# List of Experiments

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<th>Name of the Experiment</th>
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<td>3</td>
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<td>9</td>
<td>Effect of P, PD, PI, PID Controller on a second order systems</td>
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<td>Lag and lead compensation – Magnitude and phase plot</td>
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| 11    | (a) Simulation of P, PI, PID Controller.  
  (b) Linear system analysis (Time domain analysis, Error analysis) using suitable software |
| 12    | Stability analysis (Bode, Root Locus, Nyquist) of Linear Time Invariant system using suitable software |
| 13    | State space model for classical transfer function using suitable software - Verification. |
| 14    | Design of Lead-Lag compensator for the given system and with specification using suitable software |
EXPERIMENT- 1

TIME RESPONSE OF SECOND ORDER SYSTEM

AIM: To obtain time domain specifications of a second order system.

APPARATUS:

1. Oscillator
2. C.R.O.
3. Decade resistance box.
4. Decade inductance box.
5. Decade capacitance box.
6. Connecting wires.

CIRCUIT DIAGRAM:

connection_diagram.png

BLOCK DIAGRAM:

block_diagram.png

Connection Diagram for Second Order System using RLC
THEORY:

When the resistance, inductance and capacitance are connected in series to the voltage source ‘e’ and the voltage across the capacitor is taken as output.

The mathematical equations are

\[ e_i(t) = R \frac{di}{dt} + L \frac{d^2i}{dt^2} + (1/C) \int i \, dt \quad \text{and} \quad e_o = (1/C) \int i \, dt \]

\[ E_o(s)/E_i(s) = \frac{(s^2+(R/L) s+(1/LC))LC}{s^2+(R/L) s+(1/LC))LC} \]

\[ E_o(s)/E_i(s) = \frac{1}{s^2+(R/L) s+(1/LC))LC} \]

Compare with characteristic equation \( s^2+2\zeta\omega_n s+\omega_n^2 = 0 \)

\[ w_n = \frac{1}{\sqrt{LC}} \quad \text{and} \quad R = 2\zeta \sqrt{\frac{L}{C}} \]

Damping frequency = \( w_d = w_n \sqrt{1-\zeta^2} \)

TIME RESPONSE SPECIFICATIONS:

(i) Delay Time: It is the time taken to reach 50% of its final value.

\[ t_d = (1+0.7\zeta) / w_n \]

(ii) Rise Time: It is the time taken to rise from 10% to 90% for over damped system.

It is the time taken for the system response to rise from 0 to 100% for under damped system.

It is the time taken for the system response to rise from 5% to 95% for the critically damped system.

\[ t_d = [(\pi-\tan^{-1}(\sqrt{1-\zeta^2}/\zeta)]/w_d \]

(iii) Peak Time: It is the time taken for the response to reach peak value for the first attempt.

\[ t_p = \pi/w_d \]
(iv) Settling Time: It is the time taken to reach and stay within the tolerable limit (2-5%).

\[ t_s = \frac{4}{\zeta \omega_n} \]

(v) Peak Overshoot: It is the ratio of maximum peak value measured to the final value.

\[ M_p = e^{-\pi \zeta \sqrt{1 - \zeta^2}} \]

PROCEDURE:

1. Make the connections as per the connection diagram for second order system shown in figure.
2. Switch on the mains supply to the unit; observe the signal source output by selecting square wave or step input and by varying amplitude potentiometer.
3. Make sure signal source is correct before connecting the input of the second order system.
4. Now select square wave signal. Draw the input square wave signal.
5. Connect the second order system output for different values of damping factors from 0 to 2 in steps of 0.1 by varying potentiometer R provided.
6. Compare this with theoretical wave forms.
7. Measure the R values using digital DC voltmeter or multimeter between the input terminals with main switch in OFF position.

TABULAR COLUMN:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>R in ohm</th>
<th>L in Henry</th>
<th>C in microF</th>
<th>( \delta ) (Damping Factor)</th>
<th>( t_d )</th>
<th>( t_r )</th>
<th>( t_p )</th>
<th>( t_s )</th>
<th>( M_p )</th>
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RESULT:

VIVA-VOCE QUESTIONS:
1. What is delay time?
2. Define rise time.
3. What is settling time?
4. Define peak time.
5. What is peak overshoot?
6. Differentiate critically, under damped and over damped system.
EXPERIMENT-2
CHARACTERISTICS OF SYNCHRO

AIM:

(1) To obtain the stator voltages corresponding to the given rotor positions for the given Synchro transmitter and

(2) To study Synchro transmitter and receiver pair as error detector.

APPARATUS:

1. Synchro transmitter and receiver pair
2. Voltmeter (0-300V)
3. Dc power supply
4. Connecting wires

THEORY:

The most important unit in a modern transmission system is the synchro. Synchros of different types transmit, receive, or combine signals among stations which may be widely separated; for example, they transmit gun order signals from a computer to the automatic control equipment at a gun mount. The simplest types of synchro units are the Synchro transmitter (sometimes called synchro generator) and the synchro receiver (sometimes called synchro motor). The transmitter is a device that transmits an electrical signal corresponding to the angle of rotation of its shaft. The receiver is a device that, when it receives such a signal, causes its own shaft (if not appreciably loaded) to rotate to an angle corresponding to the signal.

The transmitter and receiver are identical in construction except that the motor has a damper - a device that keeps it from “running away” when there are violent changes in its electrical input.

When a current flows in the primary, it forms a magnetic field in its core. As the current changes and reverses (which it does constantly, being an alternating current), so does the magnetic field. The changes in the field induce current in the secondary (whose circuit is closed through a load). The currents in the secondary produce their own magnetic field. At any instant, the induced or secondary field opposes in direction that produced by the primary.
Now consider a synchro transmitter connected to a receiver as in fig, so that the rotors are fed by
the same AC line and the stator coils of the receiver load the corresponding coils of the
transmitter. The currents induced in the transmitter stator flow also in the receiver, and produce

the resultant stator fields shown by the white arrows. Thus the receiver rotor, which produces a
magnetic field similar to that of the transmitter rotor (because it is excited by the same AC line),
always, because it is free to rotate, assumes exactly the same angular position (relative to the
stator) as does the transmitter rotor. When the transmitter rotor is turned—say 30 degrees, as in fig,
the resultant field produced by the stator turns too, as it did in fig, so does the receiver stator field.

Fig 1.a Schematic diagram of synchro transmitter

Fig 1.b Stator voltages
Synchro control transformer has a wound rotor coil and three stator coils, but the internal construction is different. The rotor is round instead of bobbin-shaped (to keep it from tending to line up with a magnetic field as a receiver rotor does) and is wound with finer wire to increase electrical impedance and limit the amount of current it will carry. The synchro control transformer has 2 inputs, 1 mechanical (its rotor is driven by the mechanism or load whose position it regulates) and the other electrical (the synchro signal from the transmitter which is to control the load). The electrical (synchro) 3-wire input goes into the control transformer’s stator. The stator’s field acts as the primary of the transformer; the rotor is its secondary. The output thus comes from the rotor and varies with its position with respect to the stator. This output is not a synchro signal; it is a voltage whose value and polarity with respect to the AC supply depend on the position of the control transformer’s rotor with respect to the stator.

Fig.2. Synchro Transmitter and Receiver pair as error detector
PROCEDURE (SYNCHRO TRANSMITTER):

1) Connect the mains supply to the system with the help of cable provided. Do not interconnect $S_1$, $S_2$ and $S_3$ to $S_1'$, $S_2'$ and $S_3'$ any wires between the stator winding of transmitter and receiver.

2) Switch on mains supply for the unit and transmitter rotor supply.

3) Starting from zero position, note down the voltages between stator winding terminals i.e.,
4) $V_{S1S2}$, $V_{S2S3}$, & $V_{S3S1}$ in a sequential manner. Enter readings in tabular form and plot a graph of angular position v/s rotor voltages for all three phases.

5) Note that zero position of the stator rotor coincide with $V_{S3S1}$ voltage equal to zero voltage. Do not disturb this condition.

**OBSERVATION TABLE 1:**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Rotor angle in Degrees</th>
<th>Stator voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>$V_{S1S2}$</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>4</td>
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<td>7</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>12</td>
<td>330</td>
<td></td>
</tr>
</tbody>
</table>

**PROCEDURE (SYNCHRO TRANSMITTER AND RECEIVER PAIR):**

1) Connect mains supply cable.

2) With the help of patch cords, establish connections between corresponding terminals of transmitter and receiver i.e., connect S₁ to S₁, S₂ to S₂ and S₃ to S₃ of transmitter and receiver respectively.

3) Switch on rotor supply of both transmitter and receiver and also switch on the mains supply.

4) Move the pointer i.e., rotor position of Synchro transmitter in steps of 30 degrees and observe the new rotor position.

5) Enter the input angular position and output angular position in the tabular column and plot the graph.
OBSERVATION TABLE 2:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Rotation of rotor of Synchro Transmitter, $\theta_t$</th>
<th>Rotation of rotor of Synchro Receiver, $\theta_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td></td>
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<tr>
<td>...</td>
<td>60</td>
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<tr>
<td>...</td>
<td>90</td>
<td></td>
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<tr>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>330</td>
<td></td>
</tr>
</tbody>
</table>

PRECAUTIONS:

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

RESULT:

1) The graph of $V_{S1S2}$, $V_{S2S3}$, & $V_{S3S1}$ has been plotted for various positions of rotor.
   It is observed that the voltages are displaced by 120 degrees.

2) The graph of angular position of rotor of receiver v/s angular position of rotor of transmitter has been plotted.
VIVA-VOCE QUESTIONS:

1. What are the principles of synchro pair?
2. Why the rotor of control transformer is made cylindrical in shape?
3. What is the difference between Synchro transmitter and synchro control transformer?
4. What is Synchro Transmitter?
5. Synchros is a __________
6. The input to synchro Transmitter is ____________
7. The magnitude of output voltage of the synchro transmitter is function of ____________
8. Synchro transmitter-Control transformer pair acts as __________
9. The rotor of control transformer is made up of __________
10. When the two rotors of synchro pair are at right angle, then the voltage induced in control transformer is __________
11. The electrical zero of transmitter is __________
EXPERIMENT-3

PROGRAMMABLE LOGIC CONTROLLER – STUDY AND VERIFICATION OF TRUTH TABLES OF LOGIC GATES, SIMPLE BOOLEAN EXPRESSIONS, AND APPLICATION OF SPEED CONTROL OF MOTOR

AIM: To study and verification of truth tables of logic gates, simple Boolean expressions and application of speed control of motor with PLC.

APPARATUS:
- PLC kit
- PC
- Boolean Algebra kit
- Logical gate kit
- Connecting wires

SCHEMATIC DIAGRAM:
1. LOGIC GATE SIMULATION:

**Definition:** Logic Gate Simulation panel is an experimental module where the program is written in LD to simulate the LOGIC GATES, such as INV, OR, NOR, AND, EX-OR for any two given inputs. Two LED's are given to indicate the status of output Q and invQ. If the LED’s in ON it indicates 1 if LED is off it indicates 0.

Digital inputs DI -0 (X0) to DI-6 (X6) are used as two switches and DO-0 (Y0) and DO-1(Y1) is used as output to LED.

**PROCEDURE:** Connect the Digital inputs from the PLC panel to the SAP panel using patch cards. Connect DI-0 and DI-1 on the PLC trainer to DI-0 and DI-1 on the application panel respectively and DO-0 on the PLC trainer to DO-0 on the application panel.

