L6: Design of motor model for speed control

Aim: This experiment will model the DC motor by simply applying a step input to the system and observing its time domain response. Based on the transient response, the DC motor will be approximated as a first order transfer function with time delay, and its parameters will be determined consequently

Theory

In empirical model building, models are determined by making small changes in the input variable(s) about a nominal operating condition. The resulting dynamic response is used to determine the model. This general procedure is essentially an experimental linearization of the process that is valid for some region about the nominal conditions. In this experiment, the parameters of this transfer function are experimentally obtained using step response tests.

The method involves the following four actions:

1. Allow the process to reach steady state.
2. Introduce a single step change in the input variable.
3. Collect input and output response data until the process again reaches steady state.
4. Perform the calculations.

The form of the model is as follows, with U(s) denoting the input and Y(s) denoting the output, both expressed in deviation variables:

$$G(s) = \frac{\Delta Y(s)}{\Delta U(s)} = \frac{Ke^{-t_d s}}{\tau s + 1} \tag{6.1}$$

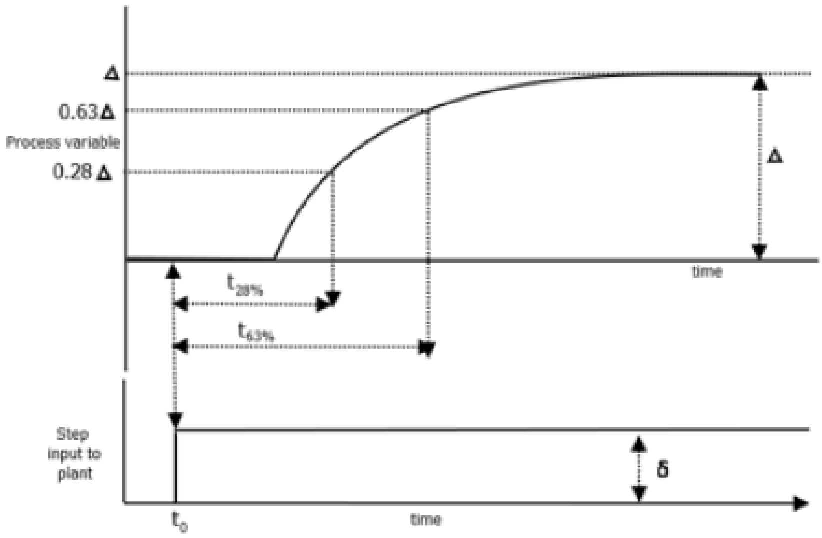


Fig.6.1 Step response

The intermediate values as can be seen from the graph are the magnitude of the input change,δ; the magnitude of the steady-state change in the output, Δ; and the times at which the output reaches 28.3 and 63.2 percent of its final value. The values from the plot can be related to the model parameters using the general expression in equation (6.1). Any two values of time can be selected to determine the unknown parameters, τ and t_d. The typical times are selected where the transient response is changing rapidly so that the model parameters can be accurately determined in spite of measurement noise

.
The parameters of the transfer function are calculated using the two-point method as follows:

$$K = \frac{\text{Difference in two steady states of output}}{\text{Difference in two steady states of input}}$$

$\tau = 1.5\,(t_{63.2} - t_{28.3})$

$t_d = t_{63.2} - \tau$

By this we have an approximate model for the motor.

Procedure

1. Go to the experiment application file (Automated_step_test), right click on it and run the file as an administrator.
2. Then, click on Play button, on the top left corner of the interface
3. If the file is running the Play button will be as shown below;
4. Select the appropriate COM port to which the USB-serial cable is connected;
5. Next, click on the RUN button;
6. In the 'open-loop' mode, input u(t) to the motor is in terms of PWM and the output y(t) is the speed in revolutions per minute (RPM). The motor is brought to an operating point by applying a suitable input and the plant output is allowed to settle at this value.
7. From this position, a step of appropriate magnitude is applied to the plant and the motor speed is allowed to settle again.
8. The experiment will run for a time of 5 seconds, and then the motor will automatically stop, and you will have the respective graphs of input and output.
9. Once the motor stops, click on STOP button;
10. After the stop button is clicked, a dialogue box showing the file path will be displayed on the interface; (Do not click the RETURN button)
11. This is the file in which the user will have the corresponding step test. Navigate to the location to access the file. It will have three columns, the first one being the time instants, second column is the input in terms of PWM and third column consists of the output speed of the dc motor in RPM.
12. The First-order Plus Time Delay (FOPTD) model is given by

$$G(s) = \frac{\Delta Y(s)}{\Delta U(s)} = \frac{Ke^{-t_d s}}{\tau s + 1}$$

We have to find parameters: gain K, time constant τ, and dead time t_d by carrying out a step-test on the DC motor.

13. Apply two-point method for system identification. From the step test data, find out

$t_{63.2}$ = Time required for the output to reach 63.2 % of the steady-state value

$t_{28.3}$ = Time required for the output to reach 28.3 % of the steady-state value.

Care has to be taken to measure the time from the instant of application of step Input.

14. The parameters of the transfer function (6.1) are calculated using the two-point method as follows:

$$K = \frac{\text{Difference in two steady states of output}}{\text{Difference in two steady states of input}}$$

$\tau = 1.5\,(t_{63.2} - t_{28.3})$

$t_d = t_{63.2} - \tau$

15. The obtained model is validated against the plant response by applying the same step input to the model and comparing the responses of the plant and the model.

Sample Results

1. The First-order Plus Time Delay (FOPTD) model is given by

$$\frac{\Delta Y(s)}{\Delta U(s)}=\frac{Ke^{-t_d s}}{\tau s+1}$$

We have to find parameters K, τ and t_d by carrying out a step-test on the DC motor.
2. In the open loop, the plant is brought to equilibrium by applying a step of 150 PWM units. The corresponding speed is around 8000 RPM, see Fig. 6.2.

3. After the motor speed settles, the PWM input is instantaneously changed to 170. As a result, the speed increases to around 9000 RPM and settles there, as shown in Fig. 6.2.

