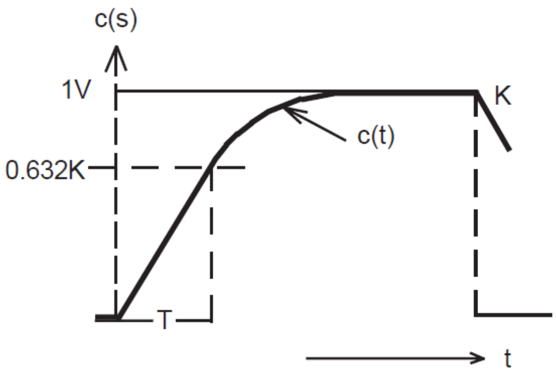


Fig 1b. Time constant response. 1/ (1 + sT)

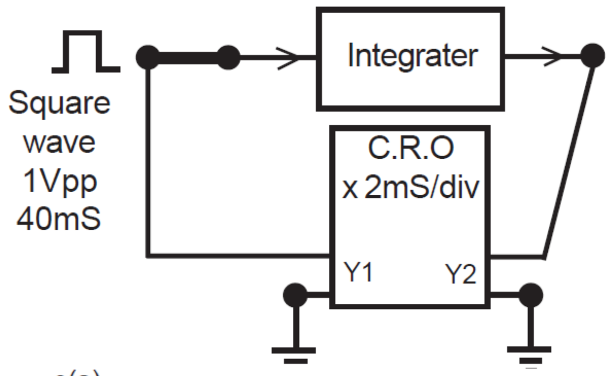


Fig 2a. Connection for evaluation integrater response.

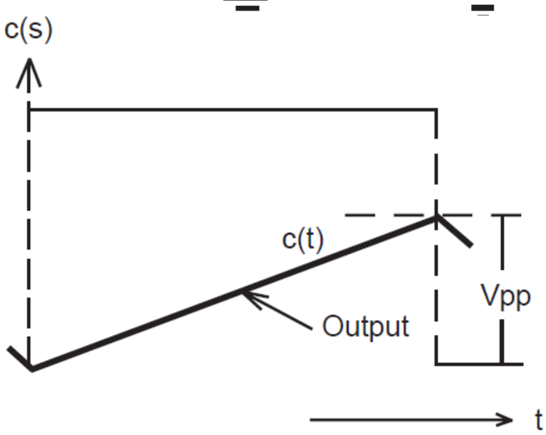


Fig 2b. Time response K/s

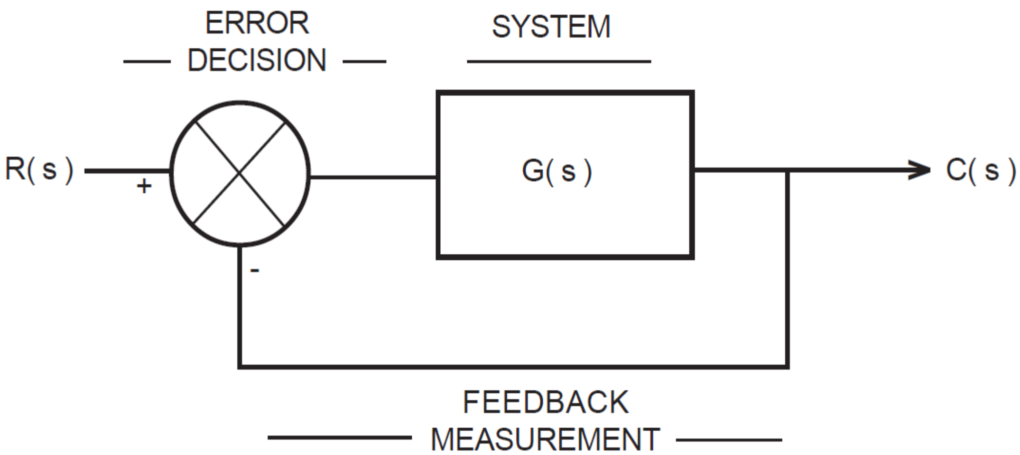


Fig -3a. Block diagram of a close loop system.

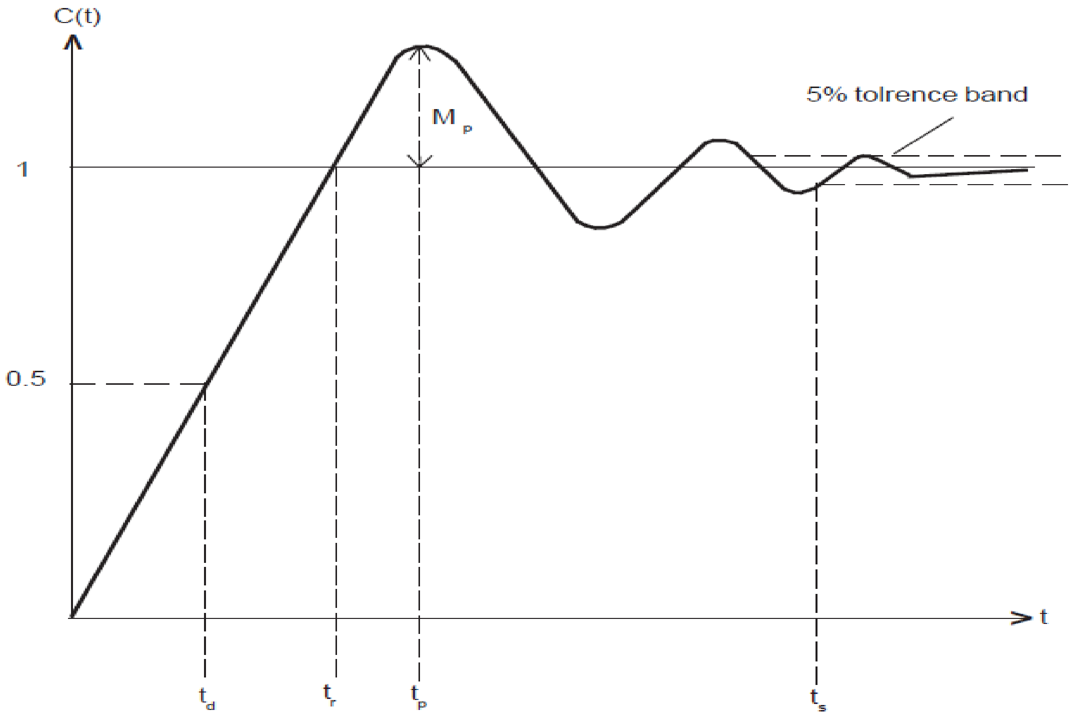


Fig. 3b. Step response of an underdamped 2nd order system.

Experiment procedure

In first step open loop response (page 8) should be carried out. For the purpose one dual trace CRO will be required.

Open loop response.

a. Error detector with gain

1. Set gain pot to 10.0.
2. Apply a 100 mVpp square wave of 25 Hz (40 mS) to any of the three inputs. Measure the pp amplitude form CRO. Note the phase relation between input / output.
3. Decrease gain to 9, 8, 5 and verify the gain decrease in multiple, e.g. for 5 it should be equal to 500 mVpp.
4. Change the input to other one and observe that gain remain same.
5. Write an equation for the output as described earlier.

b. Time constant 1.

1. Apply 1 Vpp 25 Hz square wave signal to the input of first time constant block (with single input).
2. Find the time T from the trace at which the response approaches to 63% its value. Use X - expansion facility of CRO for the purpose to evaluate T.
3. Coincide the input / output traces and note the input / output amplitudes with their phase relations.

4. Write an equation for the transfer function from the observation.
* At works it is measured as T = 1 msec.

c. Time constant 2.

1. Apply 100 mVpp 25 Hz square wave and repeat the steps as taken for Exp. - b, for both inputs one by one.

2. Write two equations for the transfer functions of the block.

d. Integrater.

1. Apply 1 Vpp 25 Hz square wav
2. e signal to the input of the integrator block.
3. Measure the pp output of the triangle wave and note its phase relation.
4. Write the transfer function of the block calculating the equation Ki = 4 Vopp / τ

(Valid if input is 1Vpp, the charge rate is 0.5/ R. l / 2C)

Otherwise calculate as: 4 Vopp / Vin.τ.

Where Vin is in volts and Vo in mV and τ in millisecond or = 1 / f.

c. Time constant 2.

1. Apply 100 mVpp 25 Hz square wave and repeat the steps as taken for Exp. - b, for both inputs one by one.
2. Write two equations for the transfer functions of the block.

The time constant is T = 1 msec and K = 1 and 10 for respective inputs.

d. Integrator 1.

1. Apply 1 Vpp 25 Hz square wave signal to the input of the integrater1.
2. Measure the pp output of the triangle wave and note its phase relation.
3. Write the transfer function of the block calculating the equation

Ki = 4 Vopp / Vin τ Where Vin is in volts and τ in second (given 40msec).

The same procedure for integrator 2.
*At works it is measured about, 9.6 for integer 1&, 13.8 for integer 2.

e. The uncommitted Amplifier

Feed 25 Hz square wave signal to the input of the amplifier block and note its output voltage and its phase between input / output.

f. The disturbance adder

1. Feed 1 Vpp 25 Hz square wave signal to the one input of disturbance adder block and note its input / output phase and gain.

2. Change the input and note the gain and phase.

Close loop system

a. First order systems

Two types of first order systems can be configured as shown in Fig. 4. Make connections as shown and proceed as follows.

1. Apply 1 Vpp 25 Hz square wave signal to the input and note the response curve on tracing papers setting gains at 1, 2, 3 and so.
2. Calculate the time constants (for type 0 system) in each case and verify the results.
3. Calculate the steady state error from above cases. In case of type - 1, system particularly it is difficult to find out the steady state error. Switch CRO to XY mode and connect its X input with the triangular wave input, keeping triangular output equal to square.
4. Find the ess from the loop as shown in Fig. 6

5. Write the results from the experiments and compare it with the theory*. * There may some imperfection since there is a tolerance between practical and theory.

b. The second order system.

The Fig. 5 shows the configurations can be made for 2nd order systems. Select one and then other for experiment. Connect the circuit in proper manner and proceed as

1. Apply 1 Vpp 25 Hz square wave signal to the input and trace the output waveforms for different settings of error detector gain K* upon paper.
2. From the traces find out the value of td, tr, tp, Mp, ts and ess. Calculate the theoretical values and compare it with practical results.
3. In case of type - 1, system use XY mode stated as before for ess evaluations.

* For type one system start K from 10.0 and then decrease it. For type 0, start from lower side settings and then increase.

c. Disturbance rejection.

Other apparatus required, low freq. sine wave signal (shown in Fig. 7), otherwise inject the given sine (PAR) signal.

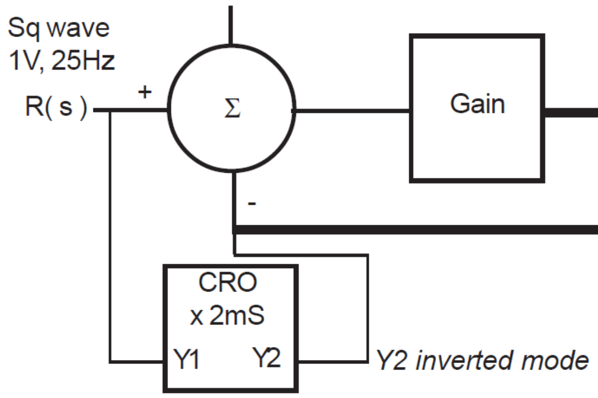
1. Connect the circuit as shown in fig 7b.
2. Feed low frequency sine wave signal (10 Hz) of 0.5Vpp or PAR signal at input of error detector. Observe the effect of disturbance upon the system.
3. Disconnect the sine wave signal from the input and connect it with output disturbance adder (Fig. 7a). Observe the effect.

* It is observed that when the disturbance signal added at input it becomes a part of command signal. When it is added at output the error detector reject it effectively.

d. Type 1, third order system (introductory).

Although it is not included in syllabi and practical approach but it can be configured as shown in Fig. 8.

1. Connect the circuit as shown in fig 8.
2. Feed 1 Vpp of 25 Hz square wave to the input and observe the output signal for gain K adjusted to 4,5, 6 alternately.
3. From the traces find out the value of td, tr, tp, Mp, ts and ess. Calculate the theoretical values and compare it with practical results.
4. In case of type - 1, system use XY mode stated as before for ess evaluations.



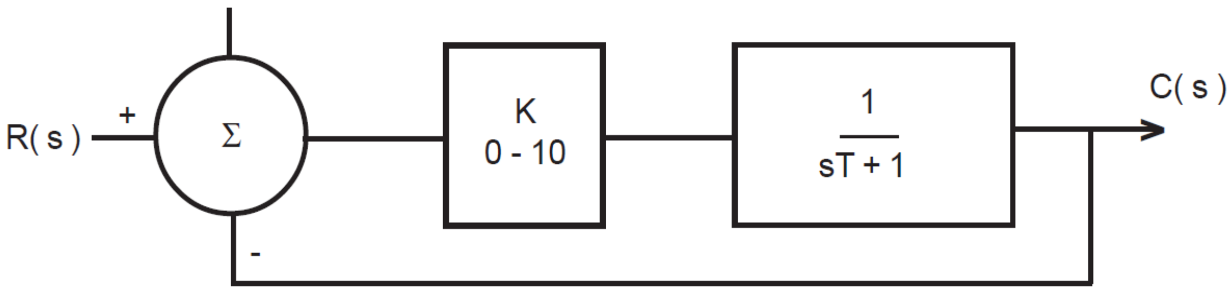
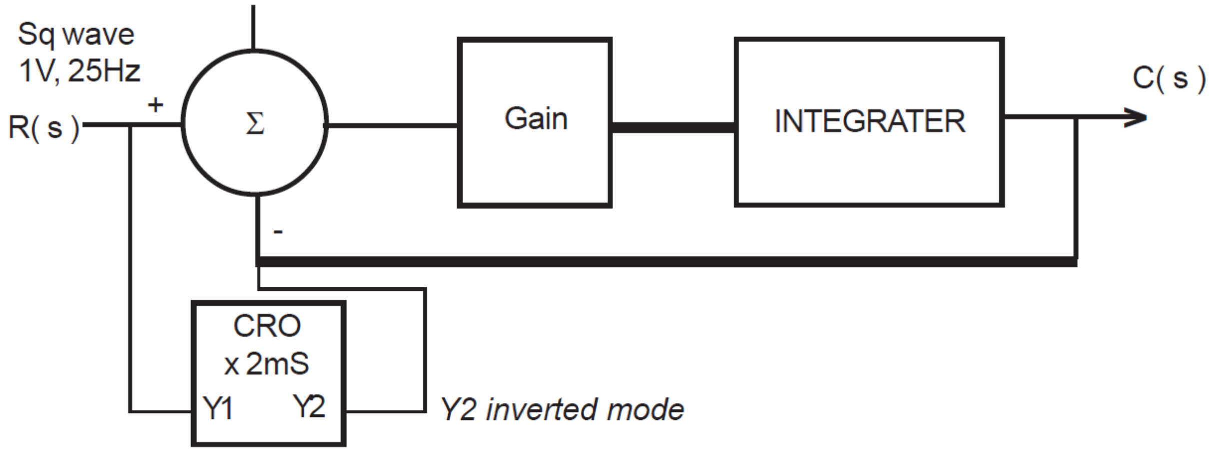


Fig 4a. First order type 0 system.



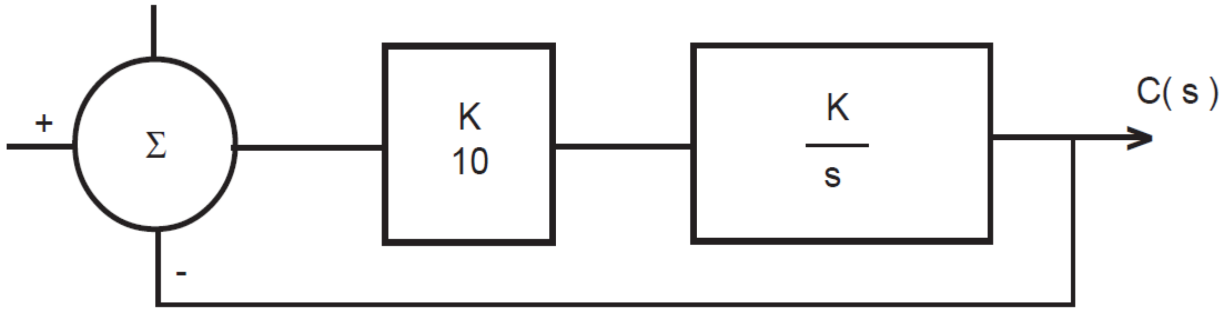
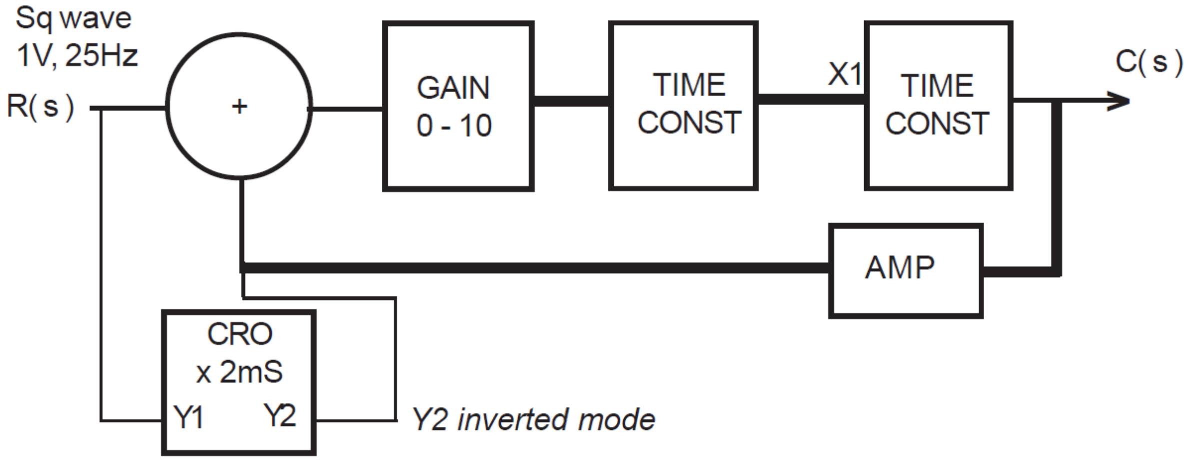


Fig. 4b. First order type 1 system.