Connect 24V power supply and Ground to the respective terminals matching the terminal color.
LOGIC GATE SAMPLE LADDER PROGRAM

0
X0
(M0)

2
X0
(M1)

4
M0 X2
(M2)

7
M0 X3
(M3)

10
M0 X4
(M4)

13
M0 X5
(M5)

16
M1 X2
(M6)

19
M1 X3
(M7)

22
M1 X4
(M8)

25
M1 X5
(M9)
1. **BOOLEAN ALGEBRA**:

![Ladder Program for Boolean Algebra](image)

**PLC TRAINER**

**BOOLEAN ALGEBRA (DEMORGAN'S THEOREM)**

- 1st LAW: \( \overline{A+B+C} \) vs. \( \overline{A} \cdot \overline{B} \cdot \overline{C} \)
- 2nd LAW: \( \overline{A+B+C} \) vs. \( \overline{A} \cdot \overline{B} \cdot \overline{C} \)

**LADDER PROGRAM FOR BOOLEAN ALGEBRA**

- 0
  - \( M0 \)
  - \( X0 \)
  - \( X1 \)
  - \( X2 \)
- 5
  - \( X0 \)
  - \( X1 \)
  - \( X2 \)
- 10
  - \( X0 \)
  - \( X1 \)
  - \( X2 \)
- 14
  - \( X0 \)
  - \( X1 \)
  - \( X2 \)
- 18
  - \( X3 \)
  - \( X4 \)
  - \( X5 \)
  - \( M1 \)
- 24
  - \( X3 \)
  - \( X4 \)
  - \( X5 \)
- 28
  - \( X3 \)
  - \( X4 \)
  - \( X5 \)
- 3791
  - END
**Definition:** Boolean Algebra (Demorgan’s Theorem) panel is an experimental module where the program is written in LD to prove Demorgan’s theorem that LHS of an equation is equal to RHS for three inputs. Two LED’s are given to indicate the status of LHS and RHS of the equation. If the LED’s in ON it indicates 1 if LED is off it indicates 0.

Digital inputs DI -0 (X0) to DI-5 (X5) are used as two switches and DO-0 (Y0) to DO-3(Y3) are used as output to LED.

**PROCEDURE:** Connect the Digital inputs from the PLC panel to the SAP panel using patch cards.

Connect DI-0 and DI-1 on the PLC trainer to DI-0 and DI-1 on the application panel respectively and DO-0 on the PLC trainer to DO-0 on the application panel. Connect 24V power supply and Ground to the respective terminals matching the terminal color.

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**2. DC MOTOR CONTROL USING RELAYS:**

**Definition:** DC Motor Control Using Relays is a working model it has a DC motor fixed on the panel.

Ladder Program is written to control the motor direction of rotation and timer control. The panel is an experimental module Two relays are used inside to control the direction of motor. These relays are driven using Digital output of PLC. Two toggle switch are provided as input to PLC to select the Direction of rotation and timer control mode.

Digital inputs DI -0 (X0) to DI-3 (X3) are used switches and DO-0 (Y0) to DO-3(Y3) are used as output to RELAYS.
**PROCEDURE:** Connect the Digital inputs from the PLC panel to the SAP panel using patch cards.

Connect DI-0 to DI-3 on the PLC trainer to DI-0 to DI-3 on the application panel respectively, And DO-0 and DO-1 on the PLC trainer to DO-0 and DO-1 on the application panel. Connect 24V power supply and Ground to the respective terminals matching the terminal color.

**DC MOTOR with relay Control Ladder Program**

![Ladder Diagram](image_url)

**RESULT:** The performance of PLC is studied and verified the truth tables of logic gates, simple Boolean expressions and application of speed control of motor.

**VIVA-VOCE QUESTIONS:**

1. What are the different types of logic gates?
2. Draw the truth table for NAND, NOR and XOR gates.
3. How does a relay functions?
4. Explain different relay instructions used in PLC programming.
5. What are the standard steps involved in developing a ladder?
Experiment-4

Effect of Feedback on DC Servo Motor

**AIM:** To study the performance characteristics of a dc motor angular position control system.

**APPARATUS:**
- DC Servo Motor kit 1 no s
- DMM 2 no s
- Connecting wires Required

**Circuit Diagram & Block Diagram:**

![Circuit Diagram](image)

Figure No.1
Front panel layout for D.C. Position control
CONTROL SYSTEMS

D.C. Position Control System
Figure No. 8

Circuit diagram for D.C. Position Control System.
THEORY:

The DC servo motors resemble a dc shunt motor turned inside out. Dc servo motors feature permanent magnets, located on the rotor, or a wound rotor excited by dc voltage through slip rings, requires that the flux created by the current carrying conductors in the stator rotate around the inside of the stator in order to achieve servo motor action. The servo motor features a rotating field is obtained by placing three stator windings around the interior of the stator punching. The windings are then interconnected so that introducing a three-phase excitation voltage to the three stator windings (which are separated by 120 electrical degrees) produces a rotating magnetic field. Brushless dc servo motor construction speeds heat dissipation and reduces rotor inertia.

The DC servo motor features permanent magnet poles on the rotor, which are attracted to the rotating poles of the opposite magnetic polarity in the stator creating torque. As in the dc shunt motor, the dc servo motor offers torque, which is proportional to the strength of the permanent magnetic field and the field created by the current carrying conductors. The magnetic field in the dc servo motor stator rotates at a speed proportional to the frequency of the applied voltage and the number of poles.

The rotor rotates in synchronism with the rotating field, thus the name synchronous motor is often used to designate servo motors of this design. More recently, this servo motor design has been called an electrically commutated motor (ECM) due to its similarity to the dc shunt motor. In the dc shunt motor, the flux generated by the current carrying winding (rotor) is mechanically commutated to stay in position with respect to the field flux. In the synchronous dc servo motor, the flux of the current carrying winding rotates with respect to the stator; but, like the dc motor, the current carrying flux stays in position with respect to the field flux that rotates with the rotor. The major difference is that the synchronous dc servo motor maintains position by electrical commutation, rather than mechanical commutation.
PROCEDURE:

OPERATION WITH OUT FEEDBACK:

(SW₁ in OFF position i.e., Tacho out)

1). Now slowly advance the input potentiometer P₁ in clockwise direction. The output potentiometer along with load will be seen to be following the change in the input potentiometer.

2). When the input is disturbed, the null indicator will be showing some indication but when it may be noted that when input pot is moved in anticlockwise direction, the output pot P₂ also moves in the reverse direction.

3). Keep the pot P₁ at around 180 degree position. Pot P₂ also will be in the same position.

4). Now change the input pot in a step fusion by 60 to 80 degrees. The output will be observed to change in oscillatory mode before it settles to a final position. The tendency for oscillations is found to be dependent on the amplifier gain setting. For high gain there are too many oscillations where as low gain oscillations are reduced but with static error.

OPERATION WITH STABILIZING FEEDBACK:

1. Now put the SW₁switch in lower position i.e., Tacho in position. SW₂ must be in down position i.e., degeneration mode.

2. Keep P₄ in fully anticlockwise direction, output again indicates oscillations.

3. Now take the pot P₁ to 180⁰ position and effect step input change in one of the directions, O/P gain indicates oscillations is found to be dependent on the amplifier gain setting. For high gain there are too many oscillations where as for low gain oscillations are reduced but with static error.

OPERATION WITH STABILIZING FEEDBACK:

1. Now put the Sw₁ in lower position.

2. Sw₂ must be in down ward position i.e degeneration mode. Keep P₄ in fully anti clock wise direction.

3. Now take the pot P₁ to 180⁰ position, effect the step input change in one of the direction, output again indicates oscillations.
4. Now advance the tachogain pot P4 in clockwise direction, the output now is observed to follow the input in a smooth fashion without oscillation. If the tachogain pot P4 is too much advanced, the output now follows input in a sluggish fashion indicating over damped system.

5. Now 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.

6. Bring the switch SW2 in down ward position.

Warning: Do not operate the DC position control in regenerative mode for long time. This can damage the potentiometers.

OBSERVATION TABLES:

Without stabilizing feedback (SW1 upward):

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Input angular position in degrees</th>
<th>Output angular position in degrees</th>
<th>Remarks</th>
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With stabilizing feedback (SW1 downward):

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<thead>
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<th>Input angular position in degrees</th>
<th>Output angular position in degrees</th>
<th>Remarks</th>
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With stabilizing feedback (SW1 downward):

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<th>Output angular position in degrees</th>
<th>Remarks</th>
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PRECAUTIONS:

1. Please do not cross zero degree position by moving pot P1 i.e., do not operate between 330 and 10 degrees.
2. Do not try to rotate output potentiometer by hand. This may damage the potentiometer.
3. Students should note the following: Try to understand the function of output potentiometer.
4. The null indicator indicates a small deviation from zero indication at various positions of angle 1 and 2. This is so because of backlash in the gear, friction and the fact that some definite torque is required to be produced by the motor, so that the system can be set in to rotation. Moreover this torque goes on changing from position to position. Hence this causes error.
5. Observe the effect of change in amplifier gain. Higher the gain, smaller is the error.
6. When system is not using, keep SW3 and SW4 in OFF position (upward position) to avoid heating and possible damage of the power stage.

RESULT:

VIVA VOCE QUESTIONS:

1. What is meant by servo motor?
2. How it is different from DC motor?
3. Explain the advantages of DC servo motor.
4. Draw the characteristics of DC servo motor.
Experiment 5
TRANSFER FUNCTION OF D.C. MOTOR

AIM: To determine the transfer function of the given D.C motor after determining the various constants.

APPARATUS:
1. Voltmeter 0-300V M.C, 0-30V M.I. 0-30V M.C
2. Ammeter 0-1A, 0-2A, 0-10A M.C
3. Rheostat 360Ω / 1.6A. 45Ω/5A
4. DPDT Switch
5. Stop watch
6. Tachometer
7. Variac 0-220V / 270V.
8. Loading Resistors (220v. 5KVA)

CIRCUIT DIAGRAM:
THEORY:

Transfer function is defined as the Laplace transform of output to Laplace transform of input with zero initial conditions. It is useful for finding the gain of the system.

The speed of D.C motor is directly proportional to armature voltage and inversely proportional to flux in field winding. In armature controlled DC motor, the desired speed is obtained by varying the armature voltage. This speed control system is an electro mechanical control system. The electrical system consists of the armature and the field circuit but for analysis purpose, only the armature circuit is considered and the field is excited by a constant voltage. The mechanical system consists of armature controlled DC motor speed control system.

From the equivalent circuit for armature by applying KVL

\[ I_a R_a + L_a \frac{di_a}{dt} + E_b = V_a \]

Since flux is constant,

Torque is proportional to \( I_a \)

\[ T = K_t I_a \]

Differential equation of a mechanical system is

\[ J \frac{d^2 \theta_m}{dt^2} + B \frac{d\theta_m}{dt} = T \]
Back e.m.f. \( E_b = K_b (d\theta_m/dt) \)

Taking Laplace transform of the above differential equations with zero initial condition and equating.

\[
T(s) = K_i I_a(s) \quad \text{and} \quad E_b(s) = K_b w_m(s)
\]

\[
T(s) = [Js^2 + sB] \theta_m(s)
\]

\[
V_a(s) - E_b(s) = [R_a + sL_a] I_a(s)
\]

The overall transfer function of DC motor is

\[
\frac{\theta(s)}{V(s)} = \frac{K}{s[(R_a + sL_a)(sJ + B) + K_a K_b]}
\]

Where \( J=\text{Moment of Inertia}=0.024 \ \text{Kg-m}^2 \)

\( B=\text{Frictional Co-efficient}=0.8 \)

**PROCEDURE:**

Load Test on DC Motor:

1. Circuit connections are made as per the circuit diagram.
2. Connect 220V fixed Dc supply to the field of DC motor and brake drum belt should be loosened.
3. Start the motor by applying 0-220V variable Dc supply from the controller till the motor rotates as its rated speed.
4. Note down meter readings which indicates no load reading.
5. Apply load in steps up to rated current of the motor and note down corresponding IL, N, F1 and F2 readings.
6. Switch OFF the armature DC supply using armature supply ON/OFF switch and then Switch OFF the MCB.

Speed control by Armature Voltage Control:

1. Circuit connections are made as per the circuit diagram.
2. Connect 220V fixed DC supply to the motor field, keep the armature control pot at its minimum position and switch at OFF position.
3. Switch ON the MCB, Switch ON the armature control switch. Vary the armature voltage and note down the speed and the corresponding meter readings.
4. Repeat the same for different armature voltages.
5. Switch OFF the armature control switch and then the mains MCB.
**TABULAR COLUMN:**

Load Test on DC Motor:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>$I_L$</th>
<th>$F_1$</th>
<th>$F_2$</th>
<th>N rpm</th>
<th>$T=(F_1-F_2)\times6.5\times9.81$ N-cm</th>
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</table>

Speed control by Armature Voltage Control:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>$I_a$</th>
<th>N</th>
<th>V</th>
<th>$E_b=V-I_aR_a$</th>
<th>$w=2\pi N/60$</th>
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**MODEL GRAPHS:**
RESULT:

VIVA-VOCE QUESTIONS:

1. Why does the speed fall slightly when the D.C. shunt motor is loaded?
2. What will happen if the field current of the D.C. shunt motor gets interrupted?
3. What are the possible errors in the experiment?
4. How will you avoid the breaking arrangements getting heated?
5. Why the motors are not operated to develop maximum power.
6. By applying which law, the direction of rotation of d.c. motor can be determined.
7. The transfer function dc motor with armature control is ____ system.
8. The transfer function dc motor with field control is ____ system.
9. What is order the of the transfer function of DC motor?
10. The motor time constant is given by: ____________
11. In armature control ________ is maintained constant.
12. Armature control is suitable for speeds ________________
EXPERIMENT 6
TRANSFER FUNCTION OF DC GENERATOR

STUDY OF DC GENERATOR

OBJECTIVE:
To Study the
1. DC Motor & DC Generator Characteristics
2. DC Motor Torque Speed Characteristics
3. Step response of DC Motor

EXPERIMENTS:

1. DC MOTOR & DC GENERATOR CHARACTERISTIC:
At no load (load step at 0) the motor is supplied with varying armature voltages, \(E_a = 4, 6, \ldots 18\) V. For each \(E_a\), the motor current \(I_a\), speed \(N\), and generator voltage \(E_g\) are recorded. Straight line approximation of the \(E_a\) v/s speed and \(E_g\) v/s speed yield the motor and generator gain constants \(K_M\) (rpm/volt) and \(K_G\) (volts/rpm).

PROCEDURE:

1. Connecting the patch cords as shown in diagram1.
2. Set ‘MOTOR’ switch to ‘ON’. Set ‘RESET’ switch to ‘RESET’. Set ‘LOAD’ switch to 0 position.
3. Vary \(E_a\) (the voltage can be observed by using DC voltmeter) in small steps and take readings as under (Table 1).

<table>
<thead>
<tr>
<th>S.No.</th>
<th>(E_a) volts</th>
<th>(I_a), amp.</th>
<th>(N), rpm</th>
<th>(E_g), volts</th>
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</thead>
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<td>1.</td>
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</table>
4. EG (Generator Voltage) can also be observed at DC Voltmeter and Ia can observed at DC ammeter.

5. Obtain the slopes and compute KM(Motor gain constant) and KG(Generator gain constant). By using formulas mentioned below.

\[ K_M = \frac{N}{E_a} \text{ rpm/volt} = \frac{\pi N}{30E_a} \text{ Rad/sec} \]

\[ K_G = \frac{E_g}{N} \text{ Volt/rpm} = \frac{30E_g}{\pi N} \text{ rad/sec} \]

6. Now plot N (Speed) V/s Ea (armature voltage) and Eg (Generator Voltage) V/s N (Speed),

7. Take average values of KM (Motor gain constant) and KG (Generator gain constant).
PROCEDURE:

1. Set ‘MOTOR’ switch to ‘OFF’, Set ‘RESET’ switch to ‘RESET’. Set ‘LOAD’ switch to 0 position.

2. Connect Ea to the voltmeter and set some value.

3. Shift the ‘MOTOR’ switch to ‘ON’. Measure armature voltage (Ea). Motor current (Ia) and motor speed in rpm. Record the readings as per Table – 2.

4. Set the ‘LOAD’ switch to 1,2,…,5 and take readings as shown in the Table 2.

5. Complete the table below with the calculated values.

6. Plot Torque Vs. Speed curves on a graph paper (approximated straight line plots)
7. Compute $B$ (Viscous friction coefficient) from the slope of Torque-Speed curve and average $K_b$ (back emf constant) from the table.

$$B = \frac{T_M \text{(Motor Torque)}}{\omega} \text{ Newton-m rad/sec}$$

$$K_b = \frac{E_a}{\omega} \text{ Volts rad/sec}$$

8. Repeat above for different $E_a$ values and record the average values of motor parameters $B$ and $K_b$.

<table>
<thead>
<tr>
<th>SNo</th>
<th>Load Step</th>
<th>$I_n$ amp</th>
<th>$N_{rpm}$</th>
<th>$\frac{2\pi N w}{60}$</th>
<th>OR $\frac{N_{rpm}}{30}$</th>
<th>$E_0 - E_1 I_4 R_5$ Volts</th>
<th>$\frac{E_5}{K_0}$</th>
<th>$\frac{T_M - K_b I_4}{w}$ Newton-m</th>
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<tr>
<td>1.</td>
<td>0</td>
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3. **STEP RESPONSE:**

The dynamics of the motor is studied with the help of its step response.
PROCEDURE:

1. Set ‘MOTOR’ switch to ‘OFF’, set ‘RESET’ switch to ‘RESET’. Set ‘LOAD’ switch to 0 position.

2. Connect Ea to the voltmeter and set some value

3. Switch 'ON' the motor and measure Eg and the speed in rpm. These are the steady state generator voltage Eg and steady state motor speed N, respectively.

4. Set Es to 63.2% of Eg measured above. This is the generator voltage at which the counter will stop counting.

5. Switch ‘OFF’ the motor. Set ‘RESET’ switch to ‘READY’.

6. Now switch the motor ‘ON’ Record the counter reading as time constant in milliseconds.

7. Repeat above for different Ea value and tabulate shown below in Table3.

8. Substitute the value of KM and \( \frac{\rho}{m} \) in eqn.(6) and write down the motor transfer function.

9. Using the average values of \( \frac{\rho}{m} \), B, Kb and Ra, calculate the motor inertia from eqn.(7).
\[ J = r_m \left( B + \frac{K_b^2}{R_a} \right) \]

Motor Transfer function is \( G(s) = \frac{\omega(s)}{E(s)} = \frac{K_M}{St_m + 1} \)

<table>
<thead>
<tr>
<th>S.No</th>
<th>( E_g ) volts</th>
<th>( E_g ) volts</th>
<th>( N_r ), rpm</th>
<th>( E_g = 0.632E_g ) volts</th>
<th>Time Constant ( \tau_m ), msec</th>
<th>Gain Constant, ( K_M = \frac{rN}{30E_g} )</th>
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For Generator, repeat the above procedure and take Generator \( E_g \) value. The tabular is shown below in Table 4 using the average values to \( r_m, B, K_b, \) and \( R_a \), calculate the Generator inertia from eqn(8).

\[ J = r_m \left( B + \frac{K_b^2}{R_a} \right) \]

Generator Transfer function is \( G(s) = \frac{K_G}{St_m + 1} \)
RESULT: The performance of DC GENERATOR is studied and characteristics are obtained.
EXPERIMENT 7
TEMPERATURE CONTROLLER USING PID

AIM: To study the performance of various types of controllers used to control the temperature of an oven.

APPARATUS:

1. Patch cards.
2. Temperature control module.
3. Stop watch.

BLOCK DIAGRAM:
CONNECTION DIAGRAMS:

P-CONTROLLER

PROPORTIONAL + INTEGRAL CONTROL (SCHEMATIC DIA.)

PROPORTIONAL + DERIVATIVE CONTROL (SCHEMATIC DIA.)
THEORY:

P-CONTROLLER:

Proportional action is a mode of controller action in which there is a continuous linear relation between values of deviation and manipulated variable. Thus the action of the controlled variable is repeated and amplified in the action of the final control element.

INTEGRAL ACTION:

Integral action is a mode of control action in which the value of the manipulated variable is changed at a rate proportional to the deviation. Thus if the deviation is doubled over a previous value, the final control element is moved twice as fast.

The integral action adjustment is the integral time. For a step change of deviation, the integral time is the time required to add and increment the response equal to the original step change of response. Integral action is alone very seldom.

The integral action is used in association with proportional action. As a result of the integral action the offset error is almost reduced to zero. But the transient response is adversely affected. In other words the integral action has a destabilizing effect on the process under the conditions of load variations.

DERIVATIVE ACTION:

Derivative control action may be defined as a control action in which the magnitude of manipulated variable is proportional to the rate of change of deviation. The net effect of the derivative action is to shift the manipulated variable ahead by the derivative time.

The advantage of derivative action is that the proportional gain may be made larger without producing excessive oscillations. This in turn reduces offset. It is sometimes possible through the use of P+D reduce offset to such a small value that integral action would not required. The P+D action improves the transient under larger load changes.

P+I+D ACTION:

Proportional+Integral+Derivative action produces smallest max. deviations and offset is eliminated, because of integral action.

The derivative action tries to improve the transient response to a greater extent.

The P+I+D action is more effective for control of process with many energy strong elements than the P+I action used alone.
PROCEDURE:

EXPERIMENT-1: P-CONTROLLER

1. Establish the connection between the conditioning unit and the model process with the help of cables provided.
2. Connect Red 3 and Black 1 with the help of patch card.
3. Set the “SET” potentiometer at the position of 18 ohms corresponds to 45 degree centigrade of temperature.
4. Set the proportional band control to 10% i.e., K1=10
5. Now turn ON the power supply and also turn ON the fan. Place the fan regulator at low position.
6. Wait until the deviation indicator stabilizes at some point. Record the deviation readings and percentage of power reading at interval of 15 seconds.
7. Now suddenly increase the fan speed to full level by moving fan control to high position.
8. Now note down the deviation meter reading when the pointer stabilizes.
   Record the deviation meter readings. The difference between the two readings i.e., step 8 and step 6 is the offset (steady state error).
9. Now increase the gain to 100 i.e., proportional band to 1% and repeat the steps 5 to 8. We can observe that the offset error is reduced.
10. Draw the graph of time v/s deviation.

EXPERIMENT-2: P+I CONTROLLER

1. Establish the connections as per fig. with the help of patch cards.
   a) SET 18 ohms (45 degree centigrade)
   b) PB=10%
   c) Course control for integral action=10 seconds
   d) Fine control=Midway

2. Turn on the fan with control on low position.
3. Wait until the process stabilizes with almost zero deviation.
4. Now suddenly increase the fan speed to high position with the help of a stop watch record, the deviation meter readings at an interval of 15 seconds. Continue the process until the deviation meter almost stabilizes at zero deviation. There might be negligible error.
5. We can observe that the integral action gives zero offset but transient response is hampered.

EXPERIMENT-3: P+D CONTROLLER

1. Establish the connections as per fig. with the help of patch cards.
   e) SET 18 ohms (45 degree centigrade)
   f) PB=10%
   g) Course control for derivative action=5 seconds
   h) Fine control=Midway
2. Turn on the fan with control on low position.
3. Wait until the process stabilizes.
4. Now introduce the load change by moving the fan control to high position with the help of a stop watch record, the deviation meter readings at an interval of 5 to 10 seconds.
   Note: We may observe that process comes to almost zero deviation point quickly. In fact in this process the performance of P+D and P+I+D are almost identical.

EXPERIMENT-4: P+I+D CONTROLLER

1. Establish the connections as per fig. with the help of patch cards. Get the indicated settings for the various controls.
2. Turn on the fan with control on low position.
3. Wait until the process stabilizes.
4. Now introduce the load change by moving the fan control to high position with the help of a stop watch record, the deviation meter readings at an interval of 5 to 10 seconds.
   Note: We may observe that the process comes to almost zero deviation point quickly. Thus the transient response is improved and offset is also avoided.

PRECAUTIONS:

1. Operate SET control point in a gentle fashion.
2. Study all the controls carefully before using the equipment.
3. ADJUST control is adjusted in proportional mode to get 50% of output power when deviation is zero.
4. Make or break the connection only after turning OFF the mains supply.
5. During winter season in view of low ambient temperature and vice-versa for summer season.

TABULAR COLUMN:

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<thead>
<tr>
<th>S.No.</th>
<th>Time in sec</th>
<th>Deviation in °C</th>
<th>Time in sec</th>
<th>Deviation in °C</th>
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### CONTROL SYSTEMS

#### ELECTRICAL AND ELECTRONICS ENGINEERING

**P+I CONTROLLER**

(FAN LOW SPEED)

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(FAN HIGH SPEED)

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**P+D CONTROLLER**

(FAN LOW SPEED)

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**RESULT:**

The performance of P, P+I, P+D and P+I+D controllers with an oven is studied.
EXPERIMENT 8
CHARACTERISTICS OF AC SERVO MOTOR

AIM: To obtain the control characteristics of AC servomotor.

APPARATUS:
1. A.C. servo motor.
2. Tachometer
3. Voltmeter 0-300V M.I. type.
4. Connecting wires.

CIRCUIT DIAGRAM:
THEORY:

The motors that are used in automatic control systems are called Servomotors. When the objective of the system is to control the position of an object then the system is called Servo Mechanism. The servomotors are used to convert an electrical signal (control Voltage) applied to them into an angular displacement of the shaft. Then can either operate in a continuous duty or step duty depending on construction.

There are different varieties of servomotors available for control system applications. The suitability of a motor for a particular application depends on the characteristic of the system, the purpose of the system and its operating conditions. In general, a servomotor should have the following features.

1. Linear relationship between the speed and electric control signal.
2. Steady state stability.
3. Wide range of speed control.
4. Linearity of mechanical characteristics throughout the entire speed range.
5. Low mechanical and electrical inertial.

Depending on the supply required to run the motor, they are broadly classified as DC Servomotor and AC Servomotor.

An AC Servomotor is basically a 2-Ph induction motor except for certain special design features. A 2-Ph servomotor differs in the following 2 ways from a normal induction motor:
i. The rotor of the servomotor is built with high resistance, so that its X/R ratio is small which results in linear speed-torque characteristics. But conventional induction motors will have high value of X/R ratio which results in high efficiency and non-linear speed torque characteristics.

ii. The excitation voltage applied to two stator windings should have a phase difference of 90°.

PROCEDURE:
1. Study all the controls carefully on the front panel.
2. Initially keep the load control switch at OFF position, indicating that the armature circuit of D.C machine is not connected to auxiliary power supply-12V DC. Keep Servomotor supply also at OFF position.
3. Ensure load potentiometer and control voltage auto transformer at minimum position.
4. Now switch ON mains supply to the unit and AC servomotor by moving the control voltage transformer. We can observe that A.C. servo motor will start rotating and speed will be indicated by tachometer in the front panel.
5. With load switch in OFF position, vary the speed of the A.C servomotor by moving the control voltage and note down e.m.f generated by the D.C machine. (i.e., now working as D.C generator or Tacho).

TABULAR COLUMN:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>SPEED (r.p.m)</th>
<th>E_b (Volts)</th>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Now load switch at OFF position, switch ON AC servomotor and keep the speed in the minimum. 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 I_a and speed and also note down control voltage and enter these readings in the table.
**TABULAR COLUMN:**

<table>
<thead>
<tr>
<th>S.No</th>
<th>N (rpm)</th>
<th>E_b</th>
<th>I_a</th>
<th>P = E_b I_a</th>
<th>T (gm-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>=\left[P \times 1.019 \times 104 \times 60 \right] \div \left[2 \times \pi \times N\right]</td>
</tr>
</tbody>
</table>

7. Repeat the above procedure for different control voltage 200V, 180V also and plot the graph of speed V/s Torque.

**MODEL GRAPH:**

![Graph showing relationship between speed (rpm) and back EMF (V) and torque (gm-cm) vs speed (rpm) for different control voltages.]

**RESULT:-**
EXPERIMENT 9
EFFECT OF P, PD, PI, PID CONTROLLER ON A SECOND ORDER SYSTEMS

OBJECTIVE:
To study the performance characteristics of an analogue PID controller using simulated systems.

EXPERIMENTAL UNIT:
This is a very well designed and compact unit for classroom experiments on the study of proportional-integral-derivative controllers. The schematic diagram of the unit shown in fig. 1 comprises of a flexible process, a PID controller, signal sources, a DVM and a regulator power source for all the sub-systems. The various sections along with their specifications are described below.

2.1. Process or Plant:
In a practical situation the process of plant is that part of the system which produces the desired response under the influence of command signal. Usual processes are higher order, nonlinear functions having inherent dead time or pure time delay. In process control studies such plants are commonly modeled by transfer functions of the form.

\[ G_p(s) = \frac{K \theta s}{\tau s + 1} \]

where \( \theta \) is the time delay in sec., \( \tau \) is the effective time constant and \( K \) is the DC gain. In the present system, the process is an analogue simulation through a few basic building blocks which may be connected suitably to form a variety of processes or plants. These blocks are,

a. Integrator – having an approximate transfer function of \( 10/s \).

b. Simple Pole – two identical units, each having a transfer function of \( \frac{1}{(1+0.0155s)} \).

c. Pure time delay – a time delay of about 5.64 m sec generated by a high order multiple pole approximation of the delay function.

Note that all the above blocks, except pure time delay, have 180 degree phase shift between input and output.
Controller:
The controller for the process is an analogue Proportional-Integral-Derivative (PID) circuit in which the PID parameters are adjustable. The values may be set within the following range through 10 turn calibrated Potentiometers:

Gain, $K_c$ : 0 to 20

Integral Time Constant, $T_i$ : 5-100 msec.

Derivative Time Constant, $T_d$ : 0-20 msec. It may be mentioned that although in an industrial PID Controller it is common to adjust the above parameters directly, but in the educational environment convenience and simplicity is more important. In the present unit, therefore, it is the proportional, integral and derivative gains viz. $K_c$, $K_i$ and $K_d$, which are made variable through 10 turn potentiometers calibrated from 0 to 1. Equations linking the time constants with the gain appear in Eq. 3 in sec. 3.2. The PID block has a phase angle of 00 between its input and output.

2.3. Error Detector:
The Error detector is a unity gain inverting adder which adds the command signal with the feedback signal. To ensure negative feedback it would therefore be necessary to have $(2n+1)$ phase shift in the forward path, for $n = 0, 1, 2$ and so on.

2.4. Uncommitted Amplifier:
It is a unity gain inverting amplifier. This amplifier may be inserted in the loop, if required, to ensure a proper phase angle.

2.5. Signal Sources: The Signal source comprises of a low frequency square and triangular wave generator. The square wave has adjustable amplitude and frequency and the triangular wave has only frequency adjustment. The square wave is used as command input to the system, while the triangular wave is used for external x-deflection in the CRO. This arrangement gives a perfectly steady display even up to very low frequencies and is convenient for CRO measurements.

Power Supply and DVM:
A regulated circuit powers the complete unit. A 3½ digit DVM of 19.99 volt range mounted on the panel may be used for DC or steady state measurements. Also a variable DC in the range 1V (min.) available on the panel may be used as a DC input or set point for the system.
3. BACKGROUND SUMMARY:

3.1. Introduction:

The performance of a physical system is not always good enough for a given application. In such a situation the characteristics of the system needs to be modified. This is referred to as ‘Compensation Design’. Standard procedure available for compensation include time and frequency domain designs of a variety of compensation networks. Such design methods have been successfully used in many practical dynamic control systems. The performance of the system is evaluated in terms of a set of performance specifications e.g. rise time, peak time, settling time, peak percent overshoot and steady state error in the time domain, and gain margin, phase margin, closed loop, bandwidth etc. in the frequency domain.

Another approach towards improving the performance of systems has been through elementary control actions – called control terms – inserted in the forward path of an existing control system. The block diagram of fig. 2 shows the location of such a controller in a unity feedback system. The controller work comprise of two or three of the following control terms.

a. Proportional, P

b. Integral, I

c. Derivative, D

The resulting controller may then turn out to be a PI, PD or PID controller.

The two, and three term controllers indicated above have been used more commonly by process industries e.g. petroleum, chemical, power, food etc., for the control of temperature, pressure, flow and similar variables. A common feature of these systems is their sluggish response which calls for accurate and slow integration and sensitive differentiation. Although near ideal electronic differentiator and integrator circuits are difficult to achieve except with high impedance operational amplifiers and good quality components, PI and PD controller valves have existed in the pneumatic and hydraulic environments for a long time.

In the present unit attempt has been made to expose the students to the study and design of PID controllers using simulated systems. The speed of response has been deliberately scaled up to have a fast and easy viewing on CRO.
3.2 The PID Controller:

3.2.1. Structure:

The equation of a PID controller is given by

\[ M(t) = K_c e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt} \]

Where

\[ e(t) = \text{error signal} \]

\[ M(t) = \text{PID output or plant input } K_c \]

\[ = \text{Proportional gain} \]

\[ K_i = \text{Integral gain} \]

\[ K_d = \text{Derivative gain} \]

In the Laplace domain, the above equation is written as

\[ M(s) = K_c E(s) + \frac{K_i}{s} E(s) + sK_d E(s) \]

Which may be represented as the block diagram of fig. 3.

An alternative representation of the, above which is more commonly used in process control literature, is as under:

\[ 1 \]

\[ M(s) = K_c \left( 1 + \frac{T_i}{s} E(s) \right) + \frac{T_d}{s} E(s) \]

Where

\[ K_c \]

\[ T_i = \text{Integral time constant } K_i \]

\[ K_d \]

\[ T_d = \text{Derivative time constant } K_c \]
It is easy to develop the structure of PD, and PI controllers from above, by substituting $K_i = 0$ and $K_d = 0$ respectively.

A special terminology used in process control literature is given below to facilitate better understanding.

$$\text{Proportional Band} = \frac{1}{K_c} \times 100\%$$

$$\text{Reset Rate} = \frac{K_i}{K_cT_i} \text{ per minute}$$

$$\text{Derivative Time} = T_d$$

In the present unit, the three gains are adjustable in the following range with the help of calibrated 10-turn potentiometers.

$K_c : 0 \text{ to } 20$

$K_i : 0 \text{ to } 1000$

$K_d : 0 \text{ to } 0.01$

Experimental determination of these value is discussed in Sec. 4.

$$G_{PID}(s) = \frac{M(s)}{E(s)} = \frac{K_ds^2 + K_cs + K_i}{s} = \frac{K_ds}{(s+\omega_1)(s+\omega_2)}$$
where \( w_1 \) and \( w_2 \) are the two zeros of the PID controller transfer function.

The above transfer function has a pole at the origin and two real zeros for \( K_c > 4K_dK_i \).

Notice that a properly designed PID controller should not, in general, have a pair of complex conjugate zeros which may result in reduced damping. Bode diagram of the PID controller is shown in fig.4.

It may be seen that the controller gain increase without limits as the frequency is decreased. This is due to the integral term, and it results in a reduction of steady state error. However, the negative phase angle introduced by the controller at low frequencies has a destabilizing effect as well. The corner frequency \( \omega_1 \) should therefore be so located that large negative phase angle occurs at sufficiently low frequencies only, where the plant already has a good stability margin.

Again, the Bode diagram of the controller fig.4. shows an increased gain at high frequencies accompanied by a positive phase angle. The

**FIG 2. BLOCK DIAGRAM OF THE SYSTEM**

**FIG 3. PID CONTROLLER**
Positive phase angle has a stabilizing effect while the large gain at high frequencies makes the system then becomes relatively more stable, as it is capable of taking ‘anticipatory’ action in the presence of signals having fast variations.

A storage CRO trace showing time response of a typical PID Controller is shown in Appendix-1.

3.2.1. Design:

The PID Controller can be designed both in the frequency domain and in the s-plane, through the classical or trail-and-error procedure. The method needs the pole-zero locations or frequency-phase responses of the plant, for its implementation. A large number of process control systems are however characterized the following:

- Incomplete or inaccurate plant equations
- Extremely slow response
- Presence of time delays
- High order transfer function
- Limited possibility of experimentation for identification of the plant
- Need for fine trimming the compensator at site.

In such a situation alternative simpler techniques of setting the controller parameters (\(K_C\), \(T_i\), \(T_d\)), or tuning, are of great practical value. Presented
Below are three techniques of tuning a PID controller aimed at obtaining a satisfactory step response of the overall system [3]. Experimental work based on these methods is outlined in section 4.

(a) Trial-and-error tuning:

This is a simple and systematic method for on-line tuning of a PID controller. The method assumes that the three parameters $K_C$, $K_I$ and $K_D$ are available for adjustment. Following are the steps for its implementation:

1. Disconnect or reduce derivative and integral block signals by setting $K_I$ and $K_D$ to zero.

2. Starting from a low value increase $K_C$ gradually till sustained oscillation sets in. This condition is tested by small disturbances generated by varying the reference signal a little. The value of proportional gain so obtained is called ultimate gain, $K_{CU}$.

3. Set $K_C$ to $\frac{1}{2}$ of the value obtained in step 2.
4. Increase $K_i$ gradually until sustained oscillations start again. Set $K_i$ to 1/3 of this value.

5. Increase $K_d$ gradually until sustained oscillations start again. Set $K_d$ to 1/3 of this value.

The above method, though very simple in operation, has the following limitations:

(i) A number of systems which are, or may be approximated to, first or second order transfer functions without time delay do not oscillate. Step 3 as above is then not possible and the method fails.

(ii) Open loop unstable systems cannot be handled by this method.

(iii) Tuning of very slow systems by this method is extremely time consuming.

(iv) Sustained oscillations may not be acceptable or may be risky in some physical processes such as large chemical process.

(b) Continuous Cycling Method:

In this method, given by Ziegler and Nichols, the first step is to determine experimentally the value of ultimate gain, $K_{cu}$ as suggested in the previous method. The time period of the resulting sustained oscillations is referred to as ultimate period $P_u$. Based on the values of $K_{cu}$ and $P_u$, the controller settings are obtained from Table 1 below which is essentially empirical in nature.
Table 1: Empirical Values of the parameters

<table>
<thead>
<tr>
<th>Controller Type</th>
<th>$K_c$</th>
<th>$T_i$</th>
<th>$T_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>$0.5 K_{cu}$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>$0.45 K_{cu}$</td>
<td>$0.833 P_u$</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>$0.6 K_{cu}$</td>
<td>$0.5 P_u$</td>
<td>$0.125 P_u$</td>
</tr>
</tbody>
</table>

The values of $K_i$ and $K_d$ may be calculated from Eq.3. for implementation on the present system.

Some variation in the coefficient settings have also been suggested by various workers. In any case the above values should be taken as the ‘initial settings’ and should invariably be followed by fine tuning via trial-and-error.

Most of the limitations of the first method are still present in this method, however the continuous cycling method is less time consuming.

(c) Process Reaction Curve Method:

This is a second on-line tuning method proposed by Ziegler and Nichols and is very attractive because it is based on a simple experimentation. The plant is modeled as a first order function with time delay. The open loop step response of the plant, called reaction curve of the process, is experimentally obtained. Typical step responses for Type-0, and higher type number systems are shown in fig. 5(a) and 5(b) respectively.

The step responses are characterized by two parameters,

(i) Slope $S$ of the tangent drawn at the point of inflection, and

(ii) Time $T$ at which the tangent intersects the X-axis.
The values of S and T are obtained graphically as shown in fig. 5. If the input step change was M then the PID parameters are given by the Table 2 below:

Table 2 PID parameters in terms of reaction curve constants

<table>
<thead>
<tr>
<th>Controller Type</th>
<th>( K_c )</th>
<th>( T_i )</th>
<th>( T_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>M</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>0.9M</td>
<td>3.33T</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>ST</td>
<td>2T</td>
<td>0.5T</td>
</tr>
</tbody>
</table>

Once again, the above values are empirical in nature and therefore fine tuning of the for implementation on the present unit.

Although the process reaction curve method based on a single experimentation is fast and simple, it does have some limitation as given below:

(i) The step response obtained in the open-loop may not be satisfactory in case the system is highly nonlinear or open loop unstable.

(ii) Accuracy is limited due to the graphical procedure involved.

In conclusion it may be said that any method used to calculate the parameters must be followed by a fine tuning on the operational process.

1. EXPERIMENTS:

A very wide range of experimentation is possible with the unit, however the ones suggested below are aimed at bringing out the features of PID controller in one or two laboratory classes of usual duration. It may be mentioned that a convenient CRO display has been obtained by a proper design of the system. Tuning of the PID controller is therefore
Very fast and avoids expensive accessories like an X-Y/t recorder.

Experimentation in the following material has been suggested with a system having a time delay block. Such a representation is closer to many real life systems which have pure time delay. However, this takes the system closer to instability which can then accept only small values of $K_C$, $K_I$ etc. As a result, the settings of P, I and D controls may be difficult to make for a beginner. In that case it is suggested that the beginner may experiment with a system with one/two time constant blocks without time delay block.

Before starting the experiments, it will be helpful to understand the calibrated dials of P, I and D control knobs. In section 4.1, the student finds out the maximum values of $K_C$, $K_I$ and $K_D$ or in other words the full scale values of these parameters. The potentiometers used are 10-turn types and each turn is divided into 10 parts by the dial scale. Each part is further divided into 5 divisions so that the total dial range of 0 to 1 has least count of 1.2. A full revolution of a knob corresponds to a change of 0.1 in dial reading. To obtain a parameter value, multiply the dial setting by the corresponding full scale value (FSV). As an example, if FSV for P-control is 20 then a dial setting of 0.032 will correspond to a $K_C = 0.032 \div 20 = 0.64$.

4.1 Controller Calibration:

The time domain response of the PID controller is of great value for a good understanding of its performance. This also enables the reader to calibrate the three potentiometers, if felt necessary. The frequency may be set at the lower end of the range and its actual value may be experimentally determined. The steps suggested are:
1. Apply a square wave signal of 100 mV p-p at the input of the error detector.

2. Connect P, I and D outputs to the summer, and display controller output on the CRO.

3. With P-potentiometer set to maximum and I- and D- potentiometers set to zero, obtain maximum value of $K_C$ as

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

4. With I-potentiometer set to maximum and P- and D- potentiometers set to zero, a ramp will be seen on CRO. Maximum value of $K_I$ is then given by:

5. p-p square wave amplitude in volts where $f$ is the frequency of the input.

6. Set D-potentiometer to maximum and P- and I- potentiometers to zero. A series of sharp pulses will be seen on the CRO. This is obviously not suitable for calibrating the D- potentiometer. Instead, applying a triangular wave at the input of the error detector a square wave is seen on the CRO.

7. where $f$ is the frequency of the input signal.

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

**RESULT:** The performance characteristics of PID controller is studied
EXPRESSMENT 10
LAG AND LEAD COMPENSATION – MAGNITUDE AND PHASE PLOT

AIM: To study the lead lag compensation design.

INTRODUCTION
The unit Lead-Lag Compensation Design has two blocks. The first block deals with the study of Lead-Lag network. In this we observe the performance characteristics of LEAD-LAG network. The second block of the unit is compensation design. Here we observe the steady state and transient response of the system and we select one parameter from steady state and transient response and force the system to meet the requirement using Compensation techniques.

STUDY OF LEAD-LAG NETWORK
PART – I
INTRODUCTION:
Every control system designed for a specific application has to meet certain performance specifications. Setting the gain is the first step in adjusting the system for satisfactory performance. In many practical cases, however the adjustment of the gain alone may not provide sufficient alteration of the system behavior to meet the given performance. As is frequently the case, increasing the gain value will improve or instability. It is then necessary to redesign the system in order to alter the overall behavior so that the system will behave as desired. An additional device inserted in the system for such purpose is called a COMPENSATOR .This device compensation for deficient performance of the original system. If the compensator GC (S) is placed in series with the unalterable transfer function G(S), then the compensation is called series compensation. If the compensator is placed in feedback path, what we have is feedback compensation. In general series compensation may be simpler than feedback compensation. However the series compensation frequently requires additional amplifier to increase the gain Numerous physical devices are used as compensators. Among the many compensators the widely used series compensators are the so called LEAD compensators, LAG compensators & LEAD – LAG compensators. This system is designed to make a detailed study of these types of compensators. They are usually electrical, mechanical, hydraulic & consist of R – C networks (Electrical, Mechanical, Pneumatic & Hydraulic) & amplifiers. We shall study compensating networks in the form of electrical R – C networks. This proposed study of the compensators will be done in the following fashion.
1. Simple Phase lead & Phase Lag networks
2. Lead, Lag & Lead – Lag compensating networks that are used in the control systems.
3. Study of Lead, Lag networks with the help of active devices and to provide isolation

PROCEDURE:

EXPERIMENTS – I: STUDY OF SIMPLE PHASE LAG NETWORK:

\[
\begin{align*}
V_2(S) &= \frac{1}{cs} \\
V_1(S) &= \frac{1}{R+1/cs}
\end{align*}
\]

\[
|T(j\omega)| = \frac{1}{\omega c} \left[\frac{\omega^2}{(1/\omega c)^2}\right]^{1/2}
\]

\[
\text{Phase shift} = -\tan^{-1}\omega c R [\text{LAG}]
\]
PHASE LAG: Variation of Magnitude and Phase for the transfer function of Phase Lag Network:

![Graph of Phase Lag Network](image)
1. Switch ON the supply.
2. Select the components R = 10K, C = 0.1mfd.
3. Make connections as shown in fig. 1.a. So as to form a phase lag network.
4. Using the CRO in X–Y mode, give input of the network to X–input of CRO and output of the network to Y-input of CRO.
5. Set the sine wave amplitude at 3V.
6. Now vary the frequency from 25Hz to 1000Hz in steps and note down the readings in the Table given below.
7. Calculate the gain and phase difference from the readings.
8. Now calculate the theoretical value of gain and phase difference from the formulae’s given.

\[
\frac{V_2(s)}{V_1(s)} = \frac{1}{s + \frac{1}{R C}} = \frac{1/Re}{s + 1/Re}
\]

and phase angle (LAG) = \( \theta = \tan^{-1} \omega Re \)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>A</th>
<th>X0</th>
<th>B</th>
<th>Y0</th>
<th>0 Practical</th>
<th>Gain Practical</th>
<th>0 Theoretical</th>
<th>Gain Theoretical</th>
</tr>
</thead>
</table>
9. Now repeat the experiment by connecting a load resistor of 10K between output and ground. Because of Loading, Characteristics of network changes drastically.

10. To avoid loading, an amplifier may be connected between the network and load. Now repeat the experiment by connecting an amplifier between the network and load.

a. Connect output of network to input of amplifier.

b. Connect the load resistor of 10K between output of amplifier and ground.

The characteristics will be similar without load and with load.

EXPERIMENT 2: SIMPLE PHASE LEAD NETWORK:

\[
\frac{V_2(s)}{V_1(s)} = T(s) = \frac{R}{R + 1/j\omega C}
\]

\[
|T(j\omega)| = \frac{R}{\sqrt{\left[R^2 + 1/\omega^2 C^2\right]}}
\]

Phase shift = \[\tan^{-1}\left(\frac{1}{\omega CR}\right)\] [LEAD]

PHASE LEAD: THE VARIATION OF MAGNITUDE & PHASE FOR THE TRANSFER FUNCTION OF A PHASE LEAD NETWORK:
\[ T(j\omega) \Rightarrow \text{Magnitude} = MR/\sqrt{R^2 + 1/\omega^2C^2} \]

\[ \text{Phase Shift (LEAD)} = \theta = \tan^{-1} \frac{1}{\omega RC} = \tan^{-1} \frac{1}{\omega Z} \]

**PROCEDURE:**

1. Switch ON the supply.
2. Select the components \( R = 10K, C = 0.1 \text{ mfd} \).
3. Make connections as shown in fig.2.a So as to form a phase lead network.
4. Repeat step 4 to step 11 of Experiment No.1.
5. Perform the Experiment without Load and with Load, without amplifier and with amplifier. Note down the column and observe the result.

**EXPERIMENT 3: STUDY OF LEAD COMPENSATOR:**

**COMPENSATOR:**

\[ \begin{align*}
\text{db} & \quad \frac{Gc(j\omega)}{	ext{Ge}(j\omega)} \\
0 & \quad 90^\circ \\
45^\circ & \quad \frac{\text{Slope 20db/decade}}{0} \\
1/\text{Z} & \quad \omega_m = 1/\text{Z}\sqrt{\infty} \\
1/\infty \text{Z} & \quad \text{Log } \omega
\end{align*} \]
BODE PLOT OF LEAD COMPENSATOR WITH AMPLIFIER GAIN A

\[ Z = R_{1C} \& \alpha = R_2/(R_1+R_2) < 1 \]

\[ \phi = \text{Phase Lead} \]

\[ = \tan^{-1}\omega \alpha - \tan^{-1}\omega \alpha \]

\[ \omega_m = 1/z\sqrt{\alpha} \quad [\phi = \phi_m] \]

\[ \alpha = \frac{1-\sin\phi_m}{1+\sin\phi_m} \]

The S plane representation of a lead compensator is shown in fig. It has a zero at \( S = -1/t \) and pole at \( S = 1/\alpha t \), with zero closer to the origin than the pole. The general form of the compensator is

\[ G_c(s) = \frac{(S+Zc)}{(S+Pc)} = \frac{(S+1/\alpha)}{(S+1/\alpha \omega)} \quad \alpha = \frac{Zc}{Pc} < 1 \]

\[ Z > 0 \]

\[ \alpha = \frac{(1+Zs)}{(1+\alpha Zs)} \]

The transfer function of this network where,

\[ \frac{V_2(s)}{V_1(s)} = \frac{S+1/R_{1C}}{S+1/(R_2/R_{1C} + R_{1C})} \quad Z = \frac{R_2}{R_1} \& \quad \alpha = \frac{R_2}{R_{1C}} < 1 \]

The values of the three network components \( R_1, R_2 \) and \( C \) are to be determined from the 2 LEAD compensators parameters. The sinusoidal transfer function, of the lead compensator is then given by:

\[ G_c(j\omega) = \frac{(1+j\omega \alpha)}{(1+j\omega \alpha \omega)} \quad \alpha = < 1 \]

The Bode diagram of the LEAD compensator with amplifier gain \( A = 1/\alpha \) is given in fig. The phase lead of the compensator at any frequency \( \omega \) is given by:

\[ \phi = \tan^{-1}\omega - \tan^{-1}\alpha \omega \]

ELECTRICAL AND ELECTRONICS ENGINEERING
PROCEDURE:

1. Switch ON the supply.
2. Select the components R1 = 10K, R2 = 10K, and C = 0.22μF.
3. Make connections on shown in fig.3.a. So as to form a lead Compensator network.
4. Repeat step 4 to step 11 of Experiment No.1.
5. Perform the Experiment without Load and with Load, without amplifier and with amplifier. Note down the readings in the Tabular column and observe the result.

EXPERIMENT 4: STUDY OF LAG COMPENSATOR:

\[
\beta = \frac{Zc}{Pc} > 1
\]

\[
Z = R_2C
\]

\[
\phi = \text{Phase angle [LAGGING]} = \tan^{-1}\frac{\omega L}{\beta} \quad \beta > 1
\]
The S plane representation of lag compensator is shown in fig. It has a pole at \(-1/\beta z\) and zero at \(-1/t\) with zero located to the left of the pole on the negative real axis. We have

\[
\begin{align*}
G_c(s) &= \frac{(S+Zc)}{(S+Pc)} = \frac{(S+1/z)}{(S+1/\beta z)} \\
\beta &= \frac{Zc}{Pc} > 1 \\
Z &= R_2c \\
\beta &= \frac{R_1 + R_2}{R_2} > 1
\end{align*}
\]

The R-C realization

\[
\frac{E_o(s)}{E_i(s)} = \frac{1}{\beta} \frac{S + 1/z}{(S+1/\beta z)} = \frac{1+z\omega}{1+\beta z\omega}
\]

The angle of phase lag can be calculated from

\[
G_c(j\omega) = \frac{(1+j\omega z)}{(1+j\omega z\beta)}
\]

Since beta is greater than unity, steady state output has lagging phase angle with respect to the sinusoidal input and hence the name LAG network. The phase lag of the compensator is at any frequency omega is given by:

\[
\phi = \tan^{-1} wz - \tan^{-1} \beta wz
\]

PROCEDURE:

1. Switch ON the supply.
2. Select the components \(R_1=10K, R_2=10K, C=0.22\mu F\).
3. Make connections on shown in fig. 4.a network.
4. Repeat step 4 to step 11 of Experiment No. 1.
5. Perform the Experiment without Load and with Load, without amplifier and with amplifier. Note down the readings in the Tabular column and observe the result.

Refer fig. 5.a. The LAG LEAD compensator is a combination of lag compensator and lead compensator. The general form of this compensator is

\[
G_{cs}(s) = \frac{(S+1/Z_1) (S+1/Z_2)}{(S+1/\beta Z_1) (S+1/\beta Z_2)} \quad \beta \ll 1
\]

Where,

\[
R_1C_1 = Z_1, \quad R_2C_2 = Z_2, \quad R_1R_2C_1C_2 = \propto \beta Z_1Z_2, \quad \propto \beta - 1.
\]
**PROCEDURE:**

1. Switch ON the supply.
2. Select the components $R_1 = 10\, \text{K}$, $R_2 = 10\, \text{K}$, and $C_1 = 0.22\, \mu\text{F}$ and $C_2 = 0.22\, \mu\text{F}$.
3. Make connections as shown in fig. 5.a. So as to form a Lead Lag Compensator network.
4. Repeat steps 4 to 11 of Experiment No.1.
5. Perform the Experiment without Load and with Load, without amplifier and with amplifier. Note down the readings in the Tabular column and observe the result.

**RESULT:** The performance characteristics of lag, lead and lead-lag compensator are studied.
EXPERIMENT 11

SIMULATION OF P, PI, PID CONTROLLER

AIM:

To control the closed loop system using PID controller

APPARATUS:
Software: NGSPICE

THEORY:

PID controllers are commercially successful and widely used as controllers in industries. For example, in a typical paper mill there may be about 1500 controllers and out of these 90 percent would be PID controllers. The PID controller consists of a proportional mode, an Integral mode and a Derivative mode. The first letters of these modes make up the name PID controller.

Depending upon the application one or more combinations of these modes are used. For example, in a liquid control system where we want zero steady state error, a PI controller can be used and in a temperature control system where zero steady state error is not specified, a simple P controller can be used.

The equation of a PID controller in time-domain is given by

\[ m(t) = k_p e(t) + \frac{k_i}{T_i} \int_0^t e(t) \, dt + k_d \frac{de(t)}{dt} \]

Where is the proportional gain, is the integral reset time and is the derivative time of the PID controller, \( m(t) \) is the output of the controller and \( e(t) \) is the error signal given by \( e(t) = r(t) - c(t) \).

The system or plant is represented by \( G(s) \). \( R(s) \) and \( D(s) \) are reference signal and disturbance signal respectively. \( Y(s), E(s) \) and \( M(s) \) are the output, error and controller output of the system respectively.

For purpose of good control, we require the system output \( Y(s) \) to track any reference signal \( F(s) \) and at the same time reject or suppress deviation due to the disturbance signal \( D(s) \). Hence the PID controller can realize this objective.

Proportional controller:

A proportional controller has a proportional term alone. The output of a proportional controller is proportional to the error \( e(t) \). The equation representing the proportional controller in time domain is

\[ M(t) = k_p e(t) \]
MATLAB PROGRAM:

```matlab
num=input('enter the numerator of the transfer function')
den=input('enter the denominator of the transfer function')
h=tf(num,den)
[gm pm wcp wcg]=margin(h)
km=10*(gm/20)
wm=wcp
kp=0.6*km
ki=(kp*wm)/pi
kd=(kp*ki)/4*wm
h1=tf([1,0],[1])
g=(kp+(kd*h1)+(ki/h1))*h
bode(g)
```

PROCEDURE:

- Note down the given transfer function.
- Sketch the bode plot for the given transfer function by Factor the transfer function into pole-zero form.
- Find the frequency response from the Transfer function.
- Use logarithms to separate the frequency response into a sum of decibel terms
- Use w=0 to find the starting magnitude.
- The locations of every pole and every zero are called break points. At a zero breakpoint, the slope of the line increases by 20dB/Decade. At a pole, the slope of the line decreases by 20dB/Decade.
- At a zero breakpoint, the value of the actual graph differs from the value of the straightline graph by 3dB. A zero is +3dB over the straight line, and a pole is -3dB below the straight line.
- Sketch the actual bode plot as a smooth-curve that follows the straight lines of the previous point, and travels through the breakpoints
- If A is positive, start your graph (with zero slopes) at 0 degrees. If A is negative, start your graph with zero slope at 180 degrees (or -180 degrees, they are the same thing).
- For every zero, slope the line up at 45 degrees per decade when w = (1 decade before the Break frequency). Multiple zeros means the slope is steeper
- For every pole, slope the line down at 45 degrees per decade when w = (1 decade
before the break frequency). Multiple poles means the slope is steeper.

- Find out the gain margin, phase margin, wc_p and wc_g

- From those calculate km,wm,kp,ki,kd

- Already transfer function h1 is given. Now find out the transfer function g and sketch bode plot for g by repeating steps.

**EXAMPLE:**

Given Transfer function = \( \frac{s}{s(s+5)(s+7)(s+9)(s+1)} \)

**THEORITICAL CALCULATIONS:**

\[ A = \]

<table>
<thead>
<tr>
<th>W</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>5</td>
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<tr>
<td>7</td>
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</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

**Phase plot:**

\[ \phi = -90 - Tan^{-1}\left(\frac{\omega}{2}\right) - Tan^{-1}\left(\frac{\omega}{\varphi}\right) - Tan^{-1}\left(\frac{\omega}{\varphi}\right) - Tan^{-1}(\omega) \]

<table>
<thead>
<tr>
<th>W</th>
<th>( \phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td></td>
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<tr>
<td>0.1</td>
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<td>7</td>
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<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

For the above transfer function

Gain margin =
Phase margin =
$W_{cp} =$
$W_{cg} =$
Now
$K_m = 10 \times \frac{gm}{20}$

$= W_m = w_{cp} =$
$K_p = 0.6 \times K_m =$
$K_i = \frac{(k_p \times K_m)}{\pi} =$
$K_d = \frac{(k_p \times K_i)}{(4 \times W_m)} =$
Transfer function $h_1 = s$
$g = [k_p + (k_d \times h_1) + (k_i/h_1)] \times h$

Bode plot for transfer function $g$: 
THEORITICAL CALCULATIONS:

Magnitude Plot:

<table>
<thead>
<tr>
<th>W</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td></td>
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<tr>
<td>0.1</td>
<td></td>
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<tr>
<td>1</td>
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<td>10</td>
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<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
</tr>
</tbody>
</table>

Phase Plot:

\[ \phi = \tan^{-1} \left( \frac{0.311w}{0.183-w^2} \right) - 180 - \tan^{-1} w - \tan^{-1} \left( \frac{w}{5} \right) - \tan^{-1} \left( \frac{w}{7} \right) - \tan^{-1} \left( \frac{w}{9} \right) \]

<table>
<thead>
<tr>
<th>W</th>
<th>\phi</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td></td>
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<tr>
<td>0.1</td>
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<td>200</td>
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<tr>
<td>500</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
</tr>
</tbody>
</table>
enter the numerator of the transfer function

\[ \text{nnum} = \]

enter the denominator of the transfer function

\[ \text{den} = \]

Transfer function:

\[ \text{gm} = \]
\[ \text{pm} = \]
\[ \text{wep} = \]
\[ \text{weg} = \]
\[ \text{km} = \]
\[ \text{wm} = \]
\[ \text{wm} = \]
\[ \text{kp} = \]
\[ \text{ki} = \]
\[ \text{kd} = \]

Transfer function:

RESULT:
EXPERIMENT-12

STABILITY ANALYSIS (ROOT LOCUS, BODE PLOT AND NYQUIST PLOT) USING OCTAVE

AIM:

To plot the Root locus for the given transfer function and verify it using OCTAVE.

\[ G(s) = \frac{k(s + 1)}{s(s + 1)(s^2 + 2s + 5)} \]

APPARATUS:

PC with OCTAVE software

THEORY (ROOT LOCUS):

In control theory, the root locus is the locus of the poles and zeros of a transfer function as the system gain \( K \) is varied on some interval. The root locus is a useful tool for analyzing single input single output (SISO) linear dynamic systems. A system is stable if all of its poles are in the left-hand side of the \( s \)-plane (for continuous systems) or inside the unit circle of the \( z \)-plane (for discrete systems).

In addition to determining the stability of the system, the root locus can be used to identify the damping ratio and natural frequency of a system. Where lines of constant damping ratio can be drawn radially from the origin and lines of constant natural frequency can be drawn as arcs whose center points coincide with the origin. By selecting a point along the root locus that coincides with a desired damping ratio and natural frequency a gain can be calculated and implemented in the controller.
Suppose there is a motor with a transfer function expression $P(s)$, and a controller with both an adjustable gain $K$ and a transfer function expression $C(s)$. A unity feedback loop is constructed to complete this feedback system. For this system, the overall transfer function is given by

$$T(s) = \frac{KC(s)P(s)}{1 + KC(s)P(s)}.$$ 

Thus the closed-loop poles (roots of the characteristic equation) of the transfer function are the solutions to the equation $1 + KC(s)P(s) = 0$. The principal feature of this equation is that roots may be found wherever $KCP = -1$. The variability of $K$ (that's the gain you can choose for the controller) removes amplitude from the equation, meaning the complex valued evaluation of the polynomial in $s$ $K(s)C(s)$ needs to have net phase of 180 deg, wherever there is a closed loop pole. We are solving a root cracking problem using angles alone! So there is no computation per se, only geometry. The geometrical construction adds angle contributions from the vectors extending from each of the poles of $KC$ to a prospective closed loop root (pole) and subtracts the angle contributions from similar vectors extending from the zeros, requiring the sum be 180. The vector formulation arises from the fact that each polynomial term in the factored $CP$, $(s-a)$ for example, represents the vector from which is one of the roots, to $s$ which is the prospective closed loop pole we are seeking. Thus the entire polynomial is the product of these terms, and according to vector mathematics the angles add (or subtract, for terms in the denominator) and lengths multiply (or divide). So to test a point for inclusion on the root locus, all you do is add the angles to all the open loop poles and zeros. Indeed a form of protractor, the "spirule" was once used to draw exact root loci.

From the function $T(s)$, we can also see that the zeros of the open loop system ($CP$) are also the zeros of the closed loop system. It is important to note that the root locus only gives the location of closed loop poles as the gain $K$ is varied, given the open loop transfer function. The zeros of a system cannot be moved.
Using a few basic rules, the root locus method can plot the overall shape of the path (locus) traversed by roots as the value of $K$ varies. The plot of the root locus then gives an idea of the stability and dynamics of this feedback system for different values of $k$.

Roots of the transfer function move on the $s$-plane tracing a particular path when gain is changed from 0 to $\infty$. This path is called root locus.

Open loop transfer function = $G(s)$

Closed loop transfer function = $\frac{G(s)}{1 + G(s)H(s)}$

The characteristic equation is $1 + G(s)H(s) = 0$

$\Rightarrow G(s)H(s) = -1$

To make above equation true, $G(s)H(s) = 180^\circ (2k + 1)$ ------(1)

$|G(s)H(s)| = 1$ ------(2)

A plot satisfying (1) and (2) is the root locus. The constant part in $G(s)H(s)$ is called the “Gain”.

**ROOT LOCUS PLOT USING OCTAVE**

The characteristic equation can be written as $1 + k \frac{num}{den} = 0$.

The command `rlocus(num, den)` gives the root locus plot.

If the system is defined in state space, root locus is obtained by the command `rlocus(A, B, C, D).`
THEORETICAL CALCULATIONS:

(-to be done by the student-)

PROCEDURE:
1. Switch on Computer with Linux operating systems.
2. Go to the search panel and search for qtoctave.
3. Click on the qtoctave.
4. Open Edit window to write the program.
5. After completion of program, save it and press on run (blue icon).
6. Observe the output results.
7. Compare with theoretical values.

PROGRAM:

```matlab
num=[1 1];
den=[1 4 9 0 0];
sys=tf(num,den);
rlocus(sys)
```
OUTPUT:

The Root locus for the given transfer function has been obtained and verified it by using OCTAVE.

EXPERIMENT-2: BODE PLOT USING OCTAVE

AIM:

To obtain the Bode Plot for the given transfer function and to verify it using OCTAVE.

\[ G(s) = \frac{50(s + 2)}{(s + 1)(s + 3)(s + 4)} \]

APPARATUS:

PC with OCTAVE software
THEORY:

A Bode magnitude plot is a graph of log magnitude versus frequency, plotted with a log-frequency axis, to show the transfer function or frequency response of a linear, time-invariant system.

The Bode plot is named after Hendrik Wade Bode. It is usually a combination of a Bode magnitude plot and Bode phase plot.

The magnitude axis of the Bode plot is usually expressed as decibels, that is, 20 times the common logarithm of the amplitude gain. With the magnitude gain being logarithmic, Bode plots make multiplication of magnitudes a simple matter of adding distances on the graph (in decibels), since

A Bode phase plot is a graph of phase versus frequency, also plotted on a log-frequency axis, usually used in conjunction with the magnitude plot, to evaluate how much a frequency will be phase-shifted. For example a signal described by: $A\sin(\omega t)$ may be attenuated but also phase-shifted. If the system attenuates it by a factor $x$ and phase shifts it by $-\Phi$ the signal out of the system will be $(A/x)\sin(\omega t - \Phi)$. The phase shift $\Phi$ is generally a function of frequency.

Phase can also be added directly from the graphical values, a fact that is mathematically clear when phase is seen as the imaginary part of the complex logarithm of a complex gain.

BODE PLOT USING OCTAVE:

A stable linear system subjected to a sinusoidal input gives sinusoidal output of the same frequency after steady state conditions are reached. However, the magnitude and phase angle change. The output magnitude and phase depends on the input frequency. Bode plot give this relation in a graphical way. It can be proved that if ‘s’ is replaced by ‘jw’, the transfer function gives steady state response to sinusoidal inputs where $w$ is the angular frequency. The command bode (num, den) produces the bode plot.
The command \( \text{mag, phase, w} = \text{bode} \text{ (num, den, w)} \) can be used for specified frequency points contained in \( w \)-vector. Result is stored in magnitude and phase matrices. The command \( \text{mag dB} = 20 \times \log (\text{mag}) \) produces magnitude in dB.

The command log space \((d_1, d_2)\) generates 50 points between \(10^{d_1}\) and \(10^{d_2}\), \(w=\log \text{ space (1, 2)}\) generates 50 points between \(10^{-1}\) and \(10^2\) i.e., and 100 rad/sec. but if we have to generate 100 points use the command, \(w=\log \text{ space (-1, 2, 100)}\).

\[
G(s) = \frac{50(s + 2)}{(s + 1)(s + 3)(s + 4)}
\]

**THEORETICAL CALCULATIONS:**

(- to be done by the student-)

**PROCEDURE:**
1. Switch on Computer with Linux operating systems.
2. Go to the search panel and search for qtoctave.
3. Click on the qtocatve .
4. Open Edit window to write the program.
5. After completion of program, save it and press on run (blue icon).
6. Observe the output results.
7. Compare with theoretical values.

**PROGRAM:**

\[
\begin{align*}
\text{num} &= [50 \ 100]; \\
\text{den} &= [1 \ 8 \ 19 \ 12]; \\
\text{sys} &= \text{tf(num,den)};
\end{align*}
\]
bode(sys)

[gm pm wcp wcg]=margin(sys)

disp('phase cross over frequency is :\n');
disp('gain cross over frequency is :\n');
disp('phase margin in degrees is :\n');
disp('gain margin in db is :\n');

GM=20*log10(gm)

if(wcg<wcp)

disp('closed loop system is stable')

elseif(wcg>wcp)

disp('closed loop system is unstable')

else

disp('close loop system is marginally stable')

end
OUTPUT: The Bode plot for the given transfer function has been obtained and verified it by using OCTAVE.