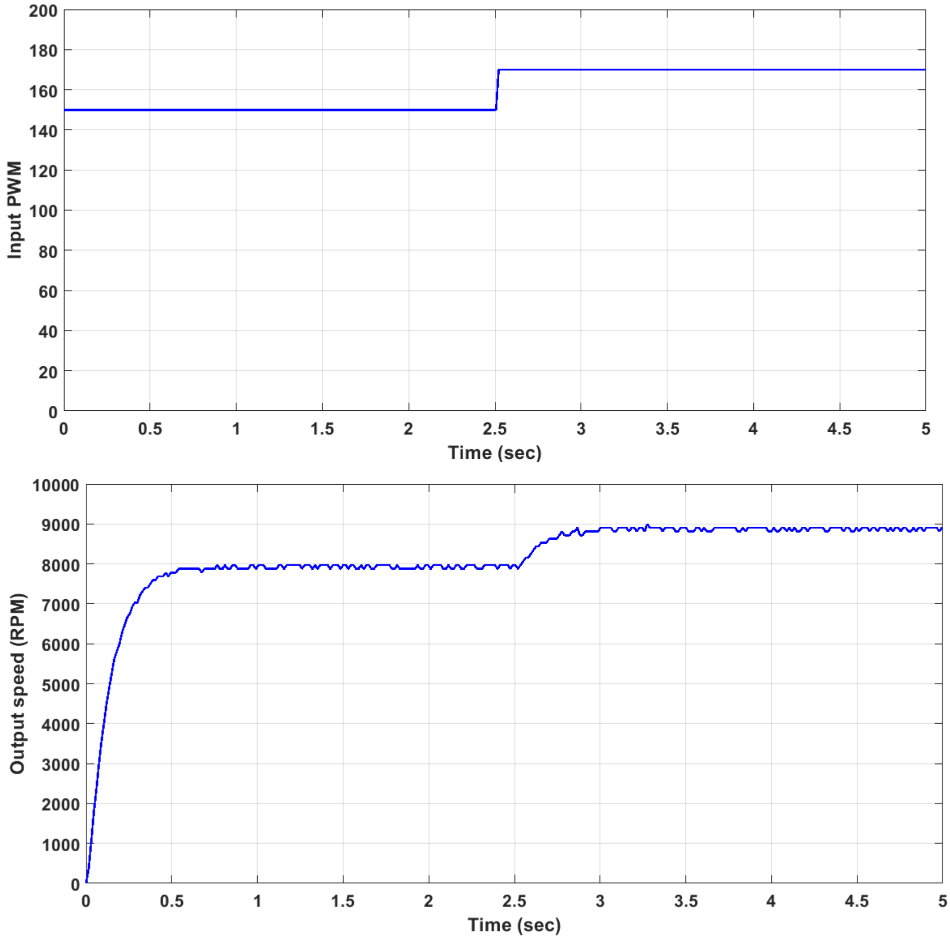


Fig.6.2 Step-test data

4. Following are noted

$t_{63.2}$ =0.135 sec $t_{28.3}$ =0.062 sec $\Delta\, u\,(t)$ =20 PWM units $\Delta\, y\,(t)$=937.5 RPM
5. Using the two-point method, we get the parameters of the transfer function (1.1) as

K=51.5625 τ=0.1095 sec L=0.0255 sec
6. The model is

$$\frac{\Delta Y(s)}{\Delta U(s)}=\frac{51.5625\exp^{-0.0255s}}{0.1095s+1}$$

7. The obtained model is validated against the plant response by applying the same step input to the model and comparing the responses of the plant and the model. It should be noted that the transfer function (1) is a linearized perturbation model around the operating point of 150

PWM, 8000 RPM. Hence for model validation, we use the deviation values of the input and output signals

$\Delta\ u(t)=u(t)-150$
$\Delta\ y(t)=y(t)-8000$

L6B: PI Control Gains for Motor Speed Control

Aim: The purpose of this experiment is to design and implement a Proportional-Integral (PI) controller for the speed control of DC motor.

Theory
The PID controller is by far the most common control algorithm. Most industrial feedback loops are based on PID control or some minor variations of it. The output of a PID controller which is the control input to the plant, in the time-domain is as follows:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \tag{6.2}$$

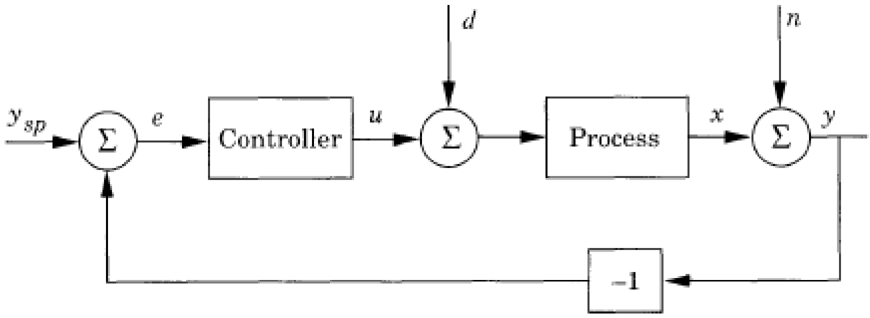


Fig.6.3 DC Motor PI speed control closed-loop block diagram

where u is the control signal and e represents the tracking error i.e. the difference between the desired input value and the actual output. This error signal e will be sent to the PID controller. The control signal u to the plant is equal to the proportional gain (K_p) times the magnitude of the error plus the integral gain (K_i) times the integral of the error plus the derivative gain (K_d) times the derivative of the error. This control signal u is sent to the plant, and the new output is obtained. The new output is then fed back and compared to the reference to find the new error signal e. The controller takes this new error signal and computes its derivative and it's integral again, ad infinitum.
The controller can also be parameterized as

$$u(t) = K_p\left(e(t) + \frac{1}{T_i} \int_0^t e(\tau)d\tau + T_d \frac{de(t)}{dt} \right) \tag{6.3}$$

Where T_i is the integral time constant and T_d is the derivative time constant.
The speed of the DC motor is controlled using a Proportional-Integral control system.
Procedure
1. First, go to the experiment file, right click on it and run the file as an administrator.
2. Then, click on Play button, on the top left corner of the interface
3. If the file is running the Play button will be as shown below;
4. Select the appropriate COM port to which the USB-serial cable is connected;

5. Next, click on the RUN button;
6. For sample PI values, click on the Sample PID values button;
7. Make sure that the motor is brought to the same operating point for which the FOPDT model was identified and is settled there. Since we are now working in the closed –loop configuration, the operating point is reached by giving a set point in RPM.
8. Give a new appropriate set point in RPM and observe that motor speed tracks the new set point and settles there. The set point can be varied from the Set Point control;
9. To check the controller performance, a negative step in the desired speed may also be given to see if the motor speed decreases accordingly and reaches to the new set point.
10. Once you are done with the experiment, click on STOP button;

Sample Results

1. We use the AMIGO tuning rule to tune the controller given in the book: Handbook of PI and PID Controller Tuning Rules by A. O'Dwyer (Imperial College Press UK,2009). The PI parameters are given by

Kc = ((0.15/K)+(0.35-((L τ)/(L+ τ)^2))*(τ /(K*L)))*
*Ti = ((0.35*L)+(6.7*L* τ ^2)/(τ ^2+2* τ *L+10*L^2))*

2. Using these relations, we get K_c = 0.0193 and T_i = 0.0016 minutes. These values are used for the implementation of PI controller.

3. After the speed settles at 8000 RPM, a step of 1000 RPM is applied. So the set point is 9000 RPM. The controller is implemented and the results are shown in Fig.6.5. It is seen that the output follows the set point and the speed settles at 9000 RPM.

4. Next, a negative step of 1000 RPM is applied. It is clearly observed from Fig. 6.4 that motor speed decreases and settles at 8000 RPM.

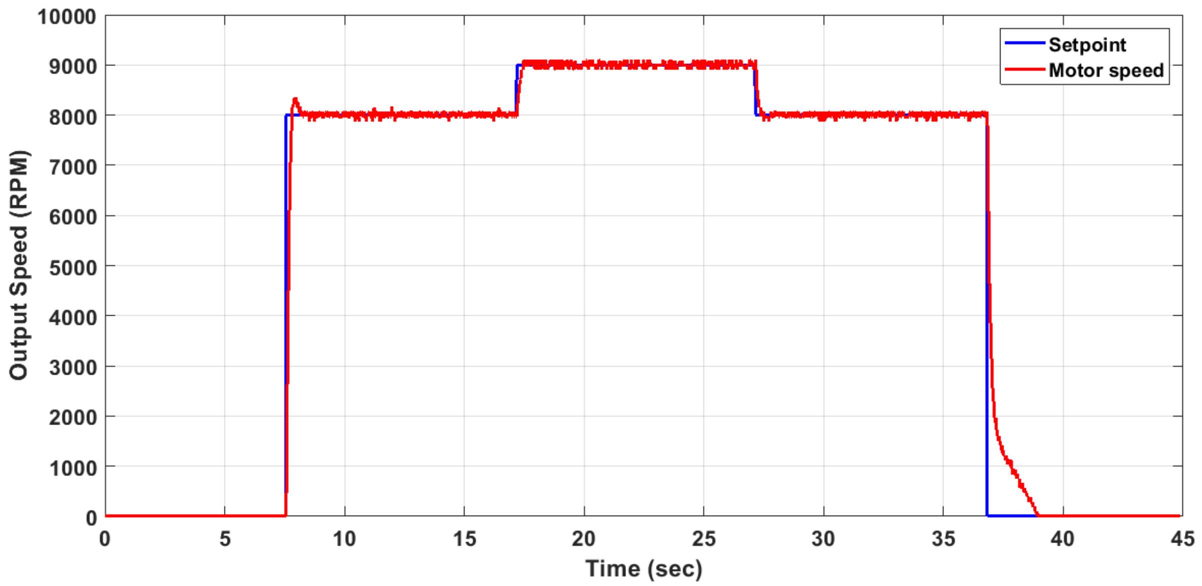


Fig. 6.4 Closed-loop step response with designed PI controller

Conclusion:

L7: Design of Motor Model for Position Control

Aim : This experiment will model the DC motor for position control. A simple step test is carried out and based on the response; DC motor is approximated as a First Order Lag plus Integral plus Delay (FOLIPD) model and its parameters will be determined consequently. The parameters of the transfer function will be fine-tuned against experimental responses, in order to validate the model.

Theory

A common actuator in control systems is the DC motor. It directly provides rotary motion and, coupled with wheels or drums and cables, can provide transitional motion. The position of the motor is the rotation of the motor shaft or the degree of the rotation which is to be controlled by giving the feedback to the controller which rectifies the controlled output to achieve the desired position. A DC position control system is basically an integrating system (i.e.) for a constant input, the system will give a constantly increasing output. Applying a step input to the motor will yield a response of a First Order Lag plus Integral plus Delay (FOLIPD) as:

$$G(s) = \frac{\Delta Y(s)}{\Delta U(s)} = \frac{Ke^{-t_d s}}{s(\tau s + 1)} \qquad (7.1)$$

where K is the gain, τ is the time constant and t_d is the dead time.
The step response of the model (7.1) is

$$s(t) = K\,(\,t - t_d - \tau\,(\,1 - e^{-(t-t_d)\tau})) \qquad (7.2)$$

The gain K and average residence time $T_{ar} = t_d + \tau$ can be determined graphically as shown in figure 7.1. The dead time L and the time constant T can be determined by fitting the equation (7.2) to one point of the step response. A suitable point is $s_{(t_d+\tau)} = K\,\tau\,e^{-1}$ which gives

$$\tau = \frac{s_{(t_d+\tau)}e^{1}}{K} \qquad (7.3)$$

By this we have an approximate FOLIPD model for the position control system.

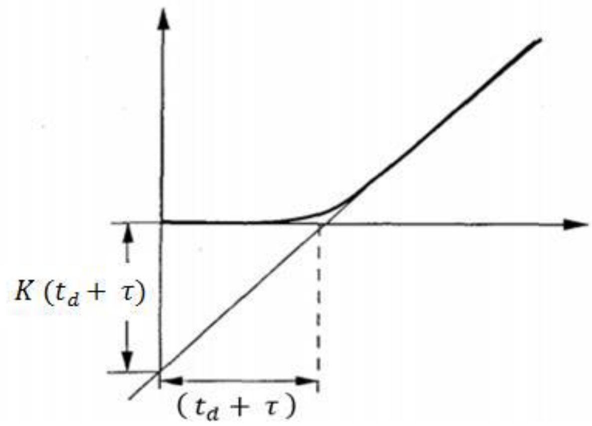


Fig.7.1 Graphical determination of a three-parameter model for an integrating process

Procedure

1. The First Order Lag plus Integral plus Delay (FOLIPD) model is given by:

$$G(s)=\frac{\Delta Y(s)}{\Delta U(s)}=\frac{Ke^{-t_d s}}{s(\tau s+1)} \tag{7.4}$$

2. In the ‘open-loop’ mode, input u(t) to the motor is in terms of PWM and the output y(t) is the angular position of the shaft of the motor.
3. First, go to the experiment file, right click on it and run the file as an administrator.
4. Then, click on Play button, on the top left corner of the interface
5. Select appropriate COM port to which the USB-serial cable is connected.
6. Put the value of PWM as 20 in PWM control box.
7. Select the sampling time as 4ms in the respective control box and click on the RUN button;
8. The experiment will run until it has reached a specific position, and then the motor will automatically stop, and you will have the respective graphs of input and output.
9. Once the motor stops, a dialogue box showing the file path will be displayed on the interface; (Do not click the STOP button)
10. For this identification procedure normalize input and output values with respect to input.
11. Determine the value of gain K and the average residence time T_{ar} graphically as in Fig 7.2
12. Compute the value of step response $s_{(td+\tau)}$ at $(td+\tau)$ time.
13.Calculate time constant and dead time $\tau=\frac{s_{(t_d+\tau)}e^1}{K}$

Sample results

1. The First Order Lag plus Integral plus Delay (FOLIPD) model is given by:

$$G(s)=\frac{\Delta Y(s)}{\Delta U(s)}=\frac{Ke^{-t_d s}}{s(\tau s+1)}$$

We have to find the parameters: gain K, time constant τ and dead time td.
2. The step response plot is given in Fig.7.2. From the plot, the following are noted

$K\ (t_d+\tau)=0.8783$; $t_d+\tau=0.0192$; $K=\frac{0.8783}{0.0192}=45.744$

3. The step response value at $(td+\tau)$ time is noted $s_{(td+\tau)}=0.23$
4. Therefore we get the value of time constant τ as

$\tau=\frac{0.23*e^1}{45.744}$; $\tau=0.0137$

5. Dead time td is $t_d+\tau=0.0779$; $t_d=0.0055$
6. Therefore the transfer function of the position control system is

$$G(s)=\frac{45.744e^{-0.0055s}}{s(0.0137s+1)}$$

7. The obtained model is validated against the plant response by applying same step input to the model and comparing responses of the plant and the model. The responses of model and plant are shown in Fig. 7.3. It is clearly seen that obtained model fairly represents the system.

L7b: PID Control Gains for Motor Position Control

Aim: The objective of this experiment is to design a closed-loop control system that regulates position of the DC motor.