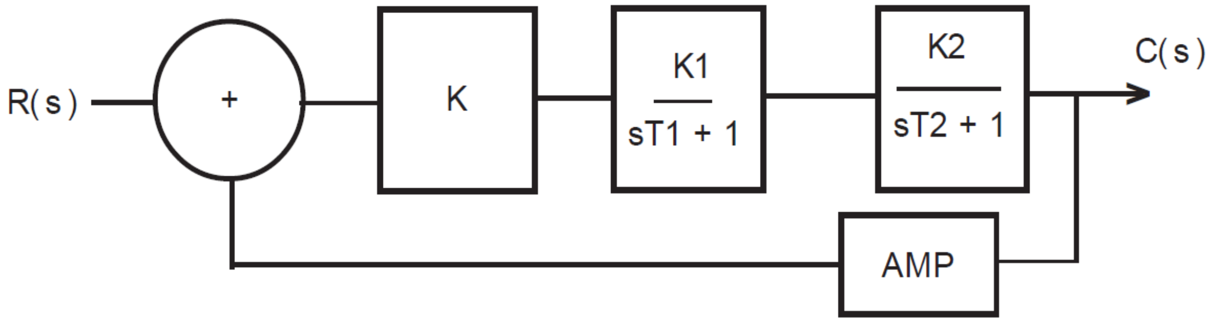
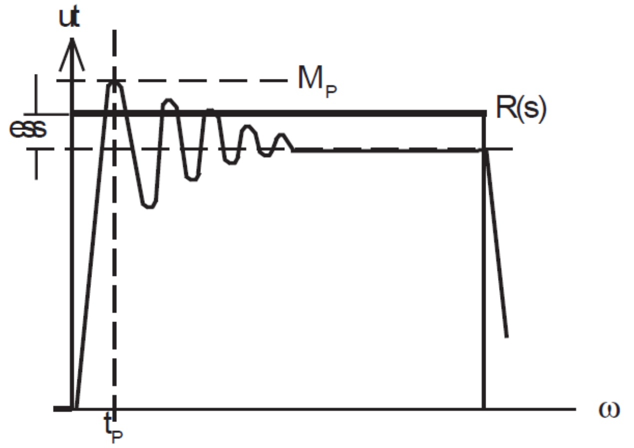
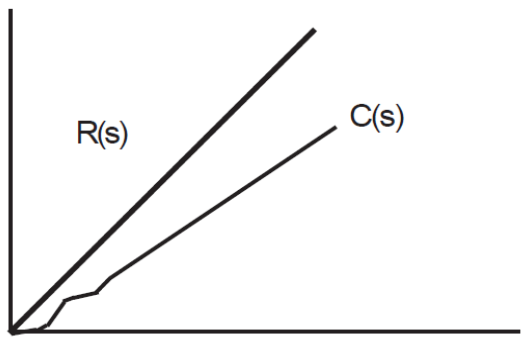


Fig. 5a. Type 0. 2nd order.



Typical response curve shown. R(s) is in form of square wave. System type 0, 2nd order.



Typical response curve shown. R(s) is in form of triangle wave. System type 0, 2nd order

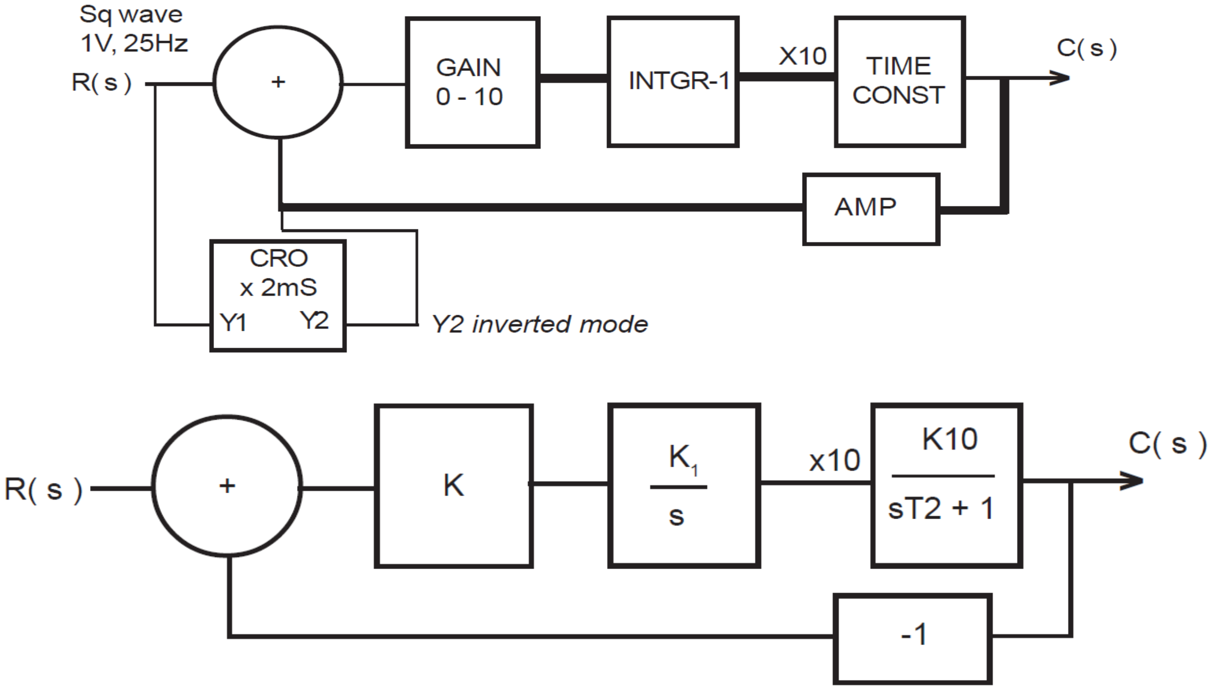
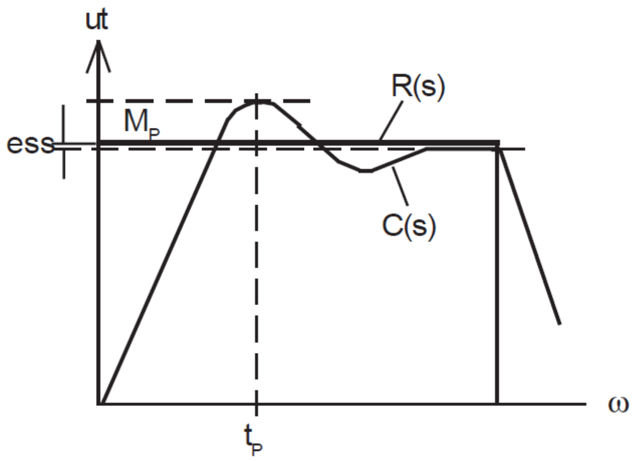
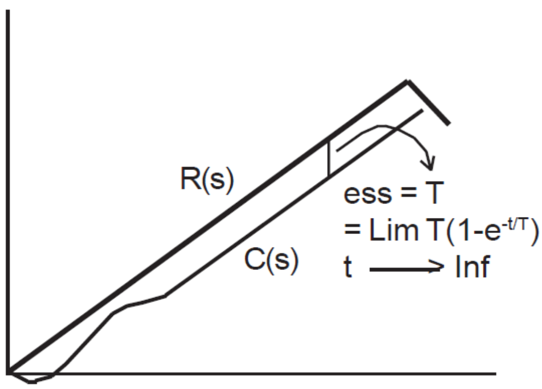


Fig. 5b. Type 1, 2nd order.



Typical response curve shown. R(s) is in form of square wave. System type 1. 2^{nd} order



Typical response curve shown. R(s) is in form of triangle wave. System type 1. 2^{nd} order

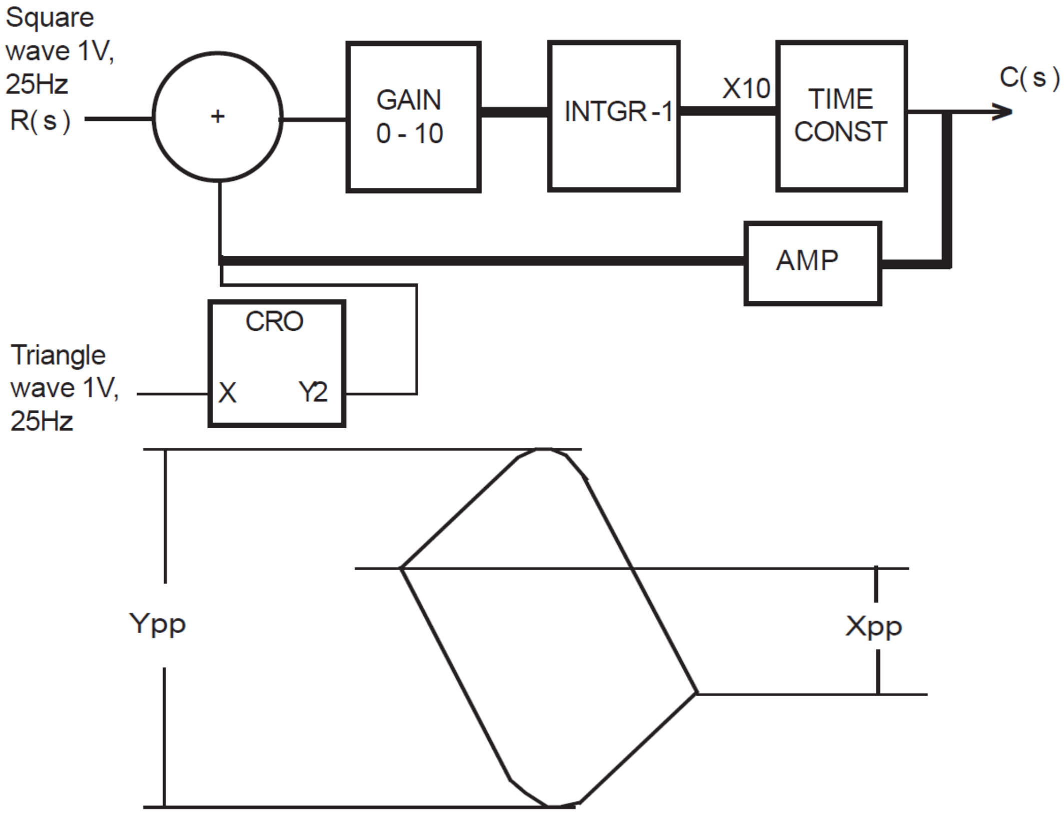


Fig 6. Above second order close loop system. XY connection.

Below the output waveform to evaluate ess = Ypp - Xpp. (see procedure)
Note: - there is some difference arise in both open loop and close loop calculations, since there are few source of errors
#The measurements are done on lab CRO and there is most possibility of mismatch in results between two the work lab and lab in practice.
#The set up implies on integrated circuits, in which bias current and other parameters affect the results between piece to piece or say between set up to set up, thus results are carried out on one set up in one production for time saving (assuming that the results are in close factor).
#As the set up performance is time dependent and time is basically found from time base of CRO under observation, then there may be possibilities arises to mismatch the results.
It is suggested that open loop performance must be carried out on same lab instrument.

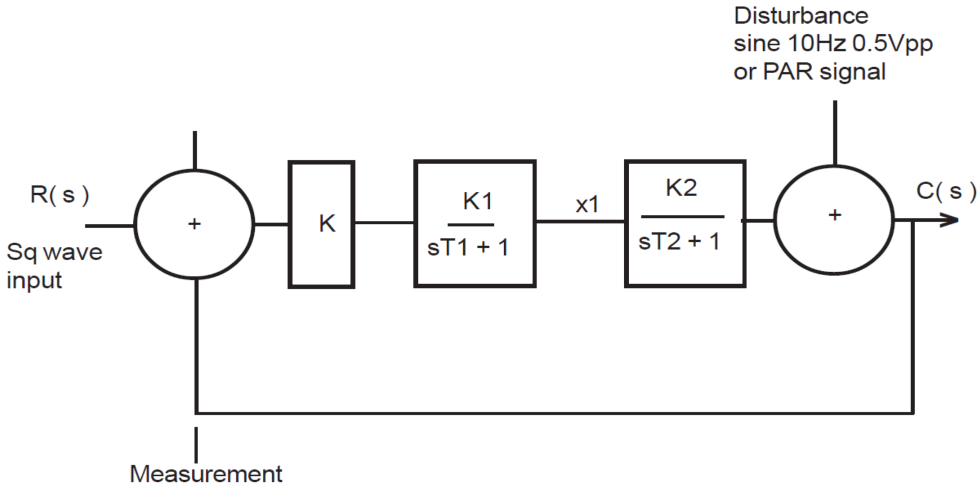


Fig. 7a. Way to connect disturbance adder in the second order circuit at output.

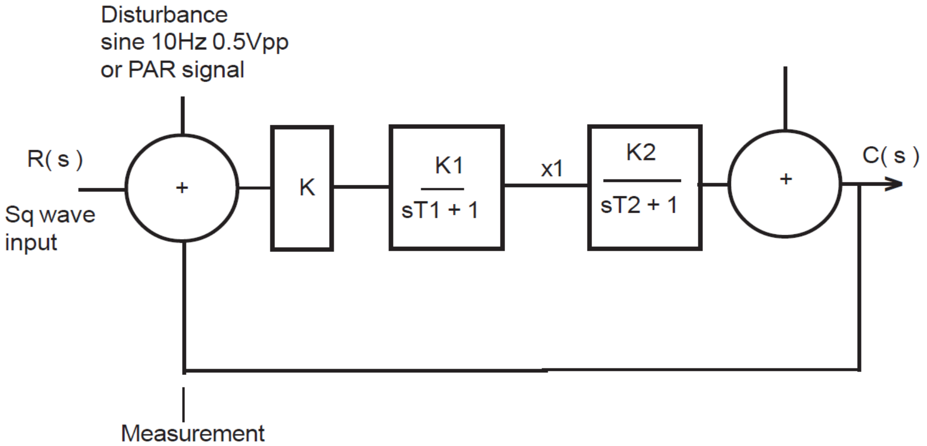
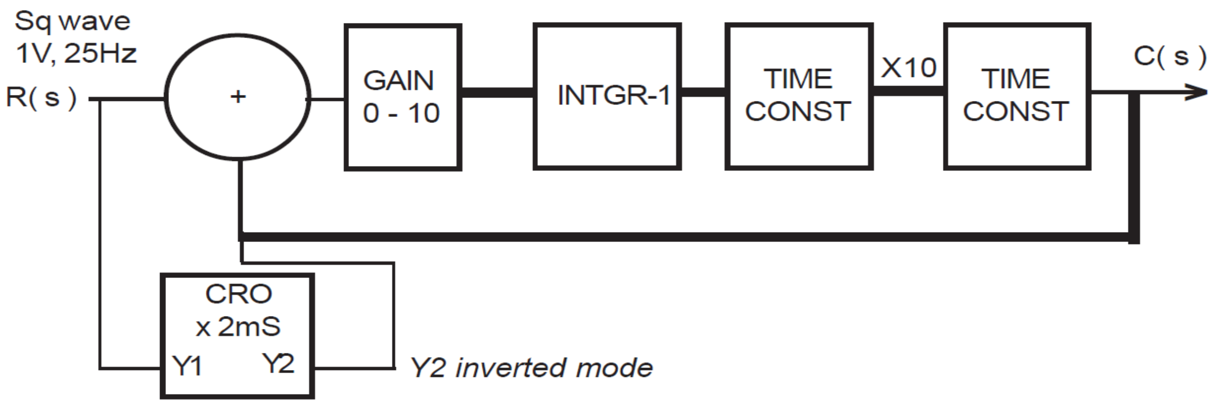


Fig. 7b. Way to connect disturbance adder in the second order circuit at input.