EXPERIMENT-3: NYQUIST PLOT USING OCTAVE

AIM:

To obtain the Bode Plot for the given transfer function and to verify it using OCTAVE.

\[ G(s) = \frac{50(s + 2)}{(s + 1)(s + 3)(s + 4)} \]

APPARATUS:

PC with OCTAVE software
THEORY:

Nyquist Plots were invented by Nyquist - who worked at Bell Laboratories, the premiere technical organization in the U.S. at the time. He was interested in designing telephone amplifiers to be placed in ocean-floor cables. In those days, between the first and second world wars, undersea cables were the only reliable means of intercontinental communication.

Undersea telephone cables needed to be reliable, and to have a constant gain that did not change as the amplifier aged. In those days, electronic amplifiers were constructed with tubes, and tubes had gains that could change dramatically as they aged.

The solution to the aging problem was to design feedback amplifiers. However, those amplifiers could become unstable. One morning - going to work on the Staten Island ferry, before the Verrazano Narrows Bridge - Nyquist had an inspiration, and wrote his work, literally, on the back of an envelope as he rode. Today, millions of control system students are tortured by instructors making them apply the Nyquist Stability criterion, and it is widely used in control system design.

Nyquist plots are used to analyze system properties including gain margin, phase margin, and stability.

`nyquist(sys)` creates a Nyquist plot of a dynamic system `sys`. This model can be continuous or discrete, and SISO or MIMO. In the MIMO case, `nyquist` produces an array of Nyquist plots, each plot showing the response of one particular I/O channel. The frequency points are chosen automatically based on the system poles and zeros.

`nyquist(sys,w)` explicitly specifies the frequency range or frequency points to be used for the plot. To focus on a particular frequency interval, set `w = [wmin, wmax]`. To use particular frequency points, set `w` to the vector of desired frequencies. Use `logspace` to generate logarithmically spaced frequency vectors. Frequencies must be in `rad/Time Unit`, where `Time Unit` is the time units of the input dynamic system, specified in `Time Unit` property of `sys`.

THEORETICAL CALCULATIONS:

(- to be done by the student-)

PROCEDURE:

1. Switch on Computer with Linux operating systems.
2. Go to the search panel and search for qtoctave.
3. Click on the qtoctave.
4. Open Edit window to write the program.
5. After completion of program, save it and press on run (blue icon).
5. Observe the output results.
6. Compare with theoretical values.

PROGRAM:

num=[50 100];
den=[1 8 19 12];
sys=tf(num,den);
nyquist(sys)

[gm pm wcp wcg]=margin(sys)
if(wcp>wcg)
disp('system is stable')
else
disp('system is unstable')
end
OUTPUT: The Nyquist plot for the given transfer function has been obtained and verified it by using OCTAVE.

RESULT:

For the given transfer function, root locus plot, bode plot and Nyquist plot are drawn and verified by using OCTAVE.

VIVA VOCE QUESTIONS:

1. Define root locus plot.
2. Give the advantages of root locus.
3. Is root locus plot drawn on open loop or closed loop system?
4. Give the advantages of bode plot and Nyquist plot.
5. Define gain cross over frequency.
6. Define phase cross over frequency.
7. Define gain margin and phase margin.
EXPERIMENT-13

CONVERSION OF TRANSFER FUNCTIONS TO STATE SPACE MODEL

AIM:

To obtain the state space model from the given transfer function and verify it using OCTAVE.

\[ T(s) = \frac{s^2 + 3s + 3}{s^3 + 2s^2 + 3s + 1} \]

THEORY:

In control engineering, a state space representation is a mathematical model of a physical system as a set of input, output and state variables related by first-order differential equations. To abstract from the number of inputs, outputs and states, the variables are expressed as vectors and the differential and algebraic equations are written in matrix form (the last one can be done when the dynamical system is linear and time invariant).

The state space representation (also known as the "time-domain approach") provides a convenient and compact way to model and analyze systems with multiple inputs and outputs. With \( p \) inputs and \( q \) outputs, we would otherwise have to write down Laplace transforms to encode all the information about a system. Unlike the frequency domain approach, the use of the state space representation is not limited to systems with linear components and zero initial conditions. "State space" refers to the space whose axes are the state variables. The state of the system can be represented as a vector within that space.

The internal state variables are the smallest possible subset of system variables that can represent the entire state of the system at any given time. State variables must be linearly independent; a state variable cannot be a linear combination of other state variables. The minimum number of state variables required to represent a given system, \( n \), is usually equal to the order of the system's defining differential equation. If the system is represented in transfer function form, the minimum number of state variables is equal to the order of the transfer function's denominator after it has been reduced to a proper fraction. It is important to
understand that converting a state space realization to a transfer function form may lose some internal information about the system, and may provide a description of a system which is stable, when the state-space realization is unstable at certain points. In electric circuits, the number of state variables is often, though not always, the same as the number of energy storage elements in the circuit such as capacitors and inductors.

THEORITICAL CALCULATIONS:

(-to be done by the student-)

PROCEDURE:
1. Switch on Computer with Linux operating systems.
2. Go to the search panel and search for qtoctave.
3. Click on the qtoctave.
3. Open Edit window to write the program.
4. After completion of program, save it and press on run (blue icon).
5. Observe the output results.
6. Compare with theoretical values.

PROGRAM:

\[
\begin{align*}
\text{NUM} &= [1 \, 3 \, 3] \\
\text{DEN} &= [1 \, 2 \, 3 \, 1] \\
[A, B, C, D] &= \text{TF2SS}(\text{NUM}, \text{DEN})
\end{align*}
\]
OUTPUT:

\[
\begin{bmatrix}
-2 & -3 & -1 \\
1 & 0 & 0
\end{bmatrix}
\]

\[A = \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0
\end{bmatrix}, \quad B = 0, \quad C = \begin{bmatrix}
1 & 3 & 3
\end{bmatrix}, \quad D = 0\]

EXPERIMENT-2:

CONVERSION OF STATE SPACE MODEL TO TRANSFER FUNCTION

AIM:

To obtain the transfer function for the given state space model and verify it using OCTAVE.

\[
\begin{bmatrix}
-2 & 1 & 0 \\
3 & 0 & 1
\end{bmatrix}
\]

\[A = \begin{bmatrix}
-3 & 0 & 1 \\
-1 & 0 & 0
\end{bmatrix}, \quad B = 3, \quad C = \begin{bmatrix}
1 & 0 & 0
\end{bmatrix}, \quad D = 0\]

THEORETICAL CALCULATIONS:

(- to be done by the student -)
PROCEDURE:

1. Switch on Computer with Linux operating systems.
2. Go to the search panel and search for qtoctave.
3. Click on the qtoctave.
4. Open Edit window to write the program.
5. After completion of program, save it and press on run (blue icon).
6. Observe the output results.
7. Compare with theoretical values

PROGRAM:

\[
A = \begin{bmatrix}
-2 & 1 & 0 \\
-3 & 0 & 1 \\
-1 & 0 & 0
\end{bmatrix}
\]

\[
B = [1; 3; 3]
\]

\[
C = [1 0 0]
\]

\[
D = [0]
\]

\[
[NUM, DEN] = \text{SS2TF}(A, B, C, D)
\]

OUTPUT:

The transfer function is

\[
T(s) = \frac{s^2 + 3s + 3}{s^3 + 2s^2 + 3s + 1}
\]
RESULT:

The state space model of the given transfer function has been verified using OCTAVE and also verified for transfer function the given state space model using OCTAVE.

VIVA VOCE QUESTIONS:

1. What do you understand by state space model?
2. Explain the advantages of state space model over transfer function approach.
3. Give the formula for transfer function in state space model.
4. What do mean by state vector?
EXPERIMENT-14

DESIGN OF LEAD-LAG COMPENSATOR FOR THE GIVEN SYSTEM AND WITH SPECIFICATION USING SUITABLE SOFTWARE

AIM:

To design lag-lead compensator using closed loop system.

APPARATUS:

Software: NGSPICE

THEORY:

A lead–lag compensator is a component in a control system that improves an undesirable frequency response in a feedback and control system. It is a fundamental building block in classical control theory.

lagts delays a financial time series object by a specified time step. newfts = lagts(oldfts) delays the data series in oldfts by one time series date entry and returns the result in the object newfts. The end will be padded with zeros, by default.

newfts = lagts(oldfts, lagperiod) shifts time series values to the right on an increasing time scale. lagts delays the data series to happen at a later time. lagperiod is the number of lag periods expressed in the frequency of the time series object oldfts. For example, if oldfts is a daily time series, lagperiod is specified in days. lagts pads the data with zeros (default).

newfts = lagts(oldfts, lagperiod, padmode) lets you pad the data with an arbitrary value, NaN, or Inf rather than zeros by setting padmode to the desired value.

leadts advances a financial time series object by a specified time step. newfts = leadts(oldfts) advances the data series in oldfts by one time series date entry and returns the result in the object newfts. The end will be padded with zeros, by default.

newfts = leadts(oldfts, leadperiod) shifts time series values to the left on an increasing time scale. leadts advances the data series to happen at an earlier time. leadperiod is the number of lead periods expressed in the frequency of the time series object oldfts. For example, if oldfts is a daily time series, leadperiod is specified in days. leadts pads the data with zeros (default).

newfts = leadts(oldfts, leadperiod, padmode) lets you pad the data with an arbitrary value, NaN, or Inf rather than zeros by setting padmode to the desired value.
PROGRAAM:

```matlab
num=input('enter the numerator')
den=input('enter the denominator')
h=tf(num,den)
kv=input('enter velocity error')
phm=input('enter the phase margin')
h1=tf([1 0],[1])
m=dcgain(h1*h)
k=kv/m
g=k*h
[mag phase w]=bode(g)
[gm pm wcm wcw]=margin(g)
e=input('enter margin of safety')
bode(g)
theta=phm+e;
bm=theta-180;
wcm=('enter wcm corresponding to bm')
a=input('enter gain corresponding to wcm')
beta=10^(a/20)
w21g=wcm/4
tou=1/w21g
w11g=1/(beta*tou)
g1=(h1+w21g)/(h1+w11g)
theta1d=theta1d*(pi/180);
alpha=(1-sin(theta1d)/(1+sin(theta1d)));
a=-20*log10(1/sqrt(alpha))
wcm1d=input('enter the value of wcm corresponding to gain a1')
w11d=wcm1d*sqrt(alpha)
w21d=wcm1d/sqrt(alpha)
g3=tf([1/w11d],[1/w21d 1])
g4=g3*g1*g
[mag3 phase3 w3]=bode(g2)
bode(g)
hold
bode(g4)
```
PROCEDURE:

- Numerator of the given transfer function is assigned to num
- Denominator of the transfer function is assigned to den
- The value of the static velocity constant is assigned to the kv
- Margin of the safety is assigned to e
- Plot is obtained by in-build function bode()
- Wcm values assigned to wcm which is obtained from above bode plot
- The gain corresponding to wcm is assigned to a
- If wcg1>wcg or wcp1>wcp, the network is compensated otherwise it is not compensated.
THEORETICAL CALCULATIONS:

Transfer function = \frac{1}{(\omega^2 + 1)(2\omega + 1)}

= \frac{1}{(j\omega)(j\omega + 1)(2j\omega + 1)}

For complex \(\omega\),

Gain =

MAGNITUDE PLOT:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Corner frequency</th>
<th>Log magnitude in dB = -20 \log(\text{factor})</th>
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<tbody>
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PHASE PLOT:

\(\Phi = \)

<table>
<thead>
<tr>
<th>(W(\text{rad/sec}))</th>
<th>(\Phi)</th>
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New phase margin required is =

Frequency corresponding to

RESULT: