

Laboratory Manual
for
CONTROL SYSTEMS LAB
II B.Tech., II Semester
MR18 Regulation

MALLA REDDY ENGINEERING COLLEGE (AUTONOMOUS)

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(Affiliated to JNTUH, Hyderabad, Approved by AICTE – Accredited by NBA & NAAC –
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LIST OF EXPERIMENTS

CONTROL SYSTEMS LAB (80212)

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2. AC Position control system
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4. ON/OFF Temperature Control system
5. Step response of second order system
6. Characteristics of AC Servomotor
7. Characteristics of synchro transmitter and receiver pair
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12. Step response and frequency response of a given plant

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERINGCONTROL SYSTEMS LABINDEX

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EXPERIMENT – 1**CHARACTERISTICS OF DC SERVOMOTOR**

Aim:- To find speed-torque characteristic of D.C servomotor.

Apparatus:- D.C servomotor set up, multimeter, connecting wires.

Theory:- A D.C motor can be controlled by varying either the field current or the armature current. The types of D.C servomotors are series motors, the shunt motors and the permanent magnet (PM) motor. These motors offer higher efficiency than an A.C motor of the same size, but radio frequency interference is a problem in some applications.

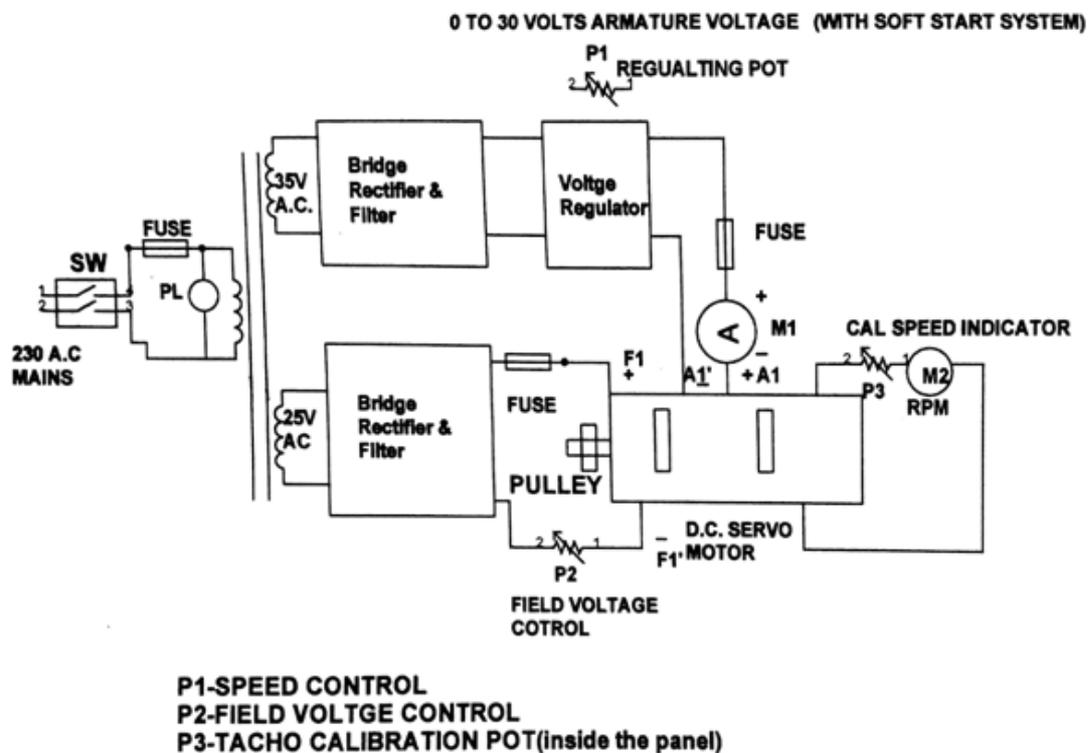
In its general form of construction the separately excited motor is similar to the series motor, but armature and field circuits are separated, control being applied either to armature or field.

Field control may utilize connection of the amplifier single ended or more frequently push-pull, requiring the centre tapped arrangement. An advantage is gained over the series connection in avoiding the larger currents required to drive the armature. The field power is only a small fraction of the armature power, which implies a power gain in the system.

The field control machine requires a constant current supply to its armature, often approximated by a constant voltage connected through a high external series resistance.

This device, which is relatively simple and inexpensive, leads to some waste of power in resistance drop and possibly, problems of heat dissipation, but in small machines this is usually unimportant. The closeness of the approximation depends on motor running at low enough speeds for the armature back emf to be small compared with the supply voltage.

Armature control, though it requires higher current handling and current reversal, provides a nearly ideal linear performance. This linearity is achieved through excitation of the field under fixed condition, so that magnet type characteristics is not imposed on the machine. More over as the armature circuit possesses a similar time constant than the field, a faster response can be obtained. It is noteworthy that the constant field connection gives machine performance equivalent to the permanent magnet motor.

Block Diagram of DC Servomotor:-**BLOCK DIAGRAM FOR D.C. SERVO MOTOR SPEED TORQUE CHARACTERISTICS SET UP****Procedure:-****Armature Control:**

1. Adjust T1 at setting with the help of knob K.
2. Ensure the POT P1 (speed control) is in the maximum anti clock wise position. Switch on supply.
3. Connect a digital or analog Multimeter across the terminals marked armature to measure armature voltage in the range volts.
4. Adjust P1 and P2 so that $V_a =$ and $V_f =$ volts.
5. Note down T1, T2 and speed and enter the results in the table 1.
6. Adjust T1 up to in the steps of to get a set of readings.
7. Now for $V_a =$ volts etc repeat step no 6.
8. From table no 1, plot the speed torque characteristics.

Field control method:-

1. You may repeat above steps for various values of field voltages by controlling POT P2 and keeping V_a at volts.

Table 1: For Armature Control

Radius of pulley= $R= 3.53\text{cm}$ Field voltage $V_f = 16\text{v}$ Armature voltage $V_a = 13\text{v}$

S.No	T1 (gm)	T2 (gm)	T1-T2 (gm)	Torque (T1-T2).R	N(r.p.m)	Ia (Amp)

Table 2: For Field Control

Field voltage $V_f = 16\text{v}$ Armature voltage $V_a = 15\text{v}$

S.No	T1 (gm)	T2 (gm)	T1-T2 (gm)	Torque (T1-T2).R	N(r.p.m)	Ia (Amp)

Precautions:-

1. The speed control knob should be always in the most anticlockwise position before switching on the equipment.
2. In order to increase the armature voltage, rotate the knob in the clockwise direction in a gentle fashion.
3. In order to increase the load on the servomotor adjust the knob.

Result:-

Torque-speed characteristics of D.C Servomotor at different Armature voltages and Field voltages are plotted.

EXPERIMENT NO: 2**AC POSITION CONTROL SYSTEM**

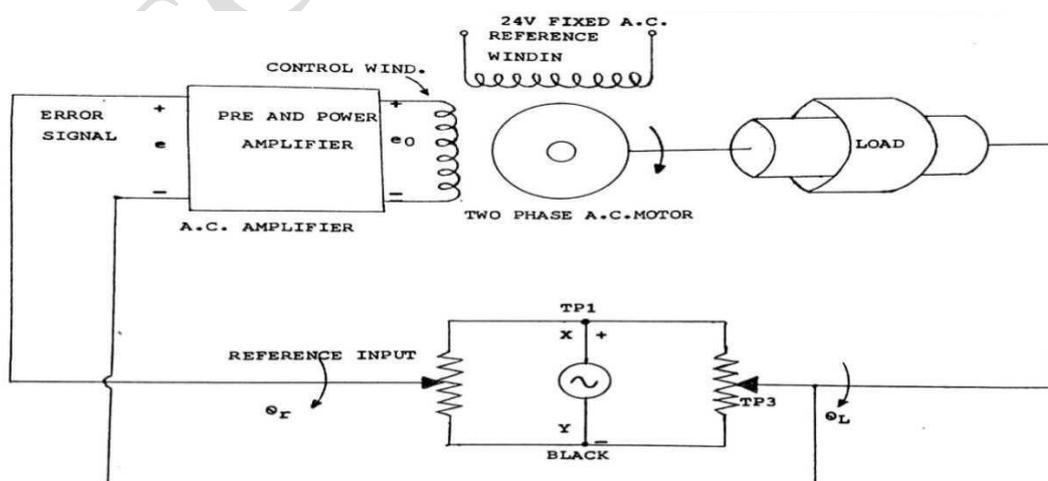
Aim: To study A.C position control system.

Apparatus: A.C position control system unit.

Theory:- A pair of precision servo potentiometers is working as an error detector. The potentiometer marked as INPUT POTENTIOMETER translates information regarding the desired angular position into a proportional A.C voltage. The potentiometer marked OUTPUT POTENTIOMETER converts the information regarding the present position of mechanical load into a proportional A.C voltage. Note that this pair of input And output potentiometers is excited by a 6 volts 50 Hz supply. $\{V\{t\}$.

Any difference of potential between the wiper contacts of servo potentiometer is amplified by means of A.C power amplifier. The power amplifier output activates the control winding of the A.C servomotor {2 phase}.The other is activated {reference winding} by means of fixed AC voltage. The load to be positioned is coupled to the output shaft of the output servomotor and gear train combination. The same shaft is also coupled to the output potentiometer.

This position control system works to make the output shaft position identical to the input shaft position. When the output shaft is being positioned, the mechanical load is also moved to a new desired position thus making error voltage always zero. The system works to make the error voltage zero after disturbance.

Block diagram of A.C position Control System:

Procedure:-

1. Switch ON the AC main supply, Switches SW1, SW2 and SW3 should be in the ON position.
2. Observe that the input and output potentiometers come in alignment.
3. Keep the gain pot in almost in maximum gain position { Almost fully clockwise position }
4. Take the input potentiometer to the starting position i.e. very near to the zero position. The output potentiometer will also follow the input potentiometer till the null indicator indicates null position.
5. Enter the observations in the tabular column given below. You may repeat the observations with lower amplifier gain, to observe that there is greater error, with higher gain {i.e. maximum gain} you may note that the output pot indicates sustained oscillations.
6. You may use the test points black, TP1, TP2, TP3 a.TP1- Black- Excitation voltage for potentiometer system.b.TP2-black –Variable point potential for I/P pot.c.TP3- Black-variable point potential for O/P pot. Note that EXCITATION point {TP1-black} for O/P pot is floating with respect to the main ground.
7. Green terminal on the left hand side indicates main ground of the system. You may connect C.R.O across the TP4 and ground {green terminal}, TP5and ground to observe the A.C preamplifier output and servo amplifier output respectively.
8. Please note that the switches SW1 SW2 and SW3 are in series with A.C preamplifier, servo amplifier output and at the input of the A.C servomotor reference and control winding

Observation:

Sl. No	I/P Angular position	O/P Angular position	Remarks

Precautions:

1. If the Red LED is not glowing, check for the front panel fuse {D.C fuse}.If it blows again; do not switch ON the unit.
2. The Switch SW3 is connected in series with A.C servomotor windings. The same may put in OFF condition when the unit is not being used.
3. Do not try to rotate the o/p by means of the knob by hand

Result-

Ac position control is studied for various gains and it is observed that error is high for low values of gain and error is less for high values of gain.

Discussion of Result:

This position Control system works to make the output shaft position identical to the input shaft position. When the output shaft is being positioned, the mechanical load is also moved to a new desired position thus making error voltage always zero.

EXPERIMENT NO: 03**D.C POSITION CONTROL SYSTEM**

Aim : To study D.C position control system.

Apparatus: D.C position control system unit.

Theory:

The D.C Position control system is so called because the D.C signals exist in the system. For example if the reference input and the controlled output are constant values a straight line can graphically represent the actuating signal.

The signals in the other part of the system can be represented in the similar manner. For D.C voltage controlled system, the actuating signal $e [t]$ is a D.C voltage. In the simplest form the output position and the reference position θ_1 and θ_2 are measured and compared by a potentiometer pair whose output voltage is proportional to error in the angular position. The error voltage is amplified and applied to servomotor whose positions the load and the output potentiometer such that the error is reduced to zero.

NEED FOR STABILIZATION

With switch SW1 in open position and the step change in the input shaft, the output shaft exhibits an oscillating behaviour. This happens because of the system elements, which are capable of storing energy i.e. capacitance, inductance inertia of moving components like rotor, load, gear train etc. Once the system is excited by change in the input signal, the various elements begin to store energy, even if the error voltage falls to zero. The stored energy causes the output shaft to move in the same direction. This creates an error of opposite polarity and the system is again instructed to work in the opposite direction. In this way, energy storing elements tend to produce overshoots and undershoot in the system. In the experimental setup, output Derivative Feedback is used for stabilization of the output.

The Tachogenerator, which is coupled to the motor, generates an output voltage, which is proportional to the rate of change of displacement. This voltage is coupled to the input of error amplifier, either in the regenerative mode or degenerative mode.

By the adjustment of potentiometer P4 amount of derivative feedback can be adjusted, while DPDT switch is meant for selection of mode of stabilizing feedback.

HOW DERIVATIVE FEEDBACK WORKS

When switch SW1 is closed [i.e. in TACHO IN position] and the degenerative feedbacks are suitably adjusted, we observe that the output shaft follows the input shaft in a smooth fashion without any unwanted oscillations.

If the mode of feedback is regenerative, then the output never reaches the stable state. Instead it keeps on oscillating around the desired position.

In short, for degenerative feedback, the damping factor of the system is decreased, thus resulting in breaking action on the moving components, prior to their final desired position. For a greater amount of feedback voltage, damping becomes excessive and the system exhibits a very sluggish response, settles to a final position. The tendency for oscillations is found to be dependent on the amplifier gain setting.

OPERATION WITH STABILIZING FEEDBACK

1. Now put the SW switch in lower position i.e. tacho in position, SW2 must be in downward position i.e. degenerative mode. Keep P4 in fully anticlockwise direction.
2. The system can be tested for operation as follows
3. Now take the pot P1 to 180 position & effect the step input change in one of the directions, output again indicates oscillations. Now advance the pot in P4 in clockwise direction and the output now is observed to follow the input in a smooth fashion without oscillation. If the P4 pot is too much advanced, the output now follows input in a sluggish fashion indicating over-damped system. Now take the pot P1 to 180 positions.
4. Now put the switch SW2 in upward position i.e. regenerative mode. Now if the pot P1 is disturbed the output pot P2 is found to oscillate continuously around the desired position. As the amount of feedback is adjusted the frequency and the amplitude of output is observed to vary.

DO NOT OPERATE THE D.C POSITION CONTROL IN THE REGENERATIVE MODE FOR A LONG TIME.

Block Diagram of DC Position Control System:

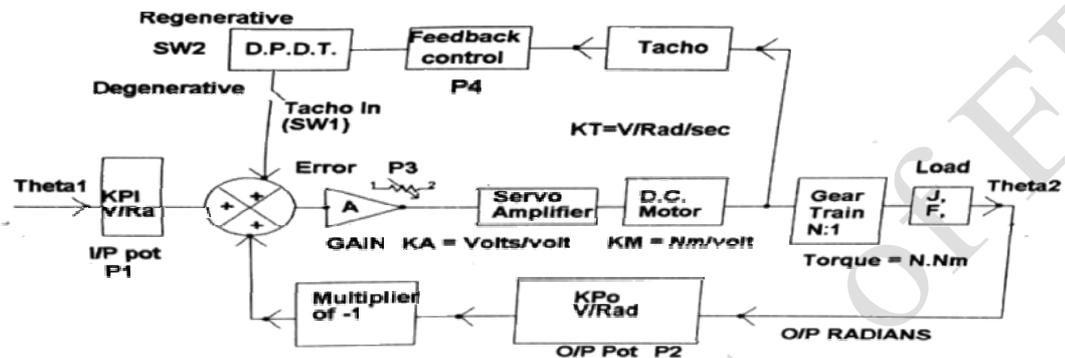
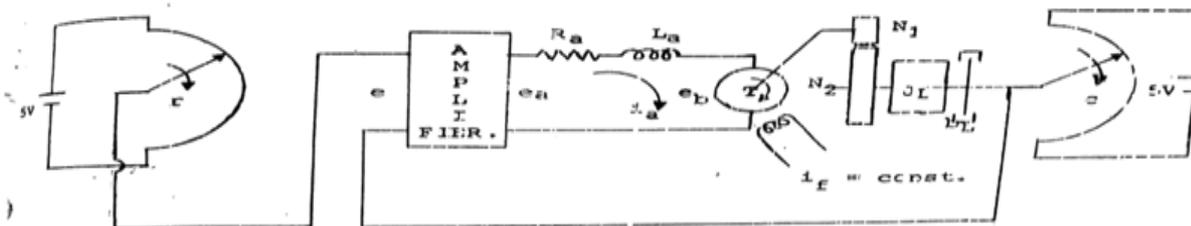


FIGURE NO.5
BLOCK DIAGRAM SHOWING TRANSFER FUNCTIONS
OF VARIOUS COMPONENTS FOR D.C.POSITION CONTROL SYSTEM

DETAILED DIAGRAM OF D.C. POSITIONAL SERVO SYSTEM.



Procedure:

1. Before switching on the main panel, see that the switches SW3, SW4 {on the LHS panel} are in the downward position i.e. ON position.
2. Ensure that SW1&SW2 are in the off position i.e upward position.
3. Keep the input position P1 in 10 positions
4. Potentiometer p3 [amplifier gain adjustment] should be in mid position.
5. Now switch on the main unit LED 'R' and LED 'G' should glow. Operation without feedback [SW1 in off position i.e. Tacho Out]
6. Now slowly advance the i/p potentiometer P1 in clockwise direction. The o/p potentiometer along with load will be seen to be following the change in the i/p potentiometer.

7. When the i/p is disturbed the null indicator will be showing some indication but when the o/p reaches desired positions, again the null indicator indicates almost zero. It may be noted that when i/p POT is moved in anti-clockwise direction, the o/p POT also moves in the reverse direction.

Step change in input

8. Now change the i/p POT in a step fashion (in fact approximating step input). The output will be observed to change in oscillatory mode.

Observations:

Plot the output angle v/s input angle for both the system i.e. without and with stabilizing feedback.

SI. No.	Input	Output	Without stabilizing feedback, remarks.

SI. No.	Input	Output	With stabilizing feedback- Degenerative mode

SI. No.	Input	Output	With stabilizing feedback Regenerative mode

Precautions:

1. Please do not cross zero degree position by moving POT P1 i.e. do not operate between 350 deg and zero deg.
2. Do not try to rotate output POT by hand .this may damage the potentiometer

Result:

The output angle v/s input angle characteristics for both the system i.e. without and with stabilizing feedback are to be observed.

Discussion of the Result:

1. Student should be able to understand the effect of amplifier gain. Higher the gain, smaller is the error.
2. Student should be able to understand the function of output potentiometer.

EXPERIMENT- 4**ON/OFF TEMPERATURE CONTROL SYSTEM**

Aim: - To study the performance of ON/OFF controller to control the temperature of an oven.

Apparatus:

1. Temperature control system unit.
2. Stop watch.
3. Oven. Fan.
4. Connecting wires.

Theory :-

On/Off controller or two position controller is one of the various controller modes which shows discontinuous changes in controller output as controlled variable error occurs.

Although an on/off type does not qualify as a control(continuous), it used in numerous residential, commercial and industrial application. It is commonly used in control of home appliance, hot plate and oven temperature control, refrigerator, temperature control and dishwasher, water level control of all residential and commercial buildings.

Types of on/off control:

- (strict)on-off control
- Two-position control
- Floating control

(strict)on-off control: This method of control is not practical one, because in the majority of applications, controller output would constantly be switching between full scale(100%) and zero (0%) output. Thus a strict on-off method of control is seldom used. A modified form of on-off control, two position control, is more commonly used.

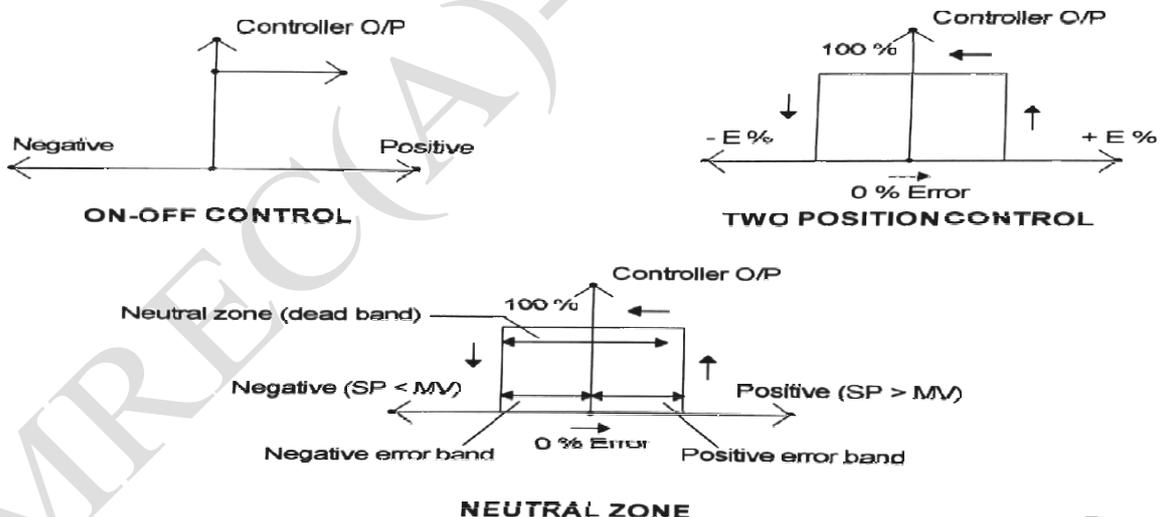
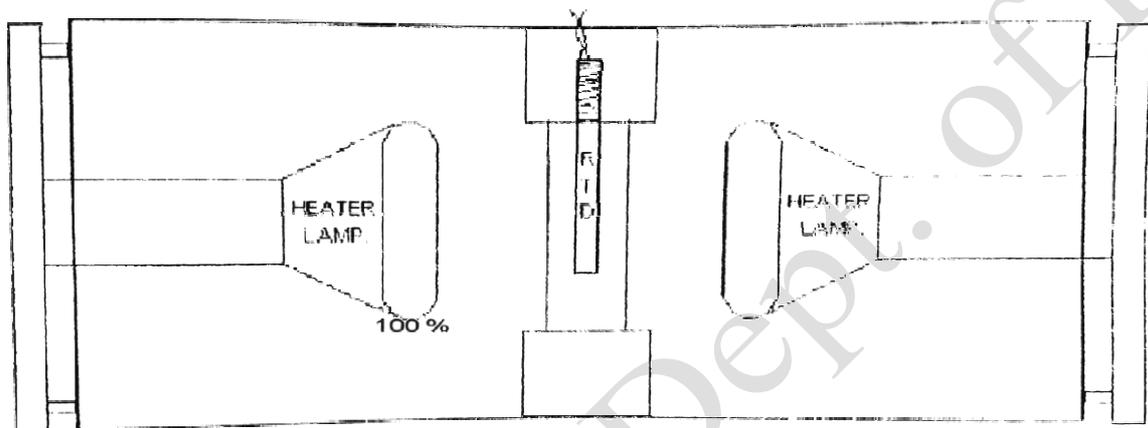
Two position control: It is an improvement over the basic on-off. The controller output still swings between 0% and 100%, but an additional hysteresis element (neutral zone) is now incorporated.

Neutral Zone

The neutral zone is the region of error over which the controller does not change its output. The neutral zone is also known by the terms dead band and error band.

Circuit Analysis: In this circuit, RTD is made an arm of a simple bridge circuit. The RTD exhibits a change of about 39% in resistance from 100 ohms at 0 degree centigrade to 139 ohms at boiling point of water. So in case of RTD is made part of a bridge circuit with equal arms. There will be a non-linear relationship between resistance change and bridge output voltage.

Diagram of on/off controller (Heater system):

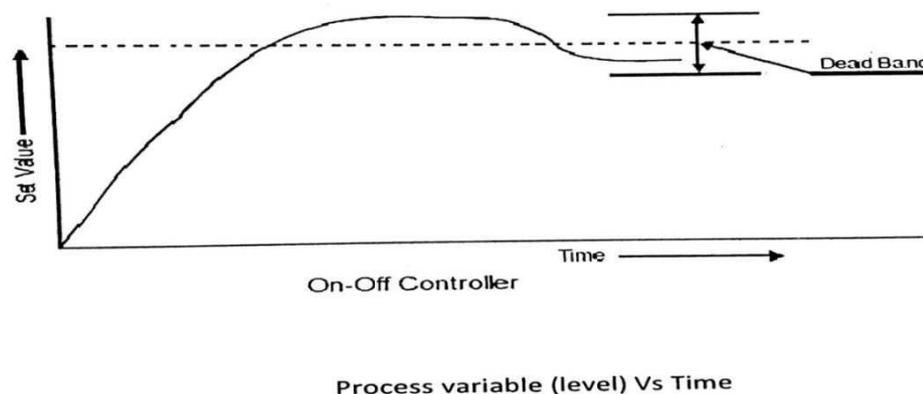


Procedure:-

1. Connect the RTD sensor PT-100 to binding post provided on the front panel.
2. Connect the heater cable on the rear side socket.
3. Keep rotary switch on front panel in 0 degree position and switch on supply.

4. The D.P.M should indicate 0.0 degree centigrade.
5. When select switch is taken to 100 degree position, DPM should indicate 100 degree centigrade. This completes calibration check and ensures that MAX and MIN controls on the PCB are properly adjusted.
6. Keep select switch in set position and adjust SET temp to 55 degree centigrade and keep dead band pot to most C.C.W position(MIN).
7. Take select switch to RTD position now you can observe the RTD temperature goes on increasing and controller keeps temperature of process around the set point depending upon dead-band adjustment.
8. You may take temp reading at regular interval of 15 sec and plot a graph for temp VS time reading.
9. You may adjust dead band to most C.W position (MAX) and repeat above process.
10. If you keep a fan near the process model you may again take another set of readings.

EXPECTED GRAPH:



Precautions:-

- Operate the select rotary switch carefully.
- RTD connection should be firm.

Result: Working of on-off temperature controller is studied.

Discussion of Result:

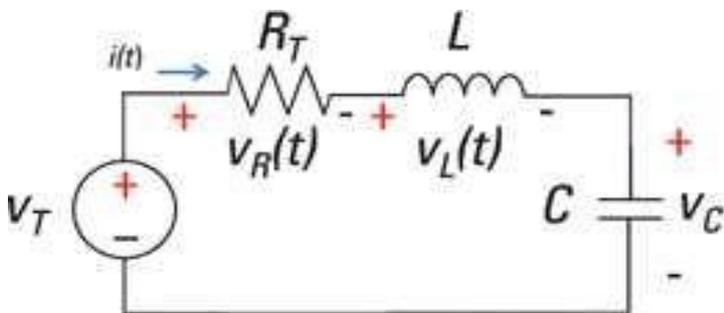
Students should be able to understand about linearity of the bridge output (RTD) with respect to changes in resistance.

EXPERIMENT – 5**TIME DOMAIN ANALYSIS OF SECOND ORDER SYSTEM**

Aim: - To perform the time domain analysis of second order system when subjected to unit a step input.

Apparatus: Signal generator, CRO probes, bread board, Resistor, Inductor, Capacitor, connecting wires.

Circuit diagram:



Theory: - Applying Laplace transforms to the circuit,

$$V_i(s) = I(s) [R + sL + 1/sC]$$

$$V_O(s) = I(s) \cdot 1/sC$$

Transfer function

$$V_O(s)/V_i(s) = \frac{1/sC}{R + sL + 1/sC}$$

$$= \frac{1}{LCs^2 + RCs + 1}$$

Comparing with standard representation second order type-1 system

$$C(S)/R(S) = \frac{\omega_n^2}{s^2 + 2\zeta s \omega_n + \omega_n^2}$$

$$= \frac{1/LC}{s^2 + \frac{R}{L}s + 1/LC}$$

$$\omega_n^2 = 1/LC \Rightarrow \omega_n = 1/\sqrt{LC} = \text{Natural frequency}$$

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

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

$$R(s) = 1/S$$

$$C(s) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} * 1/s$$

Applying inverse laplace transform and solving

$$C(t) = 1 - \frac{e^{-\xi\omega_n t}}{\sqrt{1-\xi^2}} \sin[\omega_d t + \tan^{-1} \frac{\sqrt{1-\xi^2}}{\xi}]$$

$$\omega_d = \omega_n \sqrt{1-\xi^2}$$

Steady state value of the system

$$\lim_{t \rightarrow \infty} C(t) = C_{ss} = 1$$

t->∞

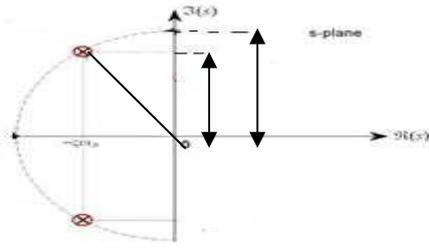
Poles of second order system

The poles S1 and S2 are

$$S1 = -\xi \omega_n + j \omega_n \sqrt{1-\xi^2}$$

$$S2 = -\xi \omega_n - j \omega_n \sqrt{1-\xi^2}$$

So if a semicircle of ω_n is plotted in S-plane having σ as real axis and $j\omega$ as imaginary axis then the various poles will be on this semi circle as shown in the fig.



Point C will represent pole and its image pole will be E.

For $\xi = 1$ then the two poles will have the values $S_1 = S_2 = -\omega_n$

(Point B) \odot critically damped case.

For $\xi > 1$ the poles will be on the real axis at $\xi \omega_n \pm \omega_n \sqrt{\xi^2 - 1}$

Oscillatory case

For $\xi = 0$, the poles will be $S_1 = S_2 = \pm j\omega_n$

Undamped case, they lie on points D and F.

Thus the semicircle will define the poles of the second order system.

Time response of the second order system will always be oscillatory ($\xi < 1$).

Delay time $\{T_d\}$ it is defined as the time taken for the system to reach to 50% of its final value.

Rise time $\{T_R\}$ it is defined as the time taken for the system to rise from 0 to 100% of the final value

$$T_r = \frac{\pi - \tan^{-1} \frac{\sqrt{1-\xi^2}}{\xi}}{\omega_d}$$

Peak time $\{T_p\}$ it is defined as the time taken for the output to reach 50% of the peak value $T_p = \frac{\pi}{\omega_d}$

Settling time $\{T_s\}$ it is defined as time taken for the output to reach the steady state value = $\frac{4}{\xi \omega_n}$

Peak over shoot $\{M_p\}$ Value of the maximum overshoot = $e^{\frac{-\pi\xi}{\sqrt{1-\xi^2}}}$

Procedure:

1. Make the connections as shown in the fig {1}
2. Give square wave signal to the input terminals.
3. Connect the input signal to the Y-Plates of the CRO
4. Connect the output signals to the X-Plates of CRO.
5. Vary the inductance value and the frequency such that damped sinusoid appears on CRO.

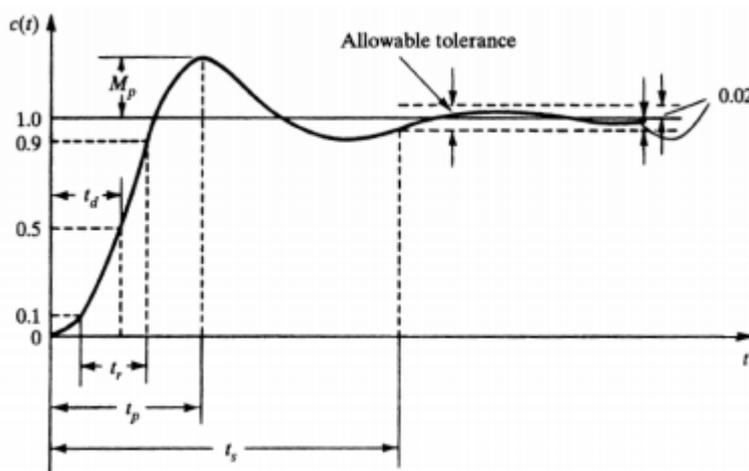
6. Note down the values of rise time, delay time, peak time, settling time and maximum overshoot.
7. Vary the inductance, repeat step {6} and take another set of values,
8. Compare the results with theoretical values.

Tabular form:

Theoretical values	Practical values

Observation:

Sketch the waveforms and insert the values in the below figure.



Result: Time domain analysis of second order system are studied when subjected to unit step input.

Discussion of result: Students are able to note down the values of rise time, delay time, peak time, settling time and maximum overshoot by varying inductance and compare it with theoretical values.

EXPERIMENT NO: 6**CHARACTERISTICS OF A.C SERVOMOTOR.**

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

Apparatus: AC servomotor setup Multimeter connecting wires

Theory:

An AC servomotor is basically a two phase induction motor except for certain special design features. A two phase induction motor consisting of two stator windings oriented 90 degree. Generally voltages which differ in time phase 90 deg phase difference are applied to the stator phases thus making their respective fields 90 deg apart in both time and phase, at synchronous speed. As the field sweeps over the rotor, voltages are induced in it producing current in the short circuited rotor the rotating magnetic field interacts with these currents producing a torque in the direction of field rotation. The shape of characteristics depends upon the ratio of rotor reactance (X) to the rotor resistance (R). In normal induction motor X/R ratio is generally kept high so as to obtain the maximum torque close to the operating region which is usually around 5% slip. A two phase servomotor differs in two ways from normal induction motor.

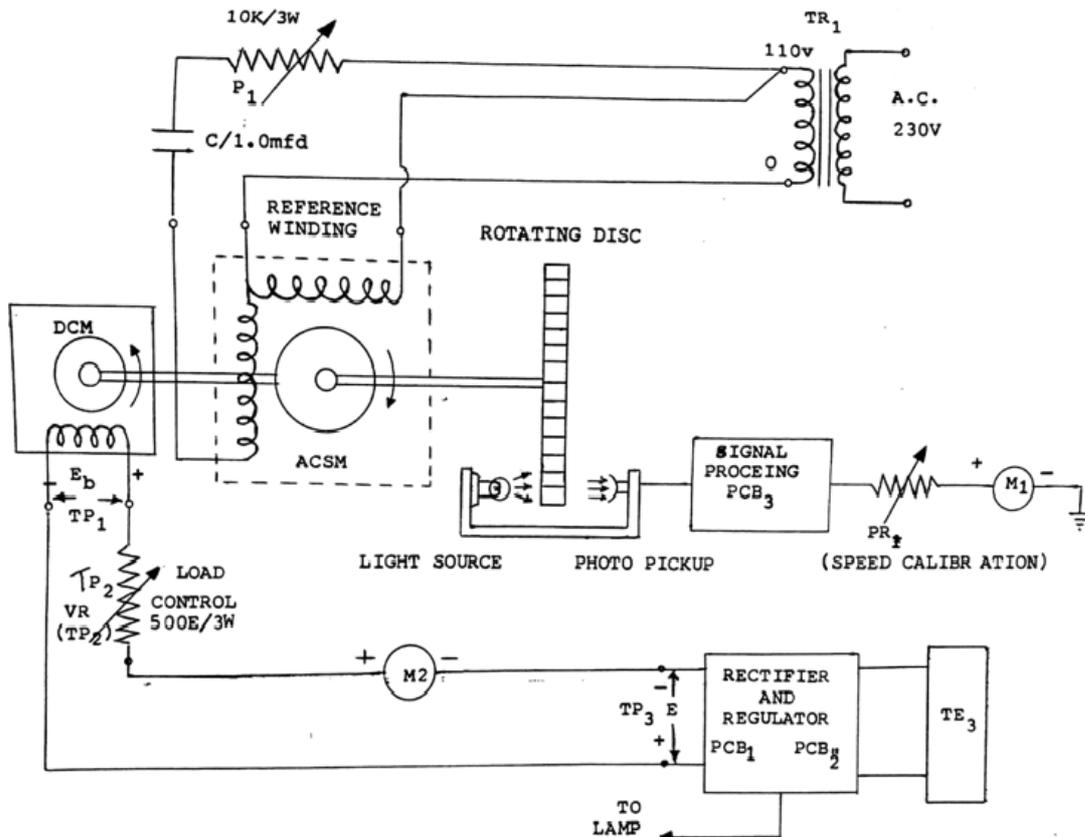
The rotor of servomotor is build with high resistance so that X/R ratio is small and torque speed characteristics are fairly linear.

Curve (B) is nearly linear in contrast to highly non linear characteristics with large X/R ratio. It must be emphasized that if a conventional induction motor with high X/R ratio is used for servo application, then because of the positive slope for part of the characteristics, the system using motor becomes unstable.

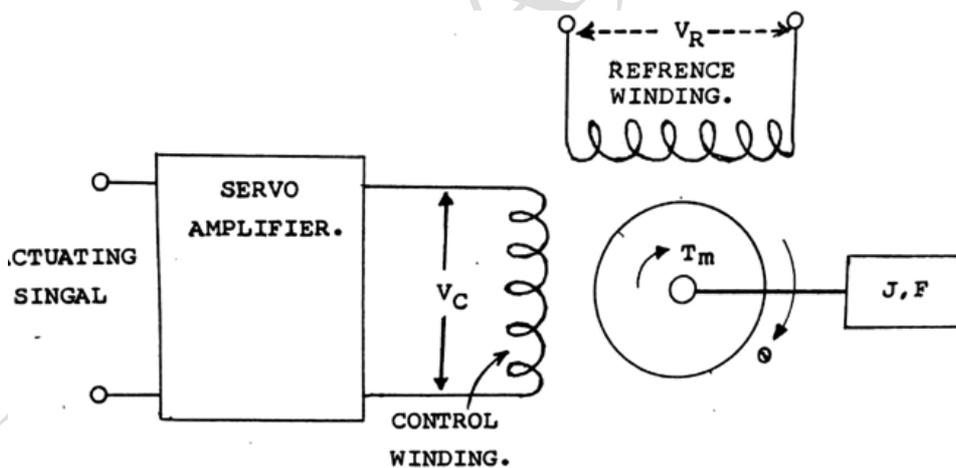
The motor construction is usually squirrel cage or drag cup type. The diameter of the motor is kept small in order to reduce the inertia and thus to obtain good accelerating characteristics. Drag cup construction is used for very low inertia operations.

In servo application, the voltages applied to the stator winding are seldom balanced. One of the phases known as the reference phase is excited by constant voltage and the other phase known as the control phase is excited with a voltage which is 90 degree out of phase with respect to the voltage supplied to the reference windings and it has a variable magnitude and polarity. The control winding voltage is supplied from a servo amplifier. For low power application, A.C servomotors are preferred because they are lightweight, rugged and there are no brush contacts to maintain

AC Servomotor Block diagram:



Schematic diagram of two phase induction motor:



Procedure:

1. Study all the controls carefully on the front panel. Keep the switch SW3 in upward position, indicating that the armature circuit of D.C machine is not connected to auxiliary power supply [12v], switch SW2 should also be in off position.
2. Ensure P1 and P2 are in fully anticlockwise position.
3. Now switch on SW1 and also switch on SW2. you can observe that A.C servomotors will start rotating and the speed will be indicated by the meter M1 on the front panel. [It is assumed that calibration procedure is already carried out for speed measurement].
4. With SW3 in off position vary the speed of the A.C servomotor by moving P1 in clockwise direction and note the e.m.f generated by the D.C machine [Now working as D.C generator or tachometer]. Enter the results in table 1. [Use a D.C voltmeter in the range 0 to 2 volts or so].
5. Now switch SW3 in off condition, switch on SW2 and keep the pot P1 in minimum position. You can observe that the A.C servomotor starts moving with speed being indicated by the RPM indicated. You can measure the reference winding voltage [about 100 volts A.C] and control winding voltage [which is variable by P1] notes the speed of A.C servomotor. Now switch SW3 and start loading A.C servomotor by values on Ia and N. Enter this in table 2.
6. Now you may set control winding voltage to a new value of 30 volts after switching off SW3. Again repeat the process as indicated in step No 5 i.e. table 2 for a new value of control winding voltage.
7. Plot the speed torque characteristics for various values of control winding voltages. Study their nature.

OBSERVATION:**Table No. 1**

SNO	RPM	EB = VOLTS

TABLE No. 2**Expected Graphs:**

SNO	Ia[Ma]	N[RPM]	Eb[Volts}	P=Eb*Ia[mW]	Torque[T]=p*1.019*10*60/2

Plot the speed Vs Torque characteristics of the A.C Servomotor.

PRECAUTIONS:

1. Before switch on P1 and P2 should be always brought to most anticlockwise position
Controls P1 and P2 should be operated in gentle fashion.

Result: The speed-torque characteristics of A.C Servomotor are studied

EXPERIMENT – 7**CHARACTERISTICS OF SNCHRO PAIR**

Aim:- To study the properties of synchro

Apparatus: Synchro setup, Digital Multimeter, Connecting wires

Theory: A synchro is an electromagnetic transducer commonly used to convert an angular position of a shaft into an electrical signal. The basic synchro is called synchro transmitter. Its construction is similar to that of three phase alternator.

Let an A.C voltage $V_r(t) = V_r \sin \omega t \dots (1)$

be applied to the rotor of the synchro transmitter. This voltage causes a flow of magnetizing current in the rotor coil which produces a the air gap along the stator periphery. Because of transformer action, voltages are induced in each of the stator coils. As the air gap flux is sinusoid ally distributed, the linking any stator coil is proportional to the cosine of the angle between rotor and stator coil axis. Let V_{s1n} , V_{s2n} , V_{s3n} respectively be the voltages induced in the stator coils S1, S2, S3 with respect to the neutral.

Then with respect to the rotor position as shown in the fig [rotor makes an angle degrees with stator S2]

$$V_{s1n} = K_v r \sin \omega t \cos [\theta - 120] \dots (2)$$

$$V_{s2n} = K_v r \sin \omega t \cos (\theta) \dots (3)$$

$$V_{s3n} = K_v r \sin \omega t \cos [\theta + 240] \dots (4)$$

Three terminal voltages of the stator are

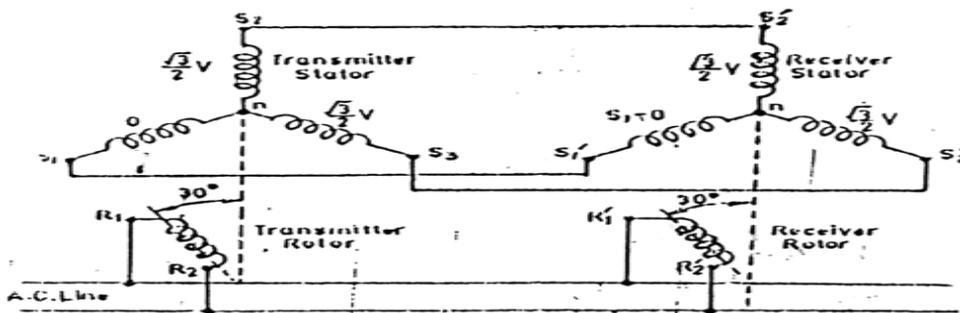
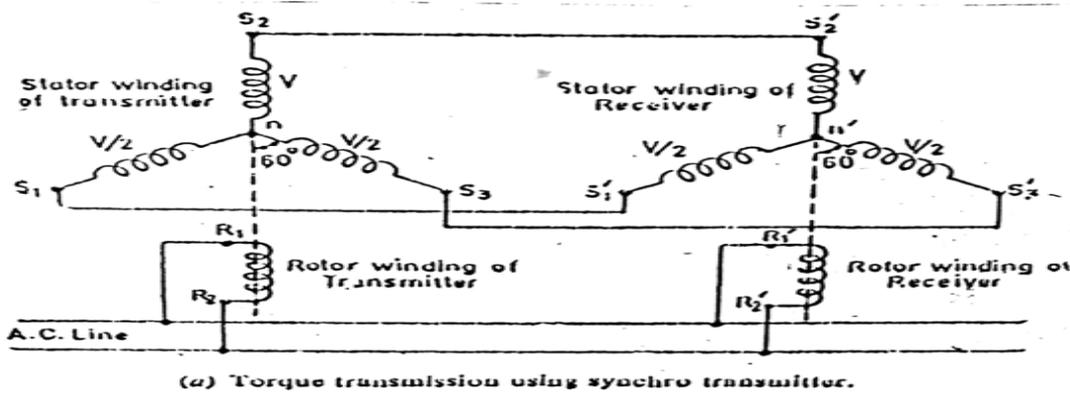
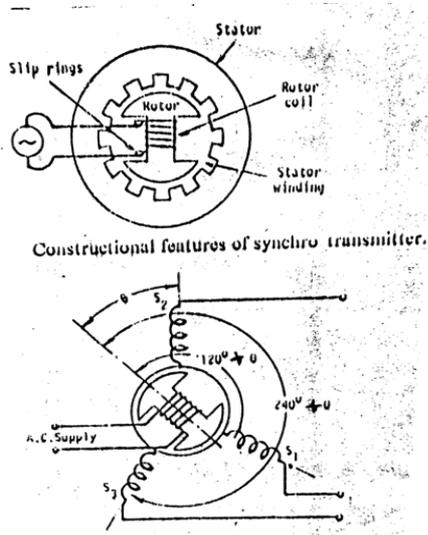
$$\begin{aligned} V_{s1s2} &= V_{s1n} - V_{s2n} \\ &= 3 K_v r \sin (\theta - 240) \sin \omega t \dots (5) \end{aligned}$$

$$\begin{aligned} V_{s2s3} &= V_{s2n} - V_{s3n} \\ &= 3 k_v r \sin (\theta - 120) \sin \omega t \dots (6) \end{aligned}$$

$$\begin{aligned} V_{s3s1} &= V_{s3n} - V_{s1n} \\ &= 3 k_v r \sin (\theta) \sin \omega t \dots (7) \end{aligned}$$

When $\theta=0$ from equations 2 & 3 it is seen that maximum voltage is induced in the stator coils S2 while it follows from equation [7] that the terminal voltage Vs3s1 is zero. The position of the rotor is defined as ELECTRICAL ZERO.POSITION.

Schematic diagram of synchro transmitter



FOLLOW UP SYSTEM OF SYNCHRO TRANSMITTER AND RECEIVER

Procedure:

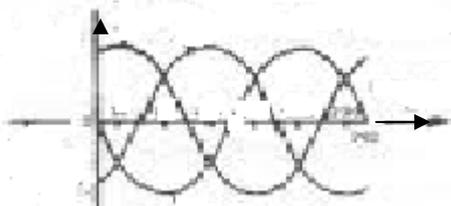
1. In this part of experiment, we can study, because of transformer action the angular position of the rotor of synchro transmitter is transformed into unique set of stator voltage.
2. Connect the mains supply to the system with the help of cable provided, do not connect any patch cords to the terminals marked S1, S2, and S3.
3. Switch on the main supply for the unit.
4. Starting from zero position, note down the voltages between stator winding terminals in a sequential manner.
5. Enter the reading in the tabular form and plot the graph of rotor voltages of all the three phase voltages.

Tabular column:

Angular position of rotor. (θ).	Stator voltages		
	V_{s1s2}	V_{s2s3}	V_{s3s1}

Expected graph

Stator voltage

*Rotar displacement*

Part II

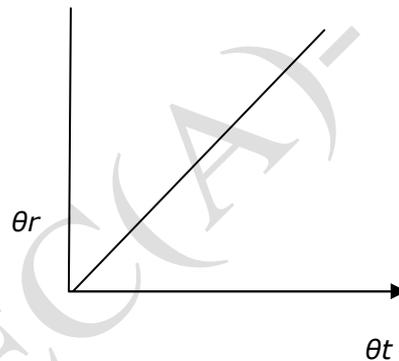
Aim : To study synchro transmitter and receiver pair.

Procedure:

1. Connect mains supply cable.
2. Connect S1 S2 and S3 terminals of transmitter to S1 S2 S3 of synchro receiver by patch cords.
3. Switch ON sw1 and Sw2 and the main supply.
4. Move the rotor position of the synchro transmitter TX in the steps of 30 deg and observe the rotor position at the receiver.
5. Enter the rotor position of the transmitter and receiver and plot the graph.

Tabular column:

θ_t (transmitter)	θ_r (receiver)

Nature of graph:**Precautions:**

- Handle the pointers for both the rotors in a gentle manner.
- Do not attempt to pull out the pointers.
- Do not short rotor or stator terminals.

Result: The properties of synchro are studied and graphs are plotted.

Discussion of Result: Students should be able to understand that because of transformer action, voltages are induced in each of the stator coil. The rotor of control transformer is made cylindrical so that air gap is practically uniform. This feature of control transformer minimizes the change in the rotor impedance with rotation of the shaft.

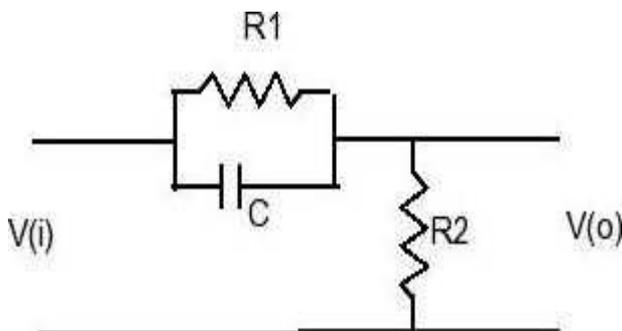
EXPERIMENT- 8**FREQUENCY RESPONSE ANALYSIS OF LEAD COMPENSATING NETWORK**

Aim: - To Plot Magnitude and Phase angle characteristics versus Frequency of LEAD compensator.

Apparatus : - Signal generator, CRO, breadboard, connecting wire, CRO probes.

Theory: In Control systems, Compensating Networks are used to improve the Performance of the systems and to meet some performance specifications. They are usually connected in series with the original systems.

Circuit Diagram and Transfer functions:



$R1 = 4.7K\Omega$, $C = 33KF$, $R2 = 1K\Omega$

Step1: Apply L.T to the network and simplifying parallel combination of $R1$ and $1/C$

$$= \frac{R1 * 1/CS}{R1 + 1/CS}$$

$$= \frac{R1}{R1CS + 1}$$

$$= \frac{R1}{R1CS + 1}$$

Step2: Analysis applying KVL to loop

$$Vi(s) = I(s) \left[\frac{R1}{R1CS + 1} + R2 \right]$$

$$Vi(s) = I(s) \left[\frac{R1 + R2 + R1R2CS}{R1CS + 1} \right]$$

$$\text{As } Vo(s) = I(s) * R2$$

$$\frac{V_o(s)}{V_i(s)} = \frac{R_2(R_1CS+1)}{R_1+R_2+R_1R_2CS}$$

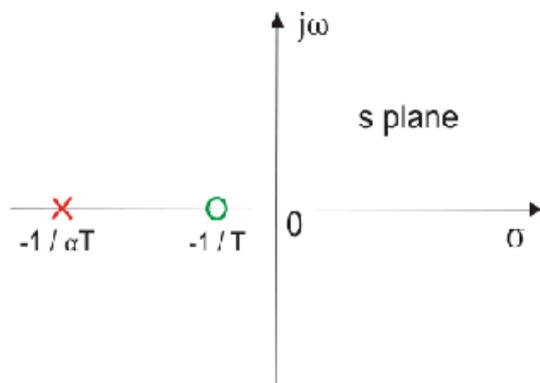
$$\frac{V_o(s)}{V_i(s)} = \frac{\alpha (\tau s + 1)}{1 + \alpha \tau s} \quad \text{where } \alpha = \frac{R_2}{R_1+R_2}, \tau = R_1C$$

Pole-Zero configuration:

Zero at $s = -1/\tau$; pole at $s = -1/\alpha\tau$ (since $\alpha < 1$)

To Design:-

(i) $\alpha = R_2/R_1+R_2$ (ii) $\sin \phi_m = 1 - \alpha/1+\alpha$, $\phi_m = \sin^{-1} \frac{1-\alpha}{1+\alpha}$



Corner Frequency:

$$1. \quad \omega c_1 = 2\pi f_1$$

$$\frac{1}{\tau} = \frac{1}{R_1C}$$

$$f_1 = \frac{1}{2\pi\tau} = \frac{1}{2\pi R_1 C}$$

$$2. \quad \omega c_2 = 2\pi f_2$$

$$\frac{1}{\alpha\tau} = \frac{1}{\alpha R_1C}$$

$$f_2 = \frac{1}{2\pi RC} = \frac{1}{2\pi R_1 C}$$

$$3. \omega_m = \sqrt{\omega_1 * \omega_2} = \frac{1}{\tau\sqrt{\alpha}}$$

Procedure:

1. Connect the circuit diagram as shown.
2. Give Sinusoidal input 2-3volts peak to peak.
3. Vary the Frequency from 500HZ and measure the amplitude and phase angle.
4. Draw the Bode Plots on the semi log sheet and measure the corner frequencies and the value of maximum phase lead angle, and the corresponding corner frequency at the maximum phase lead angle.
5. Compare the values with theoretical values.

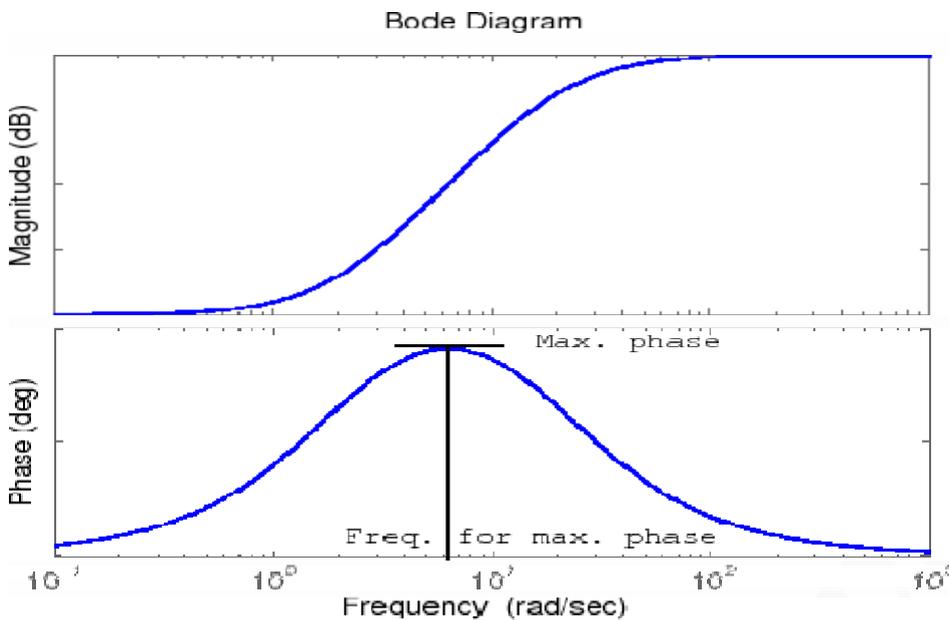
Tabular Form:

Sl. No.	Freq	Input voltage (V1)	Output voltage (V2)	a	b	Magnitude = 20log V2/V1	Phase angle = sin-1(a/b)	remarks

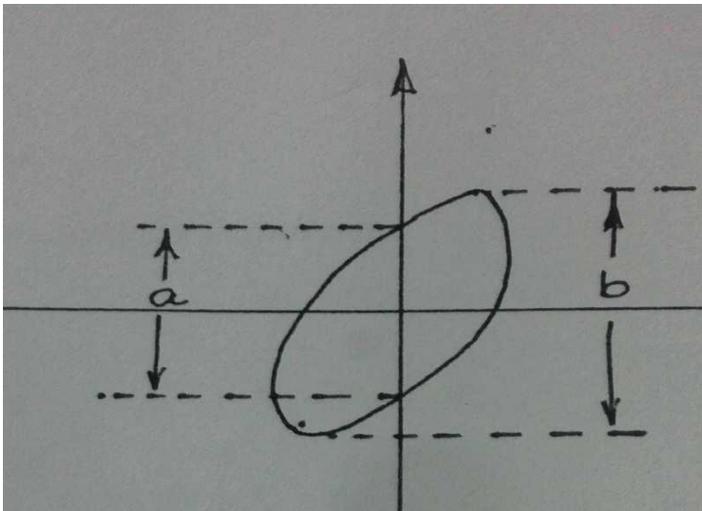
Expected graphs:

Bode plots:

To find Magnitude:



To find phase angle:



Result: Characteristics of lead compensator is studied by plotting magnitude and phase angle vs frequency.

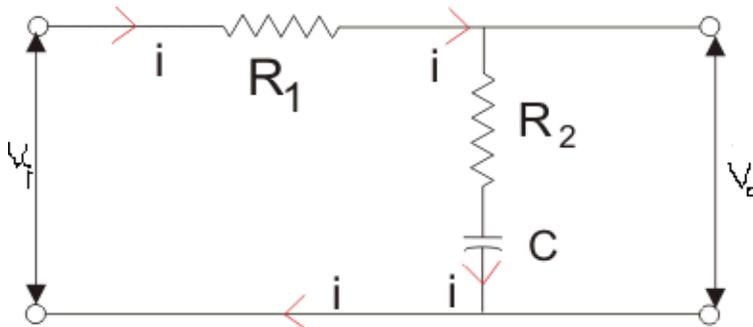
Discussion of Result: Students should be able to plot the characteristics and observe the maximum phase lead (ϕ_m) from the graph and observe that phase-lead controllers are used to improve the gain and phase stability margins and to increase the system bandwidth (decrease the system response rise time).

EXPERIMENT – 9**FREQUENCY RESPONSE ANALYSIS OF LAG COMPENSATING NETWORK**

Aim: To plot Magnitude and Phase angle characteristics versus frequency of LAG COMPENSATOR.

Theory:

In Control Systems, Compensating Networks are used to improve the performance of the system and to meet some performance specifications. They are usually connected in series with the original system.

Circuit Diagram and Transfer Function:

V_i = input from signal generator , V_o = output

Transfer Function:

Step1: Applying laplace transform to the network

$$V_o = I(s) [R_2CS + 1/CS]$$

Step2: Applying KVL

$$V_i(s) = I(s) [R_1 + R_2CS + 1/CS]$$

$$V_i(s) = I(s) [R_1CS + R_2CS + 1/CS]$$

$$V_o(s) = I(s) [R_2CS + 1/CS]$$

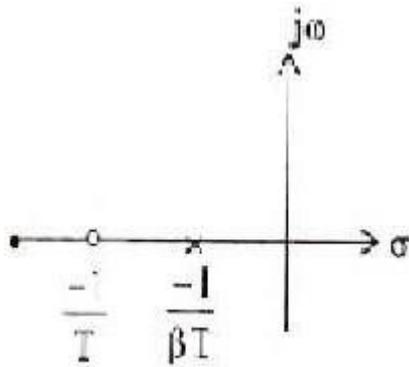
$$\frac{V_o(s)}{V_i(s)} = \frac{R_2CS+1}{R_1CS+R_2CS+1}$$

$$\frac{V_o(s)}{V_i(s)} = \frac{s+1}{\beta s + 1}$$

$$\beta = R_1+R_2/R_2, \tau = R_2C$$

Pole Zero configuration:

$$\text{Zero } S = -1/\tau \quad \text{pole } S = -1/\beta\tau (\beta > 1)$$



Corner Frequencies:

Calculate the theoretical corner frequencies using the following relation.

$$1. \omega_1 = 2\pi f_1 = \frac{1}{\beta\tau} = f_1 = 1/\beta R_2 C 2\pi$$

$$2. \omega_2 = 2\pi f_2 = \frac{1}{\tau} = f_2 = 1/R_2 C 2\pi$$

$$3. \omega_m = \sqrt{\omega_{c1}} * \sqrt{\omega_{c2}} = 1/\tau\sqrt{\beta}$$

$$\beta = R_1+R_2/R_2$$

$$\sin \phi_m = 1-\beta/1+\beta$$

Procedure:

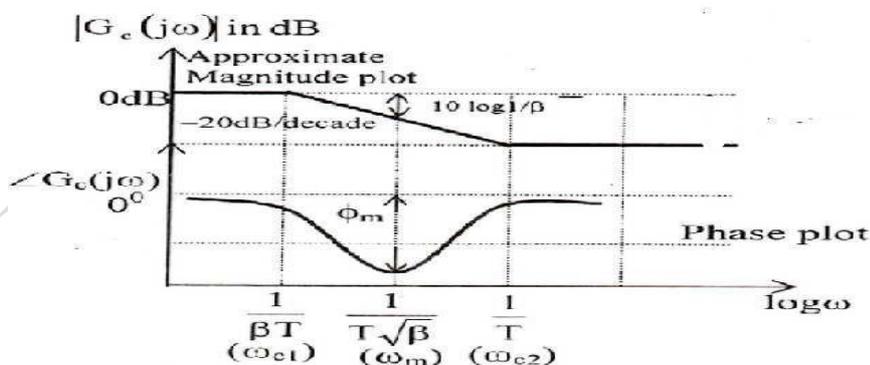
- 1 Connect the circuit diagram as shown.
- 2 Give Sinusoidal input 2-3 volts peak to peak.
- 3 Vary the Frequency from 5000HZ to 10kHz and measure the amplitude and phase angle.
- 4 Draw the Bode Plots on the semi log sheet and measure the corner frequencies t and the value of maximum phase lead angle, the corresponding corner frequency at the maximum phase lead angle.
- 5 Compare the values with theoretical values.

Tabular Form

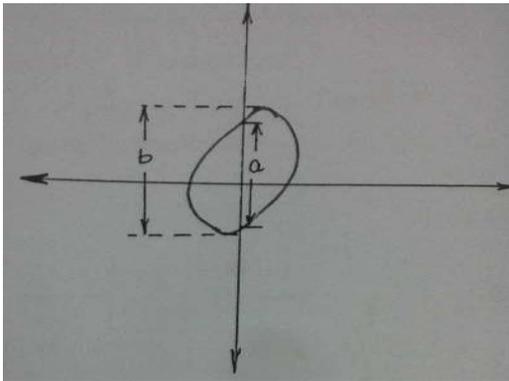
Sl. No.	Freq	Input voltage (V1)	Output voltage (V2)	a	b	Magnitude = $20\log V2/V1$	Phase angle = $\sin^{-1}(a/b)$	remarks

Bode Plots:

Magnitude determination:



Measurement of Phase Angle:



$$\phi = \sin^{-1} \frac{a}{b}$$

Result: Magnitude and Phase angle characteristics vs frequency of lag compensator is plotted and readings are compared

Discussion of result: Students should be able to find out the maximum phase-lag from the graph and observe that the phase-lag controllers are used in order to decrease the system bandwidth (to slow down the system response). In addition, they can be used to improve the stability margins (phase and gain) while keeping the steady state errors constant.

EXPERIMENT – 10**TEMPERATURE CONTROL SYSTEM**

Aim: - To study the performance of microcontroller based PID controller.

Apparatus:-

Temperature measurement system
 Solid-state relay for driving heater bulbs
 Micro controller based control unit
 LCD display

Theory: This set up is designed to demonstrate the working of a typical temperature controller using PID mode of operation.

Proportional controller is a mode of control action in which there is a continuous linear relationship between values of deviation and manipulated variable.

In order to remove the offset associated with proportional action, combination of P+I is widely used, As a result of integral action, the offset error is almost reduced to zero but the transient response is adversely affected.

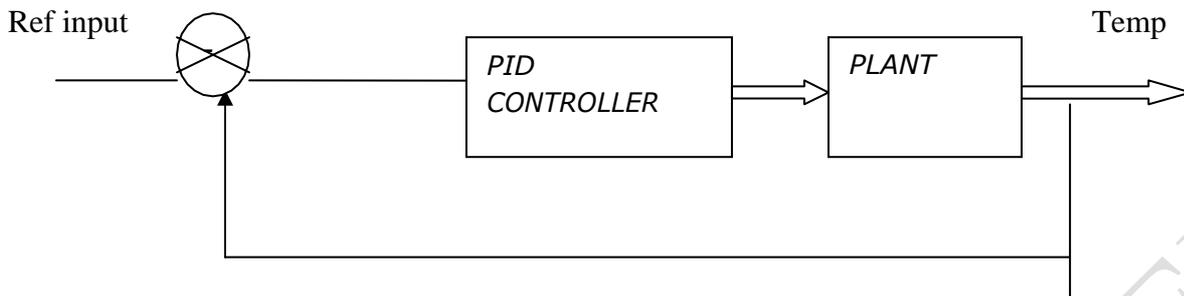
A derivative control action may be added to proportional control to form P+D action. Derivative control action may be defined as control action in which the magnitude of the manipulated variable is proportional to the rate of change of error.

P+I+D action produces smallest maximum deviation and offset is eliminated because of integral action. The derivative action provides improved transient response against load variations. In short PID approach to control problem can be summarized in terms of

The mathematical equations governing the operation

$$P(t) = K_p e(t) + K_i \int e(t) dt + \frac{K_d}{dt} e(t) + P(0)$$

A simple analysis would show that the derivative block essentially increase the damping ratio of the system and therefore improves dynamic performance by reducing overshoot, the integral action eliminates the steady state error.

Representation of controller monitoring the plant:**Procedure:****For Proportional Control (P)**

1. Keep SW3 in Test mode.
2. Keep SW2 in Mode Check
3. Then Keep $KI=0$ & $KD=0$, now system will be configured for proportional mode
4. Make proper connection for heater cable, RTD cable & fan cable.
5. Now select system as SW3 in TEST
 - SW2 in Normal
 - SW1 in PID side.
6. If selection is kept as above you will be able to set temperature with the help of P1. You will see display as ST= AT=
7. Now select system as SW3 in START
 - SW2 in NORMAL
 - SW1 in PID
8. Now system will start in proportional mode

For P+I mode:

All procedure is same as described for proportional mode

Only at pt(3) keep $KP>0$, $KI>0$ & $KD=0$ then system will be configured for P+I mode.

For P+I+D mode:

All procedure is same as described for proportional mode.

Only at pt(3) keep $KP>0$, $KI>0$ & $KD>0$ then system will be configured for P+I+D mode.

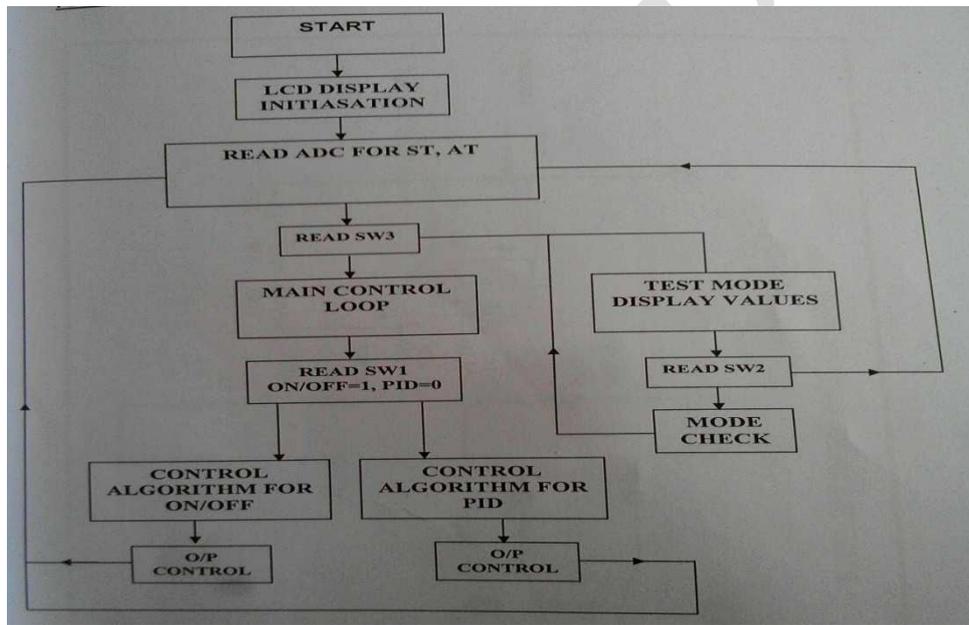
NOTE: For Modes: You can take observation with fan load on/off or by varying fan speed for creating disturbances on the system.

Fan provided acts as load on the system by taking more/less away from the modes

Observation:

Sl. No.	ACTUAL TEMPERATURE in Deg C	TIME in Seconds

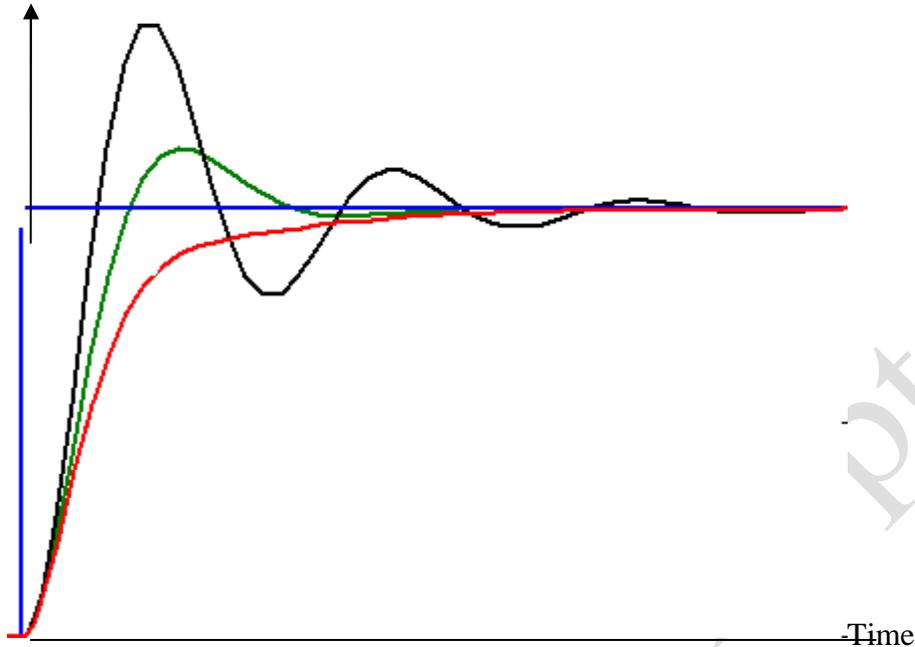
Flow Chart:



Characteristic:

The Typical PID characteristic for different settings may be as follows

Temp set pt



Result: Temperature of oven is controlled by using PID controller. By varying P,I,D values two graphs of temperature vs time is plotted.

Discussion of Result:

1. The steady state error may be reduced by proper setting of Integral controller setting.
2. The transient state is improved by adjustment of K_p & T_d .
3. For different settings of P I D different response Curves may be obtained.
4. The response Characteristics of P+I+D controller exhibit **Second Order Characteristic.**

EXPERIMENT-11**LEVEL CONTROL SYSTEM**

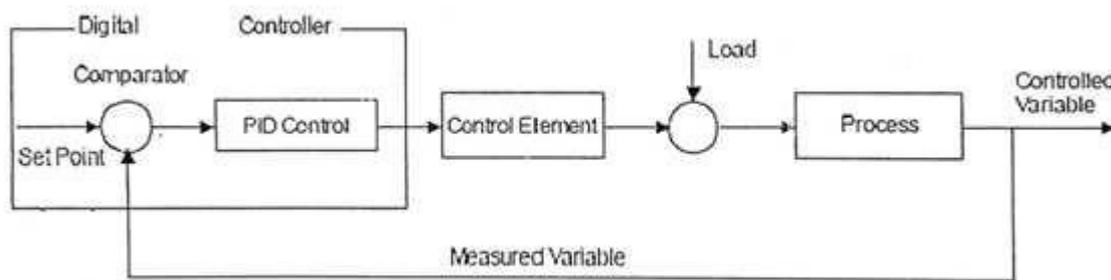
Aim: To study the on-off, P, P+I, P+I+D based level control system.

Apparatus: Level control trainer

Theory:-

ON –OFF CONTROL

In automatic controlled process the parameters to be controlled is measured with the set point by process controller. The difference between the measured signal and the set point is error. the controller performs on-line calculations based on error and other setting parameters and generates an output signal. The output signal drives the final control elements like control valves or a damper to control the process to the set point.



A special case of proportional control is On-off control. If the proportional band of the controller is made very low ($=0$) the controller output will move from one extreme position to other for slight deviation of process value from the set point. This very sensitive action is called On-off control because final control element is either open (on) or close (off) i.e. operates like a switch. There are the simplest controllers.

Hysteresis is a value set in the vicinity of on-off operating point. Upper hysteresis is value or band in which process value is allowed to operate above the set point and lower hysteresis is valve or band in which process value is allowed to operate below the set point.

Proportional-integral-derivative (PID) controllers

The three-mode controllers (PID) are the most common feedback controller used in industrial control. PID controllers are used for controlling almost all process variables like temperature, flow, level, pressure, etc. in a continuous or batch process. The output of a PID controller is given by:

$$O_p = b + 100/p_b [e + 1/t_i \int e dt + t_d \cdot de/dt]$$

Where O_p is the output, b is the bias, p_b is the proportional band in %, e is the error signal, t_i is the integral time and t_d is derivative time.

Selection of proportional band, integral time and derivative time to achieve desired process response to load changes is called tuning of controller.

The method of determination of the optimum mode gains, depending on the nature and complexity of the process is known as loop tuning. The three parameters should be selected to meet a set of defined goals. These goals typically require a plant response with minimum steady error, insensitivity to load disturbances and an acceptance transient response to set point changes and disturbances. In practice the choice of proportional band, integral time and derivative time is a compromise between the set point tracking and disturbances. If a mathematical model of the process is known, selecting the controller parameters is relatively simple. But in many industrial applications, a reliable mathematical model is not available or it is difficult to determine. So empirical rules are developed for PID tuning which do not require a mathematical model. A widely used set of rules is proposed by Ziegler-Nicholas by open loop method and closed loop method.

The controller settings described by Ziegler-Nicholas are obtained from the process reaction curve as follows

Proportional mode $K_P = 0.5K_C$

PID mode $K_P = 0.6K_C$, $t_d = TD/2$, $t_i = TC/8$

Where K_C is critical gain and TC is critical time period

Procedure:-

- Start the setup.
- Select close loop option for the control
- Set the controller to ON-OFF/PID mode. Change the set point.
- Auto set the controller settings.
- Take the process variable (level) readings at regular intervals of 10-15 sec.
- Plot graphs with PV (level) Vs time and controller Output Vs time.

Table1:On/Off Controller

TABULAR COLUMN:

Time (seconds)	Process variable (level)	Controller output

Table2: PID Controller

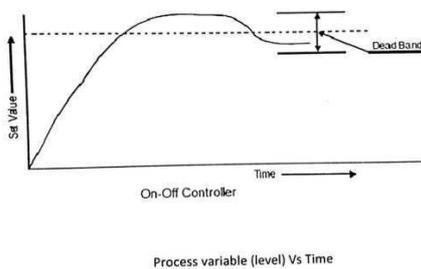
TABULAR COLUMN:

Time (seconds)	Process variable (level)	Controller output

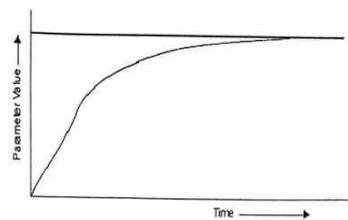
Observations:-

Observe that if the process value exceeds the set point and increases more than the value of upper hysteresis, controller switches OFF the thyristor and if the process value decreases more than the set point, thyristor switches ON. i.e. the controller operates like on-off switch.

EXPECTED GRAPH:



EXPECTED GRAPH:



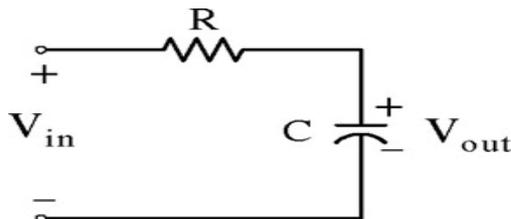
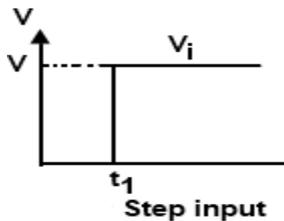
Discussion of Result:

1. In on-off controller student may observe that if process value exceeds the set point and increases then the value of upper hysteresis controller closes the valve and if process value decreases than the set point and lower hysteresis, control valve opens. i.e the process operates as on off switch.
2. In PID controller student may observe that, the transient response steady state response of the PID controller and note that the response system response is fast.

EXPERIMENT – 12**STEP & FREQUENCY RESPONSE ANALYSIS OF A PLANT**

Aim: - To perform the Step and Frequency domain analysis of first order system.

Apparatus: - Simple RC network setup.

Step Response Analysis:**Transfer Function:**

$$\begin{aligned} \frac{V_o(s)}{V_i(s)} = T(s) &= \frac{1/CS}{R+1/CS} \\ &= \frac{1}{1+RCs} \\ &= \frac{1}{1+Ts}, \text{ where } T=RC \end{aligned}$$

When unit step is applied, $V_i(s) = 1/s$

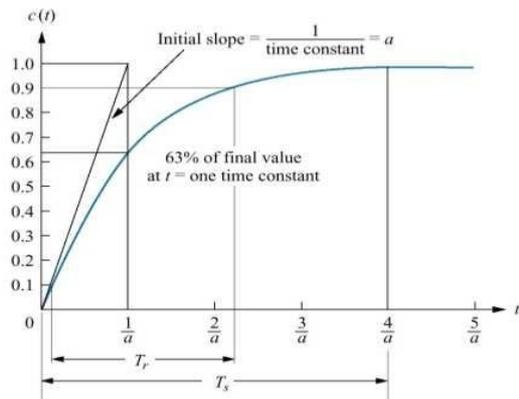
$$V_o(s) = \frac{1}{s} - \frac{1}{s + \left(\frac{1}{RC}\right)}$$

$$V_o(s) = 1 - e^{-t/RC}$$

For step input the output voltage V_o , which is a voltage across capacitor c , rises exponentially towards the final value of V with a time constant RC . The output voltage is given by $V_o(s) = 1 - e^{-t/RC}$

Expected waveform:

Tabular column:



t	Vo(t)
0	
RC	
2RC	
3RC	
4RC	

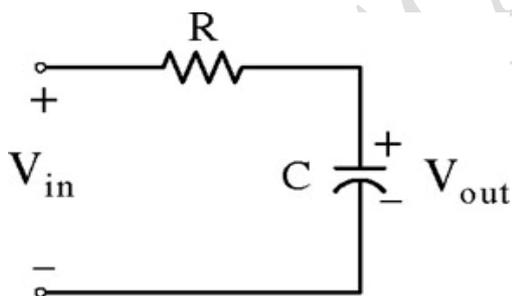
Time constant:

The Time constant can be described as the time for e^{-at} to decay to 37% of its initial value. Reciprocal of the time constant has the units(1/seconds), or frequency. Thus we call the parameter as exponential frequency.

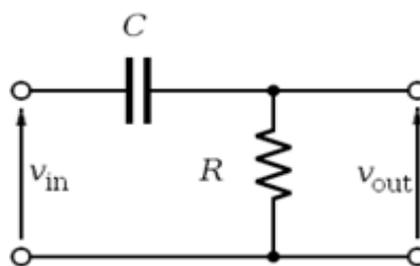
Rise Time:

It is defined as the time for the waveform to go from 0.1 to 0.9 of its initial value.

Frequency Response Analysis:



$R1 = 10K\Omega, C = 0.1mF$



$R1 = 10K\Omega, C = 0.1mF$

Step1: Apply L.T to the network and simplifying series combination Rand C

$$\text{Case i: } \frac{V_o(s)}{V_i(s)} = T(s) = \frac{1/CS}{R+1/CS}$$

$$= \frac{1}{1+RCS}$$

$$T(j\omega) = \frac{1}{(1+(\omega RC)^2)^{1/2}}$$

$$\Theta = -\tan^{-1} \omega RC$$

$$\text{Case ii: } \frac{V_o(s)}{V_i(s)} = T(s) = \frac{R}{R+1/CS}$$

$$= \frac{RCS}{1+RCS}$$

$$T(j\omega) = \frac{R}{(1+(\omega RC)^2)^{1/2}}$$

$$\Theta = \tan^{-1} 1/\omega RC$$

Procedure:

1. Make the connections as shown in fig .
2. Select the components as R=10K, C=0.1mfd.
3. Connect the components on the expo board so as to rig up the RC network and switch on the supply.
4. Check calibration of phase angle meter by throwing SW2 in CAL position. If meter does not indicate 180, adjust the CAL potentiometer and get 180 degree indication.
5. Keep SW3 in Lead position.
6. Adjust the input excitation to 3 volts R.M.S
7. Now change the audio oscillator output frequency in the range 20HZ to 1000Hz and enter the result in tabular column.
8. Calculate the theoretical values of magnitude and phase from the formulae mentioned above and plot the graphs against frequency. Find out corner frequency.
9. Connect the resistance of 10k or 1K across the output terminals of the network.

Tabular Form:

Sl. No.	Freq	Input voltage (V1)	Output voltage (V2)	Indicated Phase angle	Indicated V_0/V_i	Calculated Phase angle	Calculated V_0/V_i

Expected graphs:

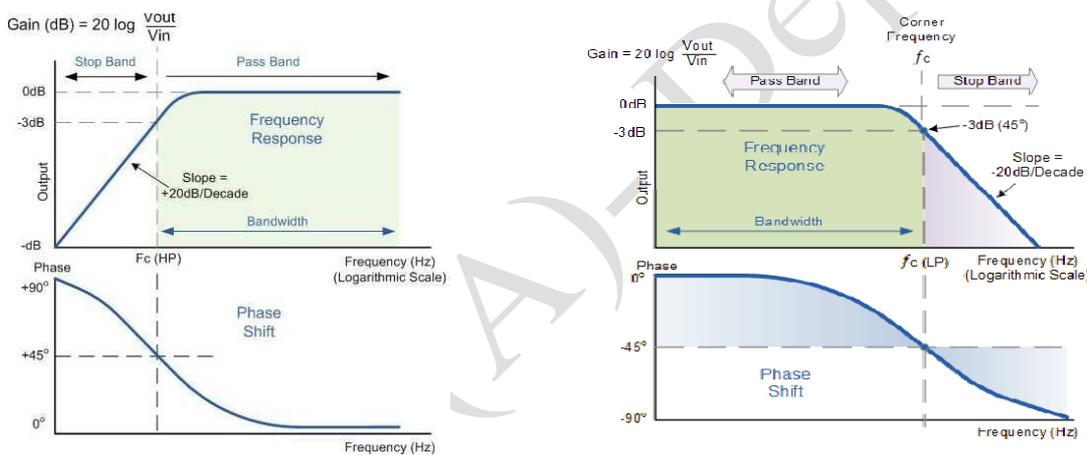


Fig. 1 Frequency response of RC (High pass) **Fig 2** Frequency response of RC (low pass)

Result: Characteristics of RC network is studied by plotting magnitude and phase angle vs frequency.

Discussion of Result: In step response the transient term is totally independent on the values of R and C and its rate of exponentially decay will get controlled by $-1/RC$ which is the pole of the system. Students should be able to plot the characteristics and because of loading effect the characteristics of network are drastically affected.