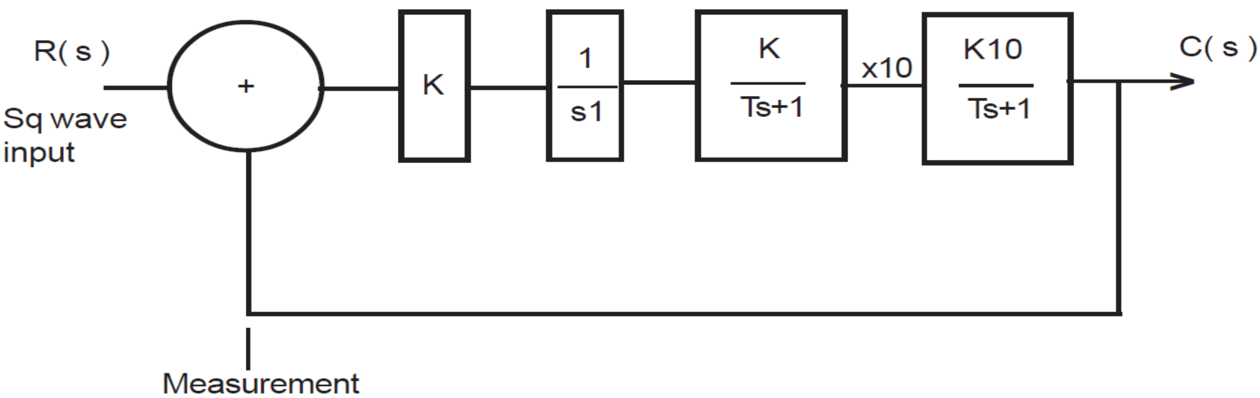
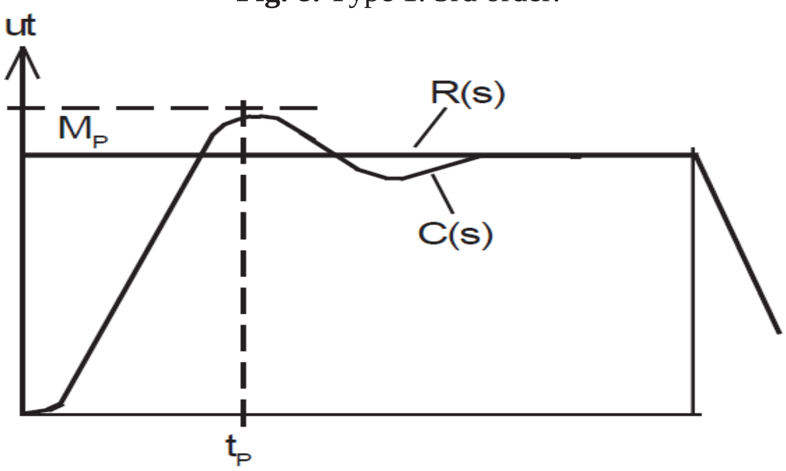


Fig. 8. Type 1. 3rd order.



Experiment No. 11

Aim: To study DC position control system.

***Introduction*: -** This set up is designed to study of dc motor position control system called servomechanism and comes first in automatic control systems. The prime advantage of this set up is near perfection to the simulated systems. The set up comprises two parts a, the motor unit and b, the control unit. The description of complete system as follow.

a. The motor unit: It consists a permanent magnet armature controlled geared servo motor. It has the technical specifications as

Operating voltage: 12 V dc, 5W.

Rated shaft speed: 50 RPM (reduced by gear train, otherwise 2400 hence n = 0.02)

Torque: 3.5 Kg / cm at load shaft.

The angular displacement is sensed by a 360^0 servo potentiometer. A graduated disc is mounted upon the potentiometer to indicate angular position with 1^0 resolution. A small dc motor is driven by the servo motor to generate the speed proportional voltage which are used as tacho output for velocity feedback. A miniature toggle switch is provided at rear side of the motor unit to change the polarity of these tacho voltages. The complete unit is housed in see through cabinet. A cable is attached to the unit with 9 pin D type connector for connection with the control unit.

b. The control unit: This unit has reference servo potentiometer, voltage source, error detector, amplifier, motor drive circuit, a RAM card and necessary regulated supplies for the circuits. The details of the controls are given below:

1. Command signal: There are two command signals are provided in the control unit. One is the continuous command which is given by the reference potentiometer. The reference potentiometer is also a 3600 servo potentiometer (electrical conduction 3400) of same value as fitted in the motor unit. Both the potentiometers are connected with same reference source of +5.00 volt dc. Sockets are provided for both the outputs for measurement purposes. A graduated dial is fitted with the reference potentiometer with 10 *resolution*.

Other command signal is in the form of a step signal of 11 second duration which is activated by briefly push upon step key. The step command is equivalent to about + 700 advance and used for quantitate study.

2. Error detector: It is a four input and one output block. Two of them are positive oriented for command signals and two negative oriented for feedback. The output of this block is ,

eO = ec1 + ec2 + (-ef1 + ef2).

Where, eC and ef are the command and feedback signals, respectively.

3. Gain blocks: there are two gain settings provided upon the panel. One block provide forward path gain KA in equal steps from 3 to 10, selected by a rotary switch provided upon the panel. The other gain block is meant for tacho and has gain K_D select from 0 to 1 in 10 steps, where tacho constant is 1 V/rad.

4. Motor driver block: The driver unit has gain equal to one and is in the form of complementary push pull stage to run the motor in either direction. A current limit circuit is attached within this block to ensure safety of output transistors during directional reversal of the motor.

5. Waveform capture / display block: The time response of the system is too slow for convenient display upon CRO. This card can capture the event, store it in a RAM and then display the stored contents on CRO for detailed studies. The stored data is erased when a new capture cycle is made. The time for capture cycle is about 8 second. Detailed operation & calibration is given at page 19.

6. DVM: A 3-1/2 digit digital voltmeter is provided to take readings of command and feedback voltages.

The unit has built in dc regulated power supplies for all blocks and motor unit, hence no external supplies are required. The only other apparatus required is CRO.

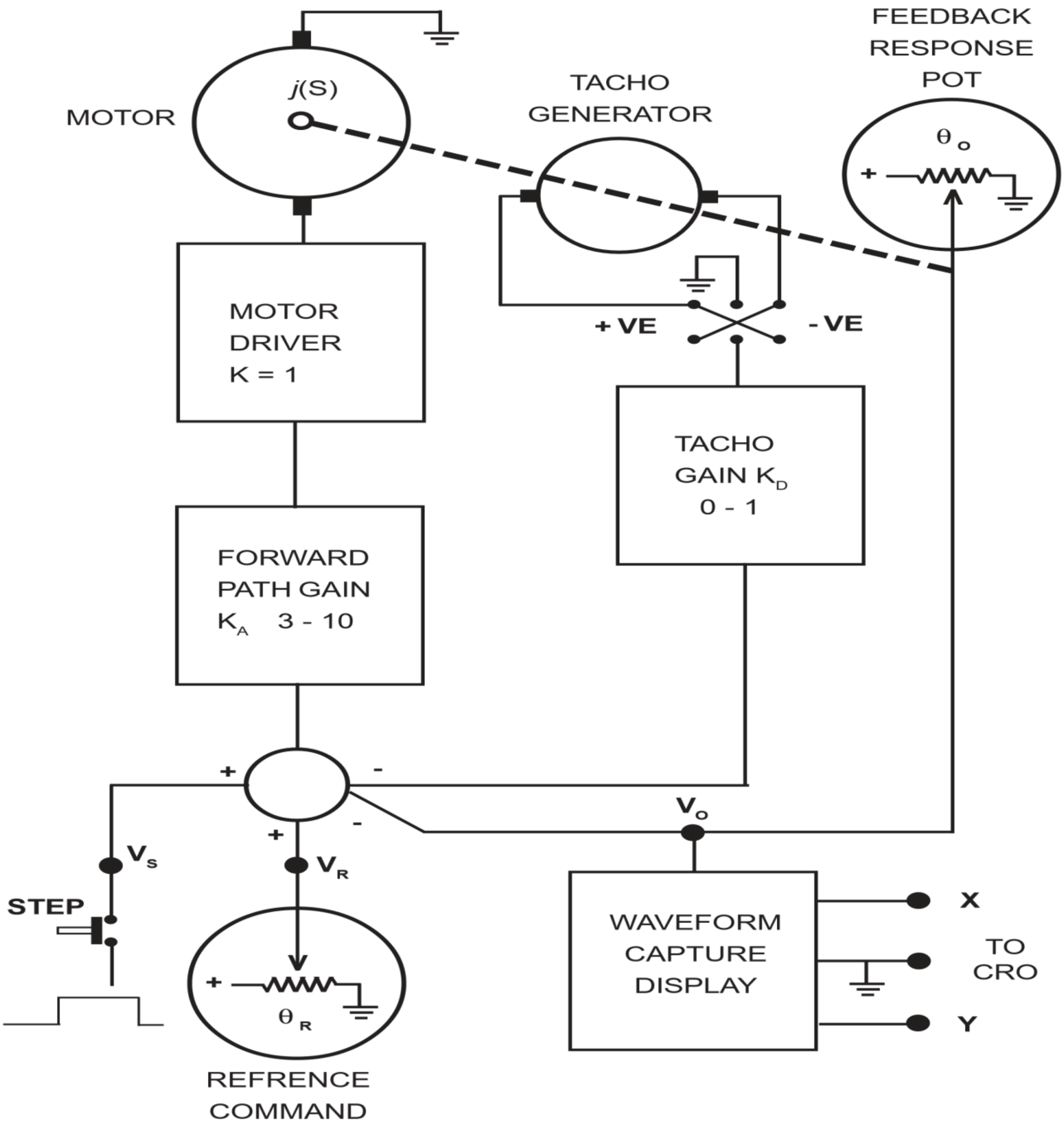


Fig. 1. System representation in block diagram.

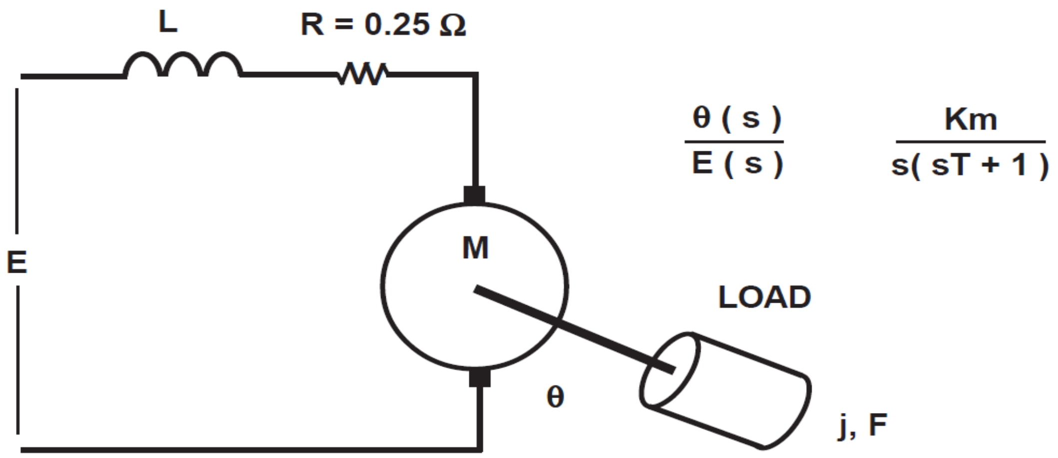


Fig. 2. Representation of motor transfer function.

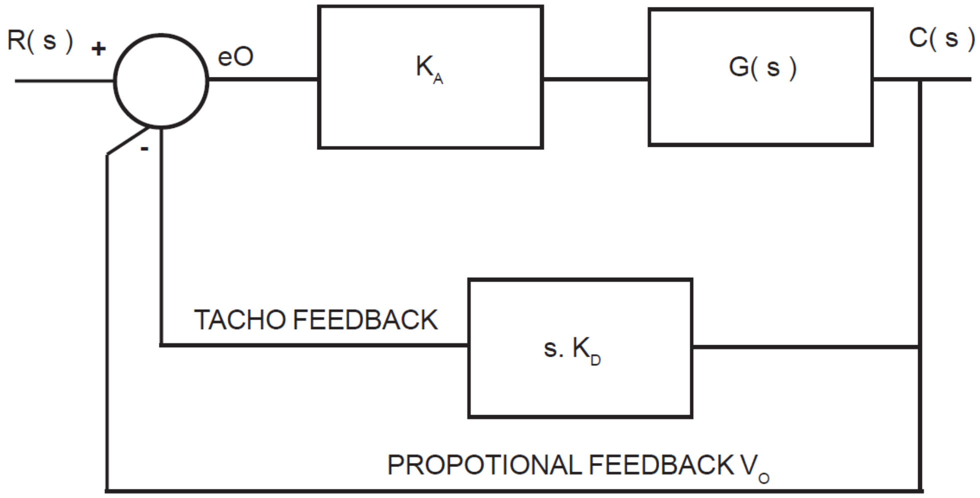


Fig. 3. Representation of simple block diagram for system.

Experiment procedure
Other apparatus required: Dual trace CRO.

Exp. a. *The potentiometer displacement constant.*

1. Connect motor unit with the control unit. Set tacho feedback = 0.

2. Switch on the power. Set K_A = 4.

3. Starting from one end say 30^0, move command potentiometer in steps of 100 approximately upto 120^0, and note the θ_R (command potentiometer) and the output reference voltage Vr from the socket given.

4. Plot a curve between the displacement and output voltage Vr. Find out the slope of the curve, sensitivity as:
Slope of the curve = Sr = ΔVr / Δθ volt / θ (in degree may be expressed in radian using conversion factor).

Sr No.	θ^0	Vr
1	30	..V
2	40	..V
3	50	..V
4	60	..V
5	70	..V
6	80	..V
7	n	..V

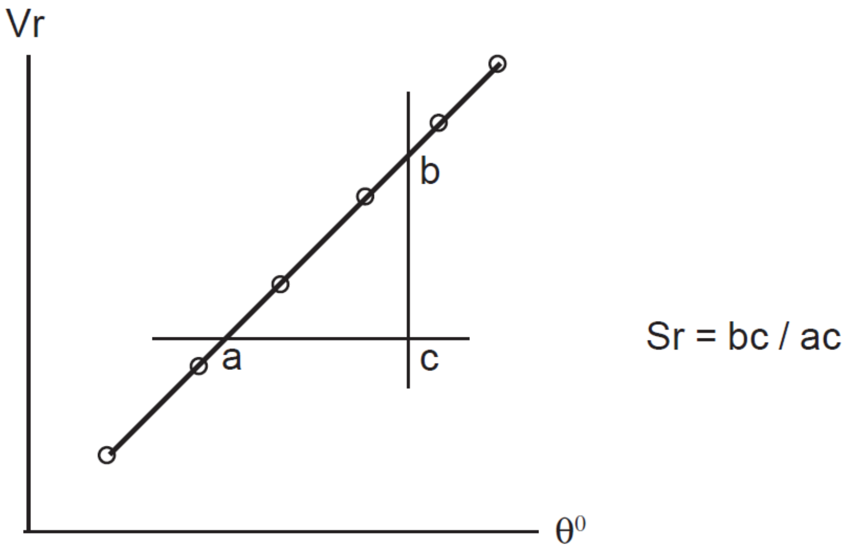


FIG. 4. Typical response curve of potentiometer. The straight line verifies the linearity.

Exp. b. *Position control through continuous command.*

1. Connect motor unit with the control unit. Set tacho feedback = 0.
2. Switch on the power. Set $K_A = 4$.
3. Starting from one end say 30^0, (of command potentiometer) move command potentiometer slowly and note the reference degree from command potentiometer where the motor start to move (as indicated by its dial). Continue move of the command potentiometer slowly and held it some position say 180^0 or above. Note the final position of motor unit dial.
4. Now select the gain $K_A = 8$. Repeat the same step (3) from 30^0 and note the reference degree where the motor move. Stop the increment of command potentiometer upto 180^0 or above and observe the motor dial movement carefully.
5. From these observations it is shown that when the gain constant is low the motor position does not follow quickly the command signal which means there is great ess (the steady state error). When gain is set to 8 or 9, the follow of motor is earlier than previous and motor does exhibit oscillation but there is a small steady state error. Graphically it is shown in Fig. 2.

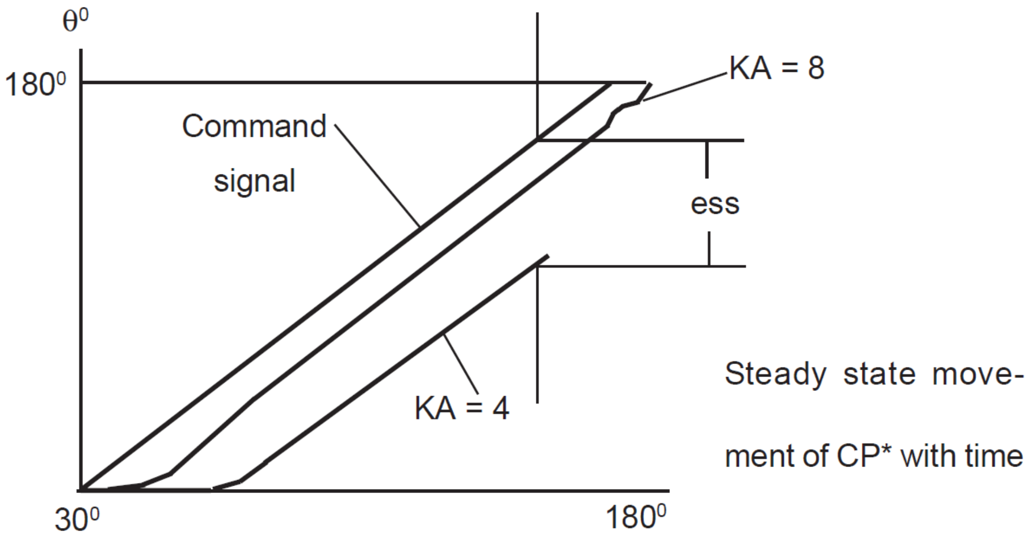


Fig. 5. The graphical representation of continuous command signal response. *CP is the command potentiometer.

Exp. c: *Position control through step command.*

1. Set KA = 3. Keep tacho feedback at 0. Command dial at 90^0. Connect given voltmeter with Vr socket and note the voltage there as Vr.
2. Connect voltmeter across VO socket. Note the voltage reading as Vo1.
3. Connect voltmeter at VS socket and apply step input by briefly push upon step key. Note the dc steady state voltage there. After time lapse of 11 second the motor will be back to its previous position.
4. Connect the voltmeter with Vo socket and reapply the step signal. Note the new reading of Vo as Vo2.
5. Calculate the step change as V1 = (Vr + Vs) and find out the ess as: ess = (V1 - Vo), where feedback voltage Vo = Vo2 - Vo1.
6. Now set KA = 8. The voltmeter is still connected with Vo socket. Apply the step signal and note the steady state voltages Vo2 and Vo1. Find out the ess.
7. From this experiment it is observed that motor does not follow a sudden change in position command (in form of step signal) when the gain of control amplifier is low, which verify by the ess rate. It is verified in next experiment.

Exp. d: *Observation of dynamic response*
1. Select KA = 3. Keep command potentiometer at 900. Connect CRO at X – Y output sockets with reference to ground in X-Y mode. Set Y at 0.2V / div and X at 0.5 volt / div. A zig - zag curve will be appearing upon CRO. If a dot appears than switch off and on the system.
2. Press capture key briefly, a spot will be appearing upon screen. Press step key briefly, the motor will be run. Wait till capture time is complete (about 8 second). After completion of capture time the captured waveform will be displayed upon screen.
Note: If some hooks are glitches appears on waveform than a fresh sample may be taken by repeating the step. The new sampling should be taken when step signal time is lapsed and motor is back to its previous position.
3. Connect given DVM at VO socket and note the voltage as initial. Apply step signal and note the voltage Vo at new position as steady state.
4. Trace the waveform appears upon screen, with screen graticules as reference.
5. Increase the gain to 5, 7, 9 and each time capture a new waveform trace it upon paper with CRO graticule as reference.

Note the Vo for each time such the initial before application of step signal and after the steady state response.

6. Select the waveform look like second order response curve (see Fig. 4). Find out the Mp, tp and tr from the curve. Calculate damping ratio, ess from the voltage observation made with each step, and ω_n from the curves. Conclude the results of system, *while the step signal is = Vs (Exp. c).*

Sr. No.	(1) Vo initial	(2) Vo steady state	ess (2-1)*
1	...V	... V	... mV

* The ess may be converted into degree or rad from Exp. a results.

Exp. e. *Step response with tacho feedback.*

1. Set KA = 7. Set K_D = 0. Briefly push CAP key and apply step signal. Observe the captured waveform with its Mp and t.

2. Set K_D = - 0.4, and its direction to -Ve from switch situated at rear side of the motor unit.

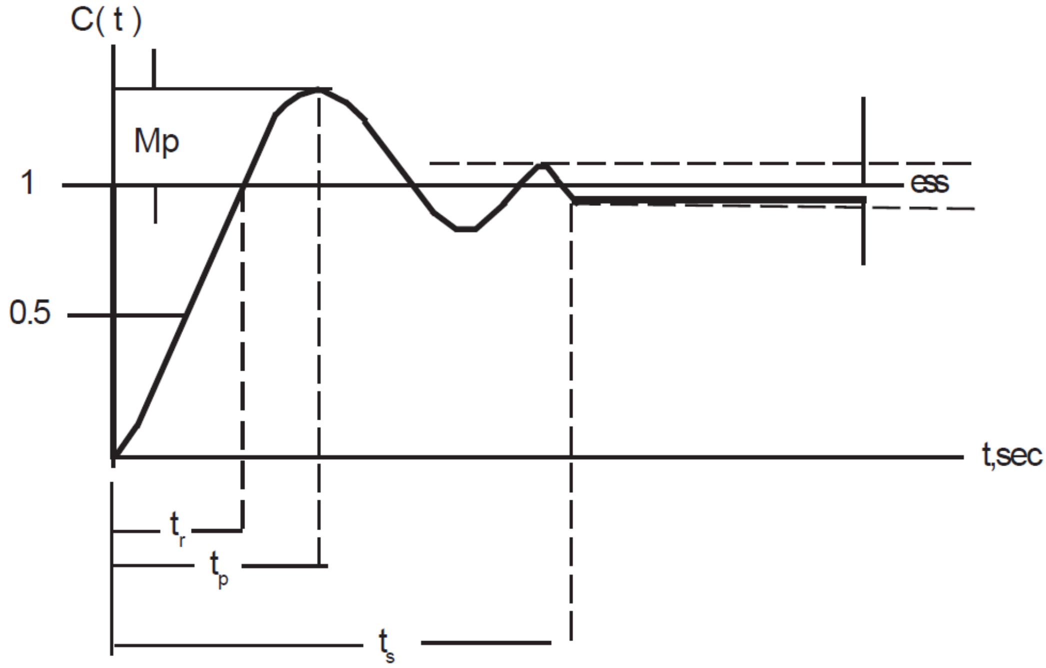


FIG. 6a. Typical step response of 2nd order system.

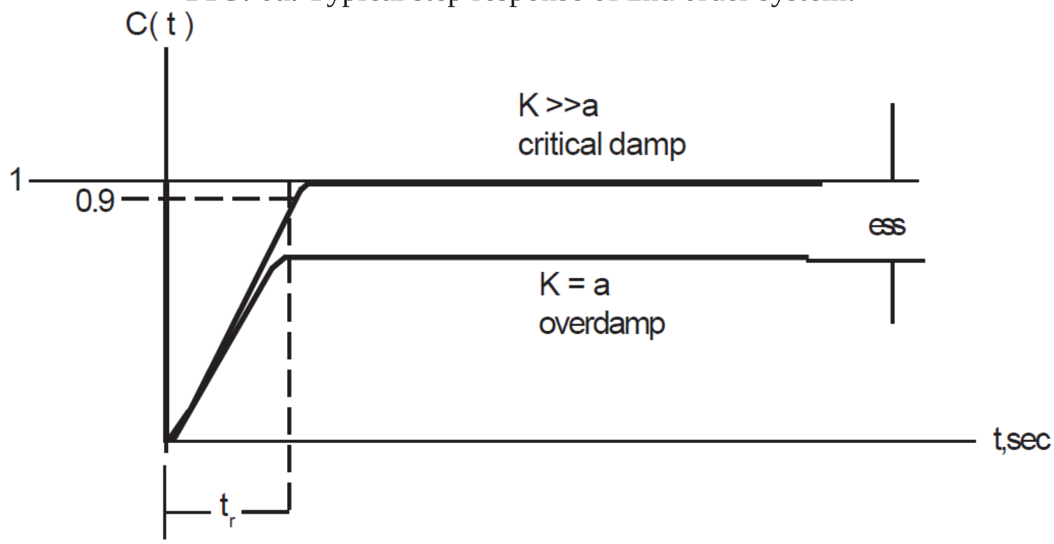


FIG. 6b. Typical step response ζ = 1 and > 1.

3. Press mode for capture cycle. Apply step input and observe the displayed curve.
4. Increase $-K_D$ to 0.6 and observe the curves applying step signal.
5. Remain $K_A = 7$. Set $K_D = 0.4$ and its direction towards +ve selected from the rear switch situated in motor unit. Conclude the difference between with and without application of tacho feedback, with the respective polarity.
Note: At higher gains K = 10 the +ve tacho feedback might unstable the system. To cure the problem either reduce gain K or switchover to -ve tacho mode.
The K_D = 1V/ rad / sec. where x is multiplying factor adjusted by panel control.

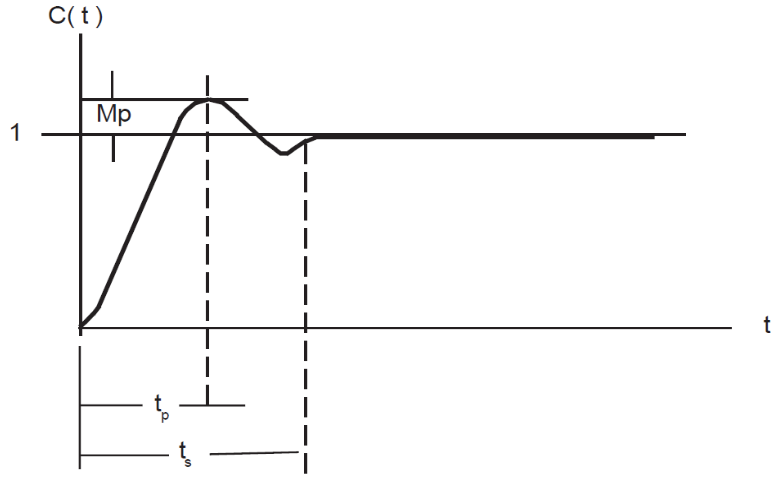


FIG. 7a. Typical step response of system with zero tacho. KA = constant.

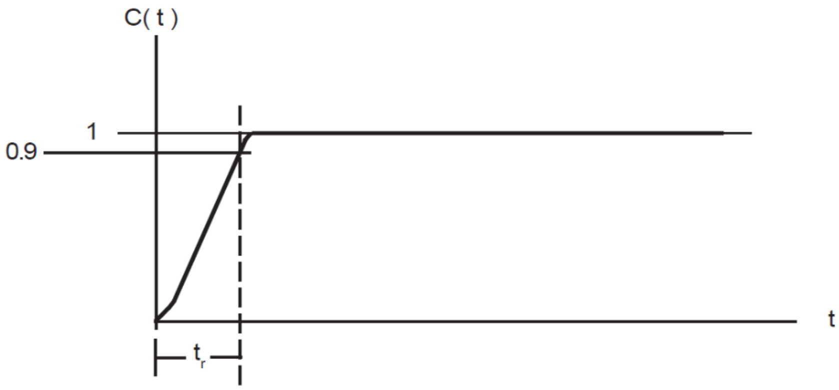


FIG. 7b. Typical step response of system with -ve tacho. KA = constant.

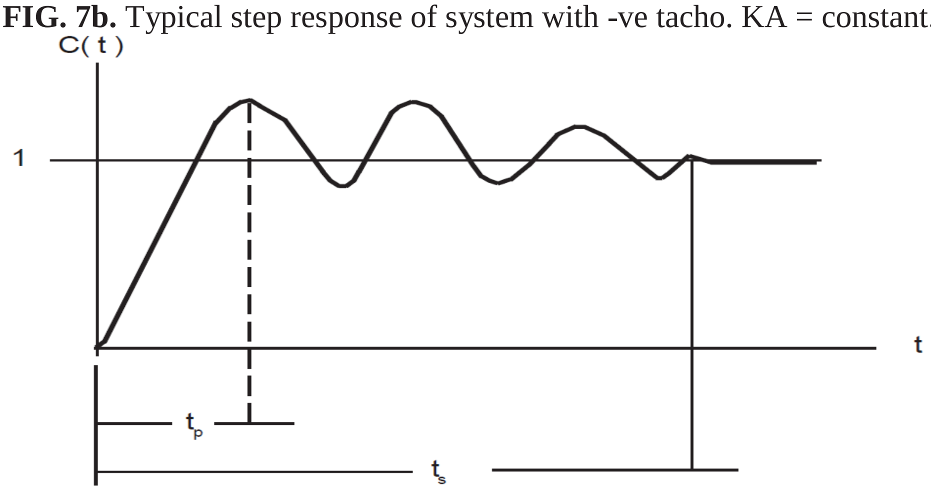
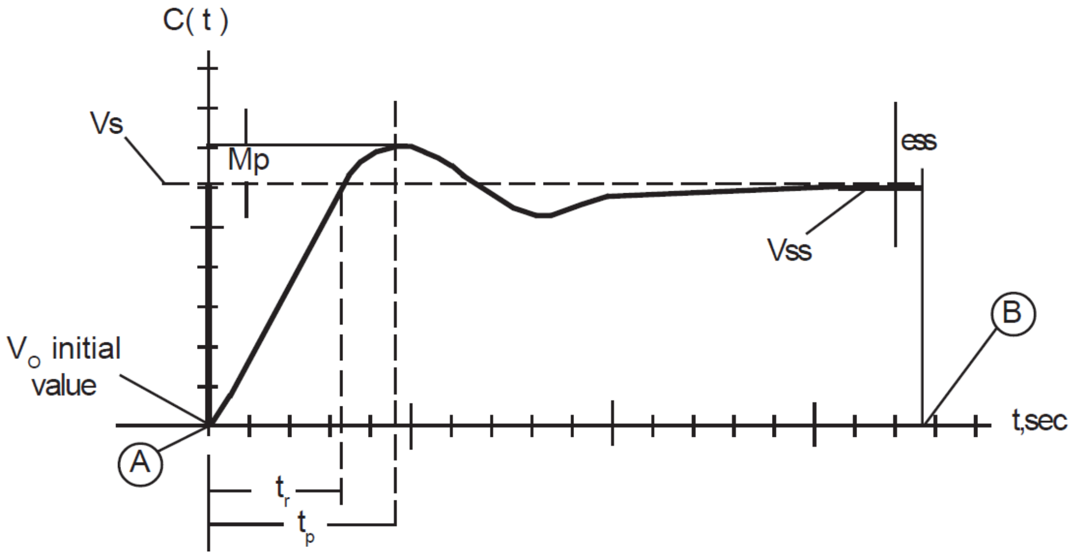


FIG. 7c. Typical Step response of system with +Ve Tacho. KA = Constant.



Typical step response of 2nd order system for example.

In Fig. above, A = start time, B = End time after completion of transient capture period, ess = (Vr + Vs) - Vo steady state or Vss. Vo initial is voltage just before the step command initiate.

Example for calculation

As shown in curve for example the maximum overshoot found

0.06V and the peak time tp is 0.95 sec, ess 0.05.

Now from Mp the equation is $Mp = \exp(-\pi\zeta / \sqrt{1-\zeta^2})$

or

$$\zeta = \frac{(\ln Mp)^2}{\pi^2 + (\ln Mp)^2} = 0.445$$

Given tp = 0.95 sec

and $tp = \pi / \omega n \sqrt{(1-\zeta^2)}$

or $\omega n = \pi / tp \sqrt{(1-\zeta^2)} = 3.69$ rad / sec

also $tp = \pi / \omega d$

or $\omega d = \pi / tp = 3.3$ rad / sec

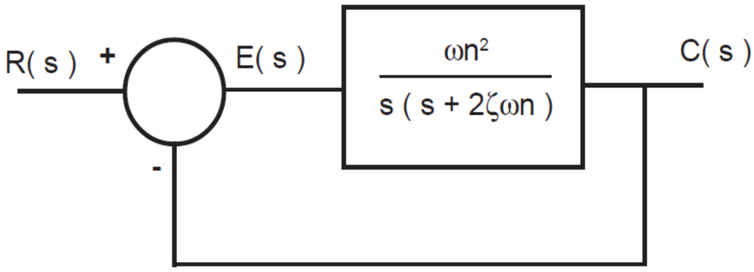
$\sigma = \zeta.\omega n = 1.64$

$\beta = \tan - 1.\ \omega d / \sigma = 1.1$rad

$tr = \pi - \beta / \omega d = 0.62$ sec

$ts = 3 / \sigma = 1.83$ sec for 5% creterion & 2.45 sec for 2% creterion.

The close loop block diagram is as shown below:



$$\frac{C(s)}{E(s)} = \frac{13.6}{s^2 + 3.284s} \qquad \frac{C(s)}{R(s)} = \frac{13.6}{s^2 + 3.284s + 13.6}$$

It is an underdamped case.

For open loop, $\omega n^2 / K_A.s(s + 2\zeta\omega n\ s)$

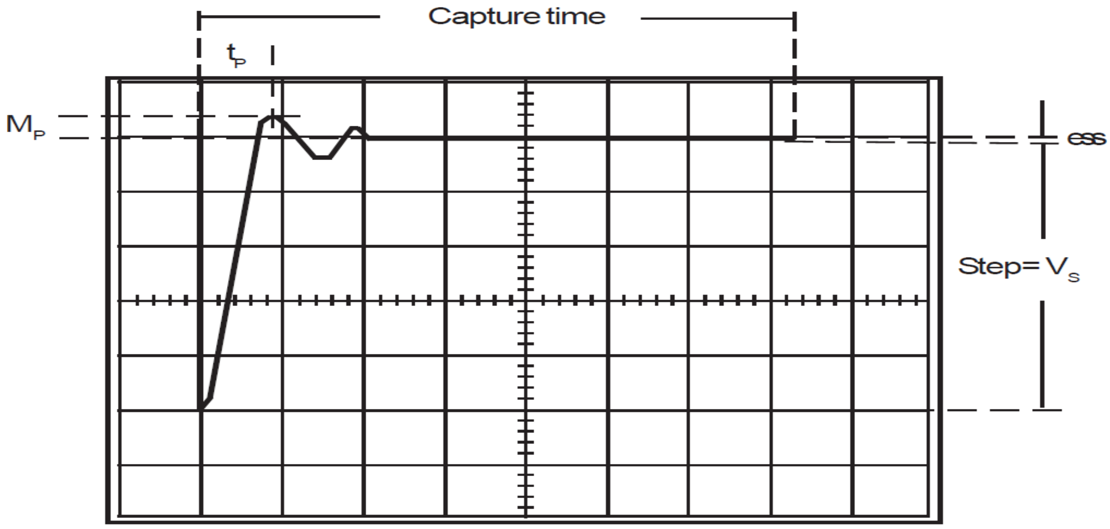
Other calculations may have performed from given motor details in page 1, whether L of the motor can be neglected.

System imperfections.

a. The sampling amplifier saturates when it exceeds input voltage more than 4 volts (the reference is between -0.6to + 4.5V). Thus a limitation is required for command position restricted to 90 + 900, (equal to VR and addition of VS makes it about 4 volt limit) although it does not produce any problem for study purpose.

b. Saturation of armature current (necessary to protect driver transistors) leads to slower response especially when motor get reversed its direction. At high drive currents motor shows integrator response, but at low drive currents motor shows dead zones by flattened curves. The peak overshoot does not increase for large KA due to current limit.

c. A fraction in gears and small voltage particularly in low gain setting does not allow motor to run, which cause high ess rate.



Typical example of step response of system KA = 6 & Kd = 0.

Experiment No. 12

Aim: To study temperature control system.

Before commencing experiment, the system should be familiarized. The process in form of oven has 9 pin D type connector which should be connected with the female socket provided upon the panel. The controller parameters are controlled by P I D controls in which I control can be out of circuit by mean of 'I ON' control switch. The D control is made out by mean of keeping D control to minimum or fully counter – clockwise direction. The set point temperature is adjusted by 'SET POINT' control while the reference temperature is read by digital display keeping TEMP switch to Set point direction. The heater may be cut - off regardless of any setting by mean of 'Heater ON' switch.

A fan is included in the oven which is used to bring temperature below when the heater is off. The similar one is used to add disturbance when the setup is running under PID control mode.

To observe the process characteristics.

Other apparatus required: *A stop watch.*

1.1. Connect the oven with the set up. Keep 'I on' switch towards off. Keep Heater switch in off position. The D control at minimum and P control near centre for P = 12, position (dial setting 6).

1.2. Switch on the power. The display will be on. Select Temperature switch (situated just below of display) to OVEN side. Note the temperature when heater is off.

1.3. Now select the Temperature selector to S.P side. Adjust SET POINT control to raise the reference temperature about 20 degrees (50-600).

1.4. Select the Temperature selector again to oven. Switch on the heater and start the stop watch simultaneously. Note the oven temperature at 5, 10, 20, 30 seconds till the temperature becomes nearly stable at any degree.

1.5. Plot the curve between the temperature and the time. Find out the inflection point (where curve bends to parallel) from the curve. Draw the tangent line and find out the T & L.

2. To observe the signal conditioner characteristics.

Other apparatus required: A digital multi-meter.

2.1. Connect the oven with the set up. Keep 'I on' switch towards off. Keep Heater switch in off position. The D control at minimum and P control at centre for P = 12, position (dial setting 6).

2.2. Switch on the power. The display will be on. Select Temperature switch (situated just below of display) to OVEN side. Note the temperature when heater is off.

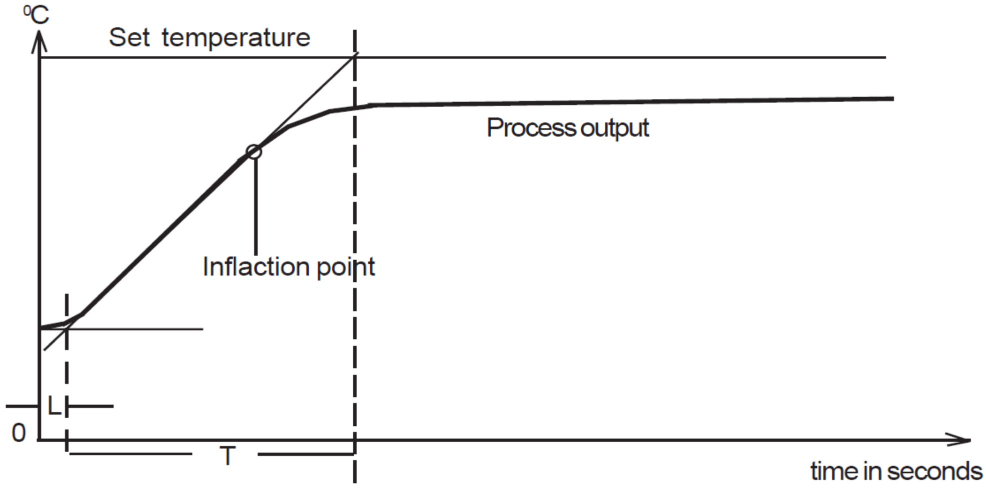


Fig. 1. Typical response curve.

2.3. Now select the Temperature selector to S.P side. Adjust SET POINT control to raise the reference temperature about 20 degrees.
2.4. Connect digital multimeter at the error detector negative mark input or in other words connect DMM (2Vdc range) across the ground '0' and signal conditioner output.
2.5. Select the temperature switch to oven side. Note the temperature and the voltage at error detector input.
2.6. Switch on the heater and note the error detector negative side input voltage as temperature becomes stable. Find out the difference between temperature and the output voltage. Find out the conversion ratio of signal conditioner (10mV/C0)
2.7. The difference between the reference input (at positive terminal input of error detector) and the signal conditioner output is called as e(t) the time generated error signal.

3. The P control.

Other apparatus required: A stop watch.
3.1. Switch off the heater and I control by mean of I ON switch. Keep D control to minimum i.e. at 0.
3.2. Select S.P at display and adjust the temperature to 600. Select the OVEN and note the current temperature. Set P control at midway Kp = 10.
3.3. Switch on the heater and start the stop watch at same instant. Note the temperature at 10 second intervals till it get nearly stable.
3.4. Switch off the heater. Switch on the fan. Allow time to cool down the heater. When temperature approach to previous value, switch off the fan.
3.5. Now adjust KP = 16 (8th major gradient). Switch on the heater and stop watch. Note the temperatures at 10 second interval.
Plot the graph between time and temperature. Find the steady state error from the plot. It is observed that ess reduced when Kp increased but it does not go minimum.

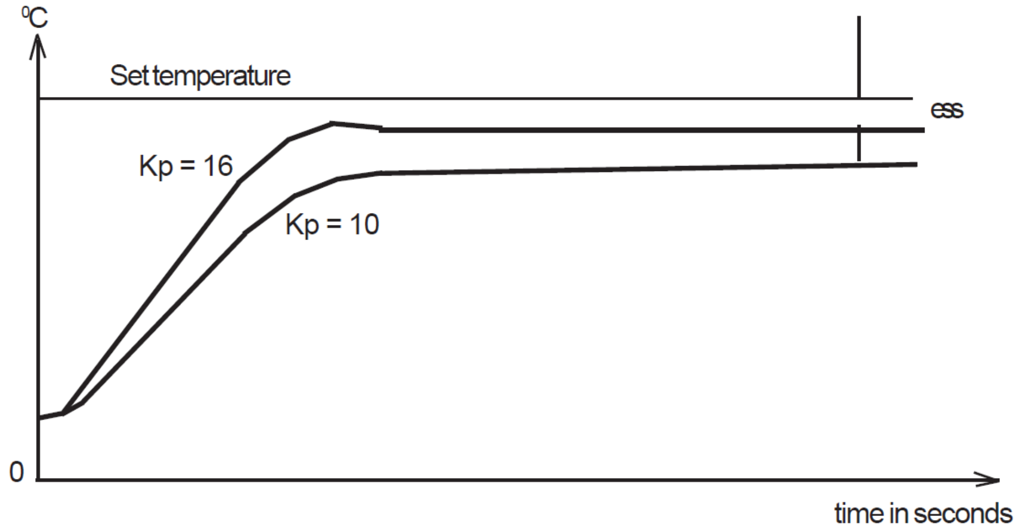


Fig. 2 Typical response curve at different Kp.

4. The PI control.

Other apparatus required: A stop watch.
4.1. From the response curve taken in experiment 1, apply Kp and Ki Values.
4.2. Set S.P at 600. Select oven temperature at display reading. Switch on the heater and start the stop watch. Note the temperature* at regular intervals of 10 seconds.
4.3. Plot the response curve from the results obtained from the experiment.
* In PI control mode the settling time may be increased to several minutes. Take a margin of minimum accessible say 3% criteria. Draw the curve to show the effect of controller. The settling time may also be evaluated from Mp and peak response time.

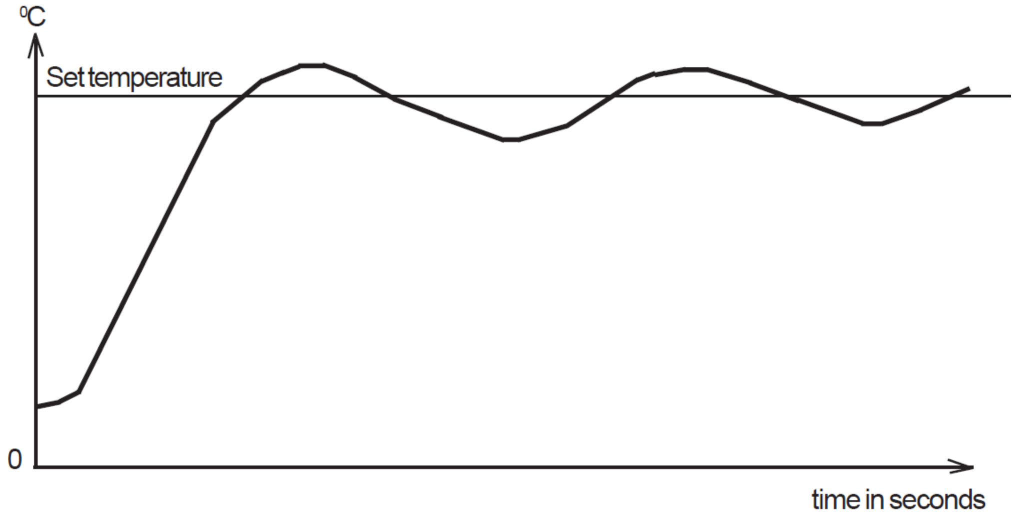


Fig. 3 Typical response curve with PI controller.

5. The PID control.

Other apparatus required: A stop watch.

5.1. From the response curve taken in experiment 1, apply Kp, Ki and Kd Values.

5.2. Set S.P at 600. Select oven temperature at display reading. Switch on the heater and start the stop watch. Note the temperature* at regular intervals of 10 seconds.

5.3. Plot the response curve from the results obtained from the experiment. Find out the %error from the plot as Tset - Toven / Tset x 100.

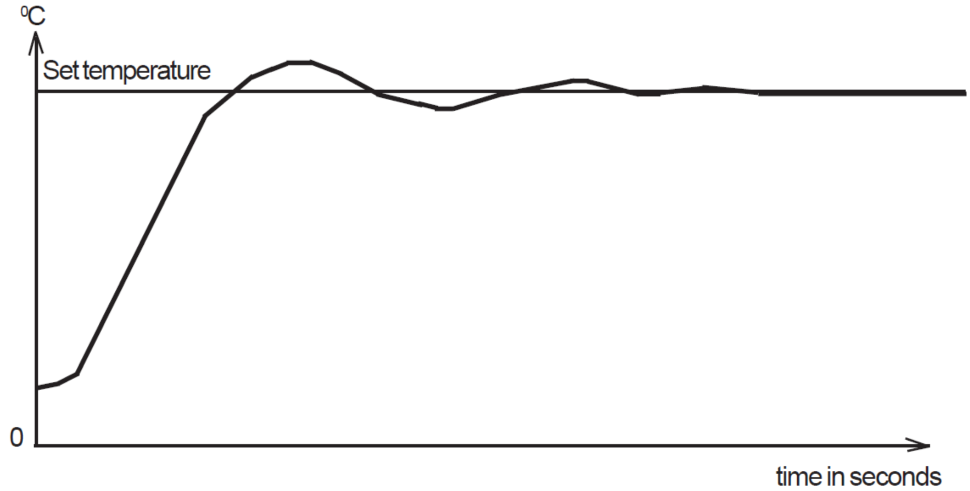


Fig. 4 Typical response curve with P.I.D controller.

5.4 Change the temperature setting and adjust Kp according to it. Note as given in page 4, the Ki and Kd is effected by Kp, and system constant does effect only Kp.

5.5. Take a final curve from the controlled process. Find out the Mp and tp from the curve. Calculate the damping factor and undamped natural frequency. Write the transfer function of the system.

6. The PID controller performance with disturbance.

6.1. From the response curve taken in experiment 1, apply Kp, Ki and Kd values.

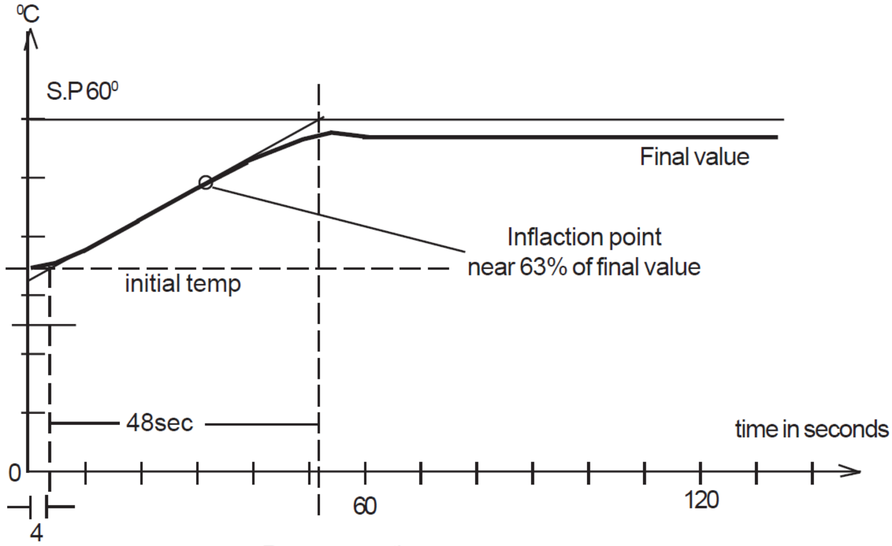
6.2. Set S.P at 600. Select oven temperature at display reading. Switch on the heater and start the stop watch. Note the temperature* at regular intervals of 10 seconds.

6.3. When temperature becomes stable, observe the controller output current. Switch on the fan to add disturbance. Observe the controller output current. It gets increased to cover up the error introduced by the disturbance.

When temperature becomes stable note it and calculate the error percent added by the disturbance.

7 Example for experiment.

The set point temperature is 600. The initial temperature is 350. Kp = max Following curve is obtained.



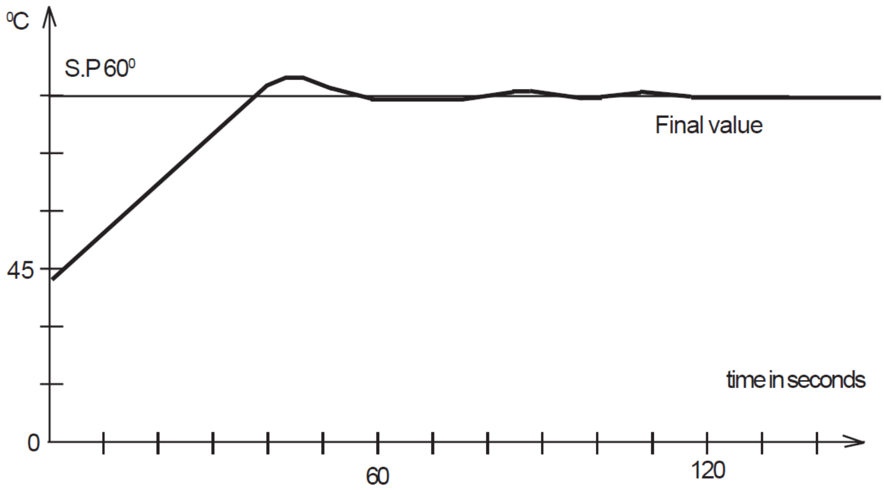
Process reaction curve.

The process has a unity gain (no amplification involved) and has an output response as 1st order system as: 1 / sT +1.

Kp is adjusted 12 (6.0 of dial setting) ess found 12% which is nominal in proportional control of such system.

Kp is adjusted for 11 (dial setting 5.5) and Ki 12.1 (dial setting at 7.5 of I). Maximum overshoot is 6.8%, with tp 60 second. Ts is very long for 5% criteria it is about 5 minute. The system is second order involvement since of integral term in controller.

Kp adjusted between 7 - 7.5 of dial position, Ki at dial 5.5, and Kd at dial 4. The response overshoot is 3.3%, tp 60 second and Ts for 2% criteria is 150 second and final ess 0.2%. The controller output is stand still. With disturbance added the ess increase to 0.5% in steady state condition.



Response curve for PID controlled system.

Experiment No. 13

Aim: To study lag-lead compensators.

Introduction:

Compensation network are oftenly used to made appreciable improvement in transient response and small change in steady state accuracy. This set up has facilitate to study and design implementation of such networks. Three of such networks are given in the set up and performance of other designed networks can be implemented using few passive components.

Set up description: The setup is divided in to three parts (a) Signal sources, (b) Uncompensated system, and (c) Compensators.

a. There are three signal sources provided in the set up.

1. **Sine Wave** : It is available through socket in marked frequencies spanning across two decades as, 10Hz to 1000Hz. The signal has (8Vpp approx.) un-calibrated output with reference to ground. The frequency selection is made with coarse selector between X10 or X100 and multiplied with dial digit.

2. **Square Wave** : It is available in fixed frequency, 40Hz. The output is fixed about 1Vpp in amplitude.

3. **Phase Angle Meter** : It is an analog meter provided to take readings of respective phase angle between given signal input - output, where its one input is connected internally with sine wave source. Tolerance ±05°, ±1 count.

b. These are simulated system of unknown dynamics

1. **Process or plant** : It consists of an active network simulation of second order system. The transfer function is, $K/(sT+1)^2$.

2. **Gain 2 Block** : It is an amplifier provided to compensate the K_c. The gain setting is variable between, $-K_c = 0 - 10$, by mean of a calibrated dial. The input/output is phase shifted by 180°.

3. **Error Detector Cum Gain** : This block has two inputs (e1, e2) and an amplifier has an output equal to $e_0 = K_A$ (e1 + e2), where K_A is variable between 1-10 by a calibrated dial and e_1 is 1Vpp Square Wave. The input/output is in phase.

4. **Compensation Circuit** : There are three compensation circuits as Lag, Lead and Lag - Lead with transfer functions in form of $Gc(s) = (K_c)\alpha(sT1+1/sT2+1)$ and $(K_c)\beta(sT1+1/sT2+1)$ where (K_c) is implemented by gain compensation amplifier by Gain 2 Block.

c. **Power Supply** : The set up has two symmetrical DC regulated power supplies for signal sources and systems.

d. **Amp.** : It is an inverting amplifier having $K=-1$, required to invert phase of feedback signal.

About the experiment:

The experimental work is divided in two parts :

1. (a - e) the open loop response and
2. (A - B) the close loop response.

In open loop response in first step the magnitude / frequency and phase / frequency plots are performed. A dual trace CRO is essential for experimental steps (optional phase angle meter).

Exp. 1 – Open loop response.

EQUIPMENT REQUIRED

1. Lead - Lad Compensator System
2. Dual Trace CRO
3. Phase Angle Meter (Optional)

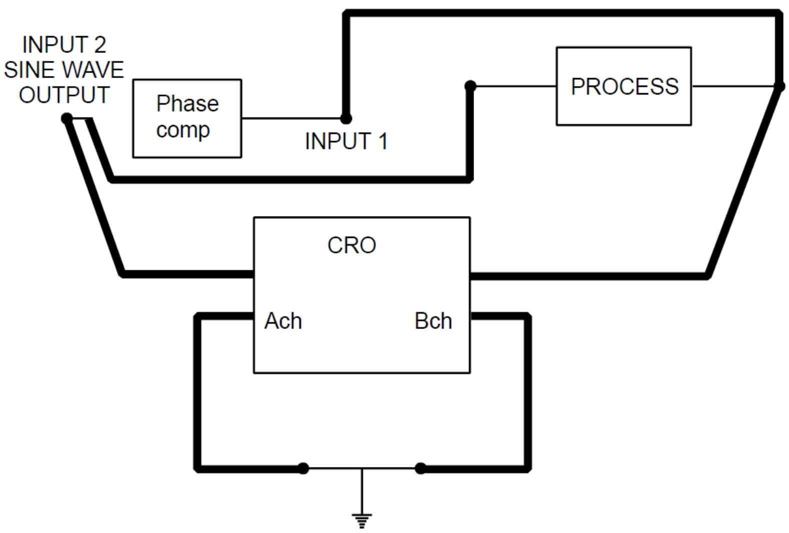


Fig. 1 Open loop response of process.

PROCEDURE

1.1 Connect the sine source with process / plant input. Connect CRO across input and output (dual trace mode). Measure input voltage A = ...Vpp.

1.2 Start from the low frequency end (10Hz), increase frequency in step of 10, 20, 30, 40, 50Hz for linear mode 10, 20, 40, 80, 100, 200 for octace mode and note the output voltage Vpp as B. Note the phase difference for each test frequency.

1.3 Prepare a table between input - output volts, the gain magnitude in dB ($20\log_{10}B/A$) and phase angle in degree.

1.4 Sketch the phase / frequency (Bode plot) response for smooth curves upon semilog paper. From the low frequency and obtain the error coefficient and required gain K_A.

Typical table (example) for plotting of response curve (Process or plant)

f Hz	A Vpp	B Vpp	Gain dB	/ ϕ
10	...V	...V	dB	n°
20	“	“	...	...
40	“	“	...	...
80	“	“	...	...
100	“	“	...	...
200	“	“	...	...
400	“	“	...	...
800	“	“	...	...
1000	“	“	...	...

Typical table (example) for plotting of response curve (Process or plant)

Freq	A Vpp	B Vpp	Gain dB	ϕ
10	...V	...	...	...
20	“	“	...	...
40	“	“	...	...
80	“	“	...	...
100	“	“	...	...
200	“	“	...	...
400	“	“	...	...
800	“	“	...	...
1000	“	“	...	...

Exp. 2 – Open loop response of Lag compensator.

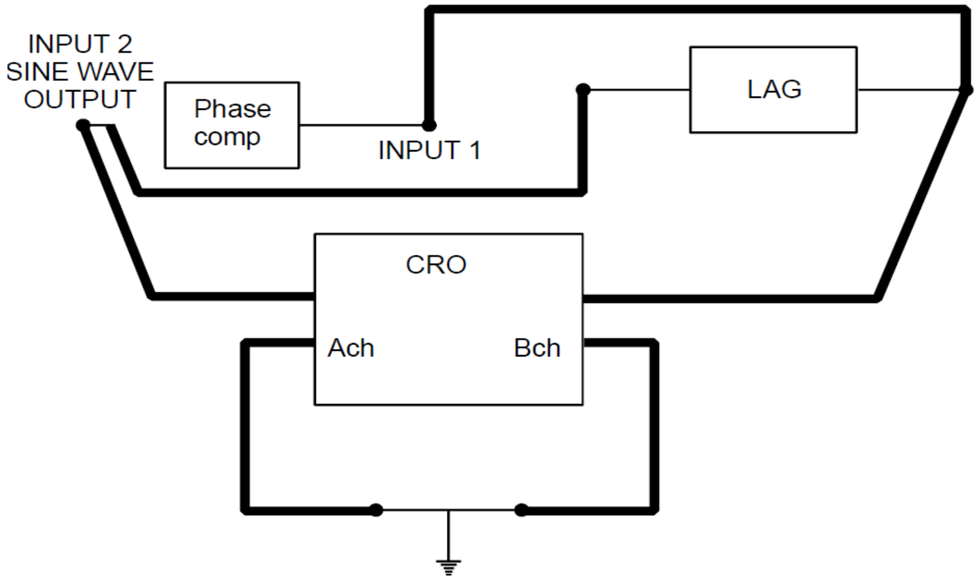


Fig. 2 Open loop response of Lag compensator.

PROCEDURE

2.1 Connect the sine source with Lag input. Connect CRO across input and output (dual trace). Measure input voltage A...........Vpp.

2.2 From the low frequency end (10Hz) note the output voltage Vpp as B. Note the phase difference for each test frequency as previous experiment.

2.3 Prepare a table between input - output volts, the gain magnitude in dB ($20\log_{10}B/A$) and phase angle in degree.

2.4 Sketch the Bode plot for smooth curves upon semilog paper. From the low frequency end obtain the error coefficient and gain K.

Typical table (example) for plotting of response curve (Lag Compensator)

Freq	A Vpp	B Vpp	Gain dB	ϕ
10	...V	...	...	...
20	"	...	...	...
40	"	...	...	...
80	"	...	...	...
100	"	...	...	...
200	"	...	...	...
400	"	...	...	...
800	"	...	...	...
1000	"	...	...	...

Exp. 3 – Open loop response of Lead compensator.

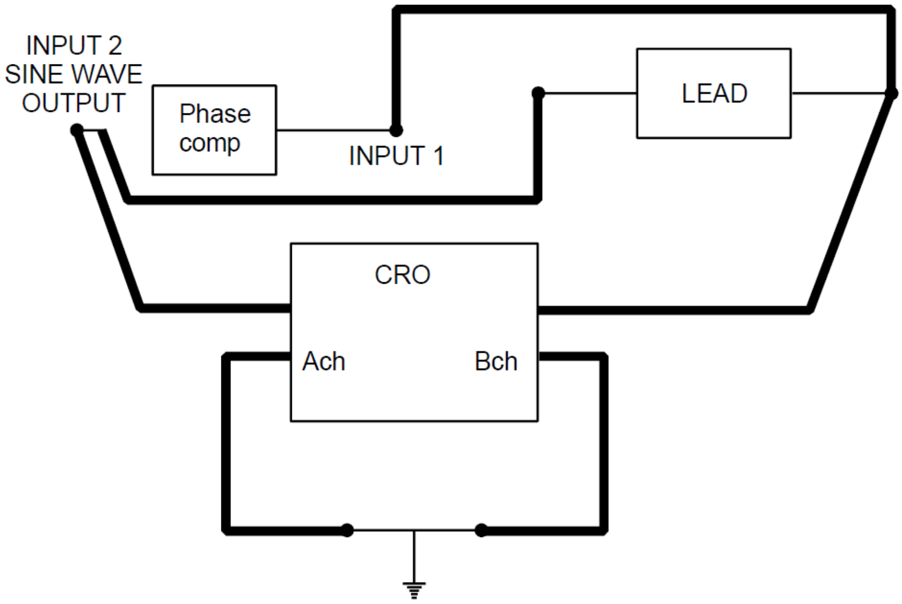


Fig. 3 Open loop response of Lead compensator.

PROCEDURE

3.1 Connect the sine source with Lag input. Connect CRO across input and output (dual trace). Measure input voltage A...........Vpp.

3.2 From the low frequency end (10Hz) note the output voltage Vpp as B. Note the phase difference for each test frequency as previous experiment.

3.3 Prepare a table between input - output volts, the gain magnitude in dB ($20\log_{10}$B/A) and phase angle in degree.

3.4 Sketch the Bode plot for smooth curves upon semilog paper. From the low frequency end obtain the error coefficient and gain K.

Typical table (example) for plotting of response curve (Lead Compensator)

Freq	A Vpp	B Vpp	Gain dB	ϕ
10	...V	...	...	...
20	"	...	...	...
40	"	...	...	...
80	"	...	...	...
100	"	...	...	...
200	"	...	...	...
400	"	...	...	...
800	"	...	...	...
1000	"	...	...	...

Exp. 4 – Open loop response of Lag-Lead compensator.

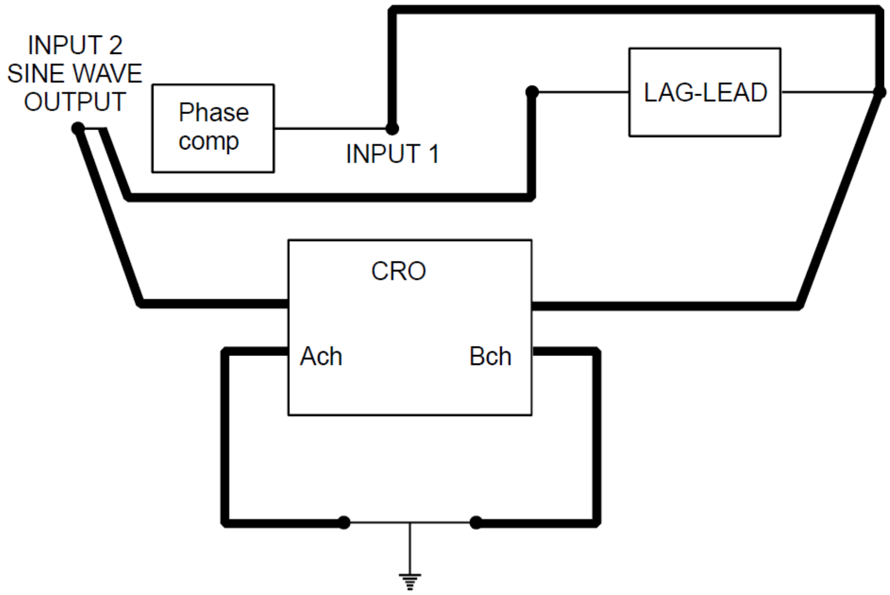


Fig. 4 Open loop response of Lag-Lead compensator.

PROCEDURE

4.1 Connect the sine source with Lag input. Connect CRO across input and output (dual trace). Measure input voltage A..........Vpp.

4.2 From the low frequency end (10Hz) note the output voltage Vpp as B. Note the phase difference for each test frequency as previous experiment.

4.3 Prepare a table between input - output volts, the gain magnitude in dB ($20\log_{10}B/A$) and phase angle in degree.

4.4 Sketch the Bode plot for smooth curves upon semilog paper. From the low frequency end obtain the error coefficient and gain K.

Typical table (example) for plotting of response curve (Lag - Lead Compensator)

Freq	A Vpp	B Vpp	Gain dB	ϕ
10	...V	...	...	...
20	"	...	...	...
40	"	...	...	...
80	"	...	...	...
100	"	...	...	...
200	"	...	...	...
400	"	...	...	...
800	"	...	...	...
1000	"	...	...	...

Exp. 5 – Open loop response of Plant with compensator.

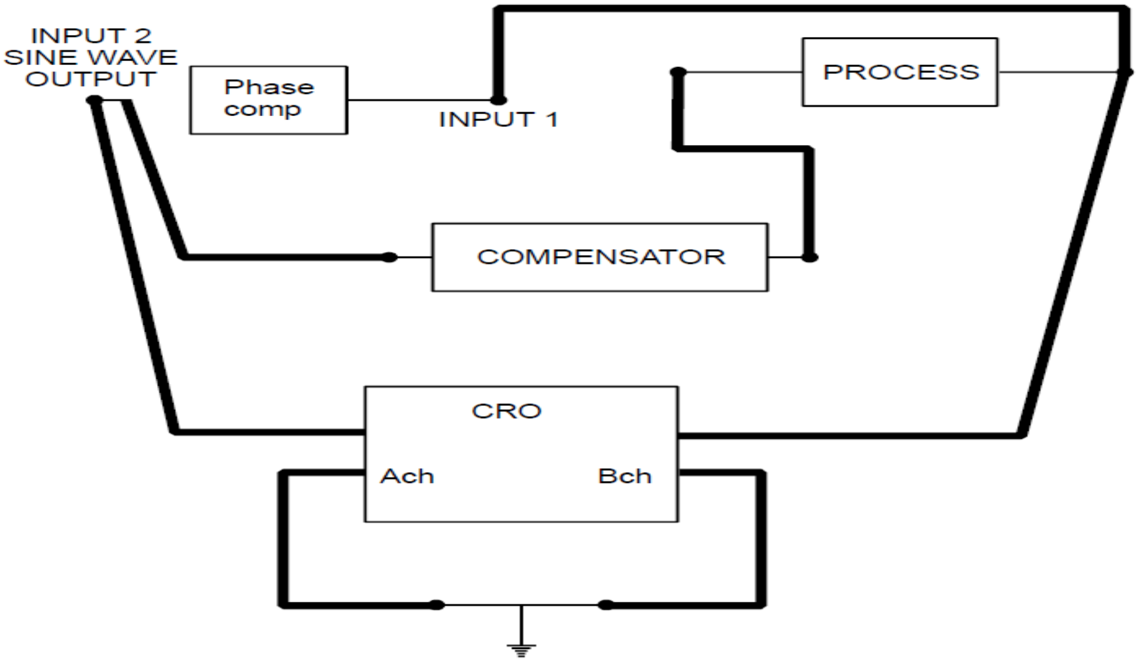


Fig. 5 Open loop response of Plant + compensator.

PROCEDURE

5.1 Connect the system as shown in fig. 3. Measure sine wave signal of .....Vpp at the input of the compensator with connecting CRO channels at input / output.

5.2 The readings between input / output as A and B, phase relation between them may be taken either by linear increment as, 10, 20, 30, 40, ... or by octave steps, as 10, 20, 40, 80, 100, 200, 400, 800 & 1000Hz.

5.3 Tabulate the results as given in exemplary tables.

Typical table (example) for plotting of response curve Plant + (Lag)

Freq	A Vpp	B Vpp	Gain dB	ϕ °
10	...V	...	...	...
20	"	...	...	...
40	"	...	...	...
80	"	...	...	...
100	"	...	...	...
200	"	...	...	...
400	"	...	...	...
800	"	...	...	...
1000	"	...	...	...

Typical table (example) for plotting of response curve Plant + (Lead)

Freq	A Vpp	B Vpp	Gain dB	ϕ °
10	...V	...	...	...
20	"	...	...	...
40	"	...	...	...
80	"	...	...	...
100	"	...	...	...
200	"	...	...	...
400	"	...	...	...
800	"	...	...	...
1000	"	...	...	...

Typical table (example) for plotting of response curve Plant + (Lag - Lead)

Freq	A Vpp	B Vpp	Gain dB	ϕ °
10	...V	...	...	...
20	"	...	...	...
40	"	...	...	...
80	"	...	...	...
100	"	...	...	...
200	"	...	...	...
400	"	...	...	...
800	"	...	...	...
1000	"	...	...	...

Exp. 6 – Closed loop response of Plant with compensator.

PROCEDURE

6.1 Connect process with Lag compensator and gain 2, in the circuit Remain the gain 1 to previous adjustment (for example 3.2). Adjust gain 2, to compensate the compensator loss (10dB/decade = gain 3.2). Note the gain 2 setting from the dial. Trace the waveform upon paper, with record of Mp, tp and e_{ss}.

Compute ζ and ωn for process with Lag compensator.

6.2 Connect process with Lead compensator and gain 2, in the circuit. Trace the waveform upon paper, with record of Mp, tp and e_{ss}.

Compute ζ and ωn for process with Lead compensator.

6.3 Connect process with Lag - Lead compensator and gain 2, in the circuit. Trace the waveform upon paper, with record of Mp, tp and e_{ss}.

Compute ζ and ωn for process with Lag-Lead compensator.

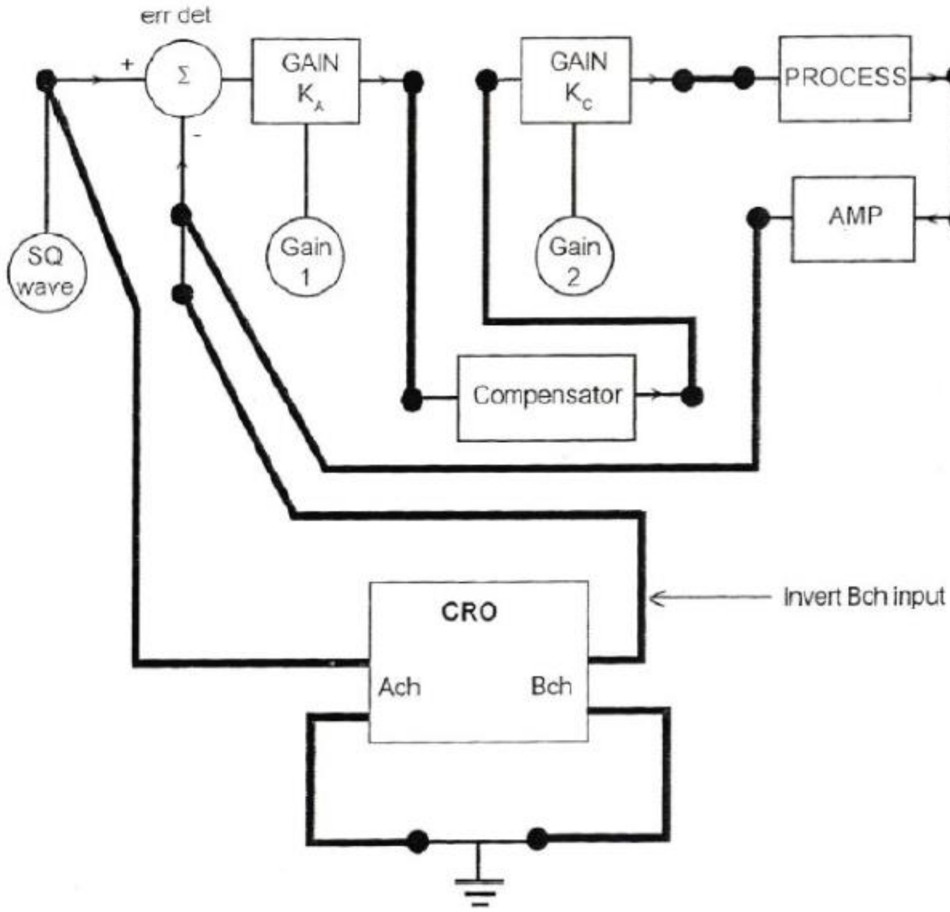


Fig. 6 Closed loop response of Plant + compensator.

Now from the transient response for each experiment tabulate the result.

Typical table (example) for comparison of close loop transient response. Test frequency 40Hz sq 1Vpp.

Configuration	Mp	tp	e_{ss}	ζ	ωn	Comment
Process only	...	...mS	...V	...	...rd	...
Process + Lag	...	...mS	...V	...	...rd	...
Process + Lead	...	...mS	...V	...	...rd	...
Process + Lag -Lead	...	...mS	...V	...	...rd	...

Experiment No. 14

Aim: To study speed-torque characteristic of AC servo motor.

INTRODUCTION :

The devices used in electrical control system are AC and DC servomotors AC servomotor has best suit for low power control applicatioins. It is rugged light weighted and has no brush contacts as in case of DC servomotors. The important parameter of AC servomotor is its speed - torque characteristics. This set up is made to study of such AC servomotor characterisitcs. The set up description is given at page.

The AC Servomotor :

An AC servomotor is basically a two phase induction motor except for certain design feature. The two phase induction motor consists of two stator windings oriented 90° electrical apart in space and excited by AC voltage which differe in time-phase by 90°. In fig. 1, the schematic diagram for balanced operation of motor is shown where voltages of equal rms magnitude and 90° phase difference are applied to the two phase stator, thus making their respective field 90° apart in both time and space, resulting in a magnetic field of constant magnitude rotating at synchronous speed. The direction of rotation depeds upon phase relationship of input voltage V1 and V2. As the field sweeps over the short - circuited rotor, voltages induced in it producing current in it. The rotating magnetic field interacts with these currents produce a torque on the rotor inthe direction of field rotation.

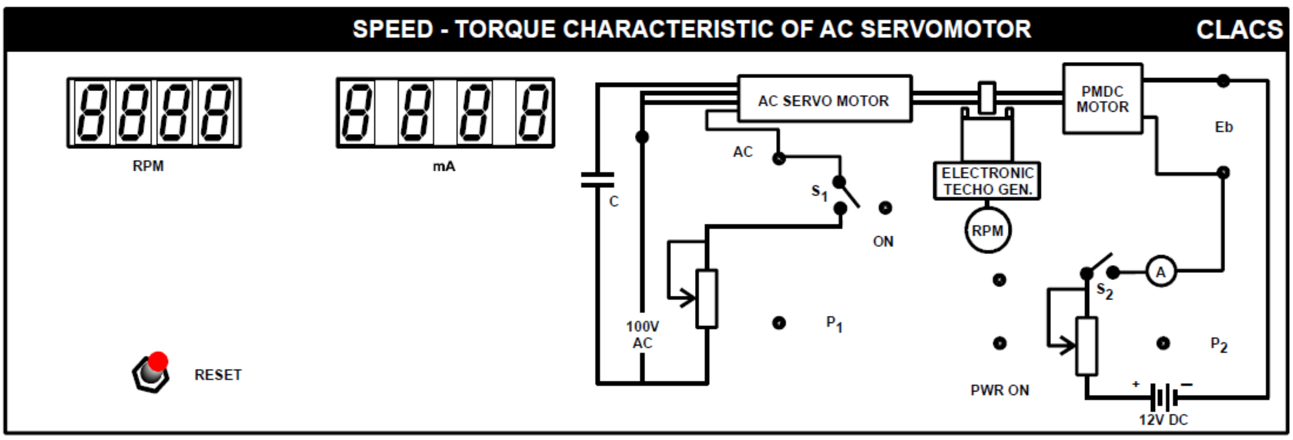


Fig. 1 Front panel view.

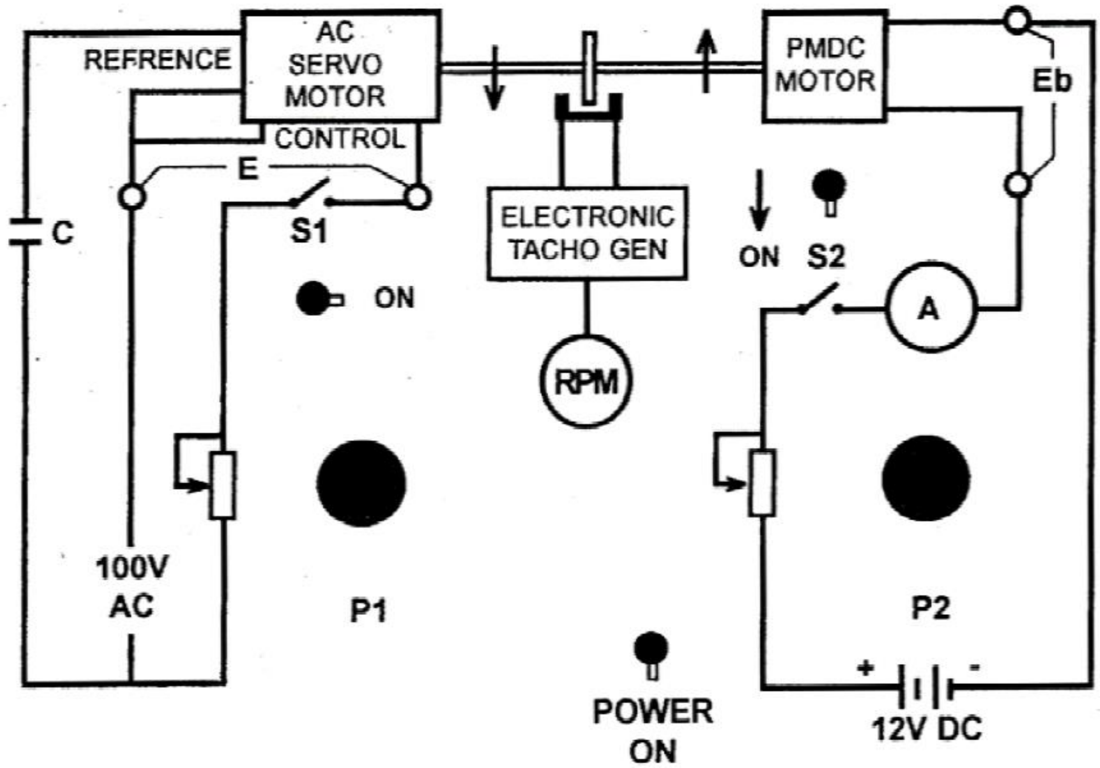


Fig. 2 Panel schematic with measurement points. P1 meant for AC servo motor speed control. P2 for DC motor speed control i.e., load control.

EXPERIMENTAL PROCEDURE :

Other apparatus required : Digital Multimeter.

Look at the panel, the S1 is meant for to cut - off the AC servomotor control winding supply, where P1 shown as variable resistor is used to control the motor speed. Two sockets are fitted acrss the control winding to measure AC voltage E, applied across it with the help of P1 control.

Switch S2 is meant to connect given 12 volt DC supply to the DC motor. An ammeter in the circuit will read the current I_a in this case. Control P2 is used to vary the load current, hence the counter speed of the DC motor. When S2 is kept in off condition a speed - propotional dc voltage E_b, developed across the sockets given across the DC motor block.

The main power is applied to the set up by third mini toggle switch designated as "Power ON".

1. Switch off the switches S1 and S2. Keep both controls P1 and P2 to minimum (fully counter - clockwise).
2. Plug in the main cord into suitable electrical outlet. Switch on the power. A LED will glow in this condition fitted just under of panel meters.
3. Switch "ON" the S1 switch. Let S2 is in off position.

4. Slowly increase control P1 so that AC servomotor start rotating. you may have to give slightly higher voltage to start the servomotor, then you may decrease the voltage for lower speed.

5. Connect digital multimeter (20V DC range) across the DC motor sockets given in RED and Black colour.

6. Vary the speed of servomotor gradually and note the speed N rpm from panel meter, and corrosponding back emf E_b developed across the dc motor.

Record the observation in Table 1.

Observation Table - 1 :

Sr. No.	Speed N rpm	E_b volts
1	....	....
2	....	....
3	....	....
4	....	....
n	....	....

7. Connect digital multimeter (range 200V AC) across the servomotor control winding sockets. Now adjust AC servo motor voltage to 80 volt AC, $E_1 = 80V$.

Note the speed rpm in Table 2

8. Switch on S_2 to impose load upon the motor. The DC supply although at zero volt but it short out the DC motor armature and fall in speed observed. Note the current I_a and speed from panel meters in steady state condition.

9. Increase the load current by mean of control P_2 in slow manner and note the corrosponding speed and I_a in steady state conditioin. Record all the observations in table 2.

10. Prepare table 2, filling the E_b data from table 1 for the corrosponding speeds. Calculate P as $P = I_a.E_b$ in watt. Calculate the torque as given in expression 4.

11. Adjust servomotor voltage to another value say $E_2 = 70V_{ac}$. Repeat the step 7 - 10 and prepare another table. Prepare more tables for different E.

12. Draw speed - torque characterisitics curves.

Observation Table - 2 : E = ...V_{ac}. No load speed .... rpm

Sr. No.	I_a amp	E_b (tab 1)	Speed N rpm	P watt	Torque
1	....	....	....	....	....
2	....	....	....	....	....
3	....	....	....	....	....
4	....	....	....	....	....
n	....	....	....	....	....

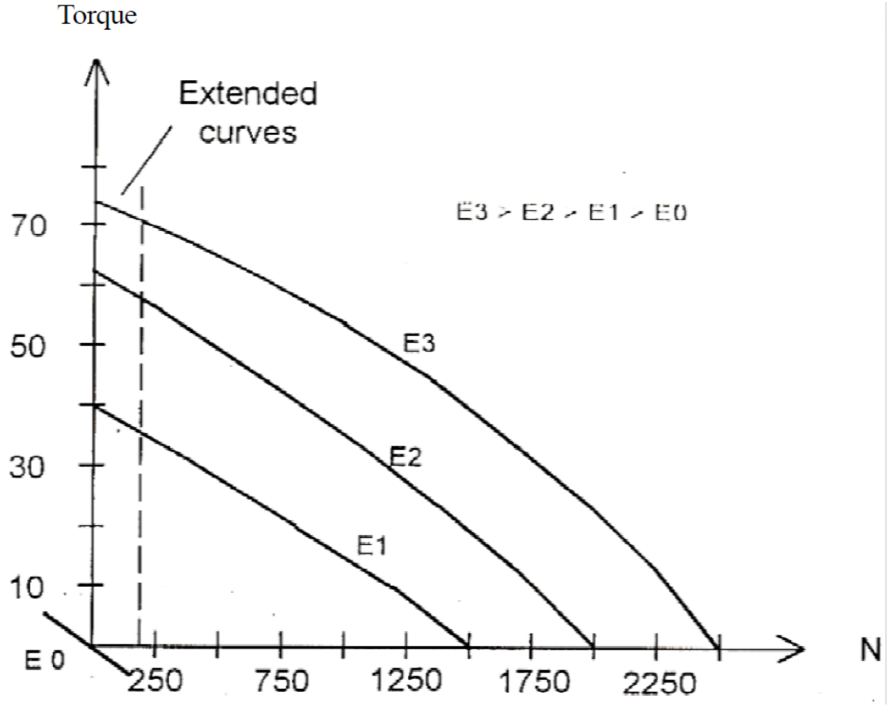


Fig. 3 Typical Speed-Torque curves for different values of E.

Speed N rpm	E_b volts
....	....
....	....
....	....
....	....
....	....

A curve drawn between back emf E_b, and speed N to find out the E_b constant. To find out E_b at any n rpm, the constant is multiplied by n.

Speed N rpm	Torque
2000	0
1600	0.12
1500	0.155
1250	0.02
1000	0.25
750	0.3
500	0.33
250	.375
0	0.4

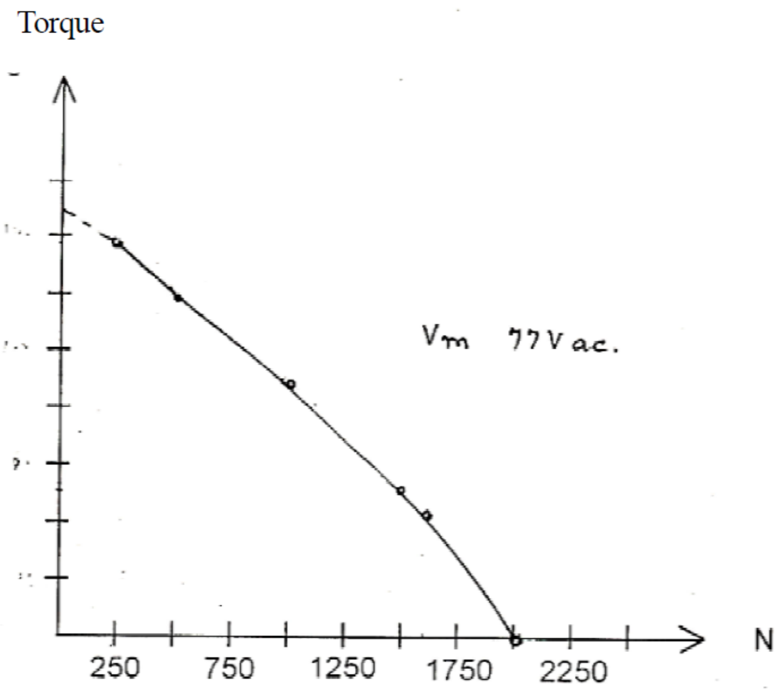


Fig. 4 Speed-Torque curves.

Speed N rpm	E_b volts
2250	4.30
2000	3.79
1750	3.36
1500	2.85
1250	2.40
1000	1.90
750	1.44
500	0.945
250	0.48

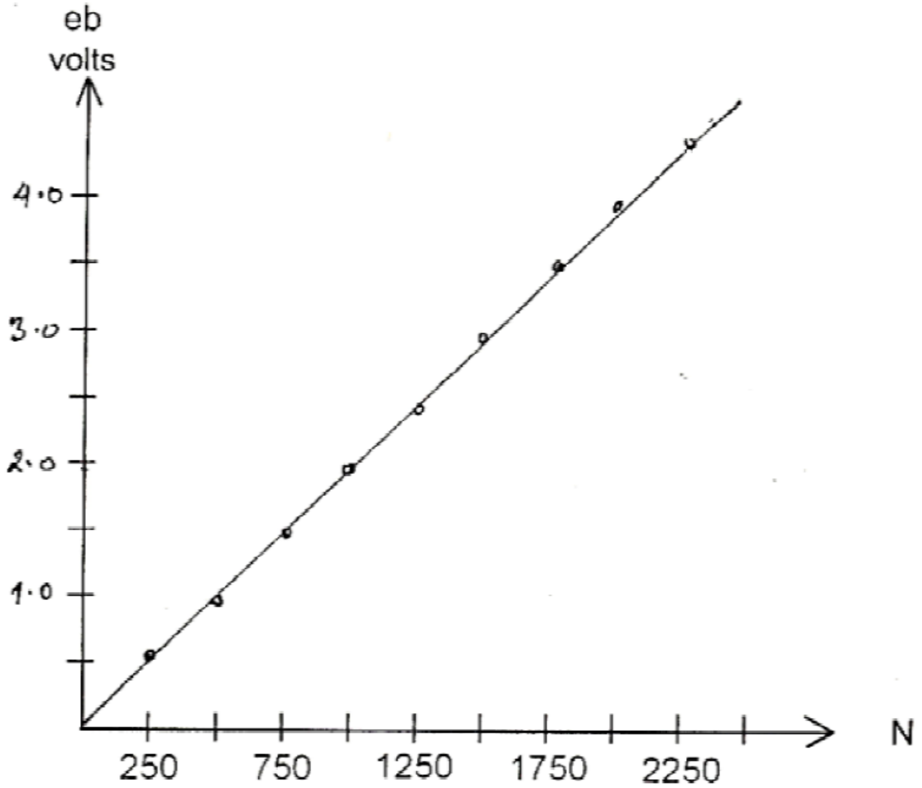


Fig. 5 Speed-Torque curves.

Measure E_b1 by multimeter while switch in OFF position. Now ON the switch, measure E_b2. Difference (E_b1-E_b2) will be the net E_b. Rotate the pot clockwise measure E_b2 and take the difference to note the reading.

Experiment No. 15

Aim: To study stepper-motor control system.

INTRODUCTION

This experimental set up is designed to study of a small stepper motor fitted with calibrated dial and servo potentiometer in see through cabinate. The main unit has a motor controller, pulse sequence generator, variable frequency square wave oscillator, single step monopulser and wobbling signal to observe dynamic response. The unit can be interface with μP kit feeding appropriate programme given at end pages.

Stepper Motor : A stepping motor is an electromagnetic incremental actuator which converts electric pulses to machanical movements. In rotary step motor the output (shaft) rotates in equal increments in response to a pulse train of input pulses. In general dc motors the speed is governed by applied motor voltages which runs contineously and its direction get reversed when the polarity of input voltages is reversed. Whether properly controlled output steps of a stepping motor are equal in number to the input pulses number. Reversing the order of pulse sequence reverse the motor direction and the speed of the motor can increament/decreament by repeatation rate. These are the prime features of a stepping motor. The features of given stepping motor used in this set up following

Type of the motor : PM Hybrid DC stepping motor, two phase biflar wounded.

Stepping angle : $1.8^0 \pm$ Non - cumulative.

Step/resolution : 200/rev

Torque : 3.0 Kg/cm.

Supply : DC 12V/0.6Amp/phase.

In basic some important points are,

- There is no control winding min stepping motor. All windings are indentical.
- The stepping rate is a matter of frequency rather than voltage.
- When motor receive no pulse it remain locked in position and no current flows through it.
- A pulse input having two phases (instead of contineous pulses) will move the shaft of the motor precisely in steps.
- Stepping motors are programmed for three main parameters namely, Direction, speed and number of steps.

Relation between phase and pulse sequence

The stepper motor used here is shown below in diagram. It has four coils wounded in such manner that there are two phases (anti wound coils) A and B. The motor is excited with pulse sequence as shown below in the table. Note that there are two logic 1, are in each sequence. The table shows that the motor runs in phase A, AB, B and AB alternatly. This provision avoid overstepping and improve the response. The reversel of direction is easier as to invert the serial of pulse sequences. The speed of the motor is a matter of repeatation frequency. This confind our required parameters as stated earlier.

Table of the motor pulse sequences

Sr	Phase 1	Phase 2	Phase 3	Phase 4
01	0	0	1	1
02	1	0	0	1
03	1	1	0	0
04	0	1	1	0

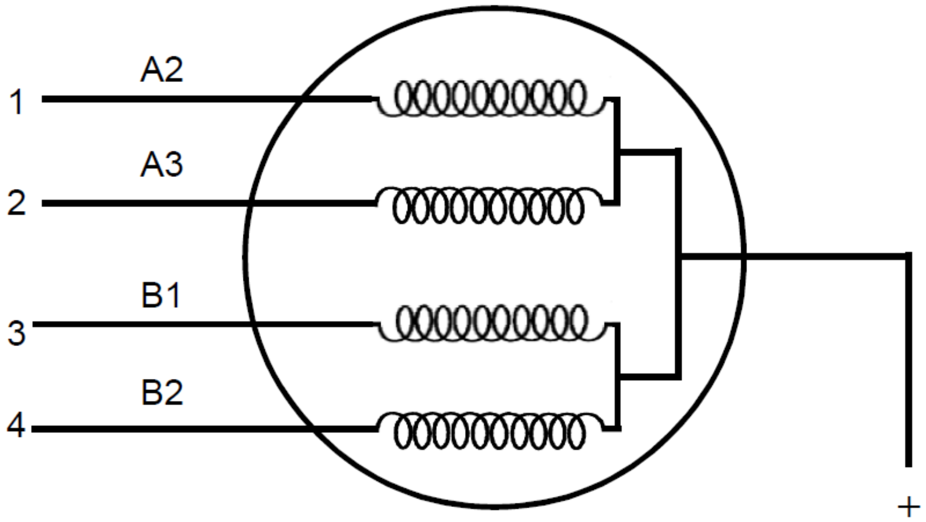


Fig. 1 Stepper motor with its phases.

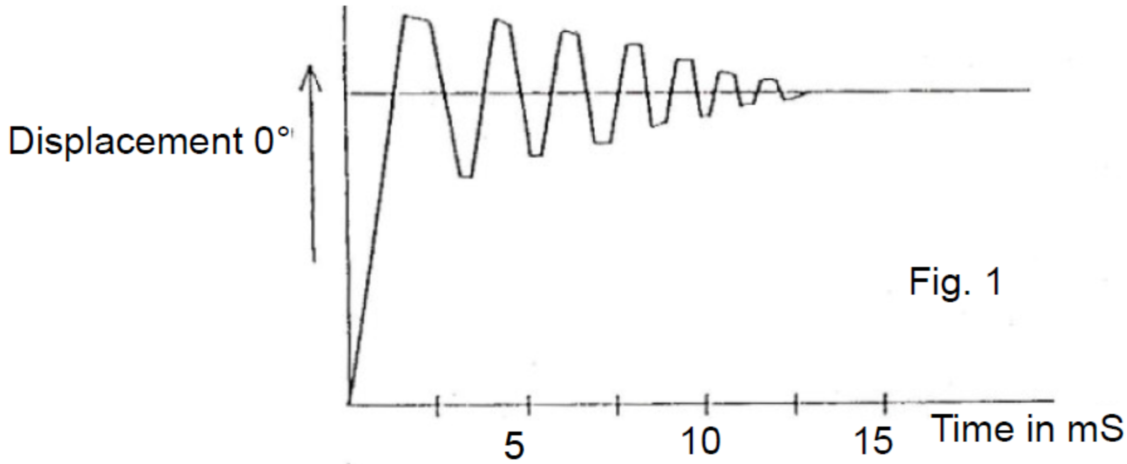
In biflar (parallel) wound coils the start of one coil is called phase one and the end of the other coil is called phase two.

About the set up

The motor unit consists a stepper motor, a dial to detect the angular displacement and servo pot to observe motor dynamic response. The main unit consists a pulse generator having frequency from 10Hz to 100Hz app. A pulse sequence generator to obtain required pulse sequences, a controller card to drive the motor. LEDs are fitted at output of controller card to visualize the sequences. A monopulser arrangement provided for single stepping studies. The motor dynamics are studied by wobbulating arrangement. Sockets are provided to change the motor phases with the drive circuit. A 9 pin D connector is fitted upon the panel for uP interface with interface circuitry.

Step response of the stepping motor (without load)

When a single step oa a motor is made a typical response is shown by a frequency the response curve change to fig 2. In fig. 1 it is clear that motor setting time depends upon loading and input sequence factor. When motor is run at higher timing sequence (freq.) it can overstepped.



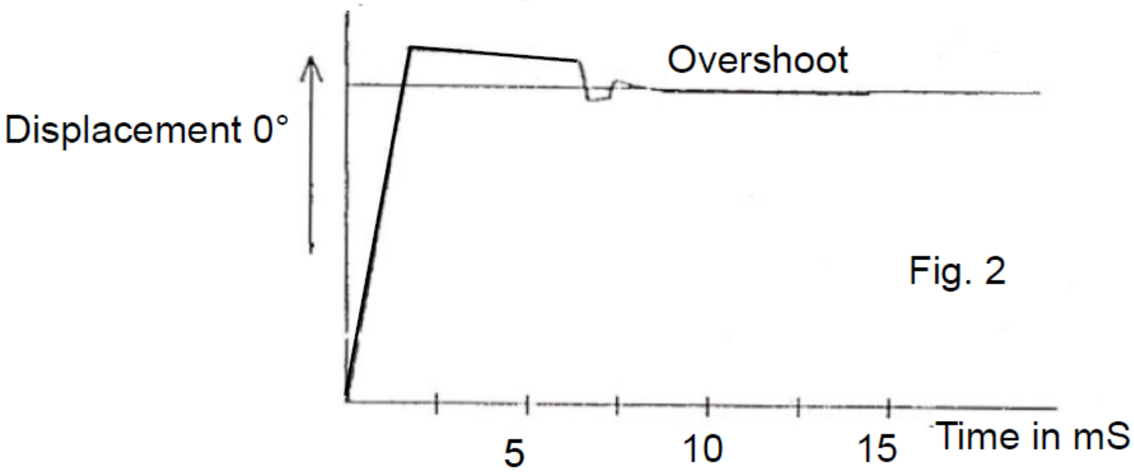
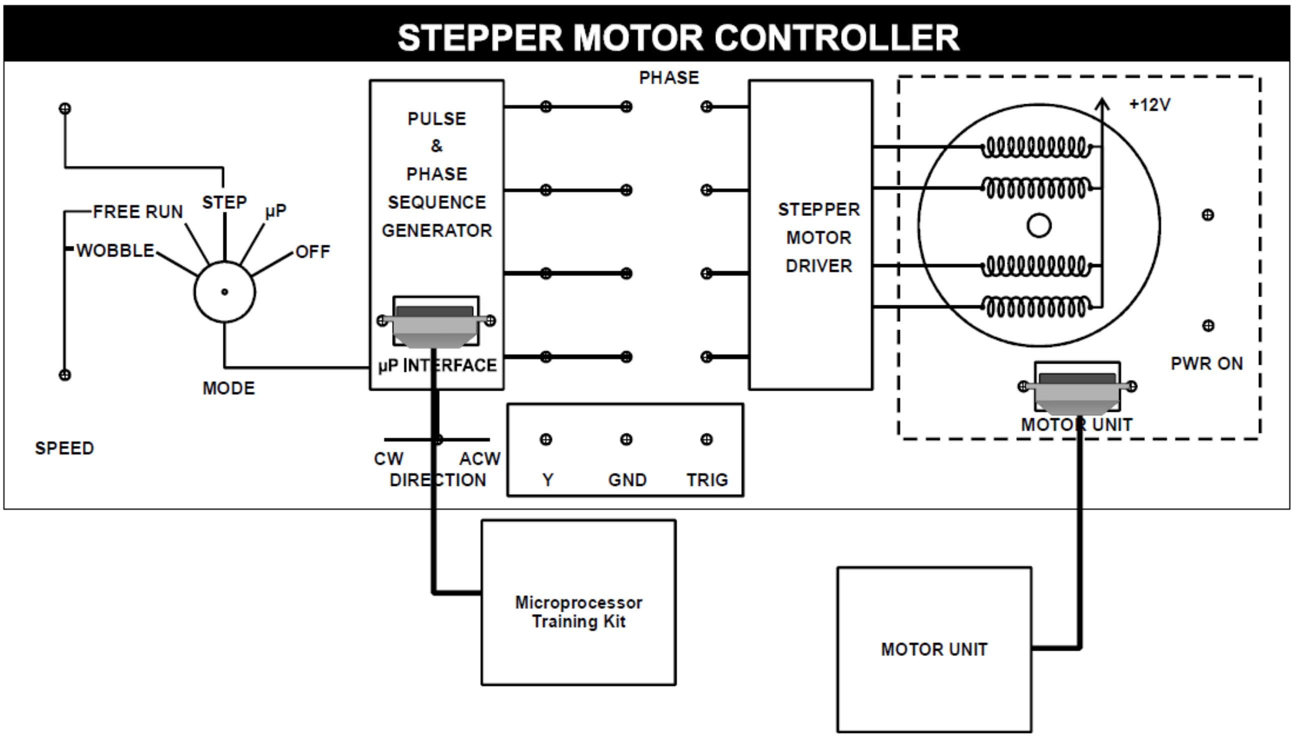


Fig. 2 Step response.



Exp. 3. Front panel view.

Exp. 1. Basic step angle movement.

PROCEDURE

1. Connect motor unit with the main unit, with D type connector marked as MOTOR UNIT. Connect all the phases of the motor to their respective outputs
   i.e. 1 with 1, 2 with 2 and so 3 and 4.
2. Select SINGLE STEP for the mode selector. Switch on the power.
3. Note the dial position in degree from the top of the motor unit. Select CW direction from the direction selector mini toggle switch. Note the LED status respect to phase.
4. Press the step key for 10 or 20 times making a delay of 1 second between two steps. Note the position of the dial.
5. Press 10 or 20 times more and note the readings as before.
6. Calculate the step angle as displacement in degree/number of key strokes (steps).
7. Plot step signal stroke v/s degree curve and find out the error/degree.
8. Repeat the above steps making direction anticlockwise.

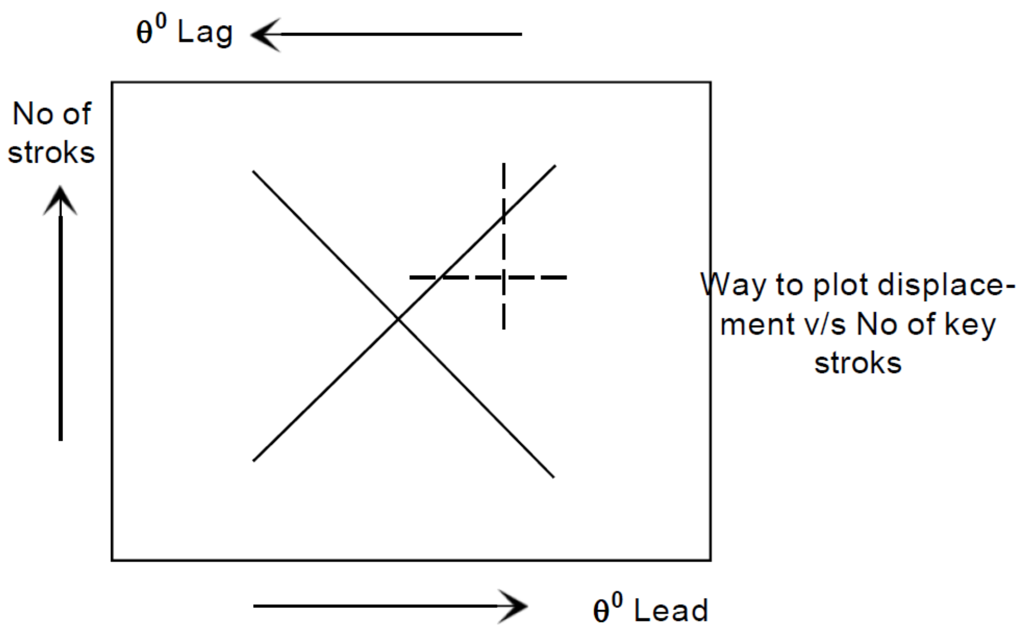
   Conclude the result.

Exp. 2. Study of phase pulse sequence.

PROCEDURE

1. Remain the set up as before. Note the position of the motor in degree Select CW direction.
2. Note the status of the LEDs in respect to the phase.
3. Apply one step by pressing key briefly and note the LED status.
4. Apply 2 or 3 pulses and note the LED status for each step. Tabulate the observations.
5. Note the dial reading and find out the rotation direction.
6. Select CCW mode and repeat the process. Find out the direction of rotation and LED status.

Tabulate the sequences of LEDs and the direction of movement (clock-wise or counter clockwise) and conclude the results.



Exp. 4. Study of speed and direction.

Other apparatus required : CRO and stop watch.

PROCEDURE

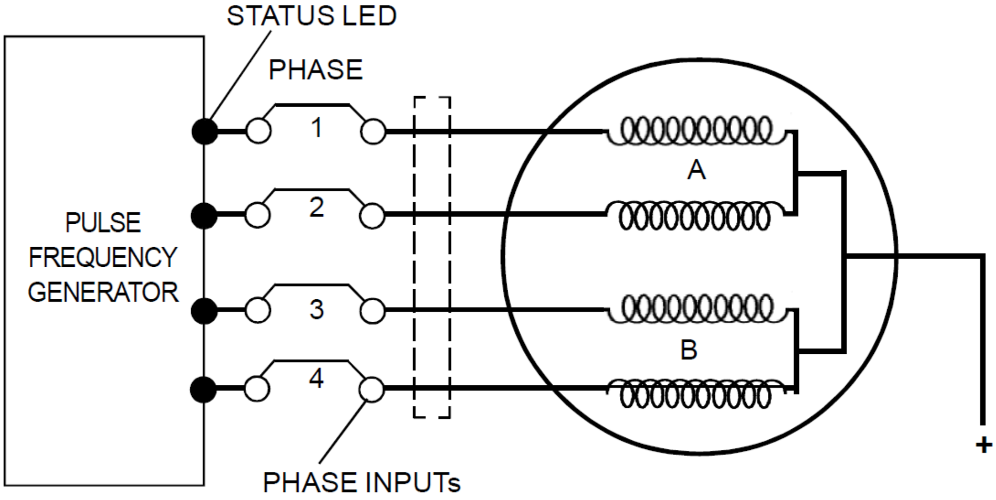
1. Remain the set up as experiment a. Select FREE RUN from the modes selector switch.
2. Connect CRO Across the ground and Trig socket. Select CW direction. Adjust free run frequency to 10Hz = 100mS from CRO
3. Measure shaft rotation with the stop watch for predetermined period say for 60 seconds and record it. Find out the motor speed from frequency repeatation rate and compare it with the recorded speed.
4. Select CCW mode and repeat the steps.
5. Adjust free run frequency to 20Hz = 50mS from CRO. Watch the increament of speed. Calculate the motor speed from the applied frequency and number of steps.
6. Adjust free run frequency to 50Hz = 20mS, and note the motor speed further increamented. Connect DRO at each of the phase and trace the pulse wavefom for each phase. If timing problem occurs connect ext trig of CRO with Trig socket. Switch off the power.

   *As it is found in last practical that the step of the motor is related with pulse sequences. In exp a, it is ound that motor advances one step/pulse. Thus for 100mS pulse the motor will run at 10 steps/sec or 3 rpm (since 200 step/rev.)

Exp. 4. Study the dynamic response.

PROCEDURE

1. Connect CRO at Y and ground free run mode from the mode switch.
2. Connect phase 1 with input 2 and phase 2 with input 1. The operation is now in phase A mode.
3. Switch on the power and adjust free run frequency to observe a stationary pattern upon CRO (start from low frequency to avoid overstepping). Trace the pattern.
4. Connect phase 3 with 4 and 4 with 3 input. The motor operation is now in phase B mode. Trace the pattern from CRO as avove.
5. Connect all phases to respective outputs. Select Wobbling and observe the pattern. When input frequency is larg compared with settling time is, the motor overstepped which can be seen from the dial position Conclude the results.



Exp. 5. Typical layout of connections.