DEPARTMENT

OF

ELECTRICAL & ELECTRONICS ENGINEERING

CONTROL SYSTEMS LABORATORY

Department of Electrical & Electronics Engineering

SIR C R REDDY COLLEGE OF ENGINEERING

ELURU - 534007 (A.P)

CONTROL SYSTEM LABORATORY

Observation - cum - Record Book

Regd. No.:

Name	
Year	
Section	

Department of Electrical and Electronics Engineering

Sir C. R. Reddy College of Engineering, Eluru-534007

CERTIFICATE

This is to certify that this is the bona fide record of work done in **CONTROL SYSTEMS LABORATORY** by Mr./Ms.___________________________________of IV/IV E.E.E. Section ___ bearing the Regd. No.__________________________ as part of course work prescribed during the second semester of the Academic Year_________________.

Total number of experiments held -

Total number of experiments done -

Lab - in - Charge *Head of the Department*

GENERAL INSTRUCTIONS

1. Objectives of the laboratory:

On completion of the course a student will be able to:

- Acquire a fair knowledge in using the Control System Components like AC Servomotor, DC Servomotor Magnetic Amplifier Synchro Transmitter and Receiver, Relay Control System, etc.
- Practically understand about the time response of second order Control System, Design of Compensators, P, PI, PID Controllers, Temperature Controllers.

2. General guidelines:

This is an observation-cum-record book. It contains instructional material for using Control System Components and its applications and control system design problems, as well as comprehensive material to understand Control system problems. The experiments are based on the courses EEE Control Systems, EEE Advanced Control Systems, EEE Digital Control Systems. **STUDENTS ARE REQUIRED TO BRING THIS BOOK TO EACH LAB SESSION FAILING WHICH THEY WILL NOT BE ALLOWED IN TO THE LAB** since THERE IS NO OTHER OBSERVATION BOOK OR RECORD BOOK. All work should be completed in this book only which will be used in grading the work. Students are therefore advised to maintain this book in good condition and preserve it till the end of the semester.

Each student when coming to the lab is expected to:

- Come prepared with answers to prelab quiz (viva questions).
- Work out theoretical solution in the work book before coming to the lab for the experiment concerned. You can take help from the reference books listed or other books.
- Draw the Circuit Diagram after coming to lab, in the book.
- Familiarize oneself with the Procedure and Connections for the experiment to be done.

- Post the observations, calculations, plots etc. in this book.
- COMPARE THE RESULTS OBTAINED FROM EXPERIMENTATION WITH THEORETICAL CALCULATIONS AND ANALYZE THE RESULTS WITH EXPLANATION.
- Write the conclusion as RESULT.

3. Scheme of instruction and evaluation:

EEE425 – CONTROL SYSTEMS LAB

Instruction	: 3 Periods per Week
University Examination	: 3 Hours
University Examination Marks	: 50
Sessional Marks	: 50
Credits	: 4

Sessional Marks Division	
Laboratory work; observation-cum-record book	25 marks
Attendance	05 marks
Internal test	20 marks
Total	**50 marks**

4. Reference books:

1. Control systems engineering by I.J. Nagrath & M.Gopal, Wiley Eastern Limited.
2. Control systems Components by R.C.Sukla, New age international (P) Ltd.
3. Automatic control systems by Benjamin C. Kuo, Prentice Hall of India.
4. Control system components by M.D.DESAI

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LIST OF EXPERIMENTS

S.No	Experiment name	Page no.	Date	Signature	Marks
1	DC speed control system				
2	DC servo motor speed torque characteristics				
3	AC servo motor speed torque characteristics				
4	Magnetic Amplifier a) Series connected Magnetic Amplifier b) Parallel connected Magnetic Amplifier				
5	AC Synchro – Transmitter and Receiver				
6	Linear System Simulator a) First order system b) Second order system				
7	Digital Control System				
8	a)On Off control using RTD b)Linear variable differential transformer (LVDT)				
9	Relay control systems				
10	Compensation Design (Lead Network) Compensation Design (Lag Network)				

1. DC MOTOR SPEED CONTROL SYSTEM

Aim: To study the performance characteristics of a D.C. motor speed control system

Apparatus Required:

S.No	Equipment	Specifications
1	DC motor unit	12V, 2400/3500 RPM Rated current-200mA-No load -290mA-Fullload Torque - 50gm-cm
2	DC speed control module	

Circuit Diagram:

Theory:

The DC motor unit consists of the following

a. A slotted aluminum disc is mounted on the shaft, which generates signals for Speed measurement.

b). An adjustable eddy current brake is provided to enable the study of the effects of the external disturbance on the systems performance.

c). **Speed measurement:** The slotted disc attached to the motor shaft generates 12 pulses for every revolution of the shaft through optical interruptions. After passing through signal conditioning and frequency scaling circuits, these pulses are then fed to a built in frequency counter to display the shaft speed directly in rpm

d).**Tacho generator:** A DC signal proportional to the shaft speed is obtained from an electronic tacho generator, a frequency voltage converter circuit, the signal is brought to a suitable level by signal conditioning to yield a tacho constant of about 0.5v /1000 rpm.

e). **Error detector and forward gain:** The speed obtained from the tacho generator is compared with the reference (Corresponding to a set speed) to obtain an error signal. The error signal is amplified to feed the driver circuit.

f). **Driver circuit:** This circuit is designed to deliver the necessary power to operate the motor. It is a unity gain power amplifier and has the necessary protection circuits.

g). **Power and signal sources:** A number of IC regulated supplies feed the electronic circuits, reference potentiometer, DVM, speed displays and the motor. Also square wave oscillator of I Hz (approx) is included for time constant studies.

h). **Digital voltmeters:** A 19.99V full-scale deflection voltmeter mounted on the panel is available for the measurement of various signals. One terminal of the DVM is internally connected to ground.

Procedure:

Open loop performance:

A). **Signal and reference:**

1. Set K_A = O. Connect DVM to measure the range of variation of reference Voltage V_R
2. Switch ON the square wave signal V_s and measure its amplitude and frequency using a calibrated CRO.

B). Motor and Tacho generator:

1. Set V_R = I V and K_A = 3, the motor may be running at a low speed. Record speed N in r.p.m and the Tacho generator output V_T.
2. Repeat with V_R = I V and K_A= 4, 5,, 10 and tabulate measured motor voltage $V_M = V_R K_A$, steady state motor speed N in rpm and Tacho generator output V_T.
3. Plot N vs V_m and V_T vs N. obtain K_M and K_T from the linear region of curves

Motor gain constant, $K_m = \frac{Shaftspeedinrad / \sec}{Motorvoltage}$

Tachogenerator gain $K_T = \frac{V_T}{W_{SS}} \frac{volt - \sec}{rad}$

4. To calculate motor time constant set V_R = 0 and K_A = 10 now switch on the square wave signal Vs and measure the peak-to-peak amplitude of the triangular wave component in V_T

Motor time constant $T = \frac{V_s(p-p)}{V_T(p-p)} \frac{K_A K_M K_T}{2f}$

Obtain motor transfer function $G_s = \frac{K_m}{sT+1}$

Disturbance:

1. Set K_A = 5 and adjust the reference V_R to get a speed-reading close to 1200 rpm. The brake setting should be at 0 i.e no breaking.
2. Record and tabulate the motor speed variation for different settings of the eddy current brake.
3. Calculate percentage decrease in speed at each setting of the motor brake, starting from no braking.

Closed loop performance:

A) **Steady state error:**

1. The feedback terminals are connected together.
2. Set V_R = 1 V and K_A = 3, the motor may be running at a low speed. Measure and record speed N in r.p.m, Tacho generator voltage V_T and the steady state error
   E_{ss} (= $V_R - V_T$)
3. Repeat above for K_A = 4,6,……… , 10.
4. Compare in each case the value of steady state error

$$e_{ss} = \frac{1}{1 + K_A K_M K_T}$$

B) Transient Performance:

1. Set V_R = 0.5V and K_A = 5. Switch ON the square wave signal and measure peak-to-peak amplitudes of Vs and V_T. System time constant T_{eff} is calculated. The value of

$$K = \frac{K_A K_M}{K_A K_M K_T + 1},$$

$$T_{eff} = \frac{V_S(p-p)}{V_T(p-p)} \text{X} \frac{K_A K_M K_T}{K_A K_M K_T + 1} \text{X} \frac{1}{2f}$$

2. Repeat above and tabulate the results for K_A = I, 10, ...

C) **Disturbance rejection:**

1. With K_A = 5, feedback terminals shorted and the brake setting at 0, adjust reference V_R to get a speed close to 1200 rpm.
2. Record and tabulate the variation in speed for different settings of the eddy current brake. Calculate percentage decrease in speed at each setting of the brake.
3. Repeat above for K_A = 10
4. Compare the percentage decrease in speed at various brake settings for open loop, closed loop with K_A= 5 and closed loop with K_A = 10.

Tabular column:

Open loop response:

V_R= f=

K_A	**Speed**	**V_T**	**V_m**	**Experimental $K_A=V_M/V_R$**

Closed loop response:

V_R= f=

K_A	**Speed N**	**V_T**	**$E_{ss}=(V_R-V_T)$ Experimental**	**$E_{ss}=1/(K_AK_MK_T+1)$ Theoritical**	**Speed with Brake ,N_b**	**$(N-N_b)$/NX100**

Disturbance Rejection:

S.no	Brake	Speed rpm	% decrease in speed

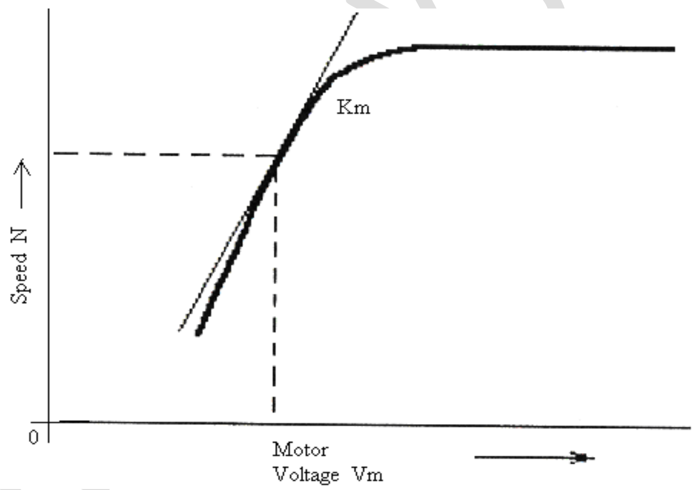
Disturbance :

Brake						
Open loop (k=5) Closed loop (k=5) Closed loop (k=10)						

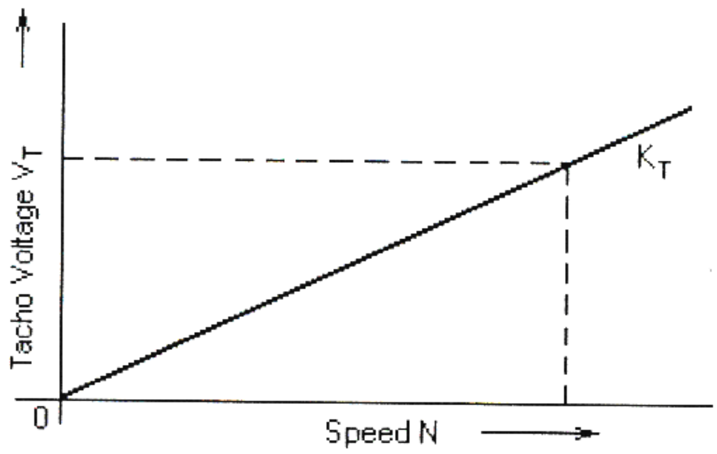
Transient Response:

KA	Vs(volts)	Vt (voltsx)	K	T

Model graph:



Motor characteristics:



Tacho characteristics

Result:

Analysis:

VIVA QUESTIONS

1. What is the necessary condition for stability?

2. What is limitedly stable system?

3. What is transient and steady state response?

4. How non linear ties are introduced in the system?

5. What is meant by critical damping?

6. What is damped oscillation?

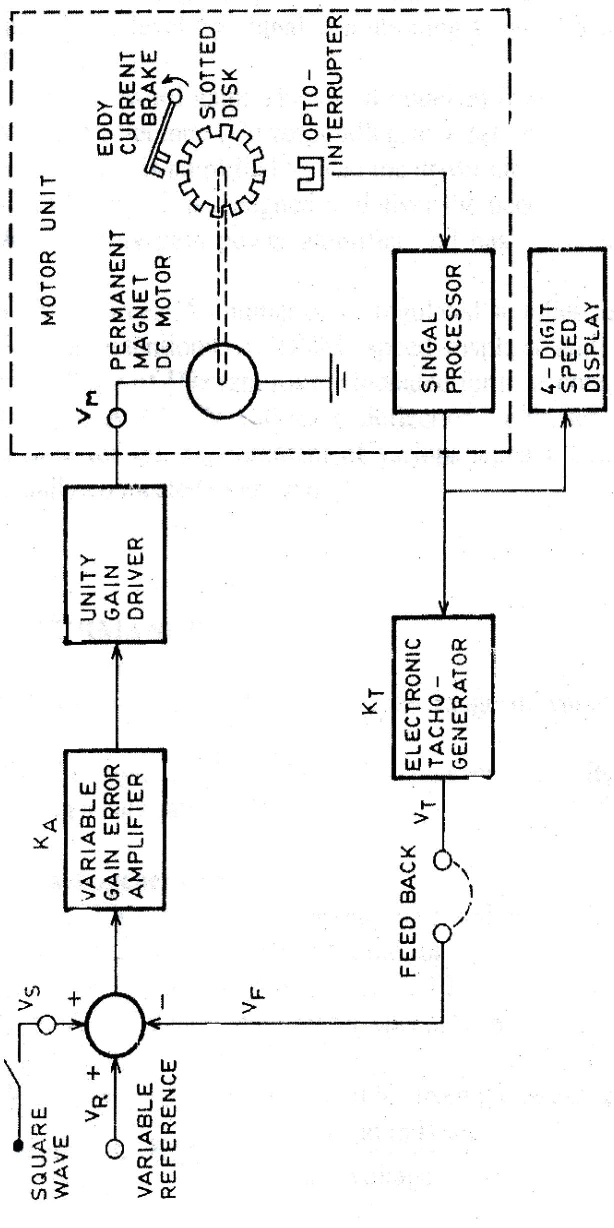
7. What is a disturbance signal?

8. What is an error signal?

9. Define system sensitivity?

10. Define Type of a system?

Circuit Diagram:



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2. DC SERVO MOTOR

Aim: To study and plot the speed torque characteristics of a DC servo motor

Apparatus Required:

S No	Equipment	Range
1	ADTRON Trainer kit	
2	Digital multi meter	
3	Mains	230v, 50Hz, 1ϕ AC Supply

Circuit diagram:

Theory:

Motor Principle: An electric motor is a machine, which converts electric energy into mechanical energy. Its action is based on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's left hand rule and whose magnitude is given by F = BIL Newton.

Significance of back emf:_When the motor armature rotates, the conductors also rotate and hence cut the flux. In accordance with the laws of electromagnetic induction, emf is induced in the conduction whose direction was found by Fleming's right hand rule; this emf is in opposition to the applied voltage.

Because of its opposing action, it is referred to as back emf, Eb. The equivalent circuit of a motor is the rotating armature generating the back emf E_b. It is like a battery of emf E_b. Obviously V has to drive the armature current Ia against the opposition of Eb. In the case of battery, this power over an initial time is converted into chemical energy but in the present case it is converted into mechanical energy. It will be seen that $I_a = \frac{V - E_b}{R_a}$ where R_a is resistance of the armature circuit. E_b is directly dependent on armature speed. So more speed implies more E_b and less armature current and vice versa.

Servo systems are basically feedback systems in which controlled parameter is either position or its derivatives. Basically a DC servomotor has windings in its armature and brushes for commutation. But this motor is slower in response. These are basically used in aerospace industry and robotics. The main disadvantages are difficult to cool and for higher ratings commutation will be a problem.

Procedure:

1. Remove the load in no load condition .switch on the module
2. Adjust the potentiometer for the rated voltage of 24V.
3. Note down the no load current and no load speed.
4. Adjust the load in steps to a maximum of 200 gm-cm and a current of 0.8Amps (do not exceed 0.8 amps).
5. At each load note down the speed.
6. Calculate the corresponding torque and plot the torque speed characteristics.

Tabular columns:

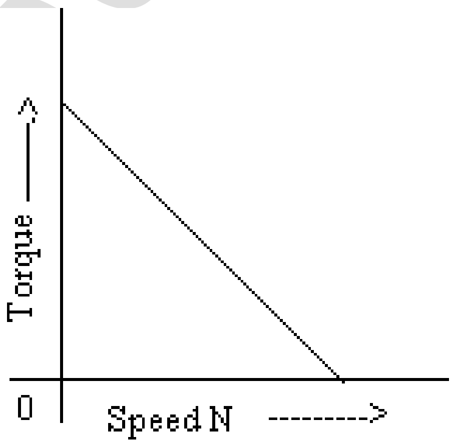
Table 1

Speed (N)	**Back E.m.f (E_b)**

Table 2

Voltage(V)	**Speed (N)**	**Current(A)**	**Load**	**W in grams**	**Torque =WXR Gram- cm**
			S1	**S2**	

Model graph:



DC servo motor speed V_s torque characteristic

Result:

Analysis:

Viva Questions:

1. What is a Servo motor?

2. What are characteristics of servomotor?

3. Compare Ac and DC Servomotors?

4. What are the different types of rotor that are used in AC Servomotor?

5. Draw the characteristics of AC servomotor?

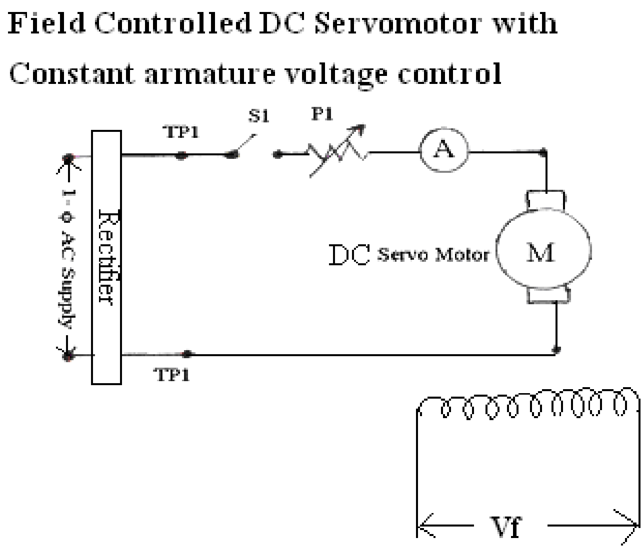
6. Mention the characteristics of negative feedback?

7. Why the negative feedback is invariably preferred in closed loop system?

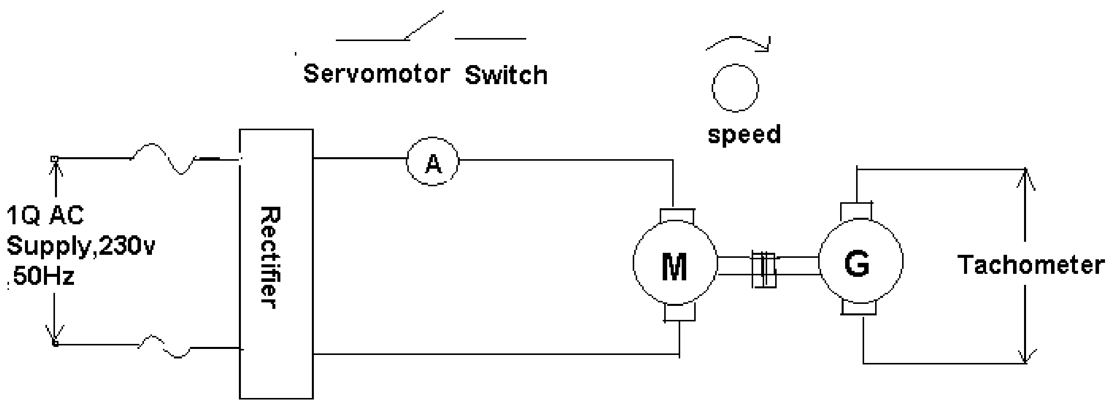
8. What is the effect of adding a zero to an open loop transfer function of a system?

9. What is the effect of adding a pole to open loop transfer function of a system?

Circuit diagrams:



Panel diagram:



Graph

3. A.C SERVO MOTOR

Aim: To Study the speed torque characteristics of A.C Servomotor

Apparatus Required:

S.No	Equipment	Specifications
1	ADTRON Trainer kit	
2	Digital multi meter	

Circuit Diagrams:

Theory:

An AC servomotor is basically a two-phase induction motor except *for* certain special design features. A two-phase induction motor consists of two stator windings oriented 90° apart in space and excited by AC voltage, which differ in time phase by 90°. A magnitude field of constant magnitude rotating at synchronous speed is obtained as voltages applied to two phases are equal in rms magnitude and 90° phase apart. The direction of rotation depends on the phase relationship between two voltages. The field includes currents (emf) in the rotor circuit. The two fields mutually interact and produce a torque in the direction of field rotation. The use of such motors in a control system is interable because of the effective slope, which represents negative damping by designing the *rotor* with very high rotor resistance.

In many applications of servomotor in feedback control systems phase 'a' is energized with fixed rated voltage, where as phase 'b' is energized by a varying control voltage. Moreover the arrangement in this configuration is such that the control voltage is frequently adjusted to be exactly 90° out of phase with the voltage applied to phase 'a'. If we proceed under the assumption that the reference voltage $\overline{V_a}$ control voltage $\overline{V_b}$ are always 90° apart in phase and if we have $P = \frac{V_b}{V_a}$ then phasor expression *for* control voltage becomes $\overline{V_b}$ = -jP$\overline{V_a}$. The -j factor accounts *for* 90° phase lag between the two voltages and the expression *for* sequence voltage becomes.

$$\overline{V_{a1}} = \frac{1}{2}\left[\overline{V_a} + j\overline{V_b}\right] = \frac{-\overline{V_a}}{2}(1+P)$$

$$\overline{V}_{a2} = \frac{1}{2}\left[\overline{V_a} - j\overline{V_b}\right] = \frac{-\overline{V_a}}{2}(1-P)$$

The curves for p = 0 are identical but reverse in position.

Procedure:

1. Initially keep load control switch at OFF position, indicating that the armature circuit of dc machine is not connected to auxiliary dc supply – 12 V dc. Keep servomotor supply switch also at OFF position.
2. Ensure load potentiometer and control voltage auto transformer at minimum position.
3. Now switch ON mains supply to the unit and also AC servomotor supply switch. Vary the control voltage transformer. You can observe that the AC servomotor will starts rotating and the speed will be indicated by the tachometer in the front panel.
4. With load switch in OFF position, vary the speed of the AC servomotor by moving the control voltage and note down back Emf generated by the dc machine (Now working as dc generator or tacho). Enter the results in the Table.
5. Now with load switch at OFF position, switch ON AC servomotor and keep the speed in the minimum position. You can observe that the AC servomotor starts moving with speed being indicated by the tachometer. Now vary the control winding voltage by varying the auto transformer and set the speed for maximum speed. Now switch ON the load switch and start loading AC servomotor by varying the load potentiometer slowly. Note down the corresponding values of Ia, speed and enter these readings in the table. And also note down the control voltage.

Tabular column:

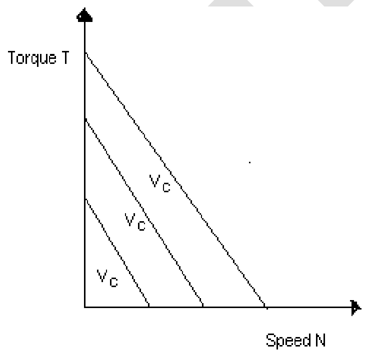
Table 1

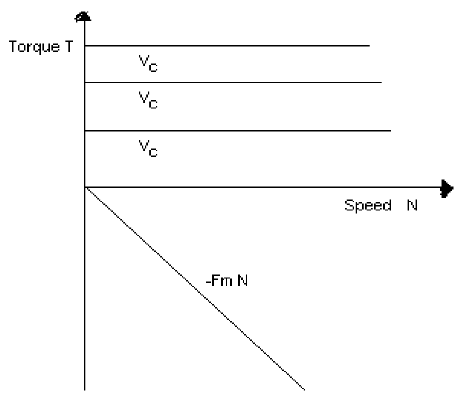
Speed (N)	Back e.m.f (E_b)

Table 2

S.No	Speed (N)	Back e.m.f (E_b) In above table	$P=I_a$ X E_b	Torque = $\frac{PX1.109X10^4X60}{2\pi N}$

Model graph:





AC Servo motor speed torque characteristics

Result:

Analysis:

Viva Questions:

1. What is Servo motor?

2. What are characteristics of servomotor?

3. Compare Ac and DC Servomotors?

4. What are the different types of rotor that are used in AC Servomotor?

5. Draw the characteristics of AC servomotor?

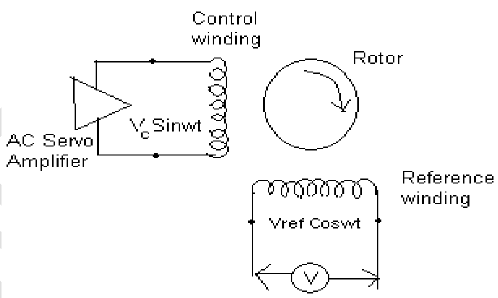
6. Mention the characteristics of negative feedback?

7. Why the negative feedback is invariably preferred in closed loop system?

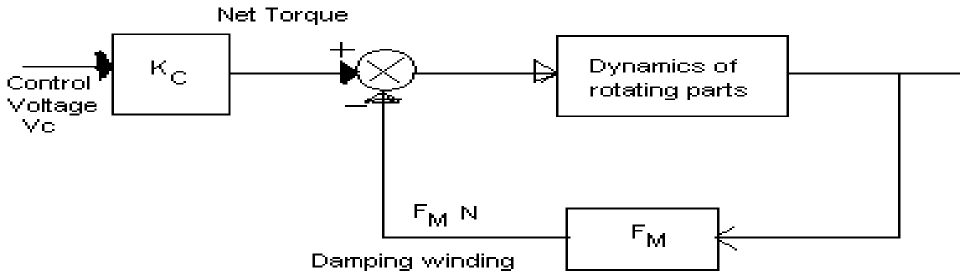
8. What is the effect of adding a zero to an open loop transfer function of a system?

9. What is the effect of adding a pole to open loop transfer function of a system?

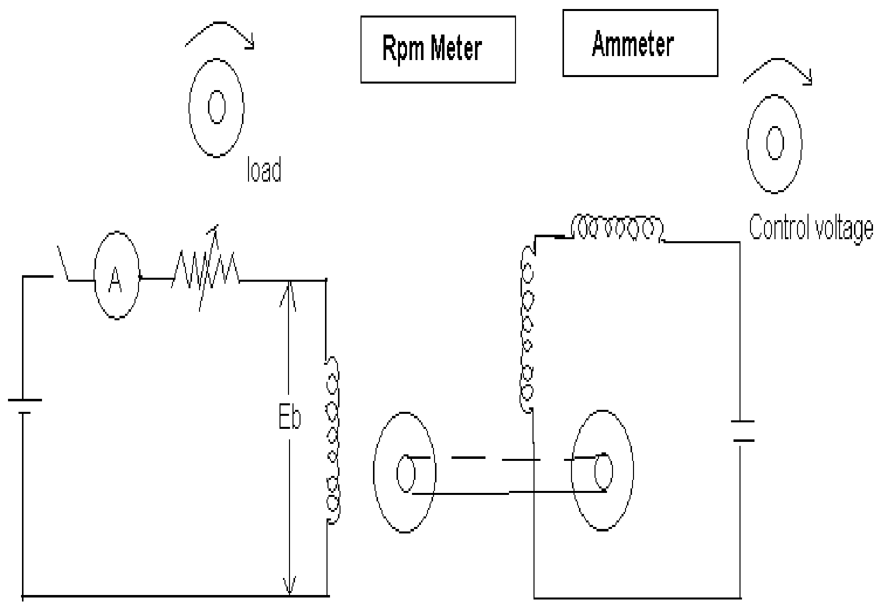
Circuit diagrams:



Block diagram:



Panel connection:



Graph

4. MAGNETIC AMPLIFIER

Aim: To study the operation of the magnetic amplifier in

a) Series connected magnetic amplifier

b) Parallel connected magnetic amplifier

Apparatus required:

S.NO	Equipment	Specification
1	ADTRON Trainer circuit	12V, 2400/3500 RPM Rated current -200mA-No load 290mA-Fullload Torque - 50gm-cm
2	DC power supply	0-30V/ I A 0-50V /1 A
3	Digital multi meter	
4	Ammeter	0-1A M.I 0-30mA M.C
5	Rheostat	0-500Ω/1.5A

Circuit diagrams:

Theory:

To control large AC circuit a saturable reactor (Magnetic device) is used in accordance with these active components. A large AC load (up to 100A) may be controlled by a small DC current. It is a connecting link and acts as a large power amplifier and by itself can serve as a low gain amplifier of large loads. The usefulness of this magnetic device can be greatly increased by the addition of rectifier in the output circuit and this combination for saturable reactor with rectifier is called half saturable (reactor) amplifier or magnetic amplifier.

The part played by a saturable reactor in a circuit, when it is connected in series with a load across an AC power supply is that of a variable inductance. Its consists of two or more windings around a core of steel. One of these windings receives a small DC current, which acts as an input signal that controls the amount of AC that can flow through the other winding and the load. The reactor can have a single core only windings or gate winding in which case the AC (current) voltage in the control circuit. Also the output will be delivered only during the one half cycles. To overcome these drawbacks most saturable reactors include two identical steel cores, each core has its own winding while the DC coil surrounds one leg of each core. Here the two gate windings can be connected in parallel or series. But connections to one of the coils reversed to meet the above objects. If a small DC is passes through the control winding a steady amount of flux will be added to the above varying flux

Saturable reactor is modified by adding a silicon diode in series with each other of its gate winding on upper case current can now flow in the gate winding through the load only when a particular term is positive, current flows in the lower case gate winding and the load only, when terminal is positive.

Thus the load received above the half cycles of AC but each core is magnetized by only a half cycle of a current. When AC power is connected to the circuit the initial flux produced in the upper core during the one half cycle, due to a small magnetizing current will not be reset during the opposite half cycle be rectifier diode blocks the current. This action continues until the first few cycles and the flux will be so high, that it operates along the flat position of the magnetization curve, throughout the entire half cycle.

DC Control: If the direction of the Dc is such that it produces DC flux that assists the flux produced by the gate windings. Then the combined flux drives the core into more complete saturation there by increasing the load current to its largest value.

Procedure:

Series connected Magnetic Amplifier:

1. Connect the circuit as shown in fig.
2. Connect the D.C voltage supply with D.C ammeter in series with control Winding.
3. Connect the load resistor and load current meter as shown.
4. Vary control winding current in steps and record corresponding load current (I_L) for different load resistance RL.
5. Plot the graph I_C vs I_L in each case.
6. Connect (0-30V)/1 A in series with bias winding and vary the bias voltage, zero current position of the control winding can be moved to any desired point on the curve of the A.C bias current.

Parallel-connected Magnetic Amplifier:

1. Repeat the steps I, 2, 3, 4 as above
2. Plot the graph I_L vs I_c.
3. Tabulate the results.

Tabular column:

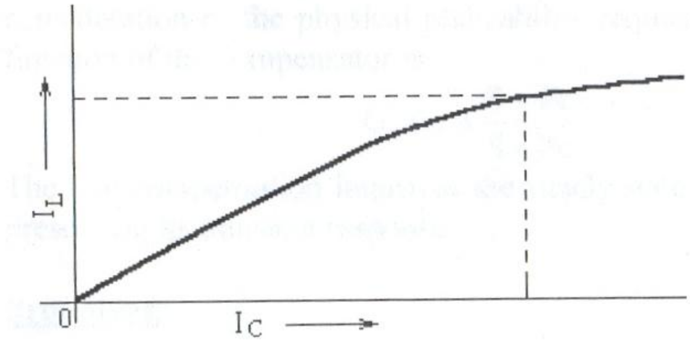
Series connected magnetic amplifier

I_C	I_L	
	300 Ohms	500 Ohms

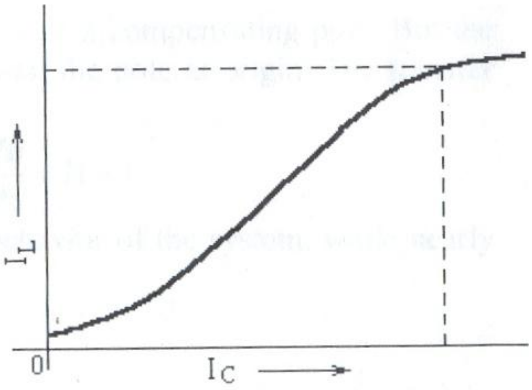
Parallel connected magnetic amplifier

I_C	I_L	
	300 Ohms	500 Ohms

Model graph:



Series Connected Magnetic Amplifier



Parallel Connected Magnetic Amplifier

Result:

Analysis:

Viva Questions:

1.What are the advantages of magnetic Amplifier?

2.Write the applications of magnetic Amplifier?

3.Write the expression for Time constant of series magnetic Amplifier ?

4.Write the expression for Time constant of parallel magnetic Amplifier ?

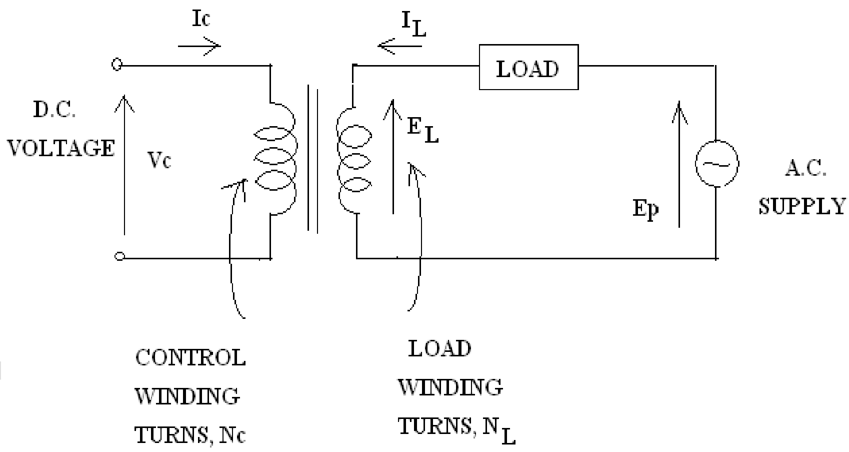
5.What is the value of input resistance of ideal series magnetic Amplifier?

6.What is the value of input resistance of ideal parallel magnetic Amplifier?

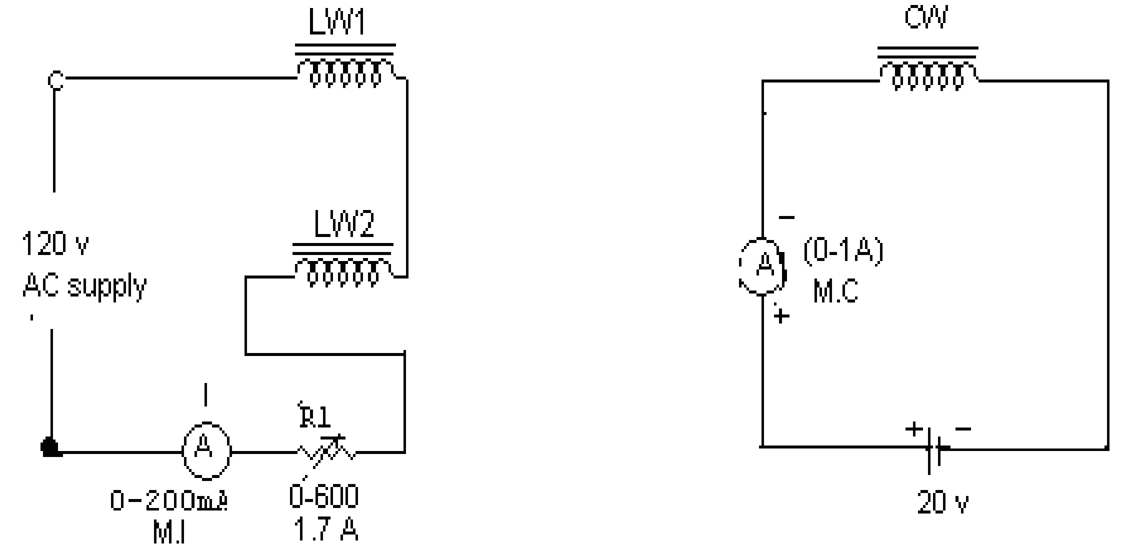
7.What is the value of inductance of ideal parallel magnetic Amplifier?

8.What is the value of inductance of ideal series magnetic Amplifier?

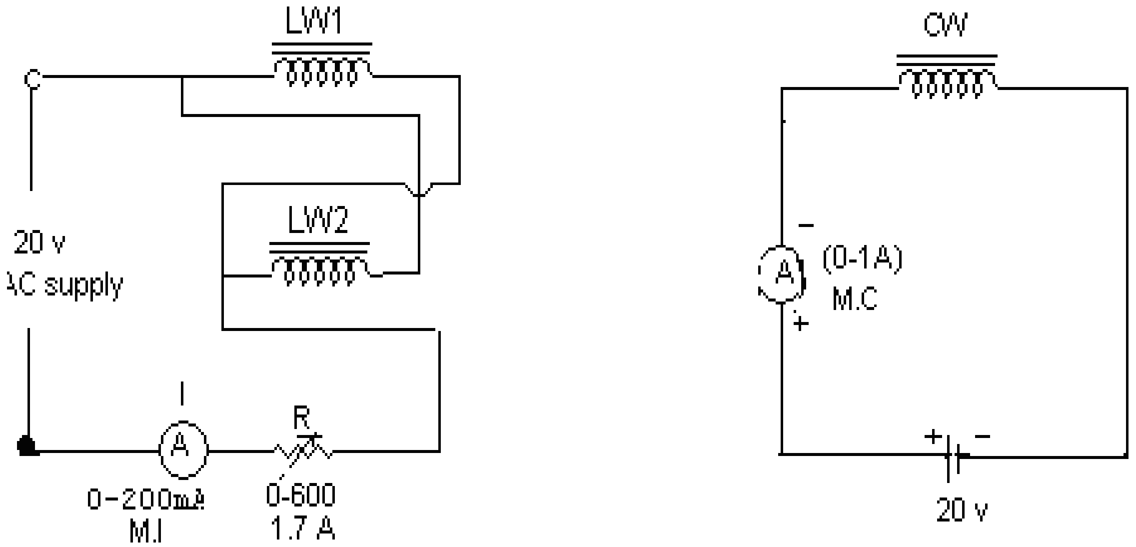
THEORITICAL CIRCUIT DIAGRAM



Panel circuit diagram:



Series conneced Magnetic Amplifier



Parallel connected Magnetic Amplifier

Graph

5. SYNCHRO TRANSMITTER & RECEIVER

Aim:_ To Study the operation of Synchro-Transmitter and Receiver.

Apparatus Required:

S.No	Equipment	Quantity
1	ADTRON Synchro transmitter unit	1
2	ADTRON Synchro receiver transmitter unit	1
3	ADTRON Synchro Power supply transmitter unit	1

Circuit Diagrams:

Theory:

Synchro's are small motor like components used for the remote transmission of shaft position in A.C servomechanism. The basic structure consists of a wound rotor and a wound stator. The windings of magnetic circuit are designed to give a substantially sinusoidal variation in magnitude coupling as a function of shaft position.

The remote indicator system consists of two components synchro generator and synchro (trans) motor. The synchro generator is a device used for transmission of an angular position. It is a two pole alternator with wound rotor connected between R 1 and R2 on the frame. Three separate stator coils are spaced 120^o apart around the stator which are shorted at one end and other three ends are connected to terminals S 1 ,S2,S3 . Synchro motor or receiver is identical to synchro generator except that the motor has flywheel on its shaft which serves the purpose of damping oscillations when the shaft is turned suddenly.

Operation:

A single phase AC line voltage is applied to the rotor windings of the generator and motor M connected in parallel. The stator windings are connected as shown in S I to S 1 and S2 to S2 and S3 to S3 . The rotor of M will follow the rotor of G, to whatever position the generator, rotor is turned for their connection.

The pointer on motor will follow the pointer on the generator and will indicate the angular displacement of the generator rotated shaft. The motor shaft follows the generator because of induced voltages in the stator windings and in the orientation of the magnetic fields about the rotor could appear in opposite directions i.e, field of rotor is 180^o out of phase. The magnetic fields of both rotors are in same direction, when the motor rotor sweeps through 180^o, the synchro system is again in equilibrium. Hence reversing the rotor connections of the synchro motor induces a 180^o phase lag in the motor but the rotor of motor follows rotation of rotor of generator.

Procedure:-

1. Arrange power supply, Synchro transmitter and Synchro receiver near to each other.
2. Connect power supply output to R_1-R_2 terminals of the transmitter and receiver.
3. Short S_1,-S_1, S_2-S_2, S_3-S_3 windings of transmitter and receiver with the help of patch cards.
4. Switch on the unit supply neon lamp will glow ON.
5. As the power is switched ON transmitter and receiver shaft will come to the same position on the dial.
6. Vary the shaft position of the transmitter and observe the corresponding change in the shaft position of the receiver.
7. Repeat the above steps for different angles of the shaft of the transmitter, it is observed that the receiver shaft moves by an equal amount as that of the

transmitter.

Reversing rotor connection: circuit 1

θ_i	θ_0	$V_{S_1-S_2}$	$V_{S_2-S_3}$	$V_{S_3-S_1}$

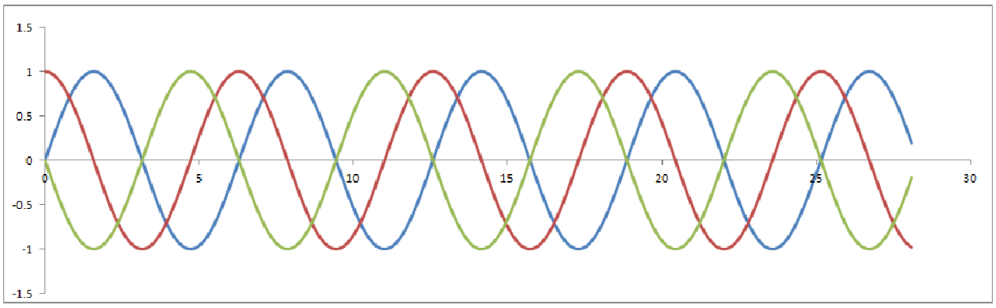
Cyclic for reversing stator connection: circuit 2

θ_i	θ_0	$V_{S_1-S_2}$	$V_{S_2-S_3}$	$V_{S_3-S_1}$

Cyclic shift of stator connections: circuit 3

θ_i	θ_0	$V_{S_1-S_2}$	$V_{S_2-S_3}$	$V_{S_3-S_1}$

Model graph :



Result:

Analysis:

Viva – Questions:

1. What is Synchro?

2. What is a synchro pair?

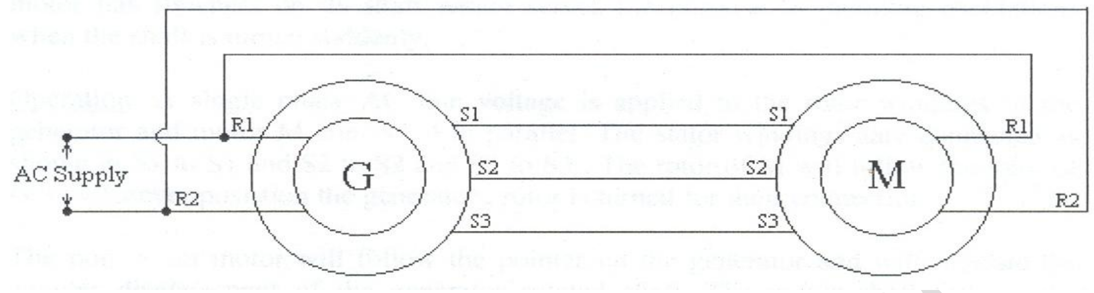
3. What is electrical zero in a synchro?

4. What is null position in synchro?

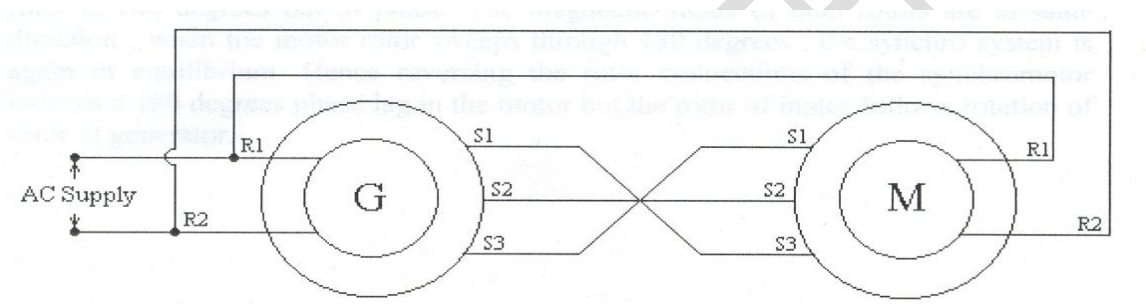
5. What are the applications of synchros?

6. What are the various frequency domain specifications?

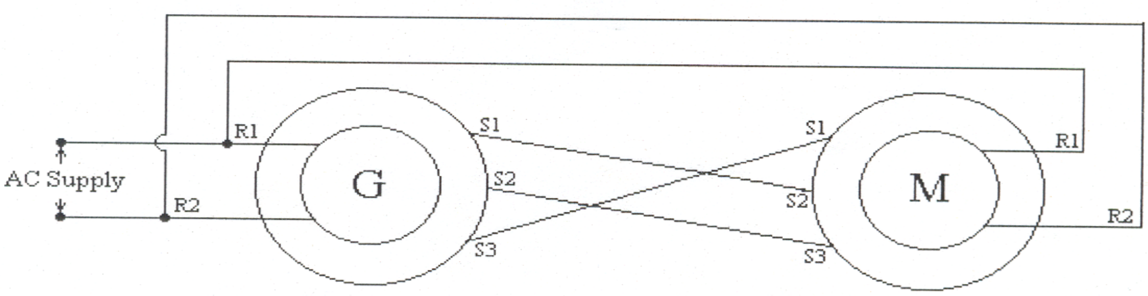
Circuit diagrams:



Circuit 1. Reversing rotor connection to synchromotor



Circuit 2. Cyclic for reversing stator connections S1 and S3



Circuit 3. Cyclic shift of stator connections

Graph

6. LINEAR SYSTEM SIMULATOR

Aim: To study the time response of a variety of simulated linear systems and to correlate the studies with theoretical results.

Apparatus:

S.NO	Equipment
1	Linear system simulator Module
2	Cathode Ray Oscilloscope

Circuit diagrams:

Theory:

First order system:
A first order system is characterized by one pole and for a zero. A pulse integrator and a single time constant baring transfer function of the form *KlS* and K/(ST + 1) are the two commonly studied representations of this type of systems. Many thermal and electrical systems RC, RL elements are examples of first order systems.

Unit step response are computed as follows:

If $\frac{C(s)}{R(s)}$ = G(s) = $\frac{K}{S}$ where R(s) = $\frac{1}{S}$

C(s) = $\frac{K}{S^2}$ and C(t) = Kt

Again if G(s) = $\frac{K}{ST+1}$ with R(s) = $\frac{1}{S}$ then C(s) = $\frac{K}{S(ST+1)}$ and that

C(t) = K(1-$e^{-t/T}$)

Time constant of the system is defined from above equation at t =Γ, we have

C(t) = K(1-e^{-1}) = 0.632KG(s)

This is an important characteristic of the system which is also defined in terms of the slope of response at t = 0.

Second order system:

These systems are characterized by two poles and up to two zeros. For the purpose of transient response studies, zeros are not considered primarily to have simplicity in calculations and also because zeros do not effect the internal modes of the system. A great deal of analytical result regarding second order systems are available which can be approximated and become basis of studying higher order systems.

A second order system is represented by the standard form as

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

Where δ is called the damping ratio and $\acute{\omega}_n$ the undamped natural frequency. Depending upon the value of δ, the poles of the system may be real, repeated or complex conjugate which is reflected in the nature of its step response. Results obtained for various cases are.

(a) Undamped case (0 < δ < I)

$$C(t) = 1- \frac{e^{-\delta\omega T^t}}{\sqrt{1-\delta^2}} \sin(\acute{\omega}_d t + \tan^{-1}\sqrt{\frac{1-\delta^2}{\delta}})$$

Where $\acute{\omega}_d = \acute{\omega}_n \sqrt{1-\delta^2}$ is termed as the damped natural frequency.

(b) Critically damped (δ>1)

$$C(t) = 1+ \frac{\omega_n}{2\sqrt{\delta^2 - 1}}\left[\frac{e^{S_1 T}}{S_1} - \frac{e^{-S\ t}}{S_2}\right]$$

Where

$$S_1 = \left(\delta + \sqrt{\delta^2 - 1}\right)\omega_n$$

$$S_2 = \left(\delta - \sqrt{\delta^2} - 1\right)\omega_n$$

(I) Delay time: T_d is defined as the time required for the response to reach 50% of its final value.

(2) Rise time: T_r is the time required to reach 100% of the final value for the first time. This is given by

$$t_p = \frac{\pi - \beta}{\omega_d} \quad \text{where} \quad \beta = \frac{\tan\sqrt{1-\delta^2}}{\delta}$$

(3) Peak time: T_p is the time taken for the response to reach the peak at the overshoot and is given by

$$t_p = \frac{\pi}{\omega_d}$$

(4) Maximum overshoot: The normalized difference between time response peak and the steady output .

(5) Setting time: T_s is the required for the system response to reach and stay with in a prescribed tolerance band which is usually taken as $\pm$ 2% or $\pm$ 5%

$$t_s = \frac{3}{\delta\omega_n} \ (\pm 5\%)$$

For a low damping ratio system

$$= \frac{4}{\delta\omega_n} \ (\pm 2\%)$$

Procedure:

Closed loop first order system:

I. Connect the circuit for first order system and supply a 1 V P-P square wave input and trace the output wave form for K = 0.5, 1, 1.5, calculate the time constant and in each result compare with the theoretical value.

2. Note down the voltage and time period and also calculate the steady state errors for the above cases and compare them with the theoretical value.

3. If the open-loop transfer function of the chosen configuration was of type- I, the steady state error above would be zero for step input. To find steady state error for ramp input, apply a 1 V P-P triangular wave input keeping the CRO in x-y mode connect system input to x-input and system output to the y-input.

4. Repeat the measurements for steady state error for different values of K and compare with theoretical results.

Closed loop second order system:

5. Choose a suitable second order system configuration, apply a 1 V_{p-p} square wave input and trace the output on a tracing paper for different values of K obtain peak per unit overshoot, ts, t_R, steady state error and calculate 'σ' and 'W_n' and compare with theoretical values.

Tabular columns:

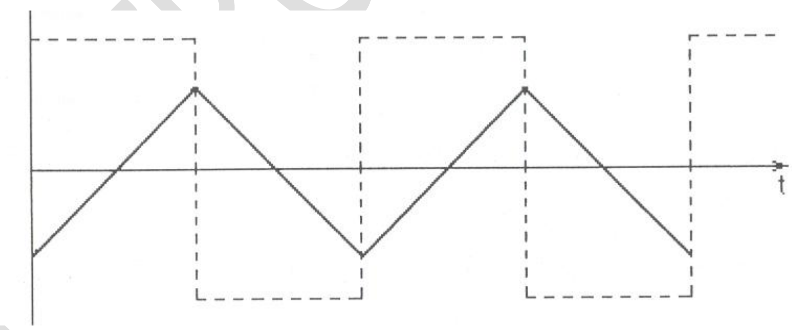
Closed loop first order system:

Gain	Output voltage

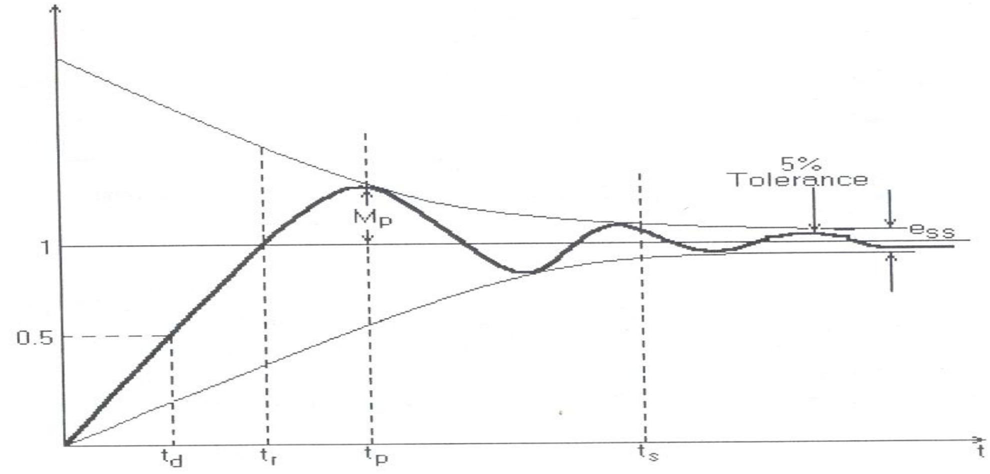
Closed loop second order system:

Gain	Output voltage

Model graph:

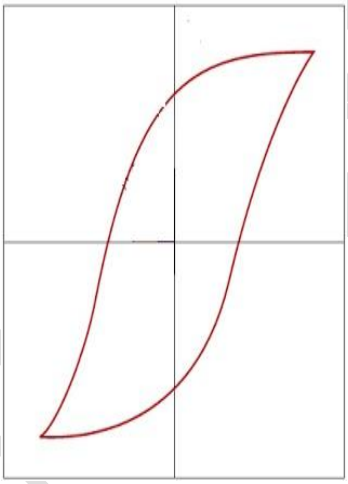


Closed loop first order system



Closed loop second order system

Steady state response:



Result:

Analysis:

Viva – Questions:

1. What are time domain specifications of linear time invariant system?

2. Define delay time?

3. Define Rise time?

4. Define peak time?

5. Define peak over shoot?

6. Define settling time?

7. Define steady state error?

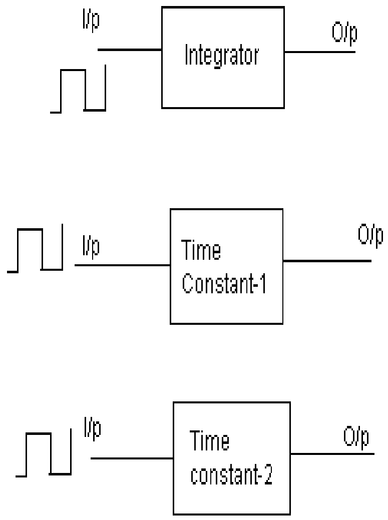
8. Classify various error constants?

9. Define positional error constant?

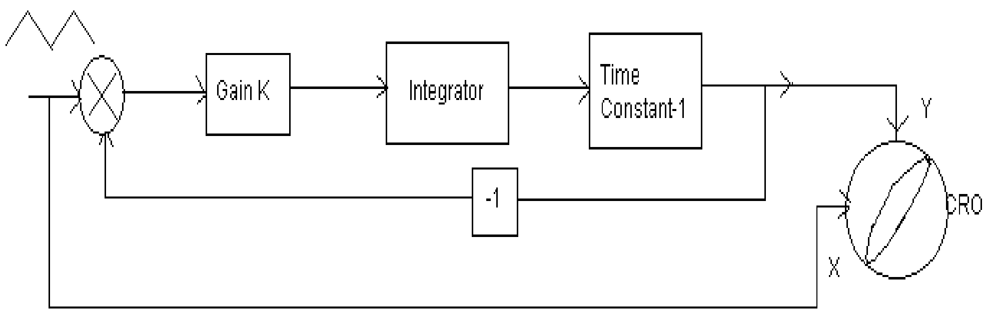
10. Define velocity error constant k_V?

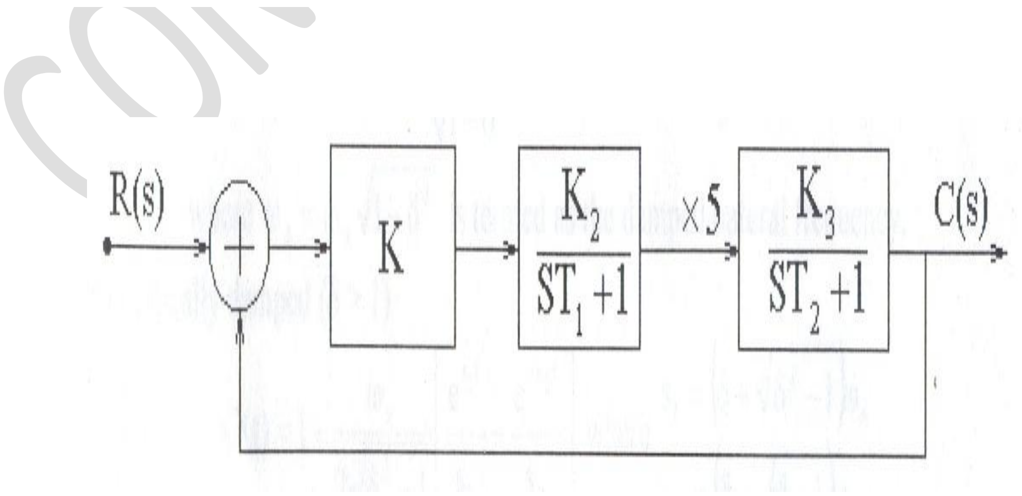
Circuit diagram:

Open loop response



Steady State error for ramp input





Connection diagram for closed loop second order system

Graph

Graph

7. DIGITAL CONTROL SYSTEM

Aim: To study the digital control of a simulated system using a 8-bit microcomputer.

Apparatus Required:

S.No	Equipment
1	Digital control system module
2	8085 µP kit
3	Oscilloscope

Circuit diagram:

Theory:

The basic structure of a feedback control systems comprising of a forward path transfer function H(s) is well known. The system attempts to keep the error close to zero at all times but fails to de so exactly. A common method of improving the performance of the system, both transient and steady state, is to insert a compensation block G(s) which is approximately a modified forward path transfer function.

In a Digital Control System the error signal is periodically sampled for converting into digital form processed in a computer and sent out to the process also and D/A converters, signals, other than the errors may be simultaneously handled.

The advantages of digital control system include

I. The possibility of implementing for better and complex control than simulating lag, lead network or PID.
2. Various controllers' actions can be affected through software modification only.
3. Externally slow systems may be handled easily.

Digital Processing:

Digital Processor is a computer which operates on the input sequence C(t) and generates an output sequence m(s). These are than sent out through the 8-bit µp PDI 8255 converted to analog form and applied for the process. The manner in which m(k) is applied form C(t) is determined by the control diagram to be implemented.

PID Algorithm:

The structure of an analog proportional integral derivative (PID) controller is of the form

$$m(t) = Kp\ [C(t) + \frac{1}{Ti}\int C(t)dt + T\theta\frac{dC(t)}{dt}]$$

where K_p is proportional gain and Ti,Tθ are respectively the integral and derivative time constants.

The pulse transfer function of the PID controller is

$$D(Z) = \frac{M(Z)}{C(Z)} = K_p + K_i\frac{Z}{Z-1} + K_D\frac{Z-1}{Z}$$

Process Identification:

The first step before a control is attempted experimentally is to determine the process parameters.

$$K = \frac{C(s)}{R}$$

$$a = \frac{1.678}{timetoreach 1/2 of steadystate}$$

$$G = \frac{Ka^2}{(s+a)^2}$$

Procedure:

1. The first step. is to determine the process parameters, a square wave input isused to connect the circuit as shown in fig.
2. Connect the circuit as shown is fig2. Execute the program available at the address 5000b. Give the value of P-gain and a delay setting of 0 when asked by the program
3. Observe the click out pulse on the CRO and measure the time between any two pulses. This is the actual sampling period.
4. Observe on the CRO the response of the system and obtain the peak over shoot by noting the peak and steady state value.

5. Repeat steps 2 to 4 for different forward gains and delay setting (1,2,3) and tabulate the results as under.

Tabular column

P Controller:

P value	Delay setting	Sampling period	C_{peak}	τ	$M_p = \frac{C_{peak} - e_{ss}}{e_{ss}} \times 100$

PID Controller:

P	I	D	C_{peak}	e_{ss}	$M_p = \frac{C_{peak} - e_{ss}}{e_{ss}} \times 100$

Model graph:

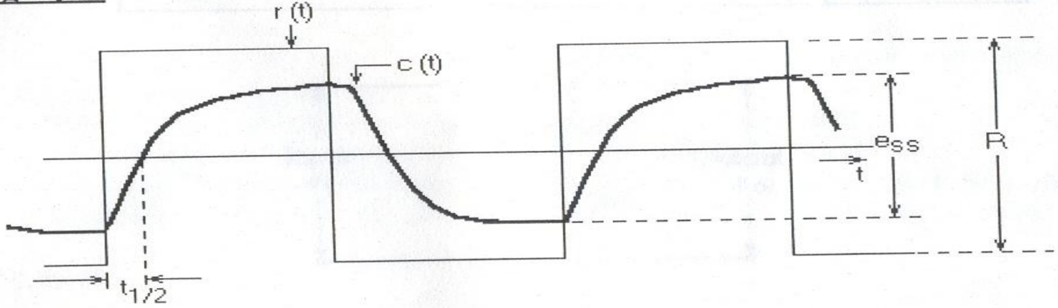


Figure 1

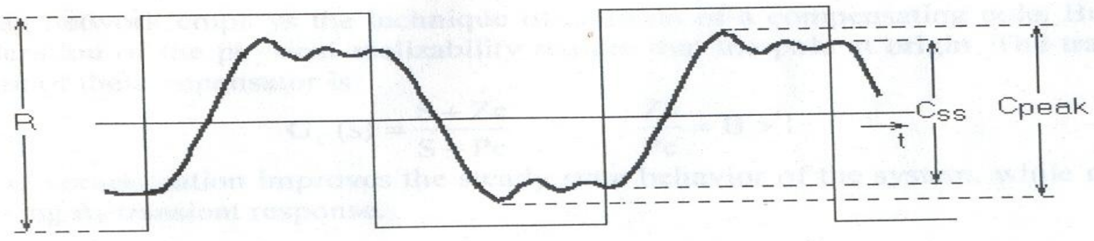


Figure 2

8085 Micro Processor Programs:

P-Controller:

1.Reset
2.Del go
3.Address 5000 fill
4.P-gain (2 to 7) fill
5.Delay time 0 fill

PID Controller:

1. Reset
2. Del go
3. 5030 Address fill
4. P gain 2 to 8 fill
5. I gain 2 to 6 fill
6. D gain 2 to 6 fill

Result:

Analysis:

Viva – Questions:

1. What is a digital controller?

2. Define Z- transform of unit step signal?

3. What is linear discrete time system?

4. What is weighting sequence?

5. What is a sampled data?

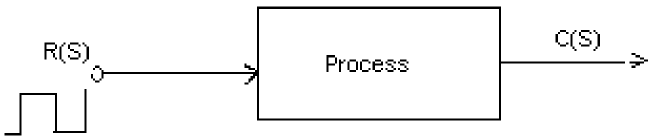
6. Define stability of a sampled data system?

7. Define sampling time period?

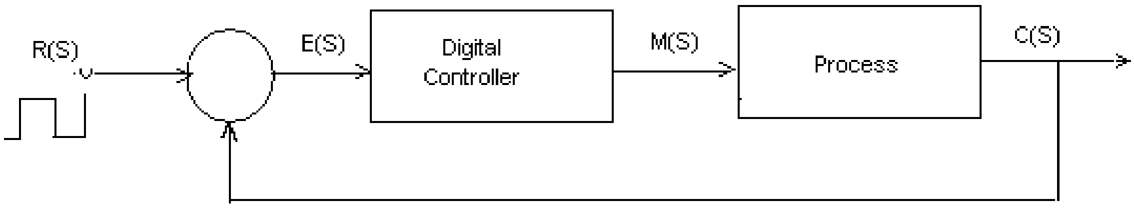
8. What is an Amplitude quantization error?

9. Define steady state error?

Circuit diagrams:



Connection diagram for Process identification



Connection diagram for Digital controller response measurements

Graph

8a. ON –OFF Control using RTD Transducer

Aim: - To demonstrate on-off control using an RTD transducer

Apparatus :-

S.NO	Equipment
1	RTD Transformer
2	RTD Unit
3	Beaker, Thermometer and heater
4	Bulb set

Theory:-

Industrial Control transducer has been designed specifically for measurement of control of temperature using RTD transducer. The board requires other apparatus like heater and beaker. The unit consists of following built in parts

± 12V DC at 100mA, IC regulated power supply,6V D.C at 100mA, IC regulated power supply,4 Op-amp, I.C Relay12V DC, one change over, NPN transistor,3 digits display panel meter to display temperature in ºC.RTD sensor with 3 pin connector.

One switch for setting temperature on one side and to read actual temperature on other side Potentiometer to control temperature.

Procedure:-

1) Connect the RTD to the points on the trainer kit. Insert the bulb set terminals in the supply socket at the back of the kit. Place the RTD, heater and thermometer in the beaker without the units touching each other. Fill up the beaker three fourth with the water

2) Switch on the heater & boil the water to about 60^0 to 70^0 (observe the thermometer). Now switch on the trainer kit and observe the temperature reading. Throw the switch to set point and observe the set point temperature.

3) Remove the RTD from the beaker and let it cool. Observe that as the RTD cools to set point temperature, the bulb switches ON.

4) Repeat the above procedure for different set points.

Table:

S.No	Set point	Voltage	Digital panel meter reading

Result:

Analysis:

8.c.Linear Variable differential transformer (LVDT)

Aim: To study the linear variable differential transformer operation .

Apparatus :

S.NO	Equipment
1	LVDT Calibration jig
2	LVDT Transducer trainer kit.

Theory:

The differential transformer employs the principle of electromagnetic induction and hence is usable only for alternating signals. Such a transformer however has a primary winding, two secondary windings I and II, and a movable core. The secondary windings are identical in respect of their number of turns as well as in respect of their placement on both sides of the primary winding as shown in Figure 2.42(a).

The secondary windings are connected in series opposition, so that the voltages in the two secondaries subtract. The movable core is connected to the shaft whose position is to be controlled. Figure 2.42(a) illustrates the principle of differential transformer. If the movable core is in the centre or middle position, equal voltages will be induced in both secondary windings because of the symmetry. Because of series opposition, the net secondary voltage will be zero as illustrated 2.42(b).

If the core is moved upwards, there will be more air gap between the primary and secondary II. The reluctance of this path will increase and therefore, less voltage will be developed in secondary II compared to secondary I and difference between the two voltages depending upon the magnitude of the movement of the core will appear across the terminals .on the other hand if the core ids moved downwards, a voltage of opposite phase will appear across the terminals. Hence the phase of the output voltages will indicate the direction of the movement of the core while the magnitude of output voltage will be proportional to the displacement of the core from the centre position.

This is the most popular magnetic type of error detector. It can be used as mechanical displacement to electrical voltage type transducer. When the core is exactly at the central position, the voltage is not zero because of residual magnetism. This is linear characteristic, symmetrical about the vertical axis. The output looses its linear relationship with displacement beyond some limits and this property restricts the range the LVDT. The drooping occurs because of the core going out of bounce. This transducer can be used for measuring pressure indirectly. Weighing machines, load cells can use this type of transducer.

Circuit Analysis:

When the secondary of LVDT are open circuited the equations of primary becomes

$$i_P R_P + L_P \frac{di_P}{dt} = e_i$$

Taking Laplace transform,

$$I_P(s) = \frac{E_i}{sL_P + R_P} = \frac{E_i(s)/R_P}{T_P s + 1} \; ; \; T_P = \frac{L_P}{R_P}$$

Now e_{S1} and e_{S2} are the voltages generated in the secondary coils due to the coefficients of mutual inductances M_1 and M_2. Thus,

$$e_{S1} = M_1 \frac{di_P}{dt} \quad \text{and} \quad e_{S2} = M_2 \frac{di_P}{dt}$$

the output voltage,

$$E_o(s) = E_{S1}(s) - E_{S2}(s) = (M_1 - M_2)\, s\, I_p(s)$$

Substuting for $I_P(s)$, we get

$$\frac{E_O(s)}{E_i(s)} = \frac{s(M_1 - M_2)/R_P}{sT_S + 1} = \left| \frac{w(M_1 - M_2)/R_P}{\sqrt{(wT_P)^2 + 1}} \right| \angle \phi$$

Where $$\phi = \frac{\Pi}{2} - \text{Tan}^{-1}(wT_P)$$

Since w, R_P, T_P and e_i are given for a given setup, the amplitude of output A_0 can be written as

$$A_0 = K\,(M_1 - M_2)$$

Where

$$K = \frac{we_i}{R_P\sqrt{(wT_P)^2 + 1}} = \text{constant}$$

The value (M_1-M_2) keeps on increasing with the displacement of the core up to a certain point and then it starts falling as the core moves past one of the secondaries.

Procedure:

1.connect the lvdt transducer to the instrument with 9 pin D type connector provided with transducer .

2. switch on the instrument using an on –off switch provided at the rear of the instrument .

3. connect the CRO at the test point at the primary windings of LVDT.Keep amplitude control of CRO at 10 volts AC ,and Frequency control at 10khz.

4. Adjust the frequency potentiometer to set the frequency at approximately 4khz.There is a finite position at which the output appears on the oscilloscope ,so turn frequency potentiometer slowly and observe the waveform .in other positions of the potentiometer the output will not be there.so make sure the output is observed on CRO.
5. Adjust the amplitude potentiometer such that the peak to peak amplitude is not more than 0.8v AC. the output can be adjusted to 4v rms,but 0.8v itself will give desired output .
6. Disconnect CRO probes from the instruments .
7. Now retract the micrometer to read 10mm on the micrometer this position is the center of LVDT core within the transducer .this is called null position of center position of the transducer.
8. Now adjust the micrometer to read 20mm on the micrometer jig. This position is called positive end of the transducer position
9. Adjust the span adjustment potentiometer to read +10.00on the display.
10. Now adjust the micrometer to read 0mmon the micrometer jig .this position is called negative end of the transducer's position. Record the readings on the displacement indicator in the table.
11. Repeat the above steps7 to 10 to observe the readings.

Equivalent diagram :

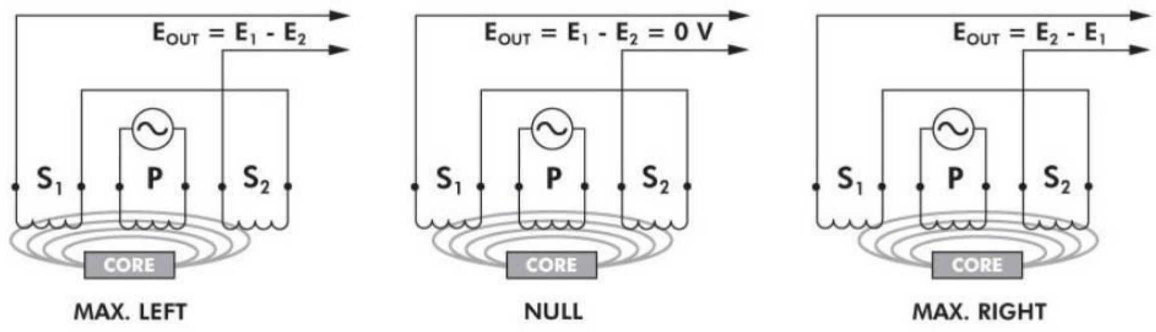


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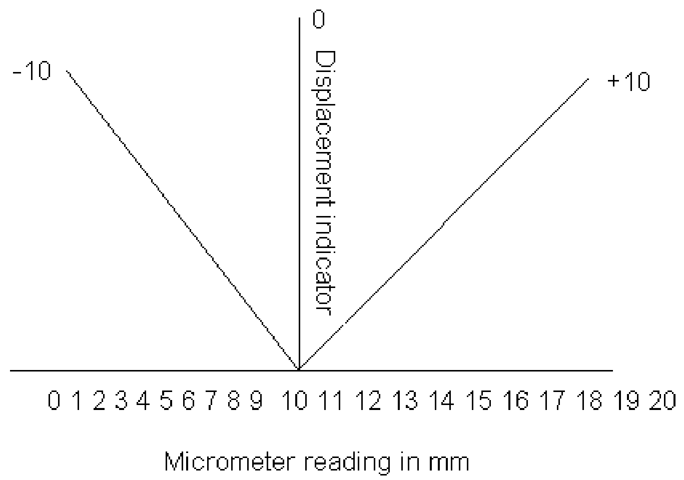
Table

Displacement in mm on micrometer	Displacement indicator reading

Model graph:



Result:

Analysis:

Graph

9. RELAY CONTROL SYSTEM

Aim:
To analyze the closed loop system with and with out relay.

Apparatus:

S No	Apparatus
1.	Relay control system kit
2.	C.R.O
3.	Connectors.

Panel diagrams:

Procedure:

1) <u>Linear system (with out relay)</u>:-

a) Connections are made for closed loop system with out the relay. The two outputs 'X' and 'Y' are connected to the 'X' and 'Y' input of the C.R.O, which is kept in X-Y mode with DC coupling.

b) Apply a square wave input of $1V_{p-p}$ at 10-40 Hz and observe the equilibrium points corresponds to positive & negative step input.

c) Vary the gain K and observe how the negative equilibrium point is modified for some value of K say 5, 10. Obtain the value of M_p and number of over shoots from the phase plane trajectory.

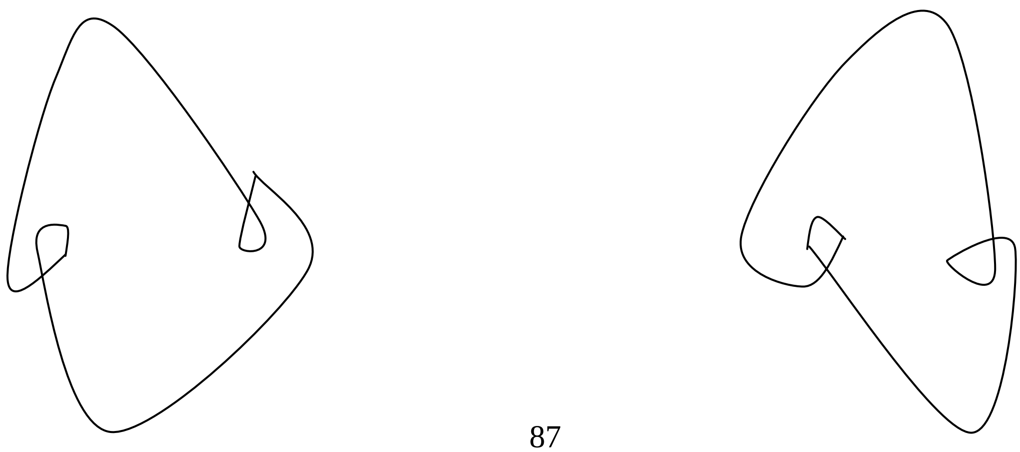
2) <u>Non linear system with relay</u>:-

When the relay is inserted in the forward path of the system, various changes occurs in the nature of equilibrium point and the shape of trajectory. Some of the effects are that the trajectory becomes discontinues at point of switching. No inputs are available to the system with in dead zone, if unsymmetrical switching results in the presence of hysteresis. Typical phase trajectories for different cases are shown in figure in which any positive step input has been considered as explained earlier.

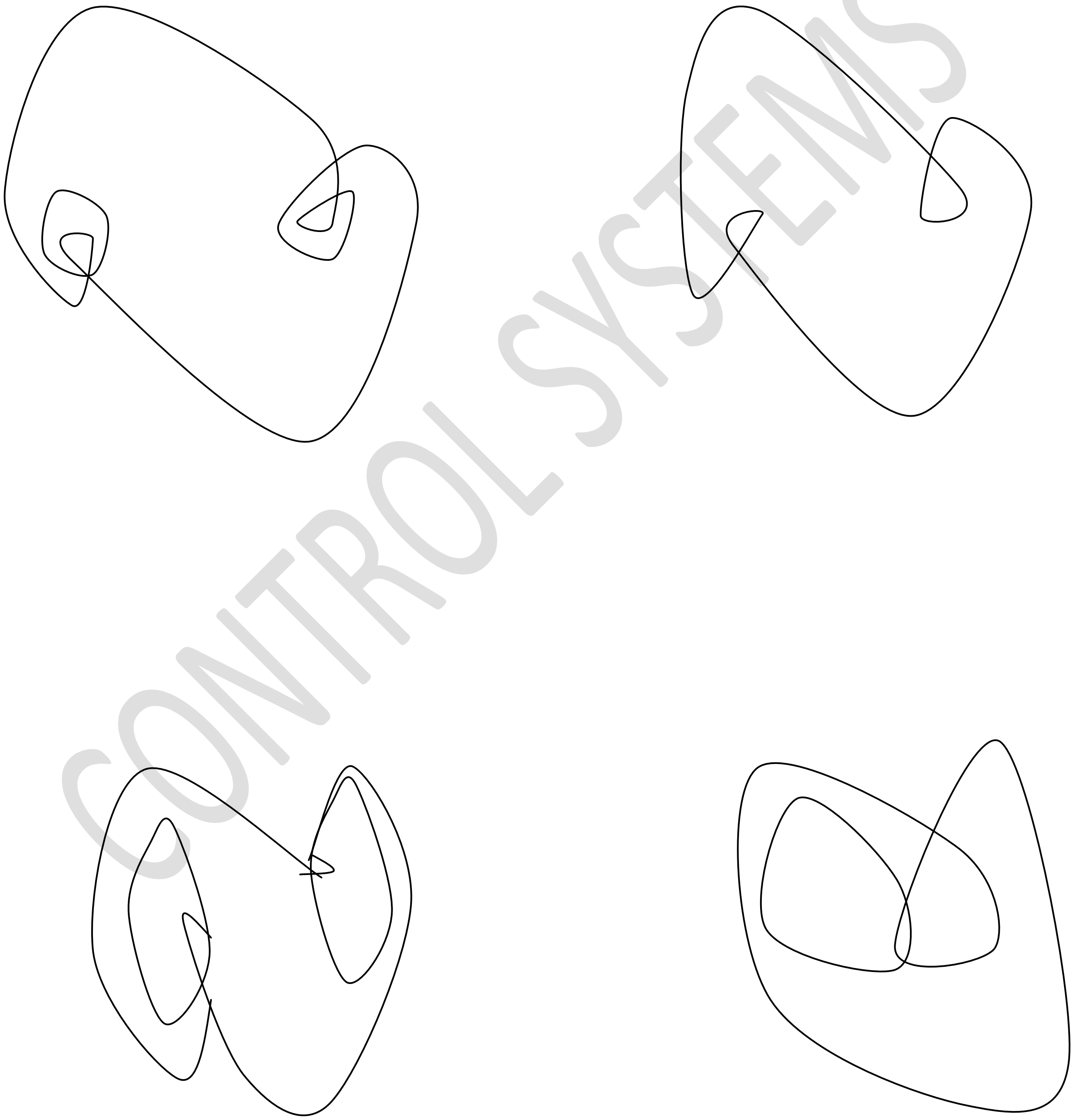
All these may be verified by proceeding as below.

1. Set K=0,H=0 and increase the dead zone to make the system stable. This can be judged by the absence of centre on the C.R.O.
2. Apply a square wave of $1V_{p-p}$, 10-40 Hz and observe the trajectory and equilibrium point. Record M_p and number of over shoots and compare with linear system results.
3. Increase the dead zone further and observe to record its effect on the singular point and hence transient response.
4. Decrease dead zone control to zero and H=0.2. Apply square wave input of $1V_{p-p}$, 10-40 Hz and observe the trajectory from nature of the singular point. Comment on the stability of the system.
5. Repeat the above steps for H=0.4 (medium) and H=0.6 (high). Comment on the effect of hysteresis.

Without relay:



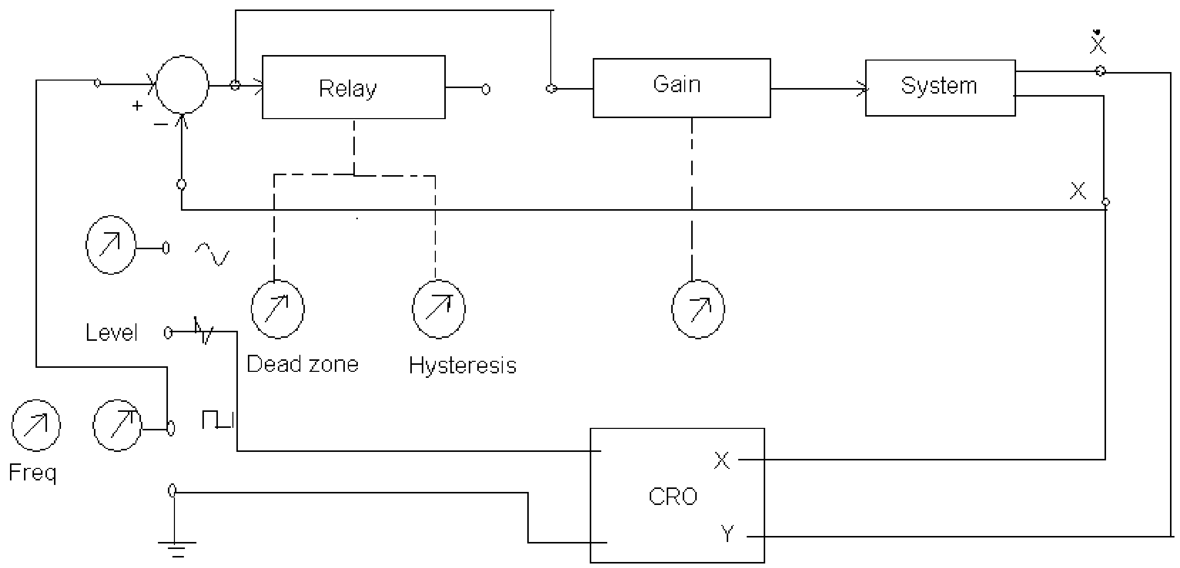
With relay :



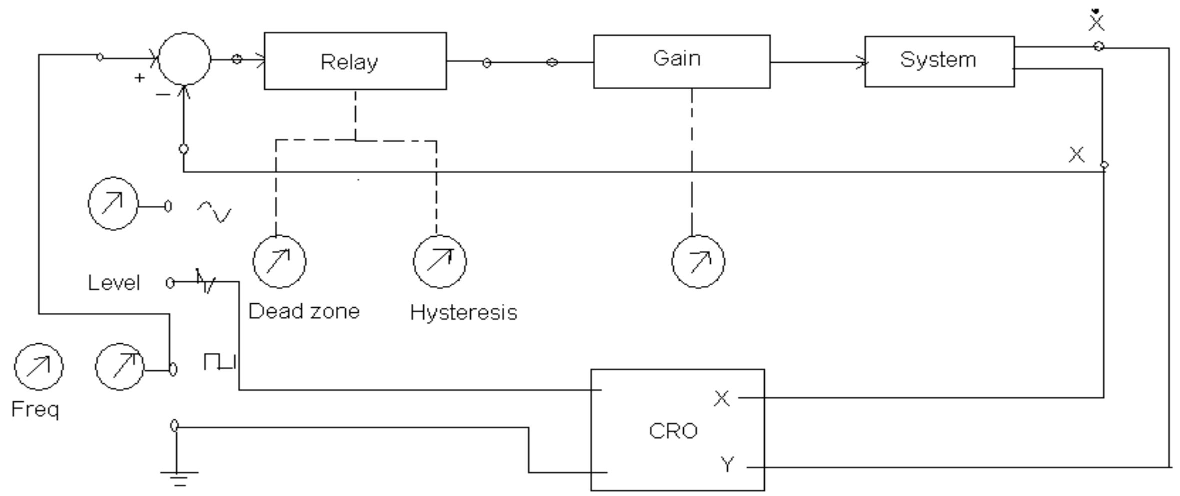
Result:

Analysis:

Circuit diagram:
without relay:



With relay:



Graph

Graph

10a. COMPENSATION NETWORK (LAG NETWORK)

Aim: To design implement and study the effects of a lag compensation network.

Apparatus:

S.NO	Equipment
1	Compensation network module
2	Cathode Ray Oscilloscope
3	Connecting wires

Circuit diagram:

Panel diagram for lag network:

Theory:

The Lag network employs the technique of addition of a compensating pole. But the consideration of the physical realizability require that the pole at origin. The transfer function of the compensator is

$$G_c\ (s) = \frac{S + Z_c}{S + p_c} \qquad \frac{Z_c}{P_c} = B>1$$

The Lag compensation improves the steady state behavior of the system, while nearly preserving its transient response.

Procedure:

1. Disconnect the compensation terminals and apply an input of 1 Vp-p to the plant from the built in sine wave source.
2. Vary the frequency and calculate plant gain in db and phase angle in degree at each frequency.
3. Sketch the bode plot on the semi log sheet.
4. Obtain the error coefficient and the steady state error from the magnitude plot.
5. Calculate the forward path gain necessary to meet the steady state error specifications
6. Calculate Mp, T p, Ess, T s and by shifting the magnitude curve by 20 log k and obtain the value of phase design.

Tabular Column:

Frequency	A	B	X_0	Y_0	Gain	Gain in db	Phase in degrees

$$\text{Gain} = \frac{B}{A} = \frac{Y_0}{X_0} = 20\log\left(\frac{B}{A}\right)\text{db}$$

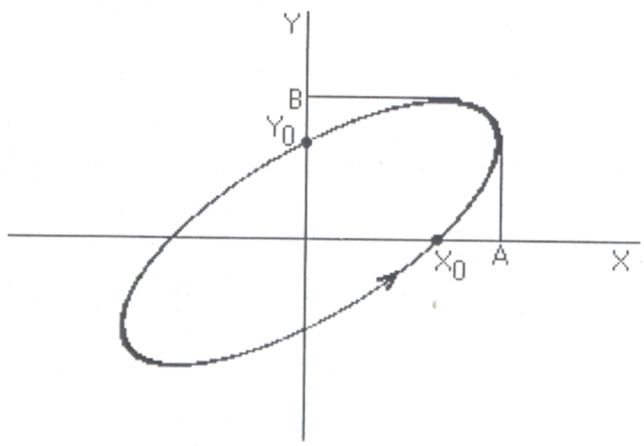
$$\text{Phase } \theta = -\sin^{-1}\left(\frac{X_0}{A}\right) = -\sin^{-1}\left(\frac{Y_0}{B}\right)$$

$$G(s) = \frac{K}{\left(1+\frac{s}{w}\right)^2}$$

Design:

1. Phase lag required $\phi_m = P_m$ specified +a safety margin. This is the new gain crossover frequency W_g new.
2. Measure gain at W_g new. This must equal the high frequency attenuation of the lag network i.e $20\log\beta$. Compute β.
3. Choose $Z_c = 1/T$ at approximately 0.1 W_g new and $P_c = 1/\beta T$
4. Write the transfer function $G_c(s)$ and calculate R_1, R_2 and C
5. Implement $G_c(s)$ with the help of a few passive components and the amplifier provided for the purpose. The gain of the amplifier must be set at unity.

Model Graph:



Result:

Analysis:

Viva – Questions:

1.What are the characteristics of Lag compensation?

2.When the Lag compensation is employed?

3.What is lag-lead compensation?

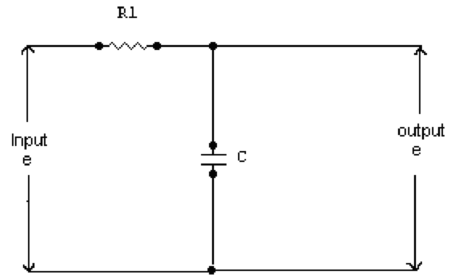
4.Why the compensation is necessary in feedback control system?

5 When the Lag-Lead compensation is employed?

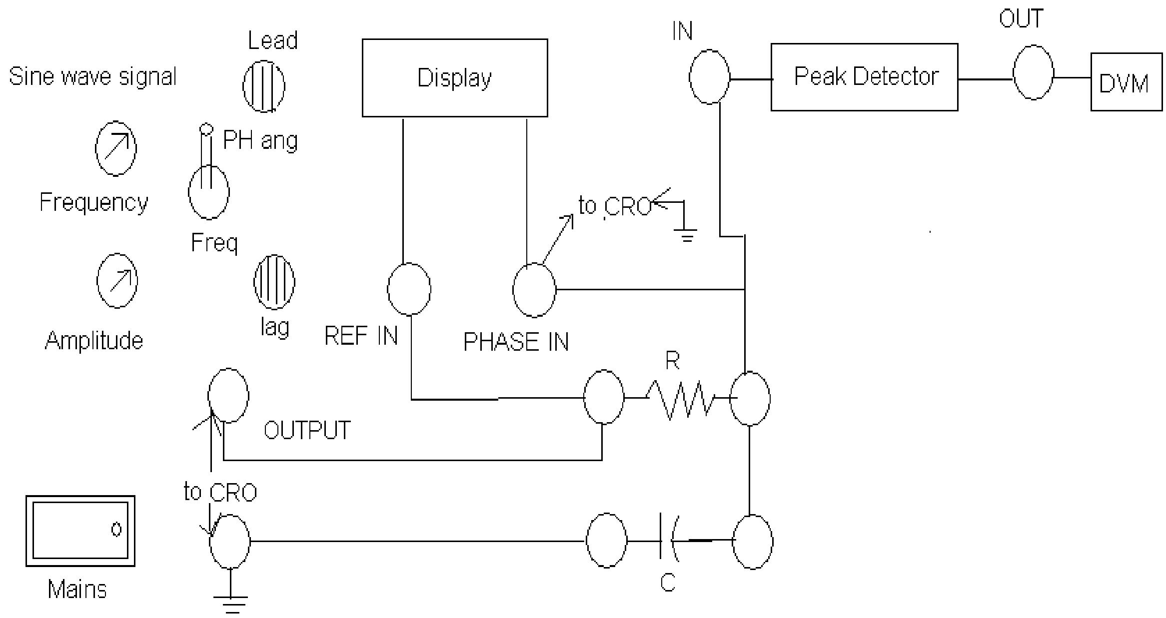
6. What are the different types of compensations?

7. What is compensation?

Circuit diagram:



Panel diagram for lag network:



Graph

10 b. COMPENSATION NETWORK (LEAD NETWORK)

Aim: To design implement and study the effects of a lead compensation network.

Apparatus Required:

S.NO	Equipment
1	Compensation network module
2	Cathode Ray Oscilloscope
3	Connecting wires

Circuit diagram:

Panel diagram for lead network:

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Theory:

A system constructed to control the operation of other components may not always be satisfactory, in meeting the requirements. A compensation network is designed at this stage to modify the system characteristics and to force it to meet the specifications. The most common form of compensation is cascade compensation apart from load compensation and feedback compensation. The signal level of the error is very low and the error is more commonly electrical in nature. So the compensation network need to be a low power electrical network which is very easy to implement.

Lead compensator speeds up the transient response and increases the margin of stability of a system it also helps to increase the system error constant through to a limited extent. These networks are physically realizable in introduces a zero into the system and thus improve its transient response, to compensate it a pole is also introduced which will effect the steady state error to a limited extent. It has a zero at s = $\frac{1}{\tau}$ and a pole at s = $l/\alpha\tau$ with zero closer to the origin than the pole. The general form of the lead compensation is

$$G_c(s) = \frac{S + Z_c}{S + p_c} = \frac{s + \frac{1}{\tau}}{s + \frac{1}{\alpha\tau}} \qquad \alpha = \frac{Z_c}{P_c} < 1 \qquad \tau > 0$$

Procedure:

1. Disconnect the compensation terminals and apply an input of 1 Vp-p to the plant from the built in sine wave source. Vary the frequency and calculate plant gain in db and phase angle in degree at each frequency.
2. From the forward frequency end of the magnitude plot obtain the error Coefficient and steady state error.
3. Calculate the forward path gain K necessary to meet the steady state error specifications
4. Set the above values of K, short the compensation terminal and observe the step response of the closed loop system. Compute the time domain performance specifications namely M_p, T_p and C_y.
5. Shift up the magnitude curve by 20 $\log_{10}$ k and obtain the value of phase margin. Compare with the given specification of phase margin

Tabular Column:

Frequency	A	B	X_0	Y_0	Gain	Gain in db	Phase in degrees

$$\text{Gain} = \frac{B}{A} = \frac{Y_0}{X_0} = 20\log\left(\frac{B}{A}\right)\text{db}$$

$$\text{Phase } \theta = -\sin^{-1}\left(\frac{X_0}{A}\right) = -\sin^{-1}\left(\frac{Y_0}{B}\right)$$

$$G(s) = \frac{K}{\left(1+\frac{s}{\omega}\right)^2}$$

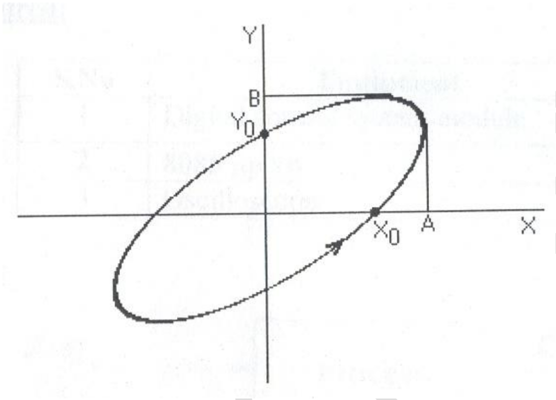
Design:

1. From the bode diagram obtained, calculate the required phase lead as Phase lead measured (~m) = phase (specified) - phase margin (available) + safety margin (5° to }0°)
2. Calculate a for lead network, $\alpha = \frac{1 - Sin\phi_m}{1 + Sin\phi_m}$
3. Calculate new gain crossover frequency

W_g new such that IGl w_g new = 10 logα
This step ensures that maximum phase lead shall be added to the new gain cross over frequency

4. The corflh frequencies are noe calculated from
5. Implement Gc(s) with the help of a few passive components and the amplifier provided for this purpose. The gain of the amplifier is to be set to $1/\alpha$
6. Insert the compensator land determine experimentally the phase margin of the plant with compensator.
7. Observe the step response of the compensated system. Obtain the values of M_p, T_p, E_{ss} and G

Model Graph:



Result:

Analysis:

Viva Questions:-

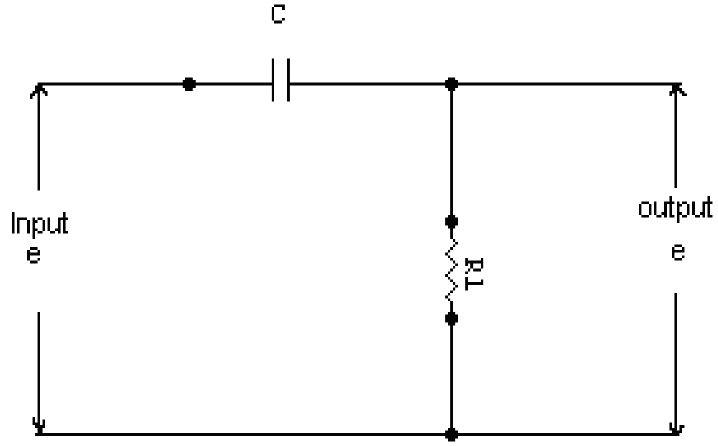
1.What is lead compensation

2. Give an example for lead compensation

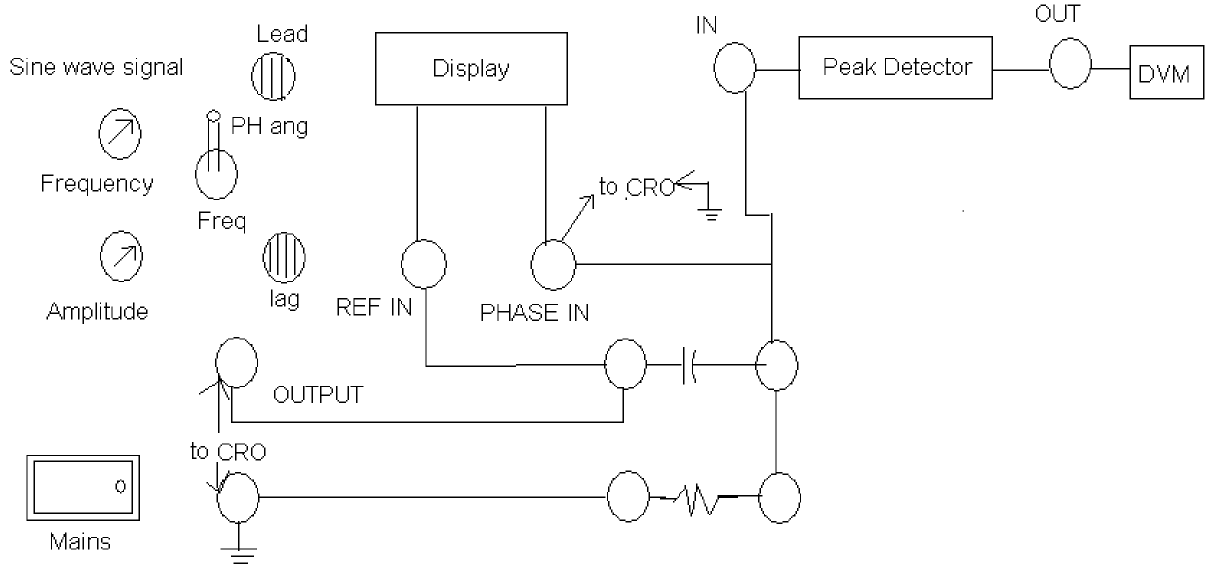
3.When the lead compensator is employed.

4.Why compensation is necessary in feedback control system

Circuit diagram:



Panel diagram:



Graph