Theory

Position control is in some sense more difficult than velocity control, because it causes system to go unstable easily due to the presence of an additional integrator in the transfer function. The goal of this experiment is for the angle of the disk load that is connected to the motor shaft which is to track a user commanded angular position. To control the position of a

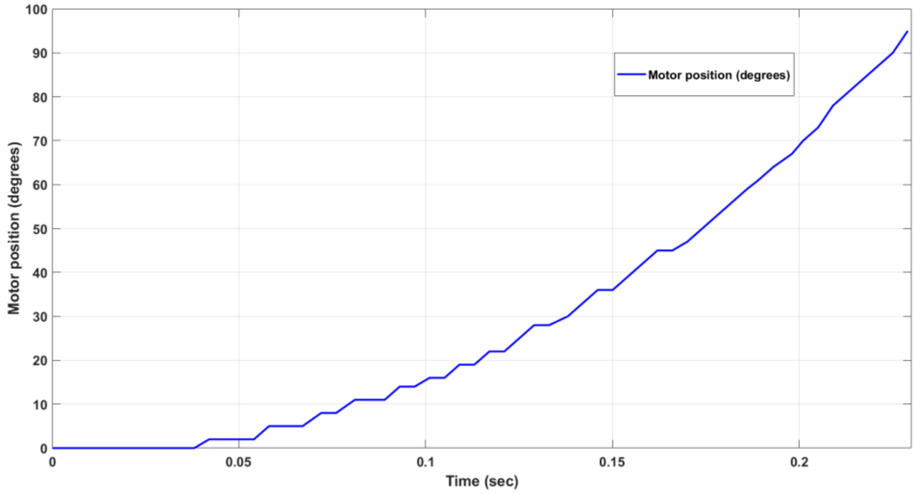


Fig.7.2 Step response

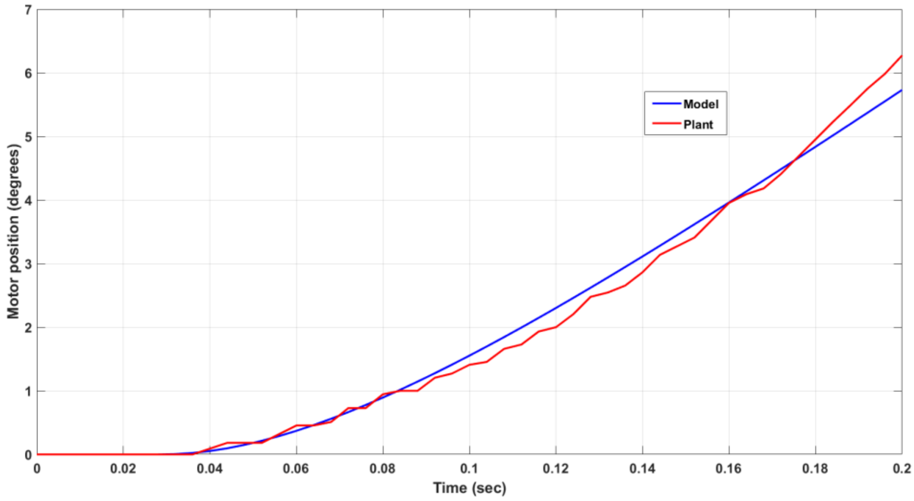


Fig. 7.3: Model validation

motor shaft, the simplest strategy is to use a PID controller which has position error as the input. The FOLIPD model obtained in experiment 7a is the mathematical representation of the DC motor shaft position and is thus used to design the PID controller. In this experiment, a PID tuning rule by Astrom and Hagglund given in the book: Handbook of PI and PID Controller Tuning Rules by A. O'Dwyer (Imperial College Press UK, 2009) is implemented. This method is suitable for FOLIPD systems. The controller parameters are calculated using the parameters like gain (K_p), time constant τ and dead time (t_d) obtained in experiment 7a.

Procedure

1. Firstly, go to the experiment file, right click on it and run the file as an administrator.
2. Then, click on Play button, on the top left corner of the interface
3. If the file is running the Play button will be as shown below;
4. Select appropriate COM port to which USB-serial cable is connected and click on RUN.
5. For sample PI values, click on the Sample PID values button;
6. Since we are now working in the closed –loop configuration, the operating point is reached by giving a set point in degrees.
7. Give a new appropriate set point in degrees and observe that motor position tracks the new set point and settles there. The set point can be varied from the Set Point control.
9. The PID controller placed in the forward path is to be designed and implemented as

$$G(s) = K_c \left(1 + \frac{1}{T_i s} + T_d s\right) = \frac{Y(s)}{U(s)} \tag{7.5}$$

where, $e(t) = y_{set}(t) - y(t)$ is the error signal and $u(t)$ is the controller output fed to the plant.

10. Using the model obtained in the previous experiment, the parameter K_c, T_i and T_d of PID controller have to be calculated.

11. A brief overview of the Astrom Hagglund method for FOLIPD system is presented is here. The PID gains are computed as

$$K_c = \frac{1}{K_p t_d}\left[0.37 + 0.02\frac{\tau}{t_d}\right];\ T_i = \frac{\left[0.37 + 0.02\frac{\tau}{t_d}\right]}{\left[0.03 + 0.0012\frac{\tau}{t_d}\right]} t_d;\ T_d = \frac{\left[0.16 + 0.28\frac{\tau}{t_d}\right]}{\left[0.37 + 0.02\frac{\tau}{t_d}\right]} t_d$$

12. Enter the values of K_c, T_i and T_d (in minutes) you have calculated in the window labeled K_c, T_i and T_d respectively.

13. Perform closed loop test.

14. Give a set point 180 degrees and then 360 degrees and observe whether the motor tracks the new set point.

15. To check the controller performance, a negative step of back to 180 degrees and then to 0 degrees is set to see if the motor position changes accordingly and reaches the new set point.

Sample Results

1. We have used a PID tuning rule by Astrom and Hagglund given in the book: Handbook of PI and PID Controller Tuning Rules by A. O'Dwyer (Imperial College Press UK, 2009).
2. Using these relations, we got K_c = 1.6686, T_i = 0.0012 minutes and T_d = 0.0001872 minutes. These values were used for the implementation of PID controller.
3. Give a set point 180 degrees and then 360 degrees and observe whether the motor tracks the new set point.
4. To check the controller performance, a negative step of back to 180 degrees and then to 0 degrees is set to see if the motor position changes accordingly and reaches the new set point.

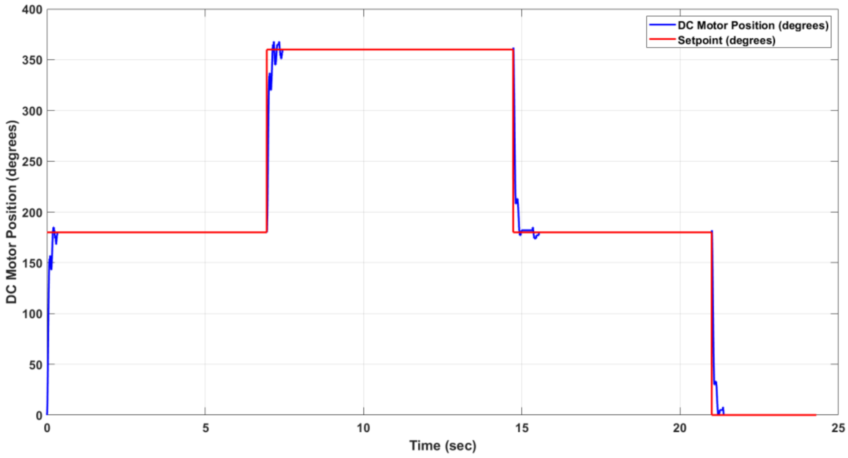


Figure 7.5: Closed-loop response with designed PID controller

Conclusion:

L8: PID Controller Characteristics

Aim: To implement & study characteristics of analog PID controller using simulated systems
Description: The PID controller analogue kit consists of two knobs at left most end used for varying the voltage and frequency level. There are two input signals present, one a square wave input and another, a triangular wave input. It also consists of various blocks like error detector, controller with the independent knobs for adjusting frequency. The maximum values of K_c, K_d and K_i constants correspond to full scale values of the P, I and D knobs. The potentiometers used are 10 turn types with each turn being divided into 10 parts by the dial scale. Each part is further divided into 5 divisions so that total dial change of 0 to 1 has a least count of 0.002. The block diagram representation of the complete PID analog kit can be seen in figure 8.1

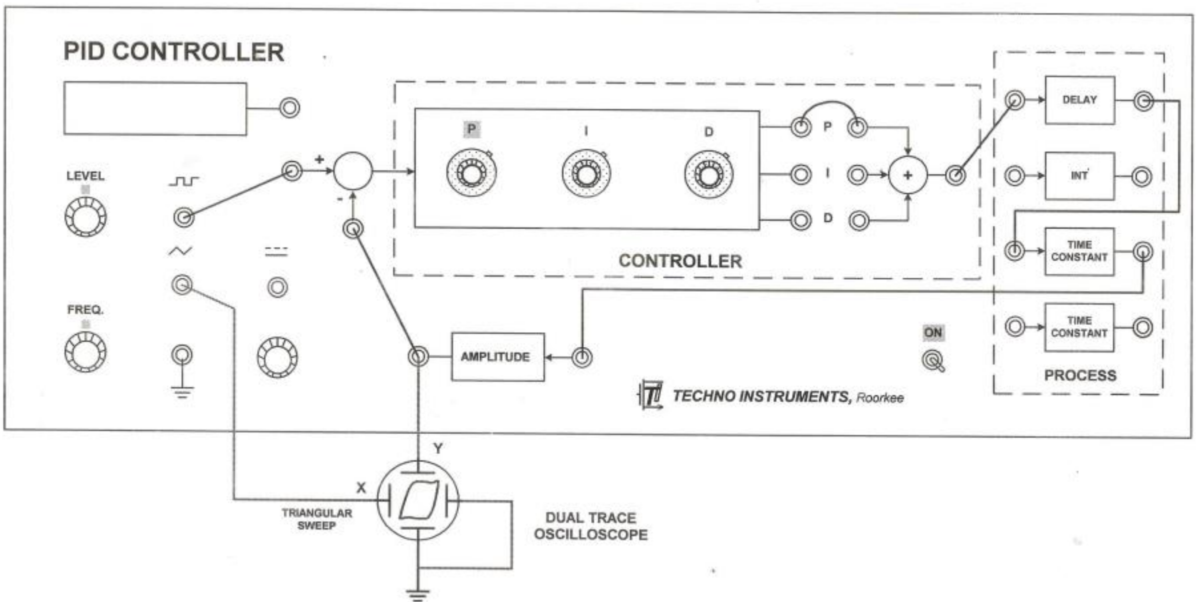


Fig 8.1: PID analog kit

Module 1: Controller Calibration

The time domain response of PID controller is of great importance for the good understanding of its performance. This will also enable calibration of the three potentiometers. The frequency may be set to the lower end range and the actual value may be determined experimentally.

Conduction steps:

a) Apply a square wave signal of 100 mV p-p at the input of the error detector. Connect the P, I and D outputs to the summer and display the controller output on the CRO.

b) With the P-potentiometer set to maximum and I- and D- potentiometer set to zero, obtain the maximum value of K_c as:

$$Kc(max) = \frac{p - p \text{ square wave output}}{p - p \text{ square wave input}}$$

c) With the I-potentiometer set to maximum and P- and D- potentiometer set to zero, a ramp is observed on the CRO. Maximum value of K_i is given by:

$$Ki(max) = \frac{4 * f * p - p \text{ triangular wave output}}{p - p \text{ square wave input}}$$

d) With the D-potentiometer set to maximum and P- and I- potentiometer set to zero, a series of sharp pulses is seen on the CRO which is not suitable for any calibration.

Instead, applying a triangular wave at the input gives a square wave output at the CRO.

$$\mathrm{Kd(max)} = \frac{\mathrm{p-p\ square\ wave\ output}}{4 * \mathrm{f} * \mathrm{p-p\ triangular\ wave\ input}}$$

Where f is the frequency of the input signal in both equations.

e) Set all the potentiometers to maximum value and apply a square wave input of 100 mV p-p. Observe and trace step response of the PID controller. Identify the effects of P, I and D control individually on the shape of this response.

Results:

a) P control

Input square wave of amplitude : 100 mV

Output square wave of amplitude: ___________

K_c(max) : ___________

b) I control

Input square wave of amplitude : 100 mV

Time period : ___________ms

Output square wave of amplitude: ___________

Ki (max) : ___________

c) D control

Input triangular wave of amplitude : 1 V

Time period : __________ ms

Output square wave of amplitude: ___________

Kd (max) : ___________

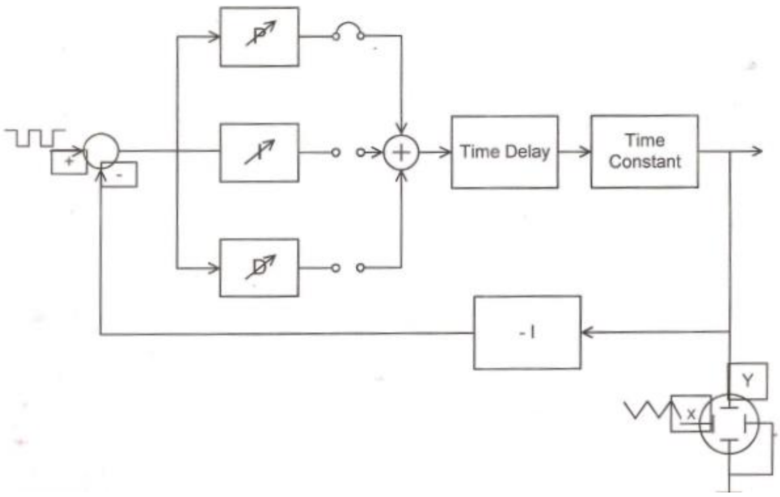


Fig 8.2: Connection Diagram

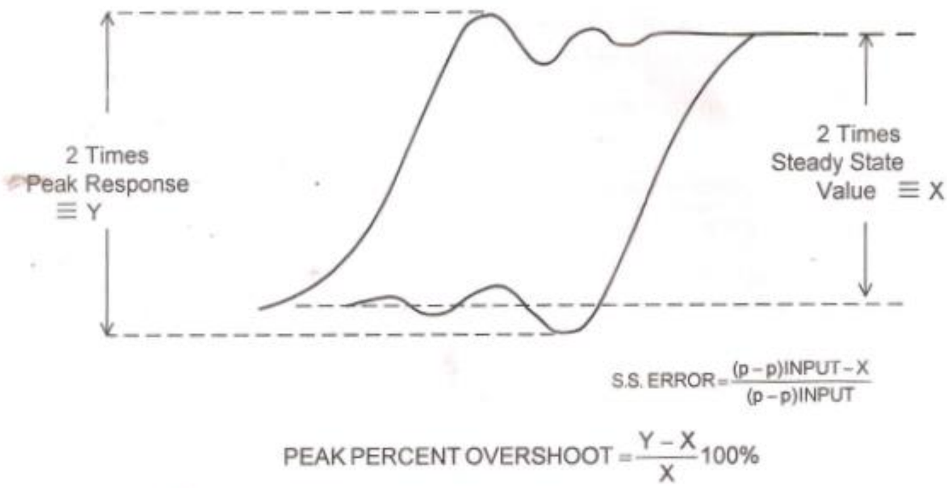


Fig 8.3: CRO display for step response

Module 2 : P, PI and PID controller action

In this section, the action of the P, I and D constants on the effect of steady state error and peak overshoot would be studied. The output from the controller is connected to an in-built time delay and time constant block.. The output signal from time constant is fed back at the input using an uncommitted inverting amplifier. The integral term results in increasing the system type number by unity and improves the steady state performance. The derivative term will cause a significant improvement in the transient performance.

Conduction steps:

a) For P controller, connect only the output of P knob to the summer amplifier. By setting the input of the square wave to an amplitude of 100 mV at a very low frequency, vary the value of P-control K_c=0.2 (2 revolutions), 0.4(4 revolutions),…etc. The connection to be followed can be seen in Figure 2. Connect the output of the time constant block and a reference triangular input signal to the CRO. Observe and measure the peak overshoot as well as steady state error of the output signal whose graphical representation is in figure 8.3.
b) For the PI controller, connect the output of P-knob and I-knob to the summing amplifier. Set the input of the square wave input pulse to an amplitude of 100 mV at a very low frequency. Connect the output of the time constant block as well as a reference triangular input signal to the CRO. By keeping K_c=0.6(6 revolutions), increase the value of K_i in small steps to measure the peak overshoot and steady state error.
c) For the PID controller, connect the output of P-knob, I-knob and D-knob to the summing amplifier. Set the input of the square wave input pulse to an amplitude of 100 mV at a very low frequency. Connect the output of the time constant block as well as a reference triangular input signal to the CRO. By keeping K_c=0.6(6 revolutions) and K_i=0.06(0 on coarse and 60 on Vernier dial), increase the value of K_d in small steps to measure the peak overshoot and steady state error.

Results :

a) P control

K_c	X	Y	S.S.E	% overshoot

b) PI control

K_c = 0.6

K_i	X	Y	S.S.E	% overshoot

c) PID control

K_c = 0.6 , K_i = 0.06

K_d	X	Y	S.S.E	% overshoot

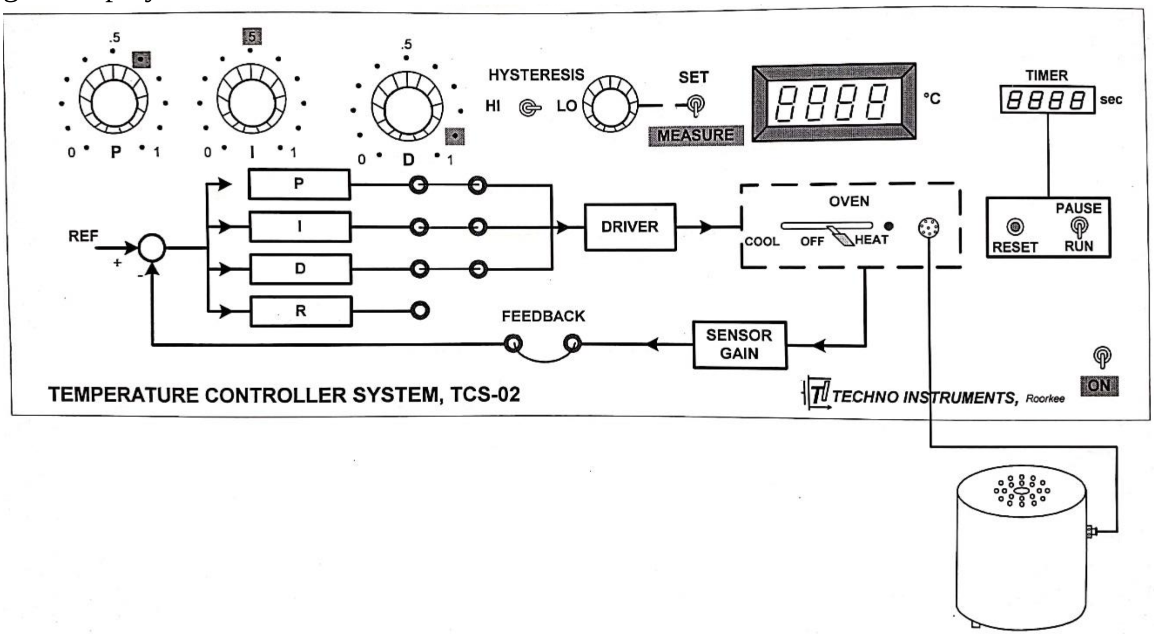
Conclusion:

L9: Oven Parameter Identification and Temperature Control

Aim : To identify the oven parameters using reaction curve method and to tune P, PI and PID parameters for temperature control.

Description of trainer kit**:**

The plant to be controlled is a specially designed oven having a short heating as well as cooling time. The temperature time data may be obtained manually. A solid state temperature sensor converts the absolute temperature information to a proportional electric signal. The reference and actual temperatures are indicated in degree Celsius on a switch selectable digital display.



Identification of Oven Parameters

Plant identification is the fir step before an attempt can be made to control it. In the present case, the oven equations are obtained experimentally from its step response as outlined below. The procedure is as per reaction curve mention.

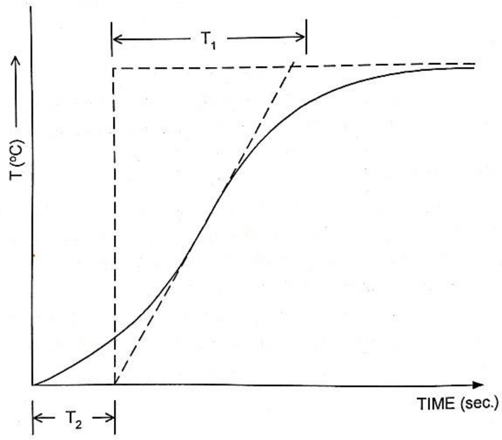
In the open-loop testing, the oven is driven through the P – amplifier set to a gain of 10. The input to this amplifier is adjusted through reference potentiometer (the one next to switch S2). This input can be seen on digital display, so that when you set 5^{O}C, the input to proportional amplifier is 50mv (@10mV/ ^{o}C) and its output (which acts as input to driver circuit is 0.5V.

Procedure:

1. Keep switch S1 to "Pause", S2 to "SET" and open 'Feedback' terminals.
2. Connect the P output to the driver input and Switch ON the unit.
3. Set P potentiometer to 0.5 which gives Kp = 10. Adjust reference potentiometer to read 5.0 on the DVM. This provides an input of 0.5 V to the driver.
4. Put switch S2 to the "Measure" position and note temperature every 10 sec., till the temperature becomes almost constant. Use the timer on the panel to monitor time.
5. Plot temperature – time curve on a graph paper, calculate T1 and T2 and hence werite the transfer function of the oven including its driver as:

$$G(s) = \frac{K\exp(-sT_2)}{(1+sT_1)}$$

$$\text{where } K = \frac{\text{Final temperature} - \text{Initial ambient temperature}}{\text{Input voltage}}$$



Proportional Controller

The value of Kp for P – controller is given as:

$$Kp = \frac{1}{K} \times \frac{T_1}{T_2}$$

Procedure:

1. Staring with a cool oven, keep switch S1 to "Pause" position and connect P output to the driver input. R, D and I outputs disconnected. Short "Feedback" terminals.
2. Set P potentiometer to Kp on the trainer kit, keeping in mind that the maximum gain is 20.
3. The measurement and interpretation of Kp and P – Control potentiometer setting need some explanation here. the formulae for Kp above is for a unity feedback system and has dimension volts/ ^oC. In the present unit a temperature sensor having a sensititvity of 10mV/^oC (0.01 V/^oC) is used between oven output and controller input. Thus the Kp calculated above will need to be divided by 0.01 to obtain the P-Control potentiometer setting.
$$Kpset = \frac{Kp}{20 * 0.01}$$
4. Select and set the desired temperature to say 60^oC.
5. Keep switch S1 to "Run" position and record temperature readings.
6. Plot the observations on a linear graph and observe the rise time, steady state error and percent overshoot.

PI Controller

The value of K_P and K_I for P-I controller is given as:

$$\boldsymbol{K_p = \frac{0.9}{K} \times \frac{T_1}{T_2}; K_I = \frac{1}{3.3T_2}}$$

Procedure

1. Starting with a cool oven, keep switch S1 to “Pause”, connect P and I outputs to driver input and disconnect R and D outputs. Short feedback terminals.
2. Set P and I potentiometers to the above values of K_P and K_I respectively, keeping in mind that the maximum value of K_P is 20 and that of K_I is 0.036.

$$\text{Kiset} = \frac{\text{Ki} * 100}{0.036}$$

3. Select and set the desired temperature to say 60^{o}C.
4. Keep switch S1 to “Run” position and record temperature readings.
5. Plot the response on a graph paper and observe the steady state error and percentage overshoot.

PID Controller

The value of K_P, K_I and K_D for PID controller is given as:

$$\boldsymbol{K_p = \frac{1.2}{K} \times \frac{T_1}{T_2}; K_I = \frac{1}{2T_2};\ K_D = 0.5T_2}$$

Procedure

1. Starting with a cool oven, keep switch S1 to “Pause”, connect P, I and D outputs to driver input and disconnect R output. Short feedback terminals.
2. Set P, I and D potentiometers to the above values of K_P, K_I and K_D respectively, keeping in mind that the maximum value of K_P is 20, K_I is 0.036 and K_D = 23.5.

$$\text{Kdset} = \frac{\text{Kd} * 100}{23.5}$$

3. Select and set the desired temperature to say 60^{o}C.
4. Keep switch S1 to “Run” position and record temperature-time readings.
5. Plot the response on a graph paper and observe the steady state error and percentage overshoot.

Conclusion:

L10: Compensator Design

Aim: To design implement and study the effects of LAG compensation network for a given system.

Description: The experiment has been designed with objective of exposing the learner with the problem of control system compensation. A simulated system of ‘unknown dynamics’ is available which can be studied in time as well as frequency domain. Before design of a particular compensator on a given system, bode plot needs to be designed by using pen & paper. The analog kit consists of three knobs for providing input signals: sine wave, square wave and trigger signal whose frequencies can be varied. The kit also consists of an uncompensated plant, error detector-cum-gain block, a compensation circuit and a power supply module. There is an additional network block where the user can insert resistances/capacitances needed for the design of lag/lead compensator.

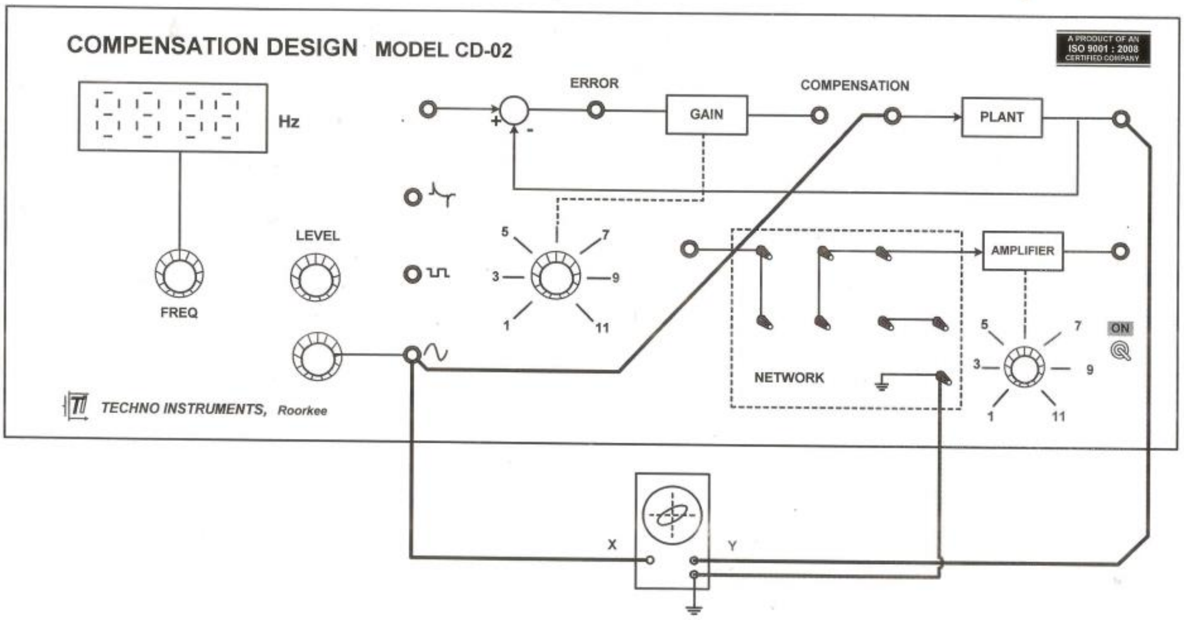


Fig 10.1: Open loop module for bode plot analysis

Module 1: Determining the Bode plot of the plant

The first step in any compensator design requires determining the transfer function of the plant by either time domain response or frequency domain response. In the present work, the bode plot analysis is carried out to determine the transfer function. The steps involved are:

1) Disconnect the COMPENSATION terminals and apply a constant input of 1 V p-p to the plant from the in-built sine wave source as seen in Fig 10.1.
2) Once the input signal is steady, put the CRO in X-Y mode for the measurements to be carried out. Vary the frequency in steps and calculate the plant gain in dB and calculate the phase angle in degree at each frequency as seen in table 1.
3) From low frequency end of magnitude plot, obtain error coefficient and the steady state error. Also, calculate the forward path gain K to meet the steady state specifications.

4) Measurements are carried out by double trace CRO. If the input x = A*cos(wt) and output y = B*cos(wt-θ) are fed to input and output plates of a CRO, the resulting trace in an ellipse and the phase, magnitude can be calculated, as observed in Fig 3, as:

$$\text{Gain} = B/A = y_0/\ x_0 \text{ or } 20 \log (B/A) \text{ Db}$$
$$\text{Phase } \theta = -\sin^{-1}(x_0/A) = -\sin^{-1}(y_0/B)$$

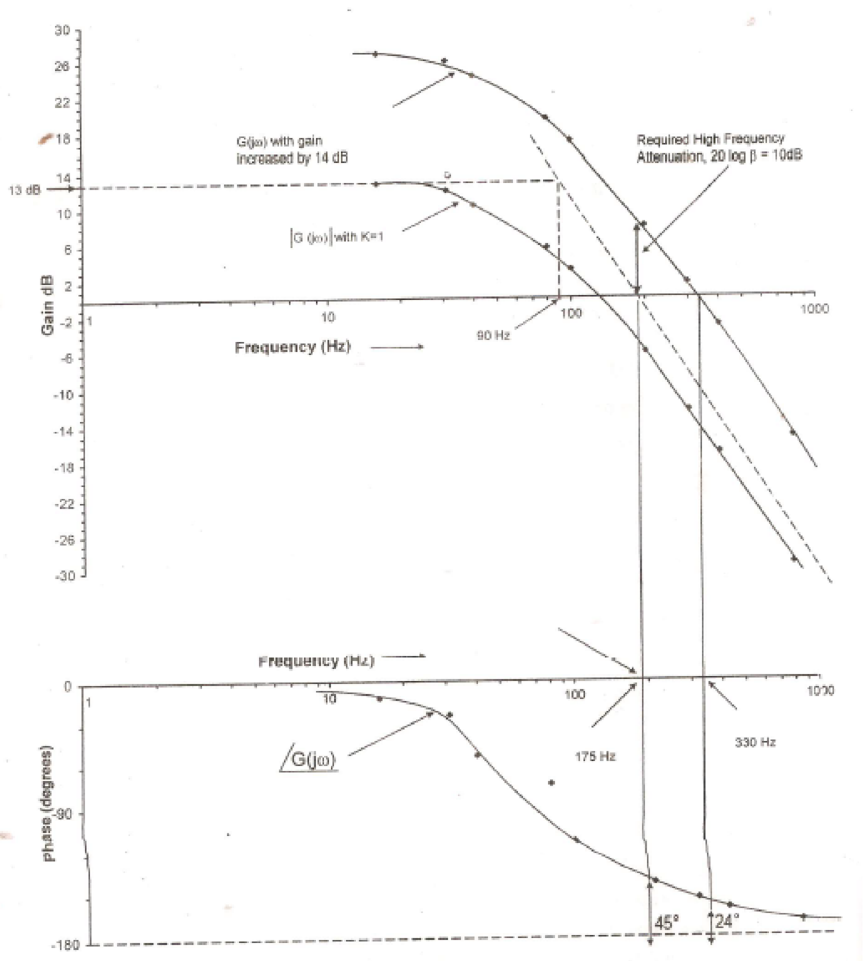


Fig 10.2 : Bode plot

5) From the table readings, plot the values of magnitude and phase in Bode plot. From the bode plot the transfer function is approximated by drawing the low and high frequency asymptotes, observing the values of low frequency gain and corner frequency (fig 10.2)

Corner frequency f_r = _________ yields T = 1 / 2*pi* f_r = _________
Gain at low frequency G= ________ yields K_1=antilog (G/20) = _________
Thus the plant transfer function is $K_1/(1+T)^2$(Note high frequency slope is -40db/sec)

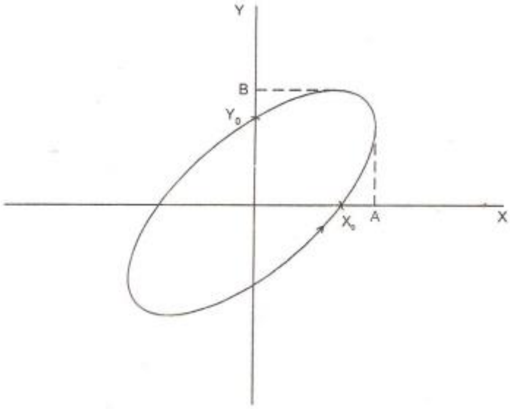


Fig 10.3: Phase and gain measurement from CRO

Freq	A	B	x_0	y_0	Gain (dB)	Phase (Deg)

Module 2: Lag Compensator design

The steps involved for the lag compensator are:

1) From the Bode plot, find a frequency where $PM_{actual} = PM_{specified}$ + safety margin (5°). This is the new cross over frequency $w_{g,new}$
2) Measure the gain at $w_{g,new}$. This must equal the high frequency attenuation of the lag network i.e 20log β. Compute β.
3) Choose $Z_c = 1/T$ at approximately 0.1* $w_{g,new}$ and $P_c = 1/\beta T$ accordingly.
4) Write the transfer function and calculate R_1, R_2 and C.
5) Implement new transfer function with the help of passive components and amplifier provided for the purpose. Amplifier gain has to be set to unity.
6) Insert compensator and find the phase margin of the plant.

The given design requirements are : Steady state error = 5% and Phase Margin = 40°
The required value error coefficient K_p to meet the steady state specifications is 19. Hence the gain K needs to be increased by 19/ K_1 or 20 log(19/ K_1) = __________ dB. Now, the magnitude plot is drawn on Bode plot shifting up by ________ dB which results in:
Gain cross over frequency w_g: _______________
Phase Margin (ϕ_1): ___________
The phase margin needed= 40°+5° = 45°

This is available naturally at $w_{g,new} = w_g /10 =$ __________

The high frequency attenuation needed is = 10dB= 20log β so that the value of β is 3.16. The design of the compensation network is thus chosen as:

$Z_c = 1/T = 2*pi* w_{g,new} =$ _________, $P_c = 1/ \beta T =$ _________

$T = R_2C = 0.009094$ & $\beta = (R_1+ R_2)/ R_2 = 3.16$

Solving the above equations, approximate values of the three components are:

$R_1 \sim 20k\Omega$; $R_2 \sim 9.1k\Omega$; $C \sim 1\mu F$.

Module 3: Lead Compensator design

The steps involved in design of a lead compensator are:

1) The phase lead (ϕ_m) = $PM_{specified}$ - $PM_{available}$+ safety margin (5° to 10°).
2) Calculate α for the lead network using $\alpha = (1-\sin \phi_m)/ (1+\sin \phi_m)$.
3) Calculate new gain cross over frequency $w_{g,new}$ such that gain G at $w_{g,new}$ = 10 log α.
4) The corner frequencies are calculated from $1/T = \sqrt{\alpha}w_m$ and $1/\alpha T = w_m/\sqrt{\alpha}$.
5) Implement the transfer function with the help of few passive components and amplifier which should be set to a gain equal to 1/α.
6) Insert compensator and find the phase margin of the plant.

The given design requirements are: Steady state error = 5% and Phase Margin = 40°

The gain setting of 5 has to be kept constant throughout the experiment.

Phase lead $\phi_m = 40° - \phi_1 + 10° =$ ___________

The value of $\alpha = (1-\sin \phi_m)/ (1+\sin \phi_m) =$ _____________

G at $w_{g,new}$ = 10 log α corresponds to $w_m = 2*pi*$_____ = _______________

$1/T = \sqrt{\alpha}w_m =$ ________________ and $1/\alpha T = w_m/\sqrt{\alpha} =$ _____________

Time constant $T = R_1C$. Choosing the value of C = 0.01μF, resistances computed are:

$R_1 = T/C =$ ___________ **Ω** ; $R_2 = \alpha R_1 / (1- \alpha) =$ ____________**Ω**

Conclusion: