Rajiv Gandhi University of Knowledge Technologies

Department of Chemical Engineering

Instrumentation Process Control Lab

(CH3802)

Course Objectives:

- To evaluate response of fist and higher order characteristics.
- Study the installed characteristics of the valve.
- Study if there is a hysteresis in the control valve and sensor.
- Evaluate the tuning of a PID control via manual and automatic tuning.
- Evaluate the effect controller on the control system

List of Experiments:

S.No	Name of the experiment
1.	Calibration of differential pressure transmitter
2.	Calibration of thermocouples
3.	Control valve characterization
4.	Interacting and non-interacting system
5.	Study of flapper nozzle
6.	Study of flow control trainer
7.	Study of I/P and P/I converter
8.	Study of level control trainer
9.	Study of temperature control trainer

Course Outcomes:

- To measure the steady state response and dynamic response of a process system
- To compare the responses with those obtained from the mathematical model
- To validate the methods for closed-loop stability analysis in context to a practical controller
- To validate the controller tuning methods in context to a practical controller.

Engineering Growth Connection

CALIBRATION OF DIFFERANTIAL PRESSURE TRANSMITTER (HD-384N)

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Contents

CALIBRATION OF DIFFERANTIAL PRESSURE TRANSMITTER

1. OBJECTIVE:

To study the Differential pressure transmitter

2. AIM:

2.1 To measure pressure/differential pressure from Differential Pressure Transmitter.

2.2 To calibrate given Differential Pressure Transmitter.

3. INTRODUCTION:

Differential pressure transmitter is a device which gives the pressure difference between any of two points. The pressure in the process tank is sensed by the pressure transmitter with the help of pressure sensor fitted in the line. For measuring the difference in the pressure a two points differential pressure transmitter are used.

4. THEORY:

Differential Pressure transmitter (DPT) mainly consists of two pressure points, high and low that is to be connected in the line where differential pressure is to be measured. In case of liquid flow it is necessary to release the air from the line. For the same purpose air vent valves provided with DPT. The differential pressure sensed by DPT is converted in current signal (mA). This transmitter converts that pressure accordingly i.e. 4mA for 0 mm and 20 mA for 1500 mm.

5. DESCRIPTION:

The set up consists of two columns with scale to check the height of water in the columns. Bottom of both of the columns are connected to Differantial Pressure Transmitter. Sump tank is provided for water storage. To provide water in to columns pump is provided. Digital current Indicator is provided to show the mA.

6. UTILITIES REQUIRED:

6.1 Electricity supply: Single phase, 220 V AC, 50 Hz.

6.2 Water supply: initial fill.

6.3 Floor area required: 1.5 m x 0.5 m

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Close all the valves.

7.1.2 Fill the sump tank.

7.1.3 Connect power supply.

7.1.4 Switch On the pump and fill water in columns.

7.1.5 Fill the columns at desired height in such a way that there should be a difference in heights.

7.1.6 Release air with the help of air release valves provided at DPT.

7.1.7 Close the air release valves.

7.1.8 Note down the heights.

7.1.9 Read the corresponding milli-amperes from mA indicator.

7.1.10 Repeat above three steps for different heights of water in columns.

7.2 Closing Procedure:

7.2.1 When experiment is over switch OFF the pump.

7.2.2 Switch OFF the main power supply.

7.2.3 Drain water from the columns with the help of drain valves.

7.2.4 Drain water from the sump tank.

8. Observation & Calculation:

8.1 Observation Table :

S. No	h_1 (cm)	h_2 (cm)	I (mA)

8.2 CALCULATION:

$H = (h_1 - h_2) \times 10$ mm

Plot the graph between H vs mA.

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
h1	Height of column-1	cm	measured
h2	Height of column-2	cm	measured
H	Head difference	mm	calculated
I	Readings of milli-ampere indicator	mA	measured

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 200 volts & more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Always keep the apparatus free from dust.

10.4 Never run the pump without water.

11. TROUBLESHOOTING:

11.1 If electric panel is not showing the input on the mains light. Check the mains supply.

12. REFERENCES:

12.1 Coughanowr, Donald R. (1991). *Process Systems Analysis and Control.* 2nd Ed. ND: Mc Graw-hill International.

12.2 Stephanopoulos, George (2006). *Chemical Process Control*. 1st Ed. ND: Prentice Hall of India Pvt. Ltd

CALIBRATION OF THERMOCOUPLE

(PC-112)

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Contents

CALIBRATION OF THERMOCOUPLE

1. OBJECTIVE:

To study the calibration of different types of thermocouple.

2. AIM:

2.1 To calibrate the different type of thermocouples.

2.2 To plot the calibration curve.

3. INTRODUCTION:

A thermocouple consists of a pair of conductors of different metals or alloys joined together at both the ends. One end, the measuring junction is placed where the temperature is to be measured. The two conductors extend out of the measurement area to the reference junction. An electromotive force (e.m.f.) is produced and is a function of the temperature difference between the two junctions.

4. THEORY:

In the simplest arrangement, the thermocouple is connected directly to the indicating instrument. The terminals of the instrument form the cold junction of the thermocouple. Seven types of thermocouple have been given letter designation. These are listed below:

Type	Composition	Temperature Range, ^{0}C
B	Pt – 6% Rh Vs Pt – 30% Rh	0 – 1727
R	Pt vs. Pt- 13% Rh	0 – 1577
S	Pt vs. Pt – 10% Rh	0 – 1577
J	Iron vs. Constantan	-173 – 827
K	Chromel vs. Alumel	-173– 1027
T	Copper vs. Constantan	-243 – 427
E	Chromel vs. Constantan	-173 –827

Constantan is a genetic name for copper – nickel alloys having a copper content any where between 45% and 60%. In type J, the alloy has 55% copper and 45% nickel. Chromel is an alloy of approximately 90% Nickle and 10% chromium. Alumel has 95%

nickel plus Aluminium, silicon and manganese. Type K is the most commonly used thermocouple in industry.

The major requirements of thermocouple materials are:

1. They must not deteriorate.
2. They must produce a measurable, stable electrical output.
3. They must be economical
4. They must be mechanically strong.

Thermocouples are available in a large variety of designs for many diverse applications. In the most common design, the conductors are joined together usually by welding to form a measuring junction. The wires are separated beyond the welded junction and insulated, usually by fibrous glass, ceramic insulators etc.

The thermocouple circuit can be represented as given below

The calibration of thermocouple is done by observing the milli volts developed across the measuring junction for a range of temperature of a liquid being heated. A is used as a reference temperature. A plot of milli volts vs. temperature is the calibration curve. The sensitivity (slope) of calibration curve is different for different types of thermocouple and none has a linear rate of change of e.m.f output per degree of temperature change. Each type of thermocouple has a unique non-linear response to temperature.

5. Description:

The setup consists of constant temperature bath with heating element. A control panel is provided to set the temperature. A thermocouple pocket is provided to insert the thermocouple in it. Milli-voltmeter is provided to measure the voltage. Three types (J, K & T type) of thermocouples are given.

6. Utilities Required:

6.1 Electricity supply: Single phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Bench area required: 0.5 m x 0.5 m.

6.3 Mercury (Hg) 50 gm.

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Ensure that all ON/OFF switches given on the panel are at OFF position.

7.1.2 Insert the thermocouple into the pocket.

7.1.3 Connect the lead wires from thermocouple to the milli-voltmeter.

7.1.4 Switch ON the panel.

7.1.5 Switch ON the power supply and set the temperature of the bath.

7.1.6 Note down the reading of voltage from the milli-voltmeter.

7.1.7 Repeat the experiment for different types of thermocouple.

7.2 Closing Procedure:

7.2.1 When experiment is over switch OFF the panel.

7.2.2 Switch OFF the power supply.

7.2.3 Remove the thermocouples and clean the apparatus.

8. Observation & Calculation:

Observation Table:

T (°C)										
V (mv)										

Plot a graph of T vs V.

9. Nomenclature:

Nom	Column Heading	Units	Type
T	Temperature	°C	Measured
V	Voltage	mv	Measured

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never exceed the set point of DTC more than 100 ^{o}C.

10.2 Always pull the needle with the help of needle puller.

10.3 Always take precaution at the time of handling the needle.

10.4 Never touch the inner mechanism.

11. TROUBLESHOOTING:

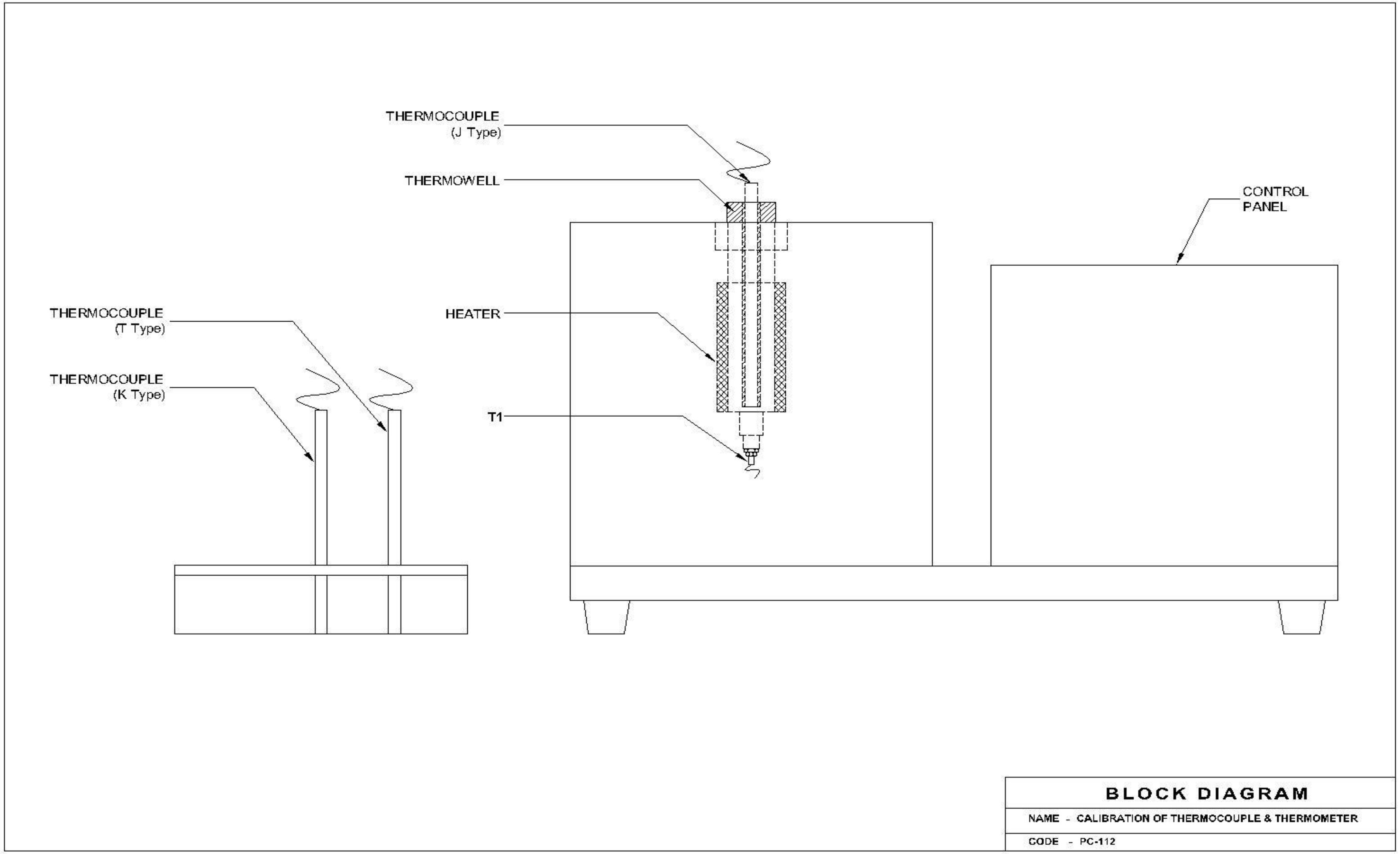
11.1 If electric panel is not showing the input on mains light. Check the main supply.

11.2 If the temperature of the bath is not rises but mains is ON, it means heater burned replace it.

12. REFERENCES:

12.1 Eckman, Donald P. (1991). *Industrial Instrumentation.* 16th Ed. ND: Wiley Eastern Limited. pp 70-74.

13. BLOCK DIAGRAM:



CONTROL VALVE

CHARACTERISTICS

(THREEE VALVES SYSTEM) (PC-108B)

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Contents

Control Valve Characteristics

(Three Valves System)

1. Objective:

To study control valve characteristics.

2. Introduction:

Valve Action & Actuator Mechanism

If a control valve is used to control fluid flow, some mechanism must physically open or close the valve. Different types of actuators are used to control the stem travel of the valve, like electrical actuators, pneumatic actuator, hydraulic actuators etc. In present set-up, pneumatic actuators are used for control valves. Spring opposed diaphragm actuator positions the valve plug in response to the controller signals. Mostly the controller signals are in the range of 3-15 psig. There are two types of actuators described below:

i) Direct acting actuator (Air to close):

Direct acting actuators basically consist of a pressure tight housing sealed by a flexible fabric reinforced elastomer diaphragm. A diaphragm plate is held against the diaphragm by a heavy compression spring. Signal air pressure is applied to upper diaphragm case that exerts force on the diaphragm and the actuator assembly. By selecting proper spring rate or stiffness, load carrying capacity, and initial compression, desired stem displacement can be obtained for any given input signal.

ii) Reverse acting actuator (Air to open):

In case of reverse acting actuators the stem gets retracted with increase in pressure.

Types Of Control Valve:

Valve is essentially a variable orifice. Control valve is a valve with a pneumatic, hydraulic, electric (excluding solenoids) or other externally powered actuator that automatically, fully or partially opens or closes the valve to a position dictated by signals transmitted from controlling instruments. Control valves are used primarily to throttle energy in a fluid system and not for shutoff purpose. Depending upon the valve plug design the control valves can be divided in three categories as under:

i) Equal % type.

ii) Linear type.

Iii) Quick opening type (On/Off type).

3. DESCRIPTION:

The present set-up consists of three nos. of pneumatic control valves. One control valve is with equal % characteristics (air to close type), second is with linear characteristics (air to open type) and third is quick opening characteristics (ON/OFF). Sump tank with pump is provided for continuous water circulation. Manometer is provided at the inlet of valves to measure pressure. Valves are given for water supply to the control valve. Valves are provided for air supply to control valves. The air regulator and pressure gauge is given for regulating air pressure.

4. UTILITIES REQUIRED:

4.1 Electricity supply: Single phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

4.2 Compressed air supply: 1 CMH @ 2 bar.

4.3 Water supply (Initial Fill).

4.4 Floor drain required.

EXPERIMENT NO. 1

STUDY OF CONTROL VALVE FLOW CO-EFFICIENT (C_v)

5.a AIM:

5.a.1 To determine the flow coefficient C_v of the linear control valve.

5.a.2 To determine the flow coefficient C_v of the equal % control valve.

5.a.3 To determine the flow coefficient C_v of the quick open control valve.

6.a THEORY:

A control valve is used to control the flow rate in a fluid delivery system to control the process. There is a close relation between the pressure and the flow rate in fluid stream passing through pipe so that if pressure is changed, the flow rate will also be changed. A control valve changes the flow rate by changing the pressure in the flow system because it introduces the constriction in the delivery system. So we can say that the flow rate through the constriction can be given as:

$$Q = \frac{K}{\sqrt{\Delta P}}$$

A most important factor associated with control valve is the correction K of the above equation. This correction factor allows selection of proper size of valve to accommodate the rate of flow that the system must support. This correction factor is called as valve coefficient and is used in valve sizing.

CONTROL VALVE FLOW CO-EFFICIENT:

$$C_v = 11.7Q\sqrt{\frac{G}{\Delta P}}$$

Where:

Cv = Flow coefficient

Q = Discharge of fluid in m^3/h

ΔP = Pressure drop in Kpa

G = Specific gravity of fluid

7.a EXPERIMENTAL PROCEDURE:

7.a.1 STARTING PROCEDURE (FOR CONTROL VALVE 1):

7.a.1.1 Close all the valves V_1- V_{10}.

7.a.1.2 Fill the sump tank 3/4th of its, with water.

7.a.1.3 Connect the air supply to the set-up.

7.a.1.4 Switch ON the power supply and pump.

7.a.1.5 Wait for fill the over tank with water.

7.a.1.6 Open the valve V_4.

7.a.1.7 Open the valve V_1 and adjust flow rate.

7.a.1.8 Open the valve V_6 completely.

7.a.1.9 Partially open the valve V_5 and wait for some time (5 min).

7.a.1.10 Record the manometer reading.

7.a.1.11 Record the rotameter reading.

7.a.1.12 Repeat the experiment by adjust the valve V_1 at different flow rate.

7.a.2 CLOSING PROCEDURE (FOR CONTROL VALVE 1):

7.a.2.1 When experiment is over stop the air supply.

7.a.2.2 Switch OFF the pump and power supply.

7.a.2.3 Open the valve V_5 fully to release the air.

7.a.2.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

7.a.3 STARTING PROCEDURE (FOR CONTROL VALVE 2):

7.a.3.1 Close all the valves V_1- V_{10}.

7.a.3.2 Fill the sump tank 3/4th of its, with water.

7.a.3.3 Connect the air supply to the set-up.

7.a.3.4 Switch ON the power supply and pump.

7.a.3.5 Wait for fill the over tank with water.

7.a.3.6 Open the valve V_2 and adjust flow rate.

7.a.3.7 Open the valve V_7 completely.

7.a.3.8 Partially open the valve V_5 and wait for some time (5 min).

7.a.3.9 Record the manometer reading.

7.a.3.10 Record the rotameter reading.

7.a.3.11 Repeat the experiment by adjust the valve V_2 at different flow rate.

7.a.4 Closing Procedure (For Control Valve 2):

7.a.4.1 When experiment is over stop the air supply.

7.a.4.2 Switch OFF the pump and power supply.

7.a.4.3 Open the valve V_5 fully to release the air.

7.a.4.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

7.a.5 Starting Procedure (For Control Valve 3):

7.1.5.1 Close all the valves V_1- V_{10}.

7.1.5.2 Fill the sump tank $3/4^{th}$ of its, with water.

7.1.5.3 Connect the air supply to the set-up.

7.1.5.4 Switch ON the power supply and pump.

7.1.5.5 Wait for fill the over tank with water.

7.1.5.6 Open the valve V_3 and adjust flow rate.

7.1.5.7 Open the valve V_8 completely.

7.1.5.8 Partially open the valve V_5 and wait for some time (5 min).

7.1.5.9 Record the manometer reading.

7.1.5.10 Record the rotameter reading.

7.1.5.11 Repeat the experiment by adjust the valve V_3 at different flow rate.

7.a.6 Closing Procedure (For Control Valve 2):

7.a.6.1 When experiment is over stop the air supply.

7.a.6.2 Switch OFF the pump and power supply.

7.a.6.3 Open the valve V_5 fully to release the air.

7.a.6.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

8.a Observation & Calculation:

8.a.1 Data:

Specific gravity relative to water G	= 1

Select the valve = ___________ (Linear valve, Equal % valve, Quick opening valve)

8.a.2 Observation Table:

S.No	H (mm of H_2O)	q (LPH)

8.a.3 Calculations:

$$\Delta P = 0.0098 \times H \text{ (Kpa)}$$

$$Q = 0.001 \times q \text{ (m}^3\text{/h)}$$

$$C_v = 11.7 \times Q\sqrt{\frac{G}{\Delta P}}$$

Calculation Table:

S.No	H (m^3/h)	C_v

9.a NOMENCLATURE:

Nom	Column Heading	Units	Type
C_v	Flow coefficient of control valves	*	Calculated
G	Specific gravity of fluid	*	Given
H	Pressure drop across valve	mm of H_2O	Measured
Q	Flow rate of liquid	m^3/h	Calculated
q	Flow rate of liquid	LPH	Measured
ΔP	Pressure drop across valve	Kpa	Calculated

* Symbols are unit less

EXPERIMENT NO. 2

STUDY OF INHERENT CHARACTERISTIC OF CONTROL VALVE

5.b AIM:

5.b.1 To study inherent characteristics of linear control valve.

5.b.2 To study inherent characteristics of equal % control valve.

5.b.3 To study inherent characteristics of quick open control valve.

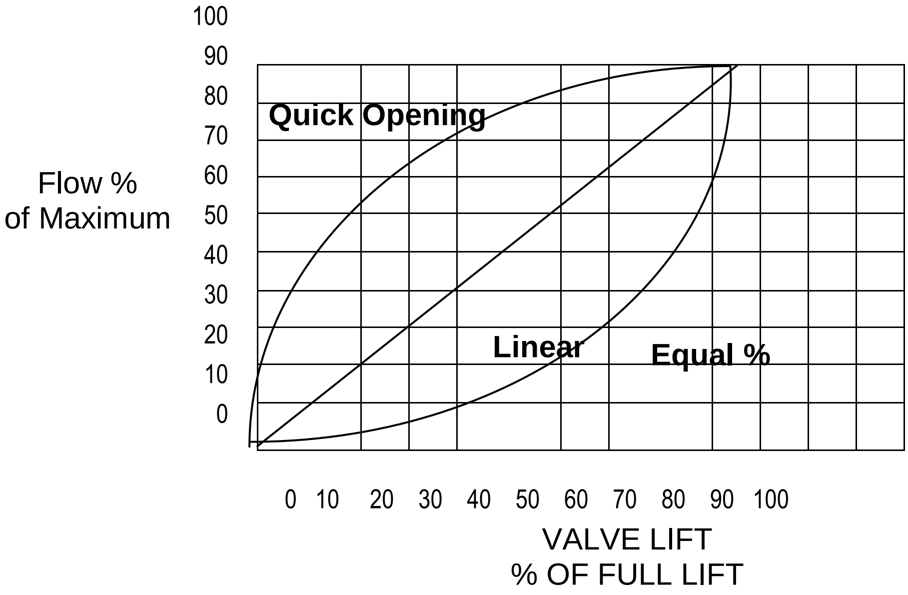
6.b THEORY:

VALVE CHARACTERISTICS:

The amount of fluid passing through a valve at any time depends upon the opening between the plug and seat. Hence there is relationship between stem position, plug position, and the rate of flow, which is described in terms of flow characteristics of a valve. Inherent and installed are two types of flow characteristics of a control valve.

INHERENT CHARACTERISTICS:

The inherent flow characteristic of control valve is the relation between the flow and the valve travel at constant pressure drop across the valve. Following are the inherent characteristics for different types of valves.



7.b Experimental Procedure:

7.b.1 Starting Procedure (For Control Valve 1):

7.b.1.1 Close all the valves V_1-V_{10}.

7.b.1.2 Fill the sump tank 3/4th of its, with water.

7.b.1.3 Connect the air supply to the set-up.

7.b.1.4 Switch ON the power supply and pump.

7.b.1.5 Wait for fill the over tank with water.

7.b.1.6 Open the valve V_1 and adjust flow rate.

7.b.1.7 Open the valve V_4 & V_6 completely.

7.b.1.8 Partially open the valve V_5 and wait for some time (5 min).

7.b.1.9 Note down the manometer reading.

7.b.1.10 Note down the rotameter reading.

7.b.1.11 Now slowly decrease the air pressure by pressure regulator.

7.b.1.12 Adjust the valveV_1 to keep pressure drop constant.

7.b.1.13 Note down the reading of rotameter and position of valve stem by scale.

7.b.1.14 Repeat the step 7.b.1.11 to 7.b.1.13 till the valve is fully closed (pressure upto 0 psi).

7.b.2 Closing Procedure (For Control Valve 1):

7.b.2.1 When experiment is over stop the air supply.

7.b.2.2 Switch OFF the pump and power supply.

7.b.2.3 Open the valve V_5 fully to release the air.

7.b.2.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

7.b.3 Starting Procedure (For Control Valve 2):

7.b.3.1 Close all the valves V_1-V_{10}.

7.b.3.2 Fill the sump tank 3/4th of its, with water.

7.b.3.3 Connect the air supply to the set-up.

7.b.3.4 Switch ON the power supply and pump.

7.b.3.5 Wait for fill the over tank with water.

7.b.3.6 Open the valve V_2 and adjust flow rate.

7.b.3.7 Open the valve V_7 completely.

7.b.3.8 Partially open the valve V_5 and wait for some time (5 min).

7.b.3.9 Note down the manometer reading.

7.b.3.10 Note down the rotameter reading.

7.b.3.11 Now slowly decrease the air pressure by pressure regulator.

7.b.3.12 Adjust the valve V_2 to keep pressure drop constant.

7.b.3.13 Note down the reading of rotameter and position of valve stem by scale.

7.b.3.14 Repeat the step 7.b.3.11 to 7.b.3.13 till the valve is fully closed (pressure upto 0 psi).

7.b.4 Closing Procedure (For Control Valve 2):

7.b.4.1 When experiment is over stop the air supply.

7.b.4.2 Switch OFF the pump and power supply.

7.b.4.3 Open the valve V_5 fully to release the air.

7.b.4.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

7.b.5 Starting Procedure (For Control Valve 3):

7.b.5.1 Close all the valves V_1-V_{10}.

7.b.5.2 Fill the sump tank 3/4th of its, with water.

7.b.5.3 Connect the air supply to the set-up.

7.b.5.4 Switch ON the power supply and pump.

7.b.5.5 Wait for fill the over tank with water.

7.b.5.6 Open the valve V_3 and adjust flow rate.

7.b.5.7 Open the valve V_8 completely.

7.b.5.8 Partially open the valve V_5 and wait for some time (5 min).

7.b.5.9 Note down the manometer reading.

7.b.5.10 Note down the rotameter reading.

7.b.5.11 Now slowly decrease the air pressure by pressure regulator.

7.b.5.12 Adjust the valveV_3 to keep pressure drop constant.

7.b.5.13 Note down the reading of rotameter and position of valve stem by scale.

7.b.5.14 Repeat the step 7.b.5.11 to 7.b.5.13 till the valve is fully closed (pressure upto 0 psi).

7.b.6 Closing Procedure (For Control Valve 3):

7.b.6.1 When experiment is over stop the air supply.

7.b.6.2 Switch OFF the pump and power supply.

7.b.6.3 Open the valve V_5 fully to release the air.

7.b.6.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

8.b Observation & Calculation:

Select the valve = ___________ (Linear valve, Equal % valve, Quick opening valve)

Observations:

H = _____ mm of H_2O

L_i = _____ mm

8.b.1 Observation Table:								
L (mm)								
q (LPH)								

8.b.2 Calculations:

$$Q = \frac{10^{-3} \times q}{3600} \ (m^3/sec)$$

Q_{max} = _____ (Maximum value of Q)

$$m = \frac{Q}{Q_{max}}$$

$$\Delta L = L - L_i \ (mm)$$

ΔL_{max} = _____ (Maximum value of ΔL)

$$x = \frac{\Delta L}{\Delta L_{max}}$$

Calculation Table:								
m								
x								

Plot m vs x on simple graph.

9.b Nomenclature:

Nom	Column Heading	Units	Type
H	Pressure drop across valve	mm of H_2O	Measured
L	Position of valve stem	mm	Measured
L_i	Initial position of valve stem	mm	Measured
m	Fraction of maximum flow rate	*	Calculated
Q	Flow rate of liquid	m^3/sec	Calculated
Q_{max}	Maximum value of flow rate	m^3/sec	Calculated

q	Flow rate of liquid	LPH	Measured
x	Fraction of maximum valve lift	*	Calculated
ΔL	Valve lift	mm	Calculated
ΔL_{max}	Maximum value of valve lift	mm	Calculated

* Symbols are unit less

Experiment No. 3

Study Of Installed Characteristic Of Control Valve

5.c Aim:

5.c.1 To study installed characteristics of linear control valve.

5.c.2 To study installed characteristics of equal % control valve.

5.c.3 To study installed characteristics of quick open valve control valve.

6.c Theory:

Valve Characteristics:

The amount of fluid passing through a valve at any time depends upon the opening between the plug and seat. Hence there is relationship between stem position, plug position, and the rate of flow, which is described in terms of flow characteristics of a valve. Inherent and installed are two types of flow characteristics of a control valve.

Installed Characteristics:

The installed characteristics of the valves described are subject to distortion due to variations in pressure drop with flow. Line resistance distorts linear characteristics towards that of quick opening valve and equal % to that of linear.

7.c Experimental Procedure:

7.c.1 Starting Procedure (For Control Valve 1):

7.c.1.1 Close all the valves V_1-V_8.

7.c.1.2 Fill the sump tank $3/4^{th}$ of its, with water.

7.c.1.3 Connect the air supply to the set-up.

7.c.1.4 Switch ON the power supply and pump.

7.c.1.5 Wait for fill the over tank with water.

7.c.1.6 Open the valve V_1 and adjust flow rate.

7.c.1.7 Open the valve V_3 & V_5 completely.

7.c.1.8 Partially open the valve V_4 and wait for some time (5 min).

7.c.1.9 Note down the manometer reading.

7.c.1.10 Note down the reading of rotameter and position of valve stem by scale.

7.c.1.11 By adjusting the valve V_1 for different manometer reading record rotameter reading and position of valve stem.

7.c.2 Closing Procedure (For Control Valve 1):

7.c.2.1 When experiment is over stop the air supply.

7.c.2.2 Switch OFF the pump and power supply.

7.c.2.3 Open the valve V_4 fully to release the air.

7.c.2.4 Drain the water from sump tank and overhead tank by open the valve V_7 & V_8.

7.c.3 Starting Procedure (For Control Valve 2):

7.c.3.1 Close all the valves V_1-V_{10}.

7.c.3.2 Fill the sump tank 3/4th of its, with water.

7.c.3.3 Connect the air supply to the set-up.

7.c.3.4 Switch ON the power supply and pump.

7.c.3.5 Wait for fill the over tank with water.

7.c.3.6 Open the valve V_2 and adjust flow rate.

7.c.3.7 Open the valve V_6 completely.

7.c.3.8 Partially open the valve V_4 and wait for some time (5 min).

7.c.3.9 Note down the manometer reading.

7.c.3.10 Note down the reading of rotameter and position of valve stem by scale.

7.c.3.11 By adjusting the valve V_2 for different manometer reading record rotameter reading and position of valve stem.

7.c.4 Closing Procedure (For Control Valve 2):

7.c.4.1 When experiment is over stop the air supply.

7.c.4.2 Switch OFF the pump and power supply.

7.c.4.3 Open the valve V_4 fully to release the air.

7.c.4.4 Drain the water from sump tank and overhead tank by open the valve V_7 & V_8.

7.c.5 Starting Procedure (For Control Valve 3):

7.c.5.1 Close all the valves V_1-V_{10}.

7.c.5.2 Fill the sump tank $3/4^{th}$ of its, with water.

7.c.5.3 Connect the air supply to the set-up.

7.c.5.4 Switch ON the power supply and pump.

7.c.5.5 Wait for fill the over tank with water.

7.c.5.6 Open the valve V_3 and adjust flow rate.

7.c.5.7 Open the valve V_8 completely.

7.c.5.8 Partially open the valve V_5 and wait for some time (5 min).

7.c.5.9 Note down the manometer reading.

7.c.5.10 Note down the reading of rotameter and position of valve stem by scale.

7.c.5.11 By adjusting the valve V_3 for different manometer reading record rotameter reading and position of valve stem.

7.c.6 Closing Procedure (For Control Valve 3):

7.c.6.1 When experiment is over stop the air supply.

7.c.6.2 Switch OFF the pump and power supply.

7.c.6.3 Open the valve V_5 fully to release the air.

7.c.6.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

8.c OBSERVATION & CALCULATION:

Select the valve = ___________ (Linear valve, Equal % valve, Quick opening valve)

OBSERVATIONS:

L_i = _____ mm

8.c.1 OBSERVATION TABLE:

L (mm)								
q (LPH)								
H (mm of H_2O)								

8.c.2 CALCULATIONS:

$$Q = \frac{10^{-3} \times q}{3600} \text{ (m}^3\text{/sec)}$$

$$\Delta L = L - L_i \text{ (mm)}$$

ΔL_{max} = _____ (Maximum value of ΔL)

$$x = \frac{\Delta L}{\Delta L_{max}}$$

CALCULATION TABLE:

Q (m^3/sec)								
x								

Plot Q vs x on a simple graph.

9.c NOMENCLATURE:

Nom	Column Heading	Units	Type
H	Pressure drop across valve	mm of H_2O	Measured
L	Position of valve stem	mm	Measured
L_i	Initial position of valve stem	mm	Measured

Q	Flow rate of liquid	m^3/sec	Calculated
q	Flow rate of liquid	LPH	Measured
x	Fraction of maximum valve lift	*	Calculated
ΔL	Valve lift	mm	Calculated
ΔL_{max}	Maximum value of valve lift	mm	Calculated

* Symbols are unit less

EXPERIMENT NO. 4

STUDY OF HYSTERESIS OF CONTROL VALVE

5.d AIM:

5.d.1 To study the hysteresis in linear control valve.

5.d.2 To study the hysteresis in equal % control valve.

5.d.3 To study the hysteresis in quick open control valve.

6.d THEORY:

Hysteresis is a predictable error resulting from the differences in the transfer functions when a reading is taken from above and below the value to be measured. In case of control valves for same actuator signal different stem travel (hence valve coefficients) are obtained depending upon the direction of change in the signal. The maximum error in stem travel (or valve coefficient) expressed in % for same actuator pressure while opening and closing the valve is indicated as hysteresis.

7.d EXPERIMENTAL PROCEDURE:

7.d.1 STARTING PROCEDURE (FOR CONTROL VALVE 1):

7.d.1.1 Close all the valves V_1-V_8.

7.d.1.2 Fill the sump tank 3/4th of its, with water.

7.d.1.3 Connect the air supply to the set-up.

7.d.1.4 Switch ON the power supply and pump.

7.d.1.5 Wait for fill the over tank with water.

7.d.1.6 Open the valve V_1 & V_3 and adjust flow rate.

7.d.1.7 Open the valve V_5 completely.

7.d.1.8 Partially open the valve V_4 and wait for some time (5 min).

7.d.1.9 Note down the reading of pressure gauge and position of valve stem by scale

7.d.1.10 Now slowly decrease the air pressure by pressure regulator.

7.d.1.11 Repeat the step 7.d.1.9 -7.d.110 till the valve is fully closed (pressure upto 0 psi).

7.d.2 Closing Procedure (For Control Valve 1):

7.d.2.1 When experiment is over stop the air supply.

7.d.2.2 Switch OFF the pump and power supply.

7.d.2.3 Open the valve V_4 fully to release the air.

7.d.2.4 Drain the water from sump tank and overhead tank by open the valve V_7 & V_8.

7.d.3 Starting Procedure (For Control Valve 2):

7.d.3.1 Close all the valves V_1-V_8.

7.d.3.2 Fill the sump tank 3/4th of its, with water.

7.d.3.3 Connect the air supply to the set-up.

7.d.3.4 Switch ON the power supply and pump.

7.d.3.5 Wait for fill the over tank with water.

7.d.3.6 Open the valve V_2 and adjust the flow rate.

7.d.3.7 Open the valve V_6 completely.

7.d.3.8 Partially open the valve V_5 and wait for some time (5 min).

7.d.3.9 Note down the reading of pressure gauge and position of valve stem by scale

7.d.3.10 Now slowly decrease the air pressure by pressure regulator.

7.d.3.11 Repeat the step 7.d.3.9 -7.d.3.10 till the valve is fully closed (pressure upto 0 psi).

7.d.4 Closing Procedure (For Control Valve 2):

7.d.4.1 When experiment is over stop the air supply.

7.d.4.2 Switch OFF the pump and power supply.

7.d.4.3 Open the valve V_4 fully to release the air.

7.d.4.4 Drain the water from sump tank and overhead tank by open the valve V_7 & V_8.

7.d.5 Starting Procedure (For Control Valve 3):

7.d.5.1 Close all the valves V_1-V_{10}.

7.d.5.2 Fill the sump tank 3/4th of its, with water.

7.d.5.3 Connect the air supply to the set-up.

7.d.5.4 Switch ON the power supply and pump.

7.d.5.5 Wait for fill the over tank with water.

7.d.5.6 Open the valve V_3 adjust flow rate.

7.d.5.7 Open the valve V_8 completely.

7.d.5.8 Partially open the valve V_5 and wait for some time (5 min).

7.d.5.9 Note down the reading of pressure gauge and position of valve stem by scale

7.d.5.10 Now slowly decrease the air pressure by pressure regulator.

7.d.5.11 Repeat the step 7.d.5.9-7.d.5.10 till the valve is fully closed (pressure upto 0 psi).

7.d.6 Closing Procedure (For Control Valve 3):

7.d.6.1 When experiment is over stop the air supply.

7.d.6.2 Switch OFF the pump and power supply.

7.d.6.3 Open the valve V_5 fully to release the air.

7.d.6.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

8.d Observation & Calculation:

Select the valve = ___________ (Linear valve, Equal % valve, Qpening valve)

Observations:

L_i = _____ mm

8.d.1 Observation Table:				
S.No	**Increasing Pressure**		**Decreasing Pressure**	
	p (psi)	**L (mm)**	**p (psi)**	**L (mm)**

8.d.2 Calculations:

$$\Delta L = L - L_i \text{ (mm)}$$

ΔL_{max} = _____ (Maximum value of ΔL)

$$x = \frac{\Delta L}{\Delta L_{max}}$$

Calculation Table:				
S.No	**Increasing Pressure**		**Decreasing Pressure**	
	p (psig)	**x**	**p (psi)**	**x**

Plot x vs p on a simple graph.

9.d Nomenclature:

Nom	Column Heading	Units	Type
p	Air pressure on valve	psi	Measured
L	Position of valve stem	mm	Measured
L_i	Initial position of valve stem	mm	Measured
x	Fraction of maximum valve lift	*	Calculated
ΔL	Valve lift	mm	Calculated
ΔL_{max}	Maximum value of valve lift	mm	Calculated

* Symbols are unitless

Experiment No. 5

Study Of Rangeability

5.e Aim:

5.e.1 To calculate rangeability of linear control valve.

5.e.2 To calculate rangeability of equal %control valve.

5.e.3 To calculate rangeability of quick open control valve.

6.e Theory:

Control valves have a characteristic such that flow changes by a constant of its instantaneous value for given change in stem position. Generally this type of valve does not shut off the flow completely in its limit of stem travel. The rangeability (R) is defined as the ratio of maximum to minimum controllable flow.

$$R = \frac{m_{\max}}{m_{\min controlable}}$$

7.e Experimental Procedure:

7.e.1 Starting Procedure (For Control Valve 1):

7.e.1.1 Close all the valves V_1-V_8.

7.e.1.2 Fill the sump tank $3/4^{th}$ of its, with water.

7.e.1.3 Connect the air supply to the set-up.

7.e.1.4 Switch ON the power supply and pump.

7.e.1.5 Wait for fill the over tank with water.

7.e.1.6 Open the valve V_1 and adjust flow rate.

7.e.1.7 Open the valveV_3.

7.e.1.8 Open the valve V_5 completely.

7.e.1.9 Partially open the valve V_4 and wait for some time (5 min).

7.e.1.10 Note down the manometer reading.

7.e.1.11 Note down the rotameter reading.

7.e.1.12 Now slowly decrease the air pressure by pressure regulator.

7.e.1.13 Adjust the valveV_1 to keep pressure drop constant.

7.e.1.14 Note down the reading of rotameter.

7.e.1.15 Repeat the step 7.e.1.12 to 7.e.1.14 till the valve is fully closed (pressure upto 0 psi).

7.e.2 Closing Procedure (For Control Valve 1):

7.e.2.1 When experiment is over stop the air supply.

7.e.2.2 Switch OFF the pump and power supply.

7.e.2.3 Open the valve V_4 fully to release the air.

7.e.2.4 Drain the water from sump tank and overhead tank by open the valve V_7 & V_8.

7.e.3 Starting Procedure (For Control Valve 2):

7.e.3.1 Close all the valves V_1-V_8.

7.e.3.2 Fill the sump tank 3/4th of its, with water.

7.e.3.3 Connect the air supply to the set-up.

7.e.3.4 Switch ON the power supply and pump.

7.e.3.5 Wait for fill the over tank with water.

7.e.3.6 Open the valve V_2 and adjust flow rate.

7.e.3.7 Open the valve V_6 completely.

7.e.3.8 Partially open the valve V_4 and wait for some time (5 min).

7.e.3.9 Note down the manometer reading.

7.e.3.10 Note down the rotameter reading.

7.e.3.11 Now slowly decrease the air pressure by pressure regulator.

7.e.3.12 Adjust the valveV_2 to keep pressure drop constant.

7.e.3.13 Note down the reading of rotameter.

7.e.3.14 Repeat the step 7.e.3.11 to 7.e.3.13 till the valve is fully closed (pressure upto 0 psi).

7.e.4 Closing Procedure (For Control Valve 2):

7.e.4.1 When experiment is over stop the air supply.

7.e.4.2 Switch OFF the pump and power supply.

7.e.4.3 Open the valve V_4 fully to release the air.

7.e.4.4 Drain the water from sump tank and overhead tank by open the valve V_7 & V_8.

7.e.5 Starting Procedure (For Control Valve 3):

7.e.5.1 Close all the valves V_1-V_{10}.

7.e.5.2 Fill the sump tank 3/4th of its, with water.

7.e.5.3 Connect the air supply to the set-up.

7.e.5.4 Switch ON the power supply and pump.

7.e.5.5 Wait for fill the over tank with water.

7.e.5.6 Open the valve V_3 and adjust flow rate.

7.e.5.7 Open the valve V_8 completely.

7.e.5.8 Partially open the valve V_5 and wait for some time (5 min).

7.e.5.9 Note down the manometer reading.

7.e.5.10 Note down the rotameter reading.

7.e.5.11 Now slowly decrease the air pressure by pressure regulator.

7.e.5.12 Adjust the valveV_3 to keep pressure drop constant.

7.e.5.13 Note down the reading of rotameter.

7.e.5.14 Repeat the step 7.e.5.11 to 7.e.5.13 till the valve is fully closed (pressure upto 0 psi).

7.e.6 Closing Procedure (For Control Valve 3):

7.e.6.1 When experiment is over stop the air supply.

7.e.6.2 Switch OFF the pump and power supply.

7.e.6.3 Open the valve V_5 fully to release the air.

7.e.6.4 Drain the water from sump tank and overhead tank by open the valve V_9 & V_{10}.

8.e Observation & Calculation:

Select the valve = ____________ (Linear valve, Equal % valve, Quick opening valve)

Observations:

H = _____ mm of H_2O

8.e.1 Observation Table:

q (LPH)									

8.e.2 Calculations:

$$Q = \frac{10^{-3} \times q}{3600} \text{ (m}^3\text{/sec)}$$

Q_{max} = _____ (Maximum value of Q)

$$m = \frac{Q}{Q_{max}}$$

m_{max} = _____ (Maximum value of m)

m_{min} = _____ (Minimum value of m)

$$R = \frac{m_{max}}{m_{min}}$$

9.e NOMENCLATURE:

Nom	Column Heading	Units	Type
H	Pressure drop across valve	mm of H_2O	Measured
m	Fraction of maximum flow rate	*	Calculated
m_{max}	Maximum value of fraction of maximum flow rate	*	Calculated
m_{min}	Minimum value of fraction of maximum flow rate	*	Calculated
Q	Flow rate of liquid	m^3/sec	Calculated
Q_{max}	Maximum value of flow rate	m^3/sec	Calculated
q	Flow rate of liquid	LPH	Measured
R	Rangeability	*	Calculated

* Symbols are unit less

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Do not run the apparatus if power supply is less than 200 volts & more than 220 volts.

10.2 Always keep apparatus free from dust.

10.3 To prevent clogging of moving parts, run pump at least once in a fortnight.

10.4 Always use clean water.

10.5 If apparatus will not in use more than one month, drain the apparatus completely.

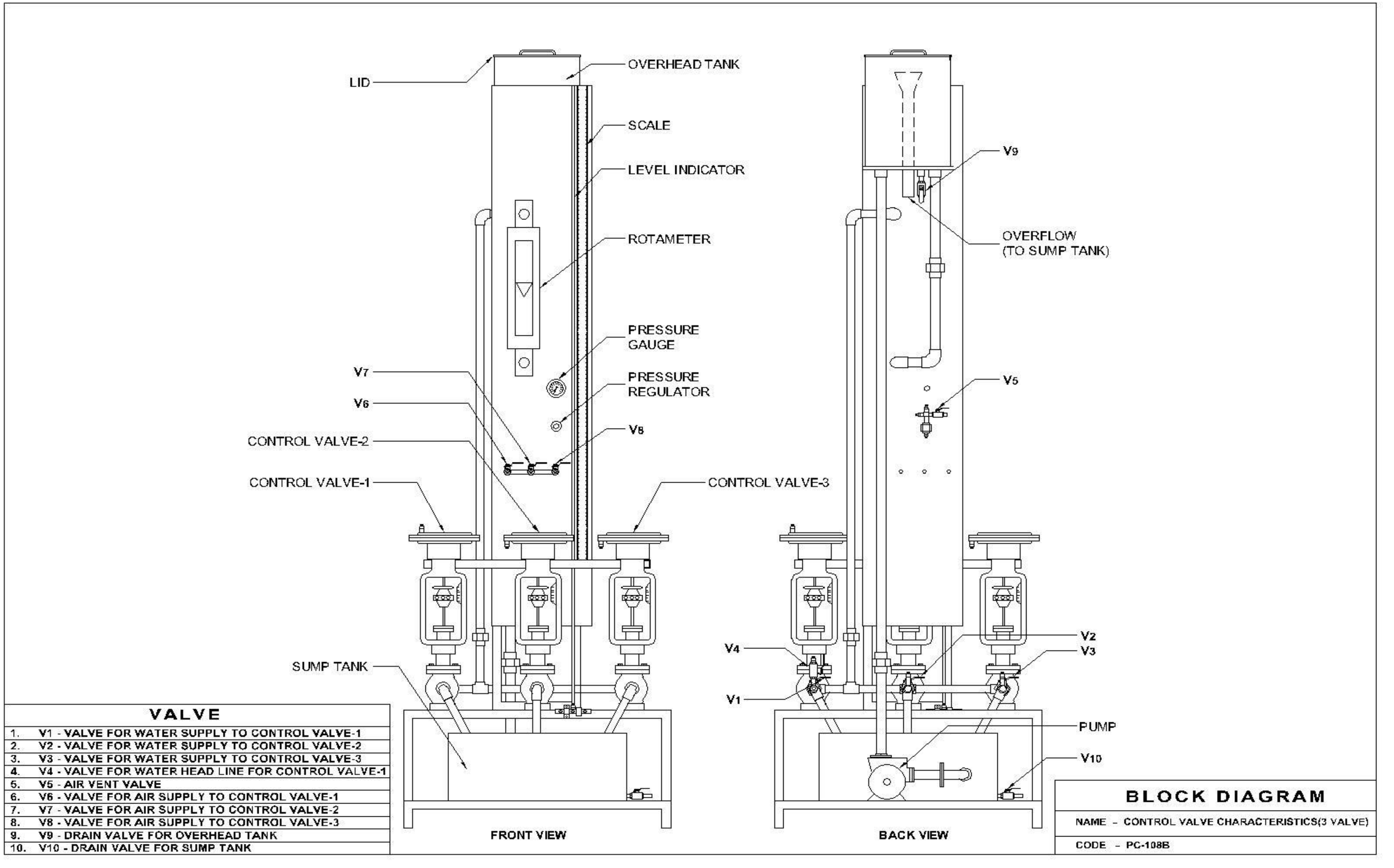
11. TROUBLESHOOTING:

11.1 If pump gets jam, open the back cover of pump and rotate the shaft manually.

12. REFERENCES:

12.1 Coughanowr, Donald R. (1991). *Process Systems Analysis and Control.* 2nd Ed. ND: Mc Graw-hill International. pp 305-310, 315.

13. Block Diagram:



VALVE	
1.	V1 - VALVE FOR WATER SUPPLY TO CONTROL VALVE-1
2.	V2 - VALVE FOR WATER SUPPLY TO CONTROL VALVE-2
3.	V3 - VALVE FOR WATER SUPPLY TO CONTROL VALVE-3
4.	V4 - VALVE FOR WATER HEAD LINE FOR CONTROL VALVE-1
5.	V5 - AIR VENT VALVE
6.	V6 - VALVE FOR AIR SUPPLY TO CONTROL VALVE-1
7.	V7 - VALVE FOR AIR SUPPLY TO CONTROL VALVE-2
8.	V8 - VALVE FOR AIR SUPPLY TO CONTROL VALVE-3
9.	V9 - DRAIN VALVE FOR OVERHEAD TANK
10.	V10 - DRAIN VALVE FOR SUMP TANK

INTERACTING AND NON-INTERACTING SYSTEM (PC-117)

Engineering Growth Connection

Foreword

Welcome to the fast growing family of K.C. product owners. We appreciate your interest in us and thank you for buying our product.

You have chosen the finest quality product in the market which is produced using latest techniques and has underwent strict quality control tests. It is a product that we are proud to build and you are proud to own it.

Our products are easy to understand and operate. They are excellent for students who are trying to gain practical knowledge through experiments.

However your comfort and safety are important to us, so we want you have an understanding of proper procedure to use the equipment. For the purpose, we urge you to read and follow the step-by-step operating instructions and safety precautions in this manual. It will ensure that your favourite product delivers reliable, superior performance year after year.

This manual includes information for all options available on this model. Therefore, you may find some information that does not apply to your equipment.

All information, specifications and illustrations in this manual are those in effect at the time of printing. We reserve the right to change specifications or design at any time without notice.

Customer satisfaction is our primary concern. Feel Free to contact us for any assistance. So what are you waiting for, roll up your sleeves and let us get down to work!

K.C. Engineers Pvt. Ltd.

Important Information About This Manual

Reminder for Safety

Modification on Equipment:

This equipment should not be modified. Modification could affect its performance, safety or disturbance. In addition damage or performance problems resulting from modification may not be covered under warranties.

Precautions and Maintenance:

This is used to indicate the presence of a hazard that could cause minor or moderate personal injury or damage to your equipment. To avoid or reduce the risk, the procedures must be followed carefully.

Contents

INTERACTING & NON-INTERACTING SYSTEM

1. OBJECTIVE:

To study the dynamic response of liquid level in single tank, two tank interacting and two tank non-interacting system

2. INTRODUCTION:

The single tank liquid level system is the physical example of first order system. Consider a system which consists of a tank of uniform cross sectional area to which is attached a flow resistance such as a valve, the volumetric flow rate through the resistance is related to the head by the linear relationship.

The principle distinction to be made in multi-capacity processes is in how the capacities are joined. If they are said to be isolated or non-interacting, the capacities behave exactly as they would alone. But if coupled, they interact with one another, in which case the contribution of each is altered by the interaction. In no-interacting system the two tanks levels does not interact because the flow from the first tank to the second tank is independent of the level in the second tank. In interacting system the levels in both tanks interact because any change in the down stream level will affect the upstream level.

The following general rules are applied to the principle of interaction;

1. The degree of interaction is proportional to the ratio of the smaller to the larger capacity (not time constant). Where this ratio is low (<0.1), the capacities may assumed not to interact
2. Interaction always works towards increasing the larger time constant and decreasing the smaller one.
3. Specifically with regard to the behavior of the system with equal time constant and of equal capacity, the effect is a combination of one large and the rest small time constants.

3. DESCRIPTION:

Apparatus is self-contained re-circulating unit. It consist a sump tank, three tanks and an over head tank. Sump tank and over head tank are connected by pump. Level indicators are provided with scale at Tank1, Tank2 and Tank3. Rotameter is provided to measure the flow rate of water. Valves are provided for the process and drainage.

4. UTILITIES REQUIRED:

4.1 Electricity supply: Single phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

4.2 Water supply (Initial fill)

4.3 Floor drain required.

4.4 Floor area required: 1 m x 1 m

EXPERIMENT NO. 1

SINGLE TANK LIQUID LEVEL SYSTEM

5.a AIM:

5.a.1 To calculate the valve resistance of single tank liquid level system.

5.a.2 To calculate the time constant of single tank liquid level system.

5.a.3 To calculate the step response of a single tank liquid level system to a step change in input flow and compare it with the theoretical response.

6.a THEORY:

A single tank liquid level system is first order in nature. The transfer function relating deviation of liquid level in the tank to the deviation in the inlet flow rate is:

$$\frac{H(s)}{Q(s)} = \frac{R}{(\tau s + 1)} \qquad \text{................ (1)}$$

where $\tau = AR$

τ is the time constant of the system.

For step input of the magnitude "M" in the inlet flow

to the tank :

$$Q(s) = \frac{M}{s}$$

$$H(s) = \frac{MR}{s}(\tau s + 1)$$

$$\frac{H(s)}{MR} = \frac{1}{s(\tau s + 1)} \qquad \text{................ (2)}$$

Taking inverse laplace transform of equation (2)

$$\frac{H(t)}{MR} = 1 - e^{-t/\tau}$$

This equation gives the theoretical variation of liquid level in the tank with respect to time for a step input of magnitude "M" in the inlet flow rate.

In the linear region $q_o = \frac{h}{R}$ where "R" is the resistance of the discharge valve. The resistance "R" is the reciprocal of slope of the tangent line to head (h) vs discharge (Q) curve at the first steady state value.

7.a EXPERIMENTAL PROCEDURE:

7.a.1 STARTING PROCEDURE:

7.a.1.1 Close all the valvesV_1-V_7.

7.a.1.2 Fill the sump tank with water.

7.a.1.3 Switch ON the power supply and the pump.

7.a.1.4 Wait till the over flow from over head tank.

7.a.1.5 Now open the flow control valveV_1 and adjust the flow rate (10-20 LPH)

7.a.1.6 Open the valve V_2 completely and partially open the valve V_4, and wait till a constant height is achieved by liquid in Tank2.

7.a.1.7 Note down the inlet flow rate and height of liquid in the tank, which is the initial height.

7.a.1.8 Now increase the inlet flow rate 10-20 LPH (step change) by valve $V_{1.}$

7.a.1.9 Simultaneously start the stopwatch and record the height of liquid level in the tank with time, till next constant height is reached.

7.a.1.10 Note down the final constant height and flow rate.

7.a.1.11 Repeat the same experiment for different step change.

7.a.2 CLOSING PROCEDURE:

7.a.2.1 If the experiment is over switch OFF the pump and power supply.

7.a.2.2 Open the drain valves V_4, V_6 & V_7.

8.a OBSERVATION & CALCULATION:

8.a.1 DATA:

Inner diameter of tank D_1	= 0.108 m
Outer diameter of the down comer D_2	= 0.022 m

8.a.2 OBSERVATION TABLE (FOR VALVE RESISTANCE):

S.No	Q_1 (LPH)	h_1 (cm)

OBSERVATIONS (FOR SYSTEM RESPONSE):

Q_i = _____ LPH

Q_f = _____ LPH

h_i = _____ cm

8.a.3 OBSERVATION TABLE (FOR SYSTEM RESPONSE):

S.No	t (sec)	h(cm)

8.a.4 CALCULATIONS (FOR VALVE RESISTANCE):

Plot a graph of Q_1 vs. h_1 and find slope S_1.

$$R = \frac{1 \times 3600 \times 1000}{S_1 \times 100} \text{ (sec/m}^2\text{)}$$

8.a.5 CALCULATIONS (FOR SYSTEM RESPONSE):

$$M = \frac{Q_f - Q_i}{1000 \times 3600} \text{ (m}^3\text{/sec)}$$

h_f = _________ (cm) [Final value of h]

$$H = \frac{h_f - h_i}{100} \text{ (m)}$$

$$A = \frac{\pi}{4}(D_1^2 - D_2^2) \text{ (m}^2\text{)}$$

$$\tau = A \times R \text{ (sec)}$$

$$\left[\frac{H}{MR}\right]_{exp} = \frac{h - h_i}{MR \times 100}$$

$$\left[\frac{H}{MR}\right]_{the} = 1 - e^{-t/\tau}$$

Calculation Table (For Tank Response):			
S. No.	**t (sec)**	$\left[\frac{H}{MR}\right]_{exp}$	$\left[\frac{H}{MR}\right]_{the}$

Plot a graph of $\left[\frac{H}{MR}\right]_{the}$ vs t and $\left[\frac{H}{MR}\right]_{exp}$ vs t.

9.a Nomenclature:

Nom	Column Heading	Units	Type
A	Cross-sectional area of Tank (2)	m^2	Calculated
D_1	Inner diameter of Tank (2)	m	Given
D_2	Outer diameter of the down comer of Tank (2)	m	Given
H	Height difference of water in the Tank (2)	m	Calculated
$\left[\frac{H}{MR}\right]_{exp}$	Experimental response	*	Calculated
$\left[\frac{H}{MR}\right]_{the}$	Theoretical response	*	Calculated

h	Height of water in the Tank (2)	cm	Measured
h_1	Height of water in the Tank (2) for valve resistance	cm	Measured
h_f	Maximum value of height of water in the Tank(2) (h)	cm	Measured
h_i	Initial height of water in the Tank(2)	cm	Measured
M	Magnitude of step change	m^3/sec	Calculated
Q_1	Inflow to the Tank(2) for valve resistance	LPH	Measured
Q_f	Final inflow to the Tank(2)	LPH	Measured
Q_i	Initial inflow to the Tank(2)	LPH	Measured
R	Resistance of the valve	sec/m^2	Calculated
S_1	Slope of the graph Q_1 vs. h_1	m^2/sec	Calculated
t	time	sec	Measured
τ	Time constant	sec	Calculated

* Symbols are unit less.

EXPERIMENT NO. 2

TWO TANK INTERACTING LIQUID-LEVEL SYSTEM

5.b AIM:

5.b.1 To calculate the valve resistance of both the tank for interacting system.

5.b.2 To calculate the time constant of two tank interacting liquid level system.

5.b.3 To calculate the step response of two tank interacting system to a step change in input flow and compare it with the theoretical response.

6.b THEORY:

A dynamic system is the one in which there is some varying amount of accumulation of conserved quantities with time. Consider a liquid level system shown below in which two tanks are arranged in series such that the response of first tank depends on the conditions in the second tank. Such a system is said to be an interacting system and is a lumped parameter system

The arrangement is such that the flow through the resistance R_1 depends on both h_1 and h_2. Such a system is known as interacting system. Selecting a macroscopic system consisting of the entire tank, the total transient material balance for:

1. Tank (2):

$$\frac{d(A_1 h_1 \rho)}{dt} = q\rho - q_1\rho$$

$$\frac{dh_1}{dt} = \frac{q}{A_1} - \frac{q_1}{A_1}$$

Assuming the flow - head relationship for resistance R_1 is linear.

$$q_1 = \frac{h_1 - h_2}{R_1}$$

$$\frac{dh_1}{dt} = \frac{q}{A_1} - \frac{h_1 - h_2}{A_1 R_1} \qquad \text{.............. (1)}$$

$$Q = f(t)$$

2. Tank (3):

$$\frac{d(A_2 h_2 \rho)}{dt} = q_1\rho - q_2\rho$$

$$\frac{dh_2}{dt} = \frac{q_1}{A_2} - \frac{q_2}{A_2}$$

Assuming the flow - head relationship for resistance R_2 is linear.

$$q_2 = \frac{h_2}{R_2}$$

$$\frac{dh_2}{dt} = \frac{q_1}{A_2} - \frac{h_2}{A_2 R_2}$$

In terms of deviation variables

$$Q = q - q_s$$

$$Q_1 = q_1 - q_{1s}$$

$$Q_2 = q_2 - q_{2s}$$

$$H_1 = h_1 - h_{1s}$$

$$H_2 = h_2 - h_{2s}$$

$$\frac{dH_1}{dt} = \frac{Q - Q_1}{A_1} \qquad \text{............ (2)}$$

$$\frac{dH_2}{dt} = \frac{Q_1 - Q_2}{A_2} \qquad \text{............ (3)}$$

In terms of deviation variables, Q_1 and Q_2 can be expressed as:

$$Q_1 = \frac{H_1 - H_2}{R_1} \qquad \text{...............(4)}$$

$$Q_2 = \frac{H_2}{R_2} \qquad \text{.......... .....(5)}$$

Taking the laplace transforms and solving the above equations we get:

$$\frac{H_2(S)}{Q(S)} = \frac{R_2}{\tau_1\tau_2 S^2 + (\tau_1 + \tau_2 + A_1 R_2)S + 1} \qquad \text{..............(6)}$$

For $\tau_1 = \tau_2$

On taking inverse Laplace transform, we obtain theoretical response of the system as:

$$H_2(t) = MR_2\left[1 + 0.17e^{-t/0.38\tau_1} - 1.17e^{-t/2.62\tau_1}\right] \qquad \text{..............(7)}$$

Equation (7) represents the theoretical response of an interacting two tank liquid level system to a step change of magnitude (M) in the feed rate to tank (2).

7.b EXPERIMENTAL PROCEDURE:

7.b.1 STARTING PROCEDURE:

7.b.1.1 Close all the valvesV_1-V_7.

7.b.1.2 Fill the sump tank with water.

7.b.1.3 Switch ON the power supply and the pump.

7.b.1.4 Wait till the over flow from over head tank.

7.b.1.5 Now open the flow control valveV_1 and adjust the flow rate (10-20 LPH).

7.b.1.6 Open the valve V_2 completely and partially open the valve V_3 & V_5, and wait till a constant height is achieved by liquid in Tank2 and Tank3.

7.b.1.7 Note down the inlet flow rate and height of Tank2 and Tank3, which is the initial heights.

7.b.1.8 Now increase the inlet flow rate 10-20 LPH (step change) by valve V_1.

7.b.1.9 Simultaneously start the stopwatch and record the heights of liquid level in the Tank2 and Tank3 with time, till next constant height is reached.

7.b.1.10 Note down the final constant heights and flow rate.

7.b.1.11 Repeat the same experiment for different step change.

7.b.2 CLOSING PROCEDURE:

7.b.2.1 If the experiment is over switch OFF the pump and power supply.

7.b.2.2 Open the drain valves V_4-V_7.

8.b OBSERVATION & CALCULATION:

8.b.1 DATA:	
Inner diameter of Tank(2) & (3) D_1	= 0.108 m
Outer diameter of the down comer of Tank(2) & (3) D_2	= 0.022 m

OBSERVATIONS:

Q_i = ______ LPH

Q_f = ______ LPH

h_{1i} = ______ cm

h_{2i} = ______ cm

8.b.2 OBSERVATION TABLE:

S.No	t (sec)	h_1 (cm)	h_2 (cm)

8.b.3 CALCULATIONS:

$$M = \frac{Q_f - Q_i}{1000 \times 3600} \quad (m^3/sec)$$

h_{1f} = __________ (cm) [Final value of h_1]

$$H_1 = \frac{h_{1f} - h_{1i}}{100} \quad (m)$$

h_{2f} = __________ (cm) [Final value of h_2]

$$H_2 = \frac{h_{2f} - h_{2i}}{100} \quad (m)$$

$$R_1 = \frac{H_1 - H_2}{M} \quad (sec/m^2)$$

$$R_2 = \frac{H_2}{M} \quad (sec/m^2)$$

$$A_1 = \frac{\pi}{4}(D_1^2 - D_2^2)\ (\text{m}^2)$$

$$A_2 = \frac{\pi}{4}(D_1^2 - D_2^2)\ (\text{m}^2)$$

$$\tau_1 = A_1 \times R_1\ (\text{sec})$$

$$\tau_2 = A_2 \times R_2\ (\text{sec})$$

$$\left[\frac{H_2}{MR_2}\right]_{\text{exp}} = \frac{h_2 - h_{2i}}{MR_2 \times 100}$$

For $\tau_1 = \tau_2$

$$\left[\frac{H_2}{MR_2}\right]_{the} = 1 + 0.17e^{\frac{-t}{0.38\tau_1}} - 1.17e^{\frac{-t}{2.62\tau_1}}$$

CALCULATION TABLE			
S. No.	**t (sec)**	$\left[\frac{H_2}{MR_2}\right]_{\text{exp}}$	$\left[\frac{H_2}{MR_2}\right]_{the}$

Plot a graph of $\left[\frac{H_2}{MR_2}\right]_{\text{exp}}$ vs t and $\left[\frac{H_2}{MR_2}\right]_{the}$ vs t

9.b NOMENCLATURE:

Nom	Column Heading	Units	Type
A_1	Cross-sectional area of Tank (2)	m^2	Calculated
A_2	Cross-sectional area of Tank (3)	m^2	Calculated
D_1	Inner diameter of Tank (2) & (3)	m	Given
D_2	Outer diameter of the down comer of Tank(2) & (3)	m	Given
H_1	Height difference of water in the Tank(2)	m	Calculated
H_2	Height difference of water in the Tank(3)	m	Calculated

$\left[\frac{H_2}{MR_2}\right]_{exp}$	Experimental response	*	Calculated
$\left[\frac{H_2}{MR_2}\right]_{the}$	Theoretical response	*	Calculated
h_1	Height of water in the Tank(2)	cm	Measured
h_{1f}	Maximum value of height of water in the Tank(2) h_1	cm	Calculated
h_{1i}	Initial height of water in the Tank(2)	cm	Measured
h_2	Height of water in the Tank(3)	cm	Measured
h_{2f}	Maximum value of height of water in the Tank(3) h_2	cm	Calculated
h_{2i}	Initial height of water in the Tank(3)	cm	Measured
M	Magnitude of step change	m^3/sec	Calculated
Q_f	Final inflow to the Tank(2)	LPH	Measured
Q_i	Initial inflow to the Tank(2)	LPH	Measured
R_1	Valve resistance of the Tank(2)	sec/m^2	Calculated
R_2	Valve resistance of the Tank(3)	sec/m^2	Calculated
t	Time	sec	Measured
τ_1	Time constant for Tank(2)	sec	Calculated
τ_2	Time constant for Tank(3)	sec	Calculated

* Symbols are unit less

EXPERIMENT NO. 3

TWO TANK NON-INTERACTING LIQUID-LEVEL SYSTEM

5.c AIM:

5.c.1 To calculate the valve resistance of both the tank for non interacting system.

5.c.2 To calculate the time constant of two tank non-interacting liquid level system.

5.c.3 To calculate the step response of two tank non-interacting system to a step change in input flow and compare it with the theoretical response.

6.c THEORY:

A dynamic system is the one in which there is some varying amount of accumulation of conserved quantities with time. Consider a liquid level system shown below in which two tanks are arranged in series such that the response of first tank doesnot depends on the conditions in the second tank. Such a system is said to be non- interacting system.

The arrangement is such that the flow through the resistance R_1 does not depends on h_2. Such a system is known as non-interacting system. Selecting a macroscopic system consisting of the entire tank, the total transient material balance for:

1. Tank (1):

$$\frac{d(A_1 h_1 \rho)}{dt} = q\rho - q_1\rho$$

$$\frac{dh_1}{dt} = \frac{q}{A_1} - \frac{q_1}{A_1}$$

Assuming the flow - head relationship for resistance R_1 is linear.

$$q_1 = \frac{h_1}{R_1}$$

$$\frac{dh_1}{dt} = \frac{q}{A_1} - \frac{h_1}{A_1R_1} \qquad \text{........ (1)}$$

$$Q = f(t)$$

2. Tank (2):

$$\frac{d(A_2h_2\rho)}{dt} = q_1\rho - q_2\rho$$

$$\frac{dh_2}{dt} = \frac{q_1}{A_2} - \frac{q_2}{A_2}$$

Assuming the flow - head relationship for resistance R_1 is linear.

$$q_2 = \frac{h_2}{R_2}$$

$$\frac{dh_2}{dt} = \frac{q_1}{A_2} - \frac{h_2}{A_2R_2} \qquad \text{......... (2)}$$

In terms of deviation variables

$$Q = q - q_s$$

$$Q_1 = q_1 - q_{1s}$$

$$Q_2 = q_2 - q_{2s}$$

$$H_1 = h_1 - h_{1s}$$

$$H_2 = h_2 - h_{2s}$$

$$\frac{dH_1}{dt} = \frac{Q - Q_1}{A_1} \qquad \text{......... (3)}$$

$$\frac{dH_2}{dt} = \frac{Q_1 - Q_2}{A_2} \qquad \text{......... (4)}$$

In terms of deviation variables, Q_1 and Q_2 can be expressed as:

$$Q_1 = \frac{H_1}{R_1} \qquad \text{.......... (5)}$$

$$Q_2 = \frac{H_2}{R_2} \qquad \text{………. (6)}$$

Taking the laplace transforms and solving the above equations we get:

$$\frac{H_2(S)}{Q(S)} = \frac{1}{\tau_1 S + 1}\frac{R_2}{\tau_2 S + 1} \qquad \text{………(7)}$$

On taking inverse laplace transform, we obtain the theoretical response of the system as:

$$H_2(t) = MR_2\left[1 - \frac{\tau_1 e^{-t/\tau_1} - \tau_2 e^{-t/\tau_2}}{\tau_1 - \tau_2}\right] \qquad \text{……… (8)}$$

Equation (8) represents the theoretical response of a non-interacting two tank liquid level system to a step change of magnitude (M) in the feed rate to tank (1).

7.c EXPERIMENTAL PROCEDURE:

7.c.1 STARTING PROCEDURE:

7.c.1.1 Close all the valvesV_1-V_7.

7.c.1.2 Fill the sump tank with water.

7.c.1.3 Switch ON the power supply and the pump.

7.c.1.4 Wait till the over flow from over head tank.

7.c.1.5 Now open the flow control valveV_1 and adjust the flow rate (10-20 LPH).

7.c.1.6 Partially open the valve V_2 & V_4, and wait till a constant height is achieved by liquid in Tank1 and Tank2.

7.c.1.7 Note down the inlet flow rate and height of Tank1 and Tank2, which is the initial heights.

7.c.1.8 Now increase the inlet flow rate 10-20 LPH (step change) by valve V_1.

7.c.1.9 Simultaneously start the stopwatch and record the heights of liquid level in the Tank1 and Tank2 with time, till next constant height is reached.

7.c.1.10 Note down the final constant heights and flow rate.

7.c.1.11 Repeat the same experiment for different step change.

7.c.2 Closing Procedure:

7.c.2.1 If the experiment is over switch OFF the pump and power supply.

7.c.2.2 Open the valve V_2, V_4, V_6 & V_7..

8.c Observation & Calculation:

8.c.1 Data:

Inner diameter of Tank(1) & (2) D_1	= 0.108 m
Outer diameter of the down comer of Tank(1) & (2) D_2	= 0.022 m

Observations:

Q_i = _____ LPH

Q_f = _____ LPH

h_{1i} = _____ cm

h_{2i} = _____ cm

8.c.2 Observation Table:

S.No	t (sec)	h_1 (cm)	h_2 (cm)

8.c.3 Calculations:

$$M = \frac{Q_f - Q_i}{1000 \times 3600} \quad (m^3/sec)$$

h_{1f} = _________ (cm) [Final value of h_1]

$$H_1 = \frac{h_{1f} - h_{1i}}{100} \quad (m)$$

H_{2f} = _________ (cm) [Final value of h_2]

$$H_2 = \frac{h_{2f} - h_{2i}}{100} \quad (m)$$

$$R_1 = \frac{H_1}{M} \text{ (sec/m}^2\text{)}$$

$$R_2 = \frac{H_2}{M} \text{ (sec/m}^2\text{)}$$

$$A_1 = \frac{\pi}{4}(D_1^2 - D_2^2) \text{ (m}^2\text{)}$$

$$A_2 = \frac{\pi}{4}(D_1^2 - D_2^2) \text{ (m}^2\text{)}$$

$$\tau_1 = A_1 \times R_1 \text{ (sec)}$$

$$\tau_2 = A_2 \times R_2 \text{ (sec)}$$

$$\left[\frac{H_2}{MR_2}\right]_{exp} = \frac{h_2 - h_{2i}}{MR_2 \times 100}$$

$$\left[\frac{H_2}{MR_2}\right]_{the} = 1 - \frac{\tau_1 e^{\frac{-t}{\tau_1}} - \tau_2 e^{\frac{-t}{\tau_2}}}{\tau_1 - \tau_2}$$

CALCULATION TABLE			
S. No.	**t (sec)**	$\left[\frac{H_2}{MR_2}\right]_{exp}$	$\left[\frac{H_2}{MR_2}\right]_{the}$

Plot a graph of $\left[\frac{H_2}{MR_2}\right]_{exp}$ vs t and $\left[\frac{H_2}{MR_2}\right]_{the}$ vs t

9.c NOMENCLATURE:

Nom	Column Heading	Units	Type
A_1	Cross-sectional area of Tank(1)	m^2	Calculated
A_2	Cross-sectional area of Tank(2)	m^2	Calculated
D_1	Inner diameter of Tank(1) &(2)	m	Given

D_2	Outer diameter of the down comer for Tank (1) & Tank (2)	m	Given
H_1	Height difference of water in Tank(1)	m	Calculated
H_2	Height difference of water in Tank(2)	m	Calculated
$\left[\frac{H_2}{MR_2}\right]_{exp}$	Experimental response	*	Calculated
$\left[\frac{H_2}{MR_2}\right]_{the}$	Theoretical response	*	Calculated
h_1	Height of water in the Tank(1)	cm	Measured
h_{1f}	Maximum value of height of water in the Tank(1) h_1	cm	Calculated
h_{1i}	Initial height of water in the Tank(1)	cm	Measured
h_2	Height of water in the Tank(2)	cm	Measured
h_{2f}	Maximum value of height of water in the Tank(2) h_2	cm	Calculated
h_{2i}	Initial height of water in the Tank(2)	cm	Measured
M	Magnitude of step change	m^3/sec	Calculated
Q_f	Final inflow to the Tank(1)	LPH	Measured
Q_i	Initial inflow to the Tank(1)	LPH	Measured
R_1	Valve resistance of the Tank(1)	sec/m^2	Calculated
R_2	Valve resistance of the Tank(2)	sec/m^2	Calculated
t	Time	sec	Measured
τ_1	Time constant for Tank(1)	sec	Calculated
τ_2	Time constant for Tank(2)	sec	Calculated

* Symbols are unit less.

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Do not run the apparatus if power supply is less than 200 volts & more than 220 volts.

10.2 Always keep apparatus free from dust.

10.3 To prevent clogging of moving parts, run pump at least once in a fortnight.

10.4 Always use clean water.

10.5 If apparatus will not in use more than one month, drain the apparatus completely.

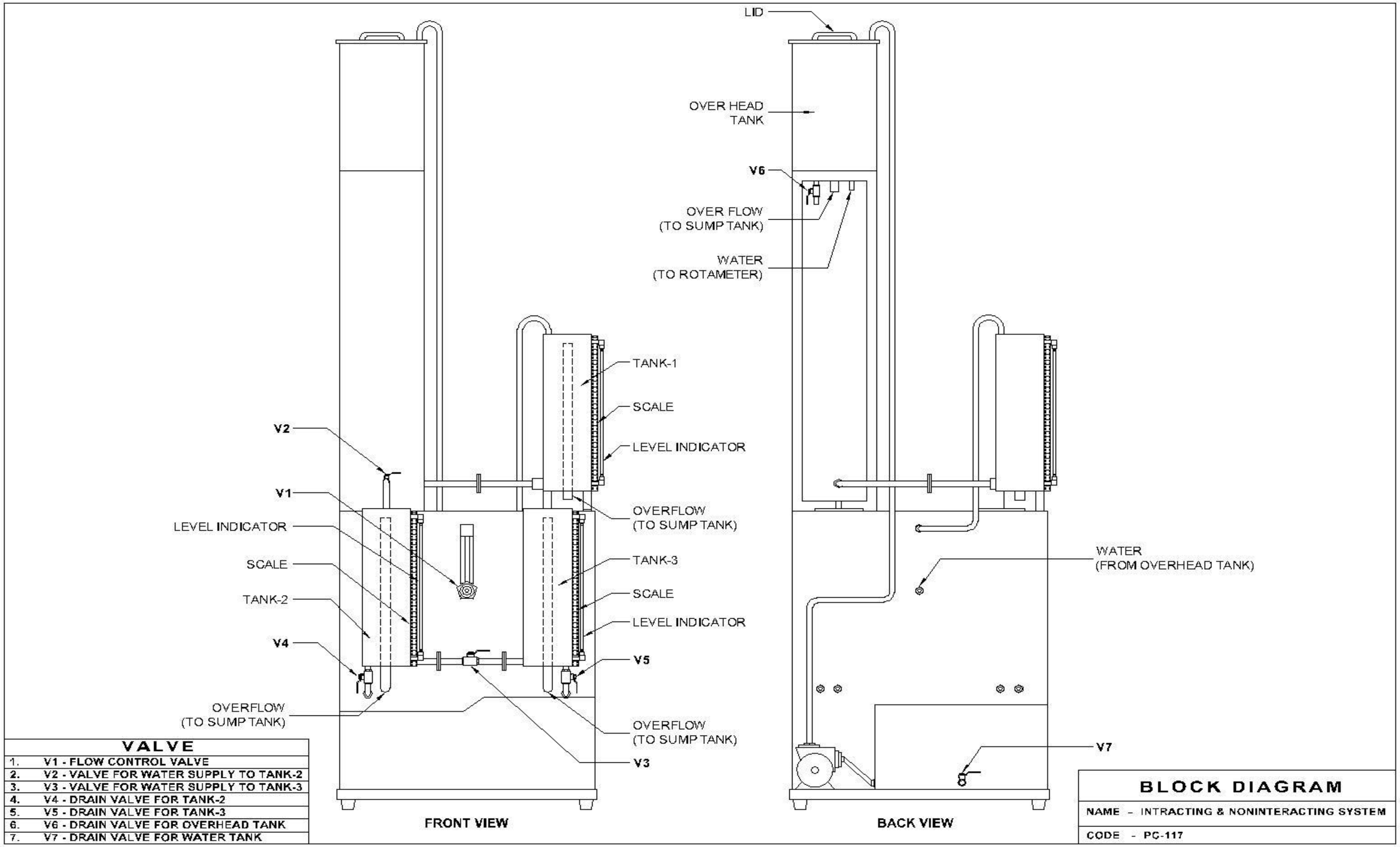
11. TROUBLESHOOTING:

11.1 If pump gets jam, open the back cover of pump and rotate the shaft manually.

12. REFERENCES:

12.1 Coughanowr, Donald R. (1991). *Process Systems Analysis and Control.* 2nd Ed. ND: Mc Graw-hill International. pp 64-66, 80-86.

13. BLOCK DIAGRAM:



FLAPPER NOZZLE SYSTEM

(MISC)

Engineering Growth Connection

Foreword

Welcome to the fast growing family of K.C. product owners. We appreciate your interest in us and thank you for buying our product.

You have chosen the finest quality product in the market which is produced using latest techniques and has underwent strict quality control tests. It is a product that we are proud to build and you are proud to own it.

Our products are easy to understand and operate. They are excellent for students who are trying to gain practical knowledge through experiments.

However your comfort and safety are important to us, so we want you have an understanding of proper procedure to use the equipment. For the purpose, we urge you to read and follow the step-by-step operating instructions and safety precautions in this manual. It will ensure that your favourite product delivers reliable, superior performance year after year.

This manual includes information for all options available on this model. Therefore, you may find some information that does not apply to your equipment.

All information, specifications and illustrations in this manual are those in effect at the time of printing. We reserve the right to change specifications or design at any time without notice.

Customer satisfaction is our primary concern. Feel Free to contact us for any assistance. So what are you waiting for, roll up your sleeves and let us get down to work!

K.C. Engineers Pvt. Ltd.

Important Information About This Manual

Reminder for Safety

Modification on Equipment:

This equipment should not be modified. Modification could affect its performance, safety or disturbance. In addition damage or performance problems resulting from modification may not be covered under warranties.

Precautions and Maintenance:

This is used to indicate the presence of a hazard that could cause minor or moderate personal injury or damage to your equipment. To avoid or reduce the risk, the procedures must be followed carefully.

Contents

FLAPPER NOZZLE SYSTEM

1. OBJECTIVE:

To Study the operation of Flapper Nozzle Trainer System.

2. AIM:

To determine the output characteristics of Flapper Nozzle Trainer System.

3. INTRODUCTION:

The Flapper Nozzle trainer is a pneumatic controlled system operates with air of fixed pressure. This flapper nozzle trainer system helps in understanding the conversion of mechanical motion to pressure signal. The main role of flapper nozzle lies in its ability to generate a large output air pressure, by placing a small obstruction at the orifice (at the nozzle) of an incoming pneumatic signal. This trainer is intended to demonstrate what a flapper nozzle is, and how it is used in typical pneumatic installations.

4. THEORY:

The Flapper Nozzle trainer is a pneumatic system. The air at fixed pressure enters a constriction (a partial obstruction) in its delivery path and enters a nozzle. The opening of the nozzle is larger than the constriction. When the flapper is moved away from the nozzle, the pressure at the nozzle falls to a low value. When the flapper is moved close to the nozzle, the pressure at the nozzle rises to the supply pressure. This pressure is now applied to a pressure amplifier, which in turn moves a beam. The purpose of this beam is to demonstrate the utility of a flapper nozzle experiment. The displacement of this moving beam is proportional to the pressure developed due to the positioning of the flapper from the nozzle.

5. DESCRIPTION:

Flapper Nozzle Trainer System mainly consists of flapper assembly, nozzle assembly, micrometer, air pressure regulator, pressure gauge, all mounted on a suitable base plate. Micrometer is provided for application of liner displacement to flapper and pressure gauge is provided for output pressure measurement.

6. Utilities Required:

6.1 Continuous Air supply, @ 2 LPM at 4 Bar.

6.2 Floor Area Required: 1 m x 0.5 m.

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Connect air supply to the set up.

7.1.2 Set the flapper plate at the outlet of the nozzle.

7.1.3 Start the air supply from the air supply source.

7.1.4 Regulate the inlet pressure with the help of air regulator within the range of 1 to 3 kg/cm^2.

7.1.5 Note the pressure gauge Reading at inlet and at the nozzle.

7.1.6 Note down the reading of micrometer.

7.1.7 Give Movement to the thimble of micrometer (say 0.1 mm).

7.1.8 Note the pressure gauge Reading at inlet and at the nozzle.

7.1.9 Note down the reading of micrometer.

7.1.10 Repeat the experiment for different displacement of flapper plate.

7.1.11 Repeat the experiment for different inlet pressure by pressure regulator.

7.2 Closing Procedure:

7.2.1 When the experiment is over, remove air supply on air regulator.

7.2.2 Close the micrometer completely.

8. Observation & Calculation:

8.1 Observation Table:

Sr.No	P_i (Kg/cm^2)	Po (Kg/cm^2)	X (mm)
1			
2			
3			
4			
5			

8.2 Calculations:

Plot The Graph between the P_o and X .

9. Nomenclature:

Nom	Heading	Units	Type
P_i	Inlet Air Supply Pressure	Kg/cm^2	Measured
P_0	Output pressure	Kg/cm^2	Measured
X_i	Displacement of micrometer	mm	Measured

10. Precaution & Maintenance Instructions:

10.1 Never run the System above 4 kg/cm^2 air pressure.

10.2 Always keep this set up free from dust.

11. Troubleshooting:

11.1 If air compressor is used as the air supply source then maintain the air pressure by switching it On, before taking reading.

11.2 If air pressure is not proper, check the air supply source.

12. REFERENCES:

12.1 S.K.Singh. "Industrial Instrumentation and Control". TATA Mc Graw Hill. pp 504-505.

FLOW CONTROL TRAINER

(PC-104)

Foreword

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Contents

FLOW CONTROL TRAINER

1. OBJECTIVE:

To study the operation of Flow Control Trainer.

2. AIM:

2.1 To study the open loop or manual control.

2.2 To study the proportional control.

2.3 To study the Two mode (P+I) control.

2.4 To study the Two mode (P+D) control.

2.5 To study the Three mode (PID) control.

2.6 To study the tuning of controller (Open loop method) using Zeigler-Nichols method.

2.7 To study the stability of the system using the BODE PLOT.

2.8 To study the autotuning of controller.

3. INTRODUCTION :

Currently, the PID algorithm is the most common control algorithm used in industry. Often, people use PID control processes that include heating and cooling systems, fluid flow monitoring, flow control and temperature control. In PID control, you must specify a process variable and a set point. The process variable is the system parameter you want to control such as temperature, pressure and flow rate and the set point is the desired value for the parameter you are controlling. A PID controller determines a controller output value, such as the heater power or valve position. The controller applies the controller output value to the system, which in turn drives the process variable towards the set point value.

CONTROL SYSTEM:

The control system is that means by which any quantity of interest in a machine, mechanism or equipment is maintained or altered in accordance with a desired manner. Control system is of two types: -

OPEN LOOP CONTROL SYSTEM:

It is shown in figure1. Any physical system, which doesn't automatically correct for variation in its output, is called open loop system. In these systems, the output remains constant for a constant input signal provided the external; conditions remain unaltered. The output may be changed to any desired value by appropriately changing the input signal but variations in external or internal parameters of the system may cause the output to vary from the desired value in an uncontrolled fashion. The open loop control is, therefore, satisfactory only if such fluctuations can be tolerated or system components are designed and constructed so as to limit parameter variations and environmental conditions as well controlled.

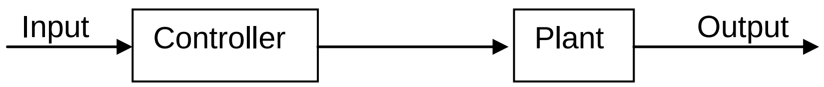


Fig. 1: Open Loop Control System

It is important to note that the fundamental difference between an open and closed loop control system is that of a feedback action. Consider, for example, traffic control system for regulating the flow of traffic at the crossing of two roads. The system will be termed open loop if red and green lights are put on by a timer mechanism set for predetermined fixed intervals of time. It is obvious that such an arrangement takes no account of varying rates of traffic flowing to the road crossing from the two directions. If on the other hand a scheme is introduced in which the rate of traffic flow along both directions are measured and are compared and the difference is used to control the timings of the red and green lights, a closed-loop system results. Thus, the concept of feedback can be usefully employed to traffic control.

Unfortunately, the feedback, which is the underlying principle of most control systems, introduces the possibility of undesirable system oscillations.

CLOSED LOOP CONTROL SYSTEM:

A closed loop control system consists of a process and a controller that automatically adjusts one of the inputs to the process in response to a signal feedback from the process output. The performance of the system can be judged by the transient response of the output to specific changes in the input. The change in the input may be a change in set point or a change in any one of the several load variables. If the purpose of the control system is to make the process follow changes in set point as closely as possible, the operation is called "servo-operation". The term "regulator operation" is used when the main problem is to keep the output almost constant in spite of changes in load. The designer must be aware of the purpose of the control system, since the system that gives optimum servo-operation will generally not be the best for regulator operation.

CONTROLLED VARIABLE & MANIPULATED VARIABLE:

The controlled variable is the quantity or condition that is measured and controlled. The-manipulated variable is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable. Normally, the controlled variable is the output of the system. Control means measuring the value of the controlled variable of the system and applying the manipulated variable to the system to correct or limit deviation of the measured value from a desired value.

PLANT:

A plant may be a piece of equipment, perhaps just a set of machine parts functioning together, the purpose of which is to perform a particular operation.

PROCESSES:

A process may be defined as natural, progressively continuing operation or development marked by a series of gradual changes that succeed one another in relatively fixed way and leads toward a particular result or end; or an artificial or voluntary, progressively continuing operation that consists of a series of controlled actions or movements systematically directed towards a particular result.

SYSTEMS:

A system is a combination of components that act together and perform a certain objective. A system is not limited to physical ones. The concept of system can be applied to abstract, dynamic phenomena such as those encountered in economics. The word system should therefore, be interpreted to imply physical, biological, economic and the like systems.

DISTURBANCES:

A disturbance is a signal that tends to adversely affect the value of the output of a system. If a disturbance is generated within the system, it is called internal, while the external disturbance is generated outside the system and is an input.

FEEDBACK CONTROL:

Feedback control refers to an operation that, in the presence of disturbance tends to reduce the difference between the output of a system and some reference input and does so on the basis of this difference. Here only the unpredictable or known disturbances can always be compensated for within the system.

DELAY TIME:

It is the time required for the response to reach 50% of the final value in first attempt. It is represented by td.

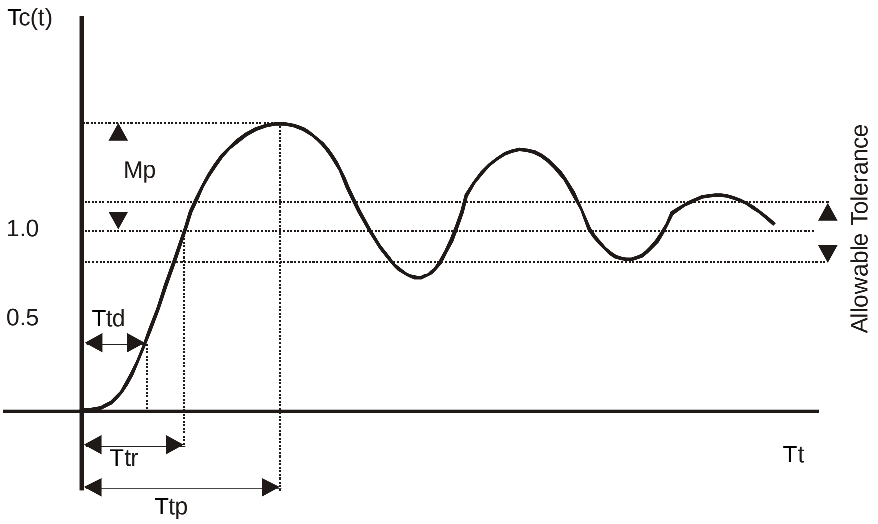


Figure : 2

RISE TIME:

It is the time required for the response to rise from 10% to 90% of the final value for over damped systems and 0 to 100% of the final value for under damped systems.

PEAK TIME:

It is the time required for the response to reach the peak of time response or the peak overshoot.

PEAK OVERSHOOT M_P:

It indicates the normalized difference between the time response peak and the steady output and is defined as:

Peak percent overshoot = [Ctp – C∞/C∞] x 100 (%)

SETTLING TIME:

It is the time required for the response to reach and stay within a specified tolerance band (Usually 2% to 5%) of its final value. It is represented by ts in figure 2.

THE CHARACTERISTICS OF P, I & D CONTROLLERS:

A proportional controller will have the effect of reducing the rise time and will reduce, but never eliminate, the steady state. An integral control will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers K_c, T_i, and T_d on a closed-loop system are summarized in the table shown below.

Controller Response	Rise Time	Overshoot	Settling Time	Steady-State Error
K_c	Decrease	Increase	Small Change	Decrease
T_i	Decrease	Increase	Increase	Eliminate
T_d	Small Change	Decrease	Decrease	Small Change

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

GENERAL TIPS FOR DESIGNING A P.I.D. CONTROLLER:

When you are designing a PID controller for a given system, follow the steps shown below to obtain a desired response.

- Obtain an open-loop response and determine what needs to be improved.
- Add a proportional control to improve the rise time.
- Add an integral control to eliminate the steady-state error.
- Add a derivative control to improve the overshoot.
- Adjust each of Kc, T_i, and T_d until you obtain a desired overall response.

Lastly, please keep in mind that you do not need to implement all three controllers (proportional, derivative, and integral) into a single system, if not necessary. For example, if a PI controller gives a good enough response, then you don't need to implement derivative controller to the system. Keep the controller as simple as possible to obtain the system with no overshoot, fast rise time, and no steady-state error.

4. THEORY:

PART-I: OPEN LOOP CONTROL SYSTEM

If the main variable is not used to adjust any of the inputs automatically, the system is an open loop control system. It is alternative method of control would be to regulate all the inputs to the process by the use of separate controller, metering pums or manually adjusted valves. With an open loop system, every input , variable must be kept constant to keep the output constant.

In these systems, the output remains constant for a constant input signal provided the external; conditions remain unaltered. The output may be changed to any desired value by appropriately changing the input signal but variations in external or internal parameters of the system may cause the output to vary from the desired value in an uncontrolled fashion. The open loop control is, therefore, satisfactory only if such fluctuations can be tolerated or system components are designed and constructed so as to limit parameter variations and environmental conditions as well as controlled, whereas in case of closed loop system, the controlled variable is measured and compared with reference input and the difference is used to control the elements.

Open loop control is used for some simple processes where close control is not needed or where the input variables do not change appreciably. At the other extreme, open-loop control may be used for complex process where feedback control is not good enough.

PART-II: PROPORTIONAL CONTROL

The proportional controller produces an output signal that is proportional to the error e. This action may be expressed as:

$$P = K_C \times e + P_S \qquad \text{-------------------------(1)}$$

In order to get steady operation when the disturbances are absent, the controlled variable must be a continuous function of error. With proportional control, the most widely used type; the controller output is a linear function of the error signal. The controller gain is the fractional change in output divided by the fractional change in input.

Where P is output signal from controller, K_C is proportional gain, e is error and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In a controller having adjustable gain, the value of the gain K_C can be varied by moving knob in the controller. The value of p_s is the value of the output signal when e is zero, and in most controller p_s can be adjusted to obtain the required output signal when the control system is at steady state and e = 0.

PART-III: TWO MODE (PROPORTIONAL+INTEGRAL) CONTROL

This mode of control is described by the following relationship:

$$P = K_C \times e + \frac{K_C}{T_i} \int e dt + P_S \qquad \text{-------------------------(1)}$$

Where P is output signal from controller, K_C is gain, e is error, T_i is time integral and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e, another term that is proportional to the integral of the error. The value of K_C and T_i may be varied by two knob in the controller.

There is no offset with the integral control, since the output keeps changing as long as any error persists. However, the initial response to an error is slow and proportional control is ordinarily used with integral control. The integral action corrects for the offset that usually occurs with proportional control only, and the effect is similar to manual adjustment or resetting of the set point after each load change. The terms “reset action” and “reset time” are widely used to characterize the integral action of a proportional – integral controller.

$$P = K_C(e + \frac{1}{T_i}\int edt) \qquad \text{------------------------(2)}$$

A small reset time corresponds to an increase in the integral action. With P action the measured value will not necessarily become equal to the set point and a deviation will usually be present. The control algorithm that applies changes in output as long as deviation exits, so as to bring the deviation to zero is called integral action. With integral action the parameters that determines how fast the output will change in corresponding to some amount.

PART-IV: TWO MODE (PROPORTIONAL+DERIVATIVE) CONTROL

This mode of control may be represented by following expression:

$$P = K_C \times e + K_C T_d \frac{de}{dt} + P_S \qquad \text{------------------------(1)}$$

Where P is output signal from controller, K_C is gain, e is error, T_d is derivative time and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e to the another term that is proportional to the derivative of the error. The value of K_C and T_d may be varied by two knob in the controller.

Derivative action is often added to proportional control to improve the response of slow systems. By increasing the output when the error is changing rapidly, derivative action anticipates the effect of large load changes and reduces the maximum error.

Larger the derivative time larger is the action. Smaller is the proportional band the larger is the derivative action.

PART-V: THREE MODE (PROPORTIONAL+INTEGRAL+DERIVATIVE) CONTROL

This mode of control is described by the following relationship

$$P = K_C \times e + \frac{K_C}{T_i}\int edt + K_C \times eT_d \frac{de}{dt} + P_S \qquad \text{---------------------} \quad (1)$$

Where P is output signal from controller, K_C is gain, e is error, T_i is time integral, T_d is derivative time and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e to the another two term that is proportional to the derivative of the error and integral of the error. The value of K_C T_i and T_d may be varied by three knob in the controller.

There is no offset with the integral control, since the output keeps changing as long as any error persists. However, the initial response to an error is slow and proportional control is ordinarily used with integral control.

Derivative action is often added to proportional control to improve the response of slow systems. By increasing the output when the error is changing rapidly, derivative action anticipates the effect of large load changes and reduces the maximum error.

PART-VI: TUNING OF CONTROLLER (OPEN LOOP METHOD)

This method is basically used to calculate the value of P, I, D using the open loop or manual control method. The values of P, I, D are selected in such a way that the error or the difference between the SP and PV should become equal to zero.

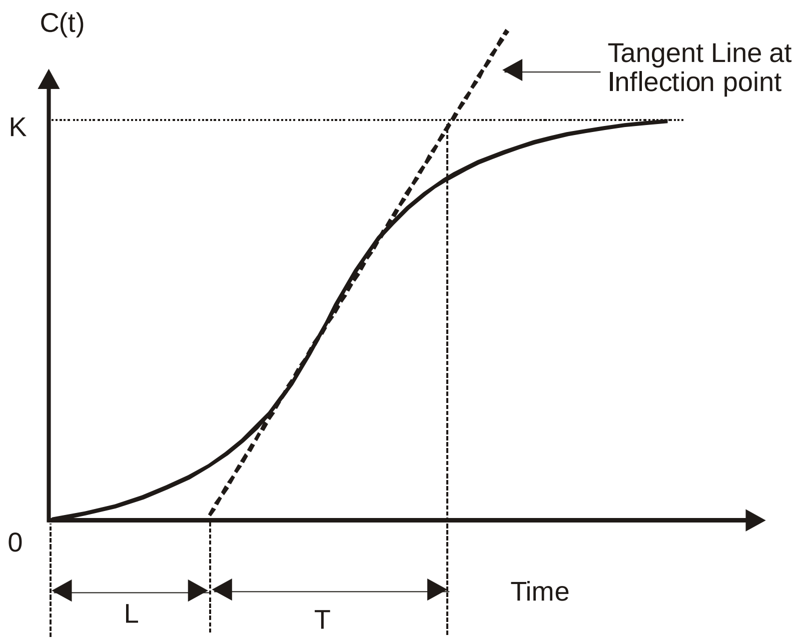


Figure : 7

S Shaped Response Curve

Since we are not given with the plant equation. So the process is assumed to be of first order with steady state gain K_C integral time T_i and derivative time T_d. The step response i.e. process reaction curve, allows to obtain the approximate values of each parameter. With the feedback loop open, a step response is applied to manipulated variable and the values of P, I and D are estimated.

The delay time T and time constant T_P are determined by drawing a tangent line at the inflection point of a S-shaped curve and determining the intersections of the tangent line with the time axis and line c (t) = K as shown in the figure obtained by performing the experiment.

For P, PI and PID controller the parameters are calculated as follows:

Mode	**K_C**	**T_i**	**T_d**
P	T_P/T	INFINITY	0
P+I	0.9 T_P/T	T/0.3	0
P+I+D	1.2 T_P/T	2T	0.5T

PART-VII: STABILITY OF SYSTEM (BODE PLOT)

For our purposes, a stable system will be defined as one for which the output response is bounded for all bounded inputs. A system exhibiting an unbounded response to a bounded input is unstable. This definition, although some what loose is adequate for most of the linear systems and simple inputs that we shall study.

Abounded input function is a function of time that always falls within certain bounds during the course of time. For example the step function and sinusoidal functions are bounded inputs.

The Bode diagrams constitute a convenient way to represent the frequency response characteristics of a system. As we can see from the amplitude ratio and the phase shift of the ultimate response of a system are functions of the frequency ω.The Bode diagram consists of a pair of plots showing;

a. How the logarithm of the amplitude ratio varies with frequency.
b. How the phase shift varies with frequency.

In order o cover a large range of frequencies, we use a logarithmic scale for the frequencies.

For first order system:

For a first order system we have seen that

Amplitude ratio $A.R. = \frac{K_p}{\sqrt{1+\omega^2\tau^2}}$

Phase lag $\phi = \tan^{-1}(-\tau\omega)$

For convenience, since τ is constant, regard $\tau\omega$ as the independent variable instead of ω. The plot of log AR versus log $\tau\omega$ and plot of ϕ versus $\tau\omega$ is known as Bode plot.

In case of Bode plot, the crossover frequency at which the phase lag is 180^0, is noted as w_{CO} on the Bode diagram. At this frequency AR is A. If A exceed unity, we know from the Bode criterion that the system is unstable.

If A is less than unity then the system is stable.

PART-VIII: AUTOTUNING OF CONTROLLER

Auto-tuning is automatic tuning of controller parameter in one experiment. It is common that commercial controllers offer auto-tuning. The operator starts the auto-tuning via some button or menu choice on the controller. The controller then executes automatically a pre-planned experiment on the uncontrolled process or on the control system depending on the auto-tuning method implemented.

Auto-tuning based on relay tuning:

The relay method for tuning PID controllers is used as the basis of auto-tuning in some commercial controllers. The principle of this method is as follows:

When the auto-tuning phase is started, a relay controller is used as controller in the control loop. This controller creates automatically sustained oscillations in control loop, and forms the amplitude and the period of these oscillations proper PID controller parameters are calculated by an algorithm in the controller.

Use auto-tuning to improve performance. Often many controllers are poorly tuned. As a result some controllers are too aggressive and some are too sluggish. PID controllers are difficult to tune, when you do not know the process dynamics or disturbance. In this case use auto-tuning.

For most systems the nonlinear relay characteristic generates a limiting cycle from which the auto-tuning algorithm identifies the relevant information needed for PID tuning. If the existing controller is proportional only the auto-tuning algorithm identifies the ultimate gain K_u and ultimate period P_u. If the existing model is PI or PID the auto-tuning algorithm identifies the dead time T and time constant T_P, which are two parameters in the integral plus dead time models.

Here we use Ziegler-Nichols heuristic method for determining the parameters of a PID controller. When you auto-tune select one of the following three types of loop performance:

- Fast (1/4 damping ratio)
- Normal (some overshoot)
- Slow (Little overshoot)

Tuning formula under P-only control (fast)			
Mode	**K_C**	**T_i**	**T_d**
P	0.5 K_u		
P+I	0.45 K_u	P_u/1.2	
P+I+D	0.6 K_u	P_u/2	P_u/8

Tuning formula under P-only control (normal)			
Mode	**K_C**	**T_i**	**T_d**
P	0.2 K_u		
P+I	0.18 K_u	0.8 P_u	
P+I+D	0.25 K_u	0.5 P_u	0.12 P_u

Tuning formula under P-only control (slow)			
Mode	**K_C**	**T_i**	**T_d**
P	0.13 K_u		
P+I	0.13 K_u	0.8 P_u	
P+I+D	0.15 K_u	0.5 P_u	0.12 P_u

Tuning formula under PI or PID control (fast)			
Mode	**K_C**	**T_i**	**T_d**
P	T_P/T		
P+I	$0.9\ T_P/T$	0.33 T	
P+I+D	$1.1\ T_P/T$	2.0 T	0.5 T

Tuning formula under PI or PID control (normal)			
Mode	**K_C**	**T_i**	**T_d**
P	$0.44\ T_P/T$		
P+I	$0.4\ T_P/T$	5.33 T	
P+I+D	$0.53\ T_P/T$	4.0 T	0.8 T

Tuning formula under PI or PID control (slow)			
Mode	**K_C**	**T_i**	**T_d**
P	$0.26\ T_P/T$		
P+I	$0.24\ T_P/T$	5.33 T	
P+I+D	$0.32\ T_P/T$	4.0 T	0.8 T

5. DESCRIPTION:

The set-up consists of water tank. DP transmitter is given to transmit the value of flow. Rotameter is given for flow measurement of water. Control valve is for flow control. Pressure regulator and pressure gauge is for set the pressure and for measurement of pressure. Safety valve and pneumatic control valve is given. Micro processer controller with PID setting, auto tuning, and fully programmable with serial communications is provided. Software is provided with facility of data logging, trend plot and offline analysis & printing.

6. Utilities Required:

6.1 Compressed Air Supply: 1 CMH @ 3 bar.

6.2 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.3 Computer: Pentium IV with CD drive, Windows XP version and MS office XP Pre- Loaded. One RS 232 serial communication port free for interfacing unit.

6.4 Table for set-up support.

7. Experimental Procedure:

7.a Start Up:

7.a.a Close all the valves V_1-V_6

7.a.b Ensure that switches given on the panel are at OFF position.

7.a.c Open valve V_4 and V_5 release air from water line and the close them.

7.a.d Open the valve V_1 and start the supply of air and set the pressure by adjust the pressure gauge and regulator..

7.a.e Connect the water supply.

7.a.f Switch ON the power supply.

7.a.g Switch ON the pump.

7.a.h Open the valve V_2 completely.

7.a.i Switch ON the computer and interface unit.

7.a.j Select the Auto mode to perform the experiment automatically and in Manual mode to change the values manually.

7.a.k Set the set point through controller.

7.a.l Valve V_3 will be use for create disturbance.

7.b Shut Down:

7.b.a Exit from the software.

7.b.b Close the valve V_1 and V_2 and open valve V_3.

7.b.c Switch OFF the interfacing unit.

7.b.d Switch OFF the pump and compressed air supply.

7.b.e Switch OFF the power supply.

7.b.f Drain the water tank by open the valve V_6.

7.a.1 Starting Procedure (For Open Loop Control):

7.a.1.1 Start up the setup as mentioned above.

7.a.1.2 Select the manual mode.

7.a.1.3 Set the controller output to 100%.

7.a.1.4 Apply a change to the controller output and wait for the process variable to reach the steady state.

7.a.1.5 Record the set point and process variable.

7.a.1.6 Repeat the experiment for different value of controller output and measure the process variable at steady state.

7.b.1 Closing Procedure (For Open Loop Control):

7.b.1.1 When experiment is over shut down the apparatus as mentioned in the starting.

7.a.2 Starting Procedure (For Proportional Control):

7.a.2.1 Start up the set up as mentioned previously.

7.a.2.2 Select the controller in AUTO mode.

7.a.2.3 Set the value of K_C as high as possible.

7.a.2.4 Observe the process and the output response.

7.a.2.5 If output response doesn't shows cycling, adjust the value of K_C to half of its previous value.

7.a.2.6 Repeat steps 4 and 5 until cycling is observed.

7.a.2.7 Then increase the value of K_C to twice its value and observe the Output response.

7.a.2.8 Repeat the above step until cycling is observed.

7.a.2.9 Record the value of K_C at which you observe the oscillations and record the overshoot.

7.a.2.10 Now increase the value of K_C in steps and observe the corresponding overshoots.

7.a.2.11 Compare the relative overshoot with the value of K_C.

7.b.2 Closing Procedure (For Proportional Control):

7.b.2.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.3 Starting Procedure (For Proportional+Integral Control):

7.a.3.1 Start up the setup as mentioned previously.

7.a.3.2 Select the controller in AUTO mode.

7.a.3.3 Select a value of set point.

7.a.3.4 Select a value of K_C and T_i as high as possible.

7.a.3.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the corresponding values of K_C or T_i so as to make PV equal to SP.

7.a.3.6 Then observe the output response curve.

7.b.3 Closing Procedure (For Proportional+Integral Control):

7.b.3.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.4 Starting Procedure (For Proportional+Derivative Control):

7.a.4.1 Start up the setup as mentioned previously.

7.a.4.2 Select the controller in AUTO mode.

7.a.4.3 Select a value of set point.

7.a.4.4 Select some value of K_C and the value of T_d to the minimum value.

7.a.4.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the value of T_d to make PV equal to SP.

7.a.4.6 Then observe the output response curve.

7.b.4 Closing Procedure (For Proportional+Derivative Control):

7.b.4.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.5 Starting Procedure (For Pid Control):

7.a.5.1 Start up the setup as mentioned previously.

7.a.5.2 Select the controller in AUTO mode.

7.a.5.3 Select a value of set point.

7.a.5.4 Select some value of K_C, T_i and T_d.

7.a.5.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the corresponding values of K_C, T_i and T_d so as to make PV equal to SP.

7.a.5.6 Using trial and error method by select the proportional gain and integral time, this gives a satisfactory response to step change in set point.

7.a.5.7 Set the derivative time to a non-zero value and carry out the above steps for different derivative time values.

7.b.5 Closing Procedure (For Pid Control):

7. b.5.1 After experimentation shut down the setup as mentioned earlier.

7.a.6 Starting Procedure (For Tuning Of Controller (Open Loop Method)):

7.a.6.1 Start up the set up as mentioned.

7.a.6.2 Select open loop option for control.

7.a.6.3 Select the value of the set point to some desired value.

7.a.6.4 Apply a 20-30% change to controller output. Record the step response. Wait for the steady state.

7.a.6.5 Start data logging and from the readings draw a step response curve.

7.a.6.6 Calculate the value of T_P and T.

7.a.6.7 From this, calculate the values of PID controller settings from the table.

7.b.6 Closing Procedure (For Tuning Of Controller (Open Loop Method)):

7.b.6.1 After experimentation, shut down the set up.

7.a.7 Starting Procedure (For Stability Of System (Bode Plot)):

7.a.7.1 Rewrite the sinusoidal transfer function in the time constant form.

7.a.7.2 Identify the corner frequencies associated with each factor of the transfer function.

7.a.7.3 Knowing the corner frequency, draw the asymptotic magnitude plot. This plot consists of a straight line segments with the line slope changing at each corner frequency by +20 db/decade for a zero and –20 db/decade for a pole For a complex conjugate zero or pole the slope changes by +/- 40 db/decade.

7.a.7.4 Draw a smooth curve through the corrected point such that it is asymptotic to the straight-line segments. This gives the actual log-magnitude plot.

7.a.7.5 Draw the phase angle curve for each factor and add them algebraically to get the phase plot.

7.a.7.6 The ultimate gain value i.e. Wco is that value when the phase angle curve crosses the 180 degree line and the corresponding gain value is called the ultimate gain i.e. Ku.

7.a.7.7 By using these two gains the other parameters that are the values of P, I and D are calculated from the table given in the theory part of the Zeigler's closed loop method.

7.b.7 Closing Procedure (For Stability Of System (Bode Plot)):

7.b.7.1 After experimentation, shut down the set up.

7.a.8 Starting Procedure (For Autotuning OF Controller):

7.a.8.1 Start up the set up as mentioned previously.

7.a.8.2 Select close loop option for control.

7.a.8.3 Select values of proportional gain disturb the system and observe the transient response.

7.a.8.4 Continue increasing the gain in small steps until the response first exhibits a sustained oscillation.

7.a.8.5 Record the time of oscillation and gain.

7.b.8 Closing Procedure (For Autotuning OF Controller):

7.b.8.1 After experimentation, shut down the set up.

8. Observations & Calculations:

Observation Table (For Open Loop Control System):

S.No.	SP (%)	PV (%)

Observation Table (For Proportional Control):

S.No.	K_C	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table (For Proportional+ Integral Control):

S.No.	K_C	T_i (min)	t (sec)	SP (%)	PV (%)	OP (%)

OBSERVATION TABLE (FOR PROPORTIONAL+ DERIVATIVE CONTROL):

S.No.	K_C	T_d (min)	t (sec)	SP (%)	PV (%)	OP (%)

OBSERVATION TABLE (FOR PROPORTIONAL+INTEGRAL+DERIVATIVE CONTROL):

S.No.	K_C	T_i (min)	T_d (min)	t (sec)	SP (%)	PV (%)	OP (%)

OBSERVATION TABLE (FOR TUNING OF CONTROL(OPEN LOOP METHOD)):

S.No.	t (sec)	PV (%)

OBSERVATION TABLE (FOR STABILITY OF SYSTEM (BODE PLOT)):

S.No.	K_C	t (sec)	w (rad/sec)

OBSERVATION TABLE (FOR AUTOTUNING OF CONTROL):				
S.No.	**P_u (min)**	**K_u**	**T (min)**	**T_P (min)**

CALCULATIONS:

(FOR OPEN LOOP CONTROL SYSTEM):

$$e = SP - PV \ (\%)$$

(FOR PROPORTIONAL CONTROL):

$$e = SP - PV \ (\%)$$

$$P_B = \frac{1}{K_C} \times 100 \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+INTEGRAL CONTROL):

$$e = SP - PV \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+DERIVATIVE CONTROL):

$$e = SP - PV \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+INTEGRAL+DERIVATIVE CONTROL):

$e = SP - PV$ (%)

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR TUNING OF CONTROLLER (OPEN LOOP METHOD)):

$T_P =$ ___________ (min) **[Refer theory PART-VI]**

$T =$ ___________ (min) **[Refer theory PART-VI]**

For P controller

$$K_C = \frac{T_P}{T}$$

For PI controller

$$K_C = 0.9\frac{T_P}{T}$$

$$T_i = \frac{T}{0.3} \text{ (min)}$$

For PID controller

$$K_C = 1.2\frac{T_P}{T}$$

$$T_i = 2T \text{ (min)}$$

$$T_d = 0.5T \text{ (min)}$$

(FOR STABILITY OF SYSTEM):

$$AR = \frac{K_C}{\sqrt{1 + w^2 t^2}}$$

$$\phi = \tan^{-1}(-tw)$$

CALCULATION TABLE:

S.No.	AR	ϕ

Plot the graph of AR vs w on semi log co-ordinates.

Plot the graph of ϕ Vs w on semi log co-ordinates.

$w_{CO} =$ ____________ [at $\phi = 180^0$]

$A = AR$ [at w_{CO}]

(FOR AUTOTUNING OF CONTROLLER):

For P-only control (fast)

For P controller

$K_C = 0.5K_u$

For PI controller

$K_C = 0.4K_u$

$T_i = 0.8P_u$ (min)

For PID controller

$K_C = 0.6K_u$

$T_i = 0.5P_u$ (min)

$T_d = 0.12P_u$ (min)

For P-only control (normal)

For P controller

$K_C = 0.2K_u$

For PI controller

$K_C = 0.18K_u$

$T_i = 0.8P_u$ (min)

For PID controller

$K_C = 0.25K_u$

$T_i = 0.5P_u$ (min)

$T_d = 0.12P_u$ (min)

For P-only control (slow)

For P controller

$K_C = 0.13K_u$

For PI controller

$K_C = 0.13K_u$

$T_i = 0.8P_u$ (min)

For PID controller

$K_C = 0.15K_u$

$T_i = 0.5P_u$ (min)

$T_d = 0.12P_u$ (min)

For PI and PID control (fast)

For P controller

$$K_C = \frac{T_P}{T}$$

For PI controller

$$K_C = 0.9\frac{T_P}{T}$$

$T_i = 0.33T$ (min)

For PID controller

$$K_C = 1.1\frac{T_P}{T}$$

$T_i = 2.0T$ (min)

$T_d = 0.5T$ (min)

For PI and PID control (normal)

For P controller

$$K_C = 0.44\frac{T_P}{T}$$

For PI controller

$$K_C = 0.4\frac{T_P}{T}$$

$T_i = 4.0T$ (min)

For PID controller

$$K_C = 0.32\frac{T_P}{T}$$

$T_i = 4.0T$ (min)

$T_d = 0.8T$ (min

For PI and PID control (slow)

For P controller

$$K_C = 0.26\frac{T_P}{T}$$

For PI controller

$$K_C = 0.24\frac{T_P}{T}$$

$T_i = 5.33T$ (min)

For PID controller

$$K_C = 0.32\frac{T_P}{T}$$

$$T_i = 4.0T \text{ (min)}$$

$$T_d = 0.8T \text{ (min)}$$

9. NOMENCLATURE:

Nom	Column Headings	Units	Type
SP	Set point	%	Measured
PV	Process variable	%	Measured
e	Error	%	Calculated
K_C	Controller gain	*	Measured
t	Time	sec	Measured
P_B	Proportional band	%	Calculated
OP	Output	%	Measured
T_i	Integral time	min	Measured
T_d	Derivative time	min	Measured
K_u	Ultimate gain	*	Measured
P_u	Ultimate period	min	Measured
w	Frequency	*	Measured
AR	Amplitude ratio	*	Calculated
ϕ	Phase angle	*	Calculated
A	Amplitude ratio	*	Calculated
w_{CO}	Cross over frequency	*	Calculated
T	Dead time	min	Measured
T_P	Time constant	min	Measured

* Symbols represent unitless quantity

10. PRECAUTIONS & MENTAINENCE:

10.1 Pressure should not be disturb during the experiment.

10.2 Do not switch OFF the power during experiment.

11. TROUBLESHOOTING:

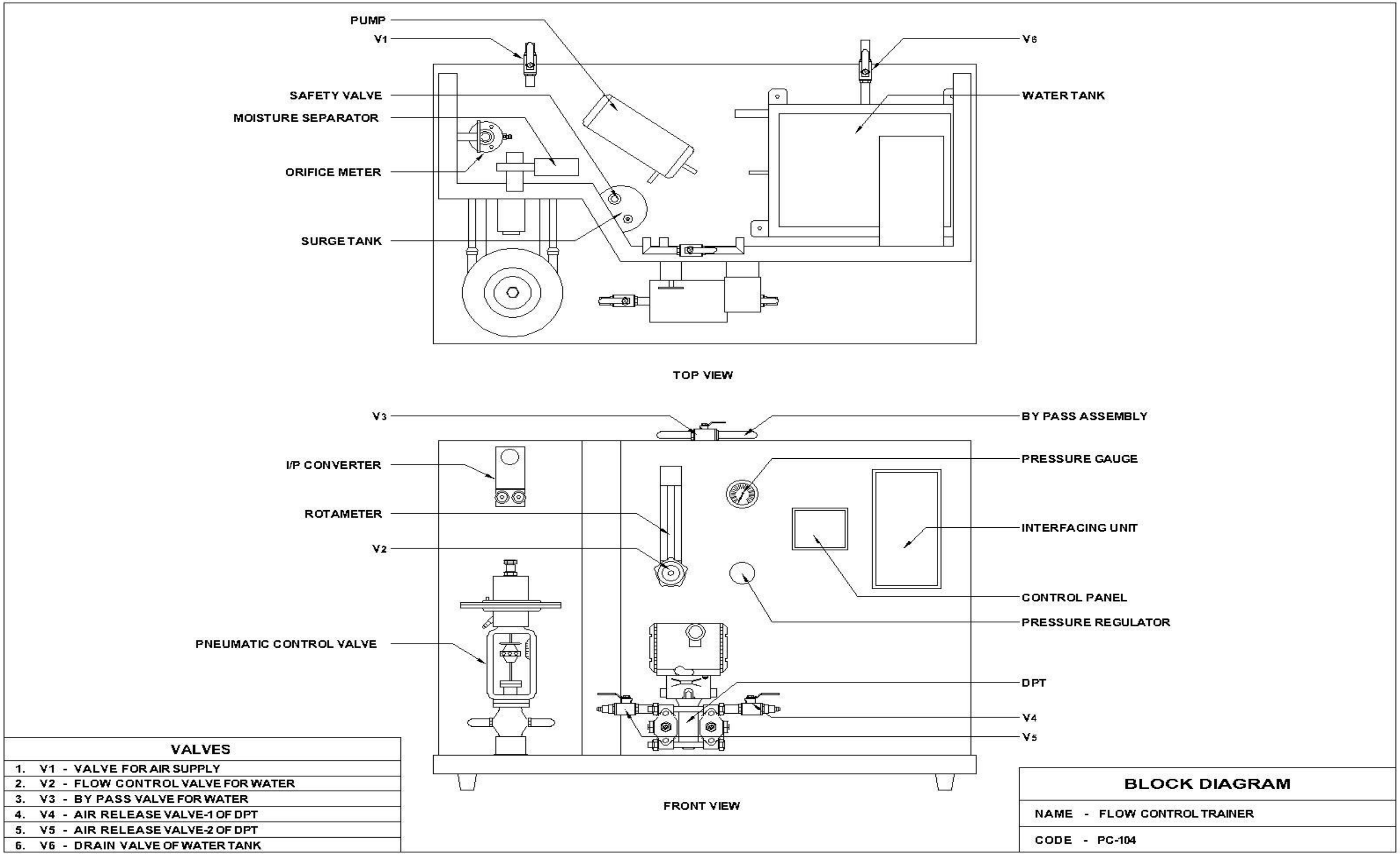
11.1 If rotameter fluctuating more than average then tight the control knob properly.

12. REFERENCES:

12.1 Coughanowr, Donald R. (1991). *Process Systems Analysis and Control.* 2nd Ed. ND: Mc Graw-hill International. pp 128-133, 164-165, 227-230.

12.2 Stephanopoulos, George (2006). *Chemical Process Control*. 1st Ed. ND: Prentice Hall of India Pvt. Ltd. p 243.

13. BLOCK DIAGRAM:



STUDY OF P/I & I/P

CONVERTER (PC-107S)

Foreword

Welcome to the fast growing family of K.C. product owners. We appreciate your interest in us and thank you for buying our product.

You have chosen the finest quality product in the market which is produced using latest techniques and has underwent strict quality control tests. It is a product that we are proud to build and you are proud to own it.

Our products are easy to understand and operate. They are excellent for students who are trying to gain practical knowledge through experiments.

However your comfort and safety are important to us, so we want you have an understanding of proper procedure to use the equipment. For the purpose, we urge you to read and follow the step-by-step operating instructions and safety precautions in this manual. It will ensure that your favourite product delivers reliable, superior performance year after year.

This manual includes information for all options available on this model. Therefore, you may find some information that does not apply to your equipment.

All information, specifications and illustrations in this manual are those in effect at the time of printing. We reserve the right to change specifications or design at any time without notice.

Customer satisfaction is our primary concern. Feel Free to contact us for any assistance. So what are you waiting for, roll up your sleeves and let us get down to work!

K.C. Engineers Pvt. Ltd.

Important Information About This Manual

Reminder for Safety

Modification on Equipment:

This equipment should not be modified. Modification could affect its performance, safety or disturbance. In addition damage or performance problems resulting from modification may not be covered under warranties.

Precautions and Maintenance:

This is used to indicate the presence of a hazard that could cause minor or moderate personal injury or damage to your equipment. To avoid or reduce the risk, the procedures must be followed carefully.

Contents

STUDY OF P/I & I/P CONVERTER

1. OBJECTIVE:

To study the operation of P/I & I/P converter

2. AIM:

2.1 To study the working principle and calibration procedure of P/I converter.

2.2 To study the working principle and calibration procedure of I/P converter.

3. INTRODUCTION:

P/I converter is a device which converts the pressure input of specified range into corresponding specified current output while I/P converter converts the current input of specified range into corresponding specified pressure output.

4. THEORY:

The pressure in the process tank is sensed by the pressure transmitter with the help of pressure sensor fitted in the line. P/I converter converts that accordingly into 4-20mA i.e. 4mA for 0 kg/cm^2 pressure and 20mA for 5 kg/cm^2 pressure.

I/P converter is basically used to convert the current to pressure having a range of 3 to 15 psi, which gives 3 psi at 4 mA and 15 psi at 20 mA. This I/P converter receives the continuous input pressure of more than 15 psi and then converts this pressure into 3 to 15 psi according to the 4 to 20 mA current received by it from the digital indicating controller.

5. DESCRIPTION:

The set up consists of process tank, air pressure regulator, pressure gauges, I/P converter and P/I converter. Gauges are provided to measure pressure of input supply and process tank. Safety valve is provided with process tank for safety. All the piping for air supply is provided.

6. UTILITIES REQUIRED:

6.1 Electricity supply: Single phase, 220 V AC, 50 Hz, 5 Amp.

6.2 Compressed air supply @2CFM at 2kg/cm^2.

6.3 Floor area required: 1.5 m x 0.5 m

7. EXPERIMENTAL PROCEDURE:

7.1(a) STARTING PROCEDURE (P to I):

7.1.1 Connect air supply.

7.1.2 With the help of pressure regulator, give air supply above 20 psi.

7.1.3 Set the desired pressure of process tank with the help of regulator in the range of 0-5 kg/cm^2.

7.1.4 Read the corresponding value of current from digital current indicator.

7.1.5 Repeat experiment for different pressure.

7.1(b) CLOSING PROCEDURE (P to I):

7.1.6 Disconnect the air supply.

7.1.7 Drain air from the process tank with the help of drain valve.

7.2(a) STARTING PROCEDURE (I to P):

7.2.1 Connect air supply.

7.2.2 With the help of pressure regulator, give air supply above 20 psi.

7.2.3 Now set the value of current in the digital current meter in the range of 4-20 mA.

7.2.4 Note down the corresponding pressure reading in the pressure gauge for process tank.

7.2.5 Repeat experiment for different values of current.

7.2(b) CLOSING PROCEDURE (I to P):

7.2.6 Disconnect the air supply.

7.1.6 Drain air from the process tank with the help of drain valve.

8. OBSERVATION & CALCULATION:

8.1 OBSERVATION TABLE (P to I):

S. no	P_a (kg/cm^2)	I_a (mA)

8.2 OBSERVATION TABLE (I to P):

S. no	I_b (mA)	P_a (Psi)

8.2 CALCULATION:

Plot the graph between P_a and I_a.

Plot the graph between I_b and P_b.

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
P_a	Pressure at the process tank	Kg/cm^2	measured
I_a	mA indicator reading	mA	measured
I_b	mA source reading	mA	measured

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 200 volts & more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Always keep the apparatus free from dust.

11. TROUBLESHOOTING:

11.1 If electric panel is not showing the input on the mains light. Check the mains supply.

12. REFERENCES:

12.1 Coughanowr, Donald R. (1991). *Process Systems Analysis and Control.* 2nd Ed. ND: Mc Graw-hill International.

12.2 Stephanopoulos, George (2006). *Chemical Process Control*. 1st Ed. ND: Prentice Hall of India Pvt. Ltd

LEVEL CONTROL TRAINER

(PC-102)

Foreword

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Contents

LEVEL CONTROL TRAINER

1. OBJECTIVE:

To study the operation of Level Control Trainer.

2. AIM:

2.1 To study the open loop or manual control.

2.2 To study the proportional control.

2.3 To study the Two mode (P+I) control.

2.4 To study the Two mode (P+D) control.

2.5 To study the Three mode (PID) control.

2.6 To study the tuning of controller (Open loop method) using Zeigler-Nichols method.

2.7 To study the stability of the system using the BODE PLOT.

2.8 To study the autotuning of controller.

3. INTRODUCTION :

Currently, the PID algorithm is the most common control algorithm used in industry. Often, people use PID control processes that include heating and cooling systems, fluid flow monitoring, flow control and temperature control. In PID control, you must specify a process variable and a set point. The process variable is the system parameter you want to control such as temperature, pressure and flow rate and the set point is the desired value for the parameter you are controlling. A PID controller determines a controller output value, such as the heater power or valve position. The controller applies the controller output value to the system, which in turn drives the process variable towards the set point value.

CONTROL SYSTEM:

The control system is that means by which any quantity of interest in a machine, mechanism or equipment is maintained or altered in accordance with a desired manner. Control system is of two types: -

OPEN LOOP CONTROL SYSTEM:

It is shown in figure1. Any physical system, which doesn't automatically correct for variation in its output, is called open loop system. In these systems, the output remains constant for a constant input signal provided the external; conditions remain unaltered. The output may be changed to any desired value by appropriately changing the input signal but variations in external or internal parameters of the system may cause the output to vary from the desired value in an uncontrolled fashion. The open loop control is, therefore, satisfactory only if such fluctuations can be tolerated or system components are designed and constructed so as to limit parameter variations and environmental conditions as well controlled.

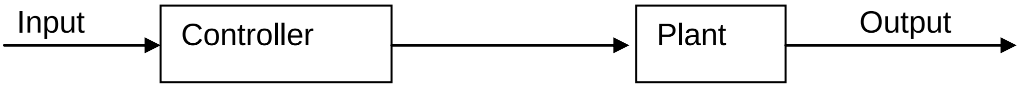


Fig. 1: Open Loop Control System

It is important to note that the fundamental difference between an open and closed loop control system is that of a feedback action. Consider, for example, traffic control system for regulating the flow of traffic at the crossing of two roads. The system will be termed open loop if red and green lights are put on by a timer mechanism set for predetermined fixed intervals of time. It is obvious that such an arrangement takes no account of varying rates of traffic flowing to the road crossing from the two directions. If on the other hand a scheme is introduced in which the rate of traffic flow along both directions are measured and are compared and the difference is used to control the timings of the red and green lights, a closed-loop system results. Thus, the concept of feedback can be usefully employed to traffic control.

Unfortunately, the feedback, which is the underlying principle of most control systems, introduces the possibility of undesirable system oscillations.

CLOSED LOOP CONTROL SYSTEM:

A closed loop control system consists of a process and a controller that automatically adjusts one of the inputs to the process in response to a signal feedback from the process output. The performance of the system can be judged by the transient response of the output to specific changes in the input. The change in the input may be a change in set point or a change in any one of the several load variables. If the purpose of the control system is to make the process follow changes in set point as closely as possible, the operation is called "servo-operation". The term "regulator operation" is used when the main problem is to keep the output almost constant in spite of changes in load. The designer must be aware of the purpose of the control system, since the system that gives optimum servo-operation will generally not be the best for regulator operation.

CONTROLLED VARIABLE & MANIPULATED VARIABLE:

The controlled variable is the quantity or condition that is measured and controlled. The-manipulated variable is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable. Normally, the controlled variable is the output of the system. Control means measuring the value of the controlled variable of the system and applying the manipulated variable to the system to correct or limit deviation of the measured value from a desired value.

PLANT:

A plant may be a piece of equipment, perhaps just a set of machine parts functioning together, the purpose of which is to perform a particular operation.

PROCESSES:

A process may be defined as natural, progressively continuing operation or development marked by a series of gradual changes that succeed one another in relatively fixed way and leads toward a particular result or end; or an artificial or voluntary, progressively continuing operation that consists of a series of controlled actions or movements systematically directed towards a particular result.

SYSTEMS:

A system is a combination of components that act together and perform a certain objective. A system is not limited to physical ones. The concept of system can be applied to abstract, dynamic phenomena such as those encountered in economics. The word system should therefore, be interpreted to imply physical, biological, economic and the like systems.

DISTURBANCES:

A disturbance is a signal that tends to adversely affect the value of the output of a system. If a disturbance is generated within the system, it is called internal, while the external disturbance is generated outside the system and is an input.

FEEDBACK CONTROL:

Feedback control refers to an operation that, in the presence of disturbance tends to reduce the difference between the output of a system and some reference input and does so on the basis of this difference. Here only the unpredictable or known disturbances can always be compensated for within the system.

DELAY TIME:

It is the time required for the response to reach 50% of the final value in first attempt.

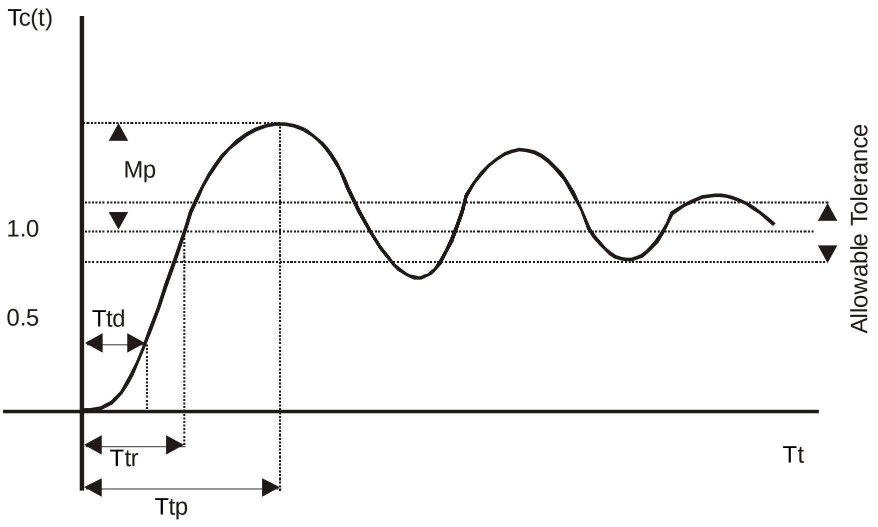


Figure : 2

RISE TIME:

It is the time required for the response to rise from 10% to 90% of the final value for over damped systems and 0 to 100% of the final value for under damped systems.

PEAK TIME:

It is the time required for the response to reach the peak of time response or the peak overshoot.

PEAK OVERSHOOT M_P:

It indicates the normalized difference between the time response peak and the steady output and is defined as:

Peak percent overshoot = [Ctp – C∞/C∞] x 100 (%)

SETTLING TIME:

It is the time required for the response to reach and stay within a specified tolerance band (Usually 2% to 5%) of its final value.

THE CHARACTERISTICS OF P, I & D CONTROLLERS:

A proportional controller will have the effect of reducing the rise time and will reduce, but never eliminate, the steady state. An integral control will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers K_c, T_i, and T_d on a closed-loop system are summarized in the table shown below.

Controller Response	Rise Time	Overshoot	Settling Time	Steady-State Error
K_c	Decrease	Increase	Small Change	Decrease
T_i	Decrease	Increase	Increase	Eliminate
T_d	Small Change	Decrease	Decrease	Small Change

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

GENERAL TIPS FOR DESIGNING A P.I.D. CONTROLLER:

When you are designing a PID controller for a given system, follow the steps shown below to obtain a desired response.

- Obtain an open-loop response and determine what needs to be improved.
- Add a proportional control to improve the rise time.
- Add an integral control to eliminate the steady-state error.
- Add a derivative control to improve the overshoot.
- Adjust each of Kc, T_i, and T_d until you obtain a desired overall response.

Lastly, please keep in mind that you do not need to implement all three controllers (proportional, derivative, and integral) into a single system, if not necessary. For example, if a PI controller gives a good enough response, then you don't need to implement derivative controller to the system. Keep the controller as simple as possible to obtain the system with no overshoot, fast rise time, and no steady-state error.

4. THEORY:

PART-I: OPEN LOOP CONTROL SYSTEM

If the main variable is not used to adjust any of the inputs automatically, the system is an open loop control system. It is alternative method of control would be to regulate all the inputs to the process by the use of separate controller, metering pums or manually adjusted valves. With an open loop system, every input , variable must be kept constant to keep the output constant.

In these systems, the output remains constant for a constant input signal provided the external; conditions remain unaltered. The output may be changed to any desired value by appropriately changing the input signal but variations in external or internal parameters of the system may cause the output to vary from the desired value in an uncontrolled fashion. The open loop control is, therefore, satisfactory only if such fluctuations can be tolerated or system components are designed and constructed so as to limit parameter variations and environmental conditions as well as controlled, whereas in case of closed loop system, the controlled variable is measured and compared with reference input and the difference is used to control the elements.

Open loop control is used for some simple processes where close control is not needed or where the input variables do not change appreciably. At the other extreme, open-loop control may be used for complex process where feedback control is not good enough.

PART-II: PROPORTIONAL CONTROL

The proportional controller produces an output signal that is proportional to the error e. This action may be expressed as:

$$P = K_C \times e + P_S \qquad \text{------------------------(1)}$$

In order to get steady operation when the disturbances are absent, the controlled variable must be a continuous function of error. With proportional control, the most widely used type; the controller output is a linear function of the error signal. The controller gain is the fractional change in output divided by the fractional change in input.

Where P is output signal from controller, K_C is proportional gain, e is error and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In a controller having adjustable gain, the value of the gain K_C can be varied by moving knob in the controller. The value of p_s is the value of the output signal when e is zero, and in most controller p_s can be adjusted to obtain the required output signal when the control system is at steady state and e = 0.

PART-III: TWO MODE (PROPORTIONAL+INTEGRAL) CONTROL

This mode of control is described by the following relationship:

$$P = K_C \times e + \frac{K_C}{T_i}\int edt + P_S \qquad \text{-------------------------(1)}$$

Where P is output signal from controller, K_C is gain, e is error, T_i is time integral and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e, another term that is proportional to the integral of the error. The value of K_C and T_i may be varied by two knob in the controller.

There is no offset with the integral control, since the output keeps changing as long as any error persists. However, the initial response to an error is slow and proportional control is ordinarily used with integral control. The integral action corrects for the offset that usually occurs with proportional control only, and the effect is similar to manual adjustment or resetting of the set point after each load change. The terms “reset action” and “reset time” are widely used to characterize the integral action of a proportional – integral controller.

$$P = K_C (e + \frac{1}{T_i} \int edt)$$ -------------------------(2)

A small reset time corresponds to an increase in the integral action. With P action the measured value will not necessarily become equal to the set point and a deviation will usually be present. The control algorithm that applies changes in output as long as deviation exits, so as to bring the deviation to zero is called integral action. With integral action the parameters that determines how fast the output will change in corresponding to some amount.

PART-IV: TWO MODE (PROPORTIONAL+DERIVATIVE) CONTROL

This mode of control may be represented by following expression:

$$P = K_C \times e + K_C T_d \frac{de}{dt} + P_S$$ -------------------------(1)

Where P is output signal from controller, K_C is gain, e is error, T_d is derivative time and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e to the another term that is proportional to the derivative of the error. The value of K_C and T_d may be varied by two knob in the controller.

Derivative action is often added to proportional control to improve the response of slow systems. By increasing the output when the error is changing rapidly, derivative action anticipates the effect of large load changes and reduces the maximum error.

Larger the derivative time larger is the action. Smaller is the proportional band the larger is the derivative action.

PART-V: THREE MODE(PROPORTIONAL+INTEGRAL+DERIVATIVE)CONTROLLER

This mode of control is described by the following relationship

$$P = K_C \times e + \frac{K_C}{T_i}\int edt + K_C \times eT_d \frac{de}{dt} + P_S \qquad \text{--------------------- (1)}$$

Where P is output signal from controller, K_C is gain, e is error, T_i is time integral, T_d is derivative time and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e to the another two term that is proportional to the derivative of the error and integral of the error. The value of K_C T_i and T_d may be varied by three knob in the controller.

There is no offset with the integral control, since the output keeps changing as long as any error persists. However, the initial response to an error is slow and proportional control is ordinarily used with integral control.

Derivative action is often added to proportional control to improve the response of slow systems. By increasing the output when the error is changing rapidly, derivative action anticipates the effect of large load changes and reduces the maximum error.

PART-VI: TUNING OF CONTROLLER (OPEN LOOP METHOD)

This method is basically used to calculate the value of P, I, D using the open loop or manual control method. The values of P, I, D are selected in such a way that the error or the difference between the SP and PV should become equal to zero.

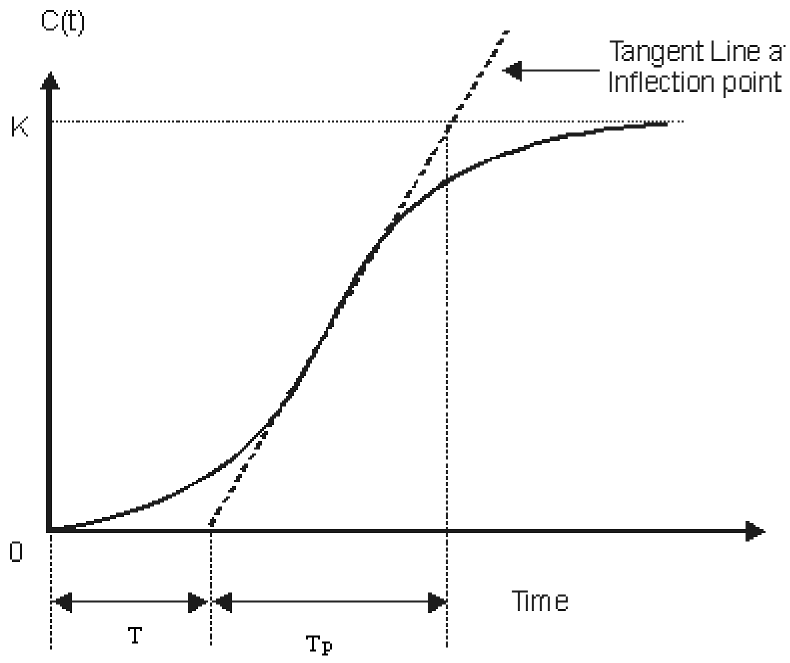


Figure : 7

S Shaped Response Curve

Since we are not given with the plant equation. So the process is assumed to be of first order with steady state gain K_C integral time T_i and derivative time T_d. The step response i.e. process reaction curve, allows to obtain the approximate values of each parameter. With the feedback loop open, a step response is applied to manipulated variable and the values of P, I and D are estimated.

The delay time T and time constant T_p are determined by drawing a tangent line at the inflection point of a S-shaped curve and determining the intersections of the tangent line with the time axis and line c (t) = K as shown in the figure obtained by performing the experiment.

For P, PI and PID controller the parameters are calculated as follows:

Mode	**K_C**	**T_i**	**T_d**
P	T/T_p	INFINITY	0
P+I	$0.9T_p/T$	T/0.3	0
P+I+D	1.2T/T	2T	0.5T

PART-VII: STABILITY OF SYSTEM (BODE PLOT)

For our purposes, a stable system will be defined as one for which the output response is bounded for all bounded inputs. A system exhibiting an unbounded response to a bounded input is unstable. This definition, although some what loose is adequate for most of the linear systems and simple inputs that we shall study.

Abounded input function is a function of time that always falls within certain bounds during the course of time. For example the step function and sinusoidal functions are bounded inputs.

The Bode diagrams constitute a convenient way to represent the frequency response characteristics of a system. As we can see from the amplitude ratio and the phase shift of the ultimate response of a system are functions of the frequency ω.The Bode diagram consists of a pair of plots showing;

a. How the logarithm of the amplitude ratio varies with frequency.

b. How the phase shift varies with frequency.

In order o cover a large range of frequencies, we use a logarithmic scale for the frequencies.

For first order system:

For a first order system we have seen that

Amplitude ratio $A.R. = \dfrac{K_p}{\sqrt{1+\omega^2\tau^2}}$

Phase lag $\phi = \tan^{-1}(-\tau\omega)$

For convenience, since τ is constant, regard $\tau\omega$ as the independent variable instead of ω. The plot of log AR versus log $\tau\omega$ and plot of ϕ versus $\tau\omega$ is known as Bode plot.

In case of Bode plot, the crossover frequency at which the phase lag is 180^0, is noted as w_{CO} on the Bode diagram. At this frequency AR is A. If A exceed unity, we know from the Bode criterion that the system is unstable.

If A is less than unity then the system is stable.

PART-VIII: AUTOTUNING OF CONTROLLER

Auto-tuning is automatic tuning of controller parameter in one experiment. It is common that commercial controllers offer auto-tuning. The operator starts the auto-tuning via some button or menu choice on the controller. The controller then executes automatically a pre-planned experiment on the uncontrolled process or on the control system depending on the auto-tuning method implemented.

Auto-tuning based on relay tuning:

The relay method for tuning PID controllers is used as the basis of auto-tuning in some commercial controllers. The principle of this method is as follows:

When the auto-tuning phase is started, a relay controller is used as controller in the control loop. This controller creates automatically sustained oscillations in control loop, and forms the amplitude and the period of these oscillations proper PID controller parameters are calculated by an algorithm in the controller.

Use auto-tuning to improve performance. Often many controllers are poorly tuned. As a result some controllers are too aggressive and some are too sluggish. PID controllers are difficult to tune, when you do not know the process dynamics or disturbance. In this case use auto-tuning.

For most systems the nonlinear relay characteristic generates a limiting cycle from which the auto-tuning algorithm identifies the relevant information needed for PID tuning. If the existing controller is proportional only the auto-tuning algorithm identifies the ultimate gain K_u and ultimate period P_u. If the existing model is PI or PID the auto-tuning algorithm identifies the dead time T and time constant T_P, which are two parameters in the integral plus dead time models.

Here we use Ziegler-Nichols heuristic method for determining the parameters of a PID controller. When you auto-tune select one of the following three types of loop performance:

- Fast (1/4 damping ratio)
- Normal (some overshoot)
- Slow (Little overshoot)

Tuning formula under P-only control (fast)			
Mode	**K_C**	**T_i**	**T_d**
P	0.5 K_u		
P+I	0.45 K_u	P_u/1.2	
P+I+D	0.6 K_u	P_u/2	P_u/8

Tuning formula under P-only control (normal)			
Mode	**K_C**	**T_i**	**T_d**
P	0.2 K_u		
P+I	0.18 K_u	0.8 P_u	
P+I+D	0.25 K_u	0.5 P_u	0.12 P_u

Tuning formula under P-only control (slow)			
Mode	**K_C**	**T_i**	**T_d**
P	0.13 K_u		
P+I	0.13 K_u	0.8 P_u	
P+I+D	0.15 K_u	0.5 P_u	0.12 P_u

Tuning formula under PI or PID control (fast)			
Mode	**K_C**	**T_i**	**T_d**
P	T_P/T		
P+I	0.9 T_P/T	0.33 T	
P+I+D	1.1 T_P/T	2.0 T	0.5 T

Tuning formula under PI or PID control (normal)			
Mode	**K_C**	**T_i**	**T_d**
P	0.44 T_P/T		
P+I	0.4 T_P/T	5.33 T	
P+I+D	0.53 T_P/T	4.0 T	0.8 T

Tuning formula under PI or PID control (slow)			
Mode	**K_C**	**T_i**	**T_d**
P	0.26 T_P/T		
P+I	0.24 T_P/T	5.33 T	
P+I+D	0.32 T_P/T	4.0 T	0.8 T

5. DESCRIPTION:

The set-up consists of water tank. Level transmitter is given to transmit the value of level. Rotameter is given for flow measurement of water. Pump is for circulation of water. Control valve is for flow control. Pressure regulator and pressure gauge is for set the pressure and for measurement of pressure. Safety valve and pneumatic valve is also provided. Micro processer controller with PID setting, autotuning, and fully programmable with serial communications is provided. Software is provided with facility of data logging, trend plot and offline analysis & printing.

6. UTILITIES REQUIRED:

6.1 Water Supply.

6.2 Compressed Air Supply: 1 CMH @ 3 bar.

6.3 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.4 Computer: Pentium IV with CD drive, Windows XP version and MS office XP pre-loaded. One RS 232 serial communication port free for interfacing unit.

6.5 Table for set-up support.

7. Experimental Procedure:

7.a Start Up:

7.a.a Close all the valves V_1-V_4.

7.a.b Ensure that switches given on the panel are at OFF position.

7.a.c Open the valve V_1 and start the air supply and set the pressure 20-25 psi by pressure regulator and gauge.

7.a.d Switch ON the power supply.

7.a.e Connect the water supply.

7.a.f Switch ON the pump.

7.a.g Open the by pass valve V_3 and start the water supply to process tank.

7.a.h Switch ON the computer and interfacing unit.

7.a.i Set the set point according open the valve V_2 and set the water flow rate.

7.a.j Select the Auto mode to perform the experiment automatically and in Manual mode to change the values manually.

7.b Shut Down:

7.b.a Exit from the software.

7.b.b Switch OFF the interfacing unit.

7.b.c Switch OFF the pump and compressed air supply.

7.b.d Switch OFF the power supply.

7.b.e Drain the water tank by open the valve V_4.

7.a.1 Starting Procedure (For Open Loop Control):

7.a.1.1 Start up the setup as mentioned above.

7.a.1.2 Select the manual mode.

7.a.1.3 Set the controller output to 100%.

7.a.1.4 Apply a change to the controller output and wait for the process variable to reach the steady state.

7.a.1.5 Record the set point and process variable.

7.a.1.6 Repeat the experiment for different value of controller output and measure the process variable at steady state.

7.b.1 Closing Procedure (For Open Loop Control):

7.b.1.1 When experiment is over shut down the apparatus as mentioned in the starting.

7.a.2 Starting Procedure (For Proportional Control):

7.a.2.1 Start up the set up as mentioned previously.

7.a.2.2 Select the controller in AUTO mode.

7.a.2.3 Set the value of K_C as high as possible.

7.a.2.4 Observe the process and the output response.

7.a.2.5 If output response doesn't shows cycling, adjust the value of K_C to half of its previous value.

7.a.2.6 Repeat steps 4 and 5 until cycling is observed.

7.a.2.7 Then increase the value of K_C to twice its value and observe the Output response.

7.a.2.8 Repeat the above step until cycling is observed.

7.a.2.9 Record the value of K_C at which you observe the oscillations and record the overshoot.

7.a.2.10 Now increase the value of K_C in steps and observe the corresponding overshoots.

7.a.2.11 Compare the relative overshoot with the value of K_C.

7.b.2 Closing Procedure (For Proportional Control):

7.b.2.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.3 Starting Procedure (For Proportional+ Integral Control):

7.a.3.1 Start up the setup as mentioned previously.

7.a.3.2 Select the controller in AUTO mode.

7.a.3.3 Select a value of set point.

7.a.3.4 Select a value of K_C and T_i as high as possible.

7.a.3.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the corresponding values of K_C or T_i so as to make PV equal to SP.

7.a.3.6 Then observe the output response curve.

7.b.3 Closing Procedure (For Proportional+ Integral Control):

7.b.3.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.4 Starting Procedure (For Proportional+ Derivative Control):

7.a.4.1 Start up the setup as mentioned previously.

7.a.4.2 Select the controller in AUTO mode.

7.a.4.3 Select a value of set point.

7.a.4.4 Select some value of K_C and the value of T_d to the minimum value.

7.a.4.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the value of T_d to make PV equal to SP.

7.a.4.6 Then observe the output response curve.

7.b.4 Closing Procedure (For Proportional+Derivative Control):

7.b.4.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.5 Starting Procedure (For Pid Control):

7.a.5.1 Start up the setup as mentioned previously.

7.a.5.2 Select the controller in AUTO mode.

7.a.5.3 Select a value of set point.

7.a.5.4 Select some value of K_C, T_i and T_d.

7.a.5.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the corresponding values of K_C, T_i and T_d so as to make PV equal to SP.

7.a.5.6 Using trial and error method by select the proportional gain and integral time, which gives a satisfactory response to step change in set point.

7.a.5.7 Set the derivative time to a non-zero value and carry out the above steps for different derivative time values.

7.b.5 Closing Procedure (For Pid Control):

7.b.5.1 After experimentation shut down the setup as mentioned earlier.

7.a.6 Starting Procedure (For Tuning Of Control (Open Loop Method)):

7.a.6.1 Start up the set up as mentioned.

7.a.6.2 Select open loop option for control.

7.a.6.3 Select the value of the set point to some desired value.

7.a.6.4 Apply a 20-30% change to controller output. Record the step response. Wait for the steady state.

7.a.6.5 Start data logging and from the readings draw a step response curve.

7.a.6.6 Calculate the value of T and T_p.

7.a.6.7 From this, calculate the values of PID controller settings from the table.

7.b.6 Closing Procedure (For Tuning Of Control (Open Loop Method)):

7.b.6.1 After experimentation, shut down the set up.

7.a.7 Starting Procedure (For Stability Of System (Bode Plot)):

7.a.7.1 Rewrite the sinusoidal transfer function in the time constant form.

7.a.7.2 Identify the corner frequencies associated with each factor of the transfer function.

7.a.7.3 Knowing the corner frequency, draw the asymptotic magnitude plot. This plot consists of a straight line segments with the line slope changing at each corner frequency by +20 db/decade for a zero and – 20 db/decade for a pole For a complex conjugate zero or pole the slope changes by +/- 40 db/decade.

7.a.7.4 Draw a smooth curve through the corrected point such that it is asymptotic to the straight-line segments. This gives the actual log-magnitude plot.

7.a.7.5 Draw the phase angle curve for each factor and add them algebraically to get the phase plot.

7.a.7.6 The ultimate gain value i.e. Wco is that value when the phase angle curve crosses the 180 degree line and the corresponding gain value is called the ultimate gain i.e. Ku.

7.a.7.7 By using these two gains the other parameters that are the values of P, I and D are calculated from the table given in the theory part of the Zeigler’s closed loop method.

7.b.7 Closing Procedure (For Stability Of System (Bode Plot)):

7.b.7.1 After experimentation, shut down the set up.

7.a.8 Starting Procedure (For Autotuning Control):

7.a.8.1 Start up the set up as mentioned previously.

7.a.8.2 Select close loop option for control.

7.a.8.3 Select a value of proportional gain disturbs the system and observe the transient response.

7.a.8.4 Continue increasing the gain in small steps until the response first exhibits a sustained oscillation.

7.a.8.5 Record the time of oscillation and gain.

7.b.8 Closing Procedure (For Autotuning Control):

7.b.8.1 After experimentation, shut down the set up.

8. Observations & Calculations:

Observation Table (For Open Loop Control System):

S.No.	SP (%)	PV (%)

Observation Table (For Proportional Control):

S.No.	K_C	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table (For Proportional+ Integral Control):

S.No.	K_C	T_i (min)	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table For Proportional+ Derivative Control):

S.No.	K_C	T_d (min)	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table (For Proportional+Integral+Derivative Control):

S.No.	K_C	T_i (min)	T_d (min)	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table (For Tuning Of Controller (Open Loop Method)):

S.No.	t (sec)	PV (%)

OBSERVATION TABLE (FOR STABILITY OF SYSTEM (BODE PLOT)):			
S.No.	K_C	t (sec)	w (rad/sec)

OBSERVATION TABLE (FOR AUTOTUNING OF CONTROLLER):				
S.No.	P_u (min)	K_u	T (min)	T_P (min)

CALCULATIONS:

(FOR OPEN LOOP CONTROL SYSTEM):

$$e = SP - PV \ (\%)$$

(FOR PROPORTIONAL CONTROL):

$$e = SP - PV \ (\%)$$

$$P_B = \frac{1}{K_C} \times 100 \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+INTEGRAL CONTROL):

$$e = SP - PV \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+DERIVATIVE CONTROL):

$e = SP - PV$ (%)

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+INTEGRAL+DERIVATIVE CONTROL):

$e = SP - PV$ (%)

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR TUNING OF CONTROLLER (OPEN LOOP METHOD)):

$T_P =$ ____________ (min) **[Refer theory PART-VI]**

$T =$ ____________ (min) **[Refer theory PART-VI]**

For P controller

$$K_C = \frac{T_P}{T}$$

For PI controller

$$K_C = 0.9\frac{T_P}{T}$$

$$T_i = \frac{L}{0.3} \text{ (min)}$$

For PID controller

$$K_C = 1.2\frac{T_P}{T}$$

$$T_i = 2T \text{ (min)}$$

$$T_d = 0.5T \text{ (min)}$$

(FOR STABILITY OF SYSTEM):

$$AR = \frac{K_C}{\sqrt{1 + w^2 t^2}}$$

$$\phi = \tan^{-1}(-tw)$$

CALCULATION TABLE:		
S.No.	**AR**	**ϕ**

Plot the graph of AR vs w on semi log co-ordinates.

Plot the graph of ϕ Vs w on semi log co-ordinates.

$w_{CO} =$ ____________ [at $\phi = 180^0$]

$A = AR$ [at w_{CO}]

(FOR AUTOTUNING OF CONTROLLER):

For P-only control (fast)

For P controller

$K_C = 0.5K_u$

For PI controller

$K_C = 0.4K_u$

$T_i = 0.8P_u$ (min)

For PID controller

$K_C = 0.6K_u$

$T_i = 0.5P_u$ (min)

$T_d = 0.12P_u$ (min)

For P-only control (normal)

For P controller

$K_C = 0.2K_u$

For PI controller

$K_C = 0.18K_u$

$T_i = 0.8P_u$ (min)

For PID controller

$K_C = 0.25K_u$

$T_i = 0.5P_u$ (min)

$T_d = 0.12P_u$ (min)

For P-only control (slow)

For P controller

$K_C = 0.13K_u$

For PI controller

$K_C = 0.13K_u$

$T_i = 0.8P_u$ (min)

For PID controller

$K_C = 0.15K_u$

$T_i = 0.5P_u$ (min)

$T_d = 0.12P_u$ (min)

For PI and PID control (fast)

For P controller

$$K_C = \frac{T_P}{T}$$

For PI controller

$$K_C = 0.9\frac{T_P}{T}$$

$T_i = 0.33T$ (min)

For PID controller

$$K_C = 1.1\frac{T_P}{T}$$

$T_i = 2.0T$ (min)

$T_d = 0.5T$ (min)

For PI and PID control (normal)

For P controller

$$K_C = 0.44\frac{T_P}{T}$$

For PI controller

$$K_C = 0.4\frac{T_P}{T}$$

$T_i = 4.0T$ (min)

For PID controller

$$K_C = 0.32\frac{T_P}{T}$$

$T_i = 4.0T$ (min)

$T_d = 0.8T$ (min

For PI and PID control (slow)

For P controller

$$K_C = 0.26\frac{T_P}{T}$$

For PI controller

$$K_C = 0.24\frac{T_P}{T}$$

$T_i = 5.33T$ (min)

For PID controller

$$K_C = 0.32\frac{T_P}{T}$$

$$T_i = 4.0T \text{ (min)}$$

$$T_d = 0.8T \text{ (min)}$$

9. NOMENCLATURE:

Nom	Column Headings	Units	Type
SP	Set point	%	Measured
PV	Process variable	%	Measured
e	Error	%	Calculated
K_C	Controller gain	*	Measured
t	Time	sec	Measured
P_B	Proportional band	%	Calculated
OP	Output	%	Measured
T_i	Integral time	min	Measured
T_d	Derivative time	min	Measured
K_u	Ultimate gain	*	Measured
P_u	Ultimate period	min	Measured
w	Frequency	*	Measured
AR	Amplitude ratio	*	Calculated
ϕ	Phase angle	*	Calculated
A	Amplitude ratio	*	Calculated
w_{CO}	Cross over frequency	*	Calculated
T	Dead time	min	Measured
T_P	Time constant	min	Measured

* Symbols represent unitless quantity.

10. PRECAUTIONS & MENTAINENCE:

10.1 Pressure should not be disturb during the experiment.

10.2 Do not switch OFF the power during experiment.

11. TROUBLESHOOTING:

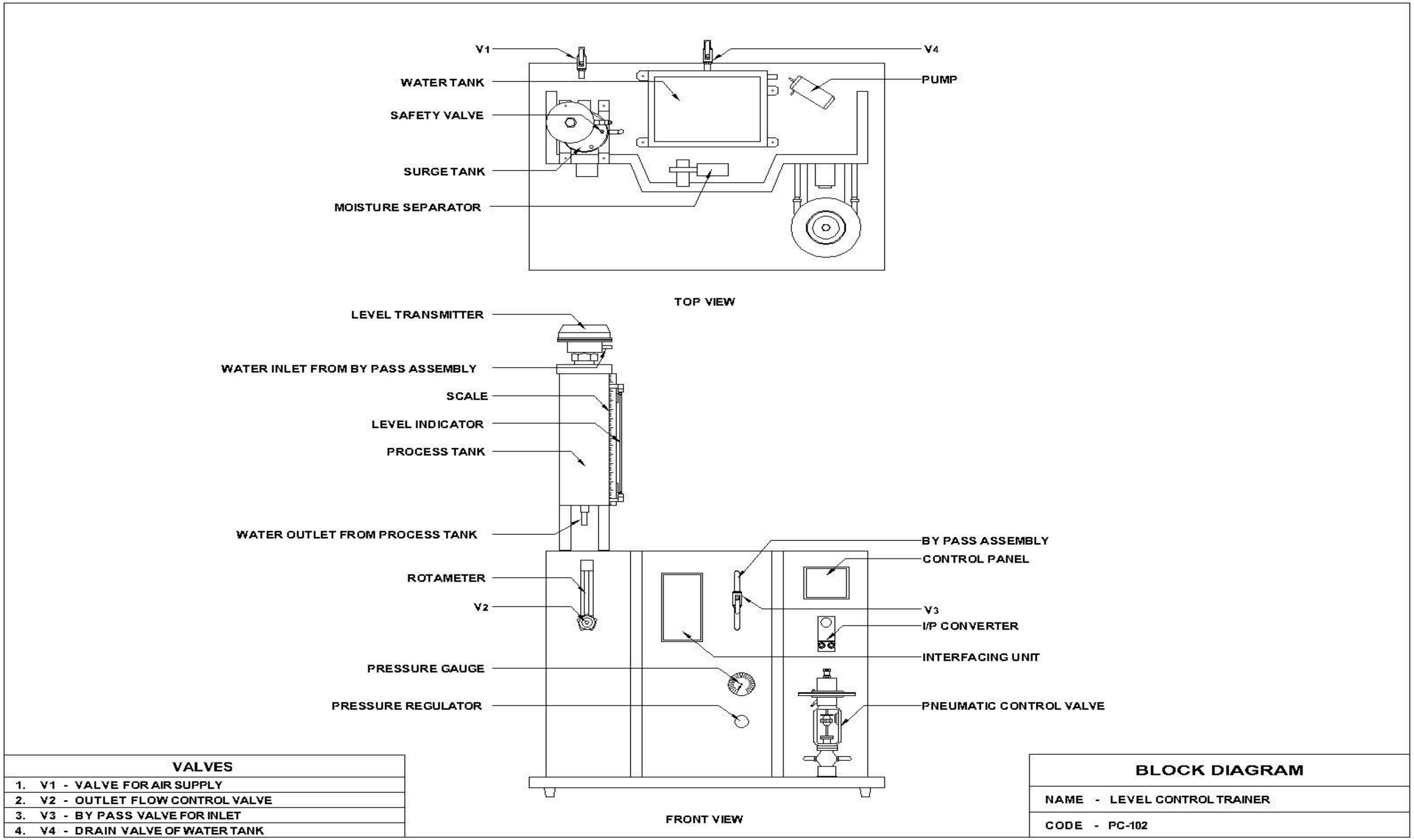
11.1 If rotameter fluctuating more than average then tight the control knob properly.

12. REFERENCES:

12.1 Coughanowr, Donald R. (1991). *Process Systems Analysis and Control.* 2nd Ed. ND: Mc Graw-hill International. pp 128-133, 164-165, 227-230.

12.2 Stephanopoulos, George (2006). *Chemical Process Control*. 1st Ed. ND: Prentice Hall of India Pvt. Ltd. p 243.

13. BLOCK DIAGRAM:



TEMPERATURE CONTROL

TRAINER (PC-103)

Foreword

Welcome to the fast growing family of K.C. product owners. We appreciate your interest in us and thank you for buying our product.

You have chosen the finest quality product in the market which is produced using latest techniques and has underwent strict quality control tests. It is a product that we are proud to build and you are proud to own it.

Our products are easy to understand and operate. They are excellent for students who are trying to gain practical knowledge through experiments.

However your comfort and safety are important to us, so we want you have an understanding of proper procedure to use the equipment. For the purpose, we urge you to read and follow the step-by-step operating instructions and safety precautions in this manual. It will ensure that your favourite product delivers reliable, superior performance year after year.

This manual includes information for all options available on this model. Therefore, you may find some information that does not apply to your equipment.

All information, specifications and illustrations in this manual are those in effect at the time of printing. We reserve the right to change specifications or design at any time without notice.

Customer satisfaction is our primary concern. Feel Free to contact us for any assistance. So what are you waiting for, roll up your sleeves and let us get down to work!

K.C. Engineers Pvt. Ltd.

Important Information About This Manual

Reminder for Safety

Modification on Equipment:

This equipment should not be modified. Modification could affect its performance, safety or disturbance. In addition damage or performance problems resulting from modification may not be covered under warranties.

Precautions and Maintenance:

This is used to indicate the presence of a hazard that could cause minor or moderate personal injury or damage to your equipment. To avoid or reduce the risk, the procedures must be followed carefully.

Contents

TEMPERATURE CONTROL TRAINER

1. OBJECTIVE:

To study the operation of Temperature Control Trainer.

2. AIM:

2.1 To study the open loop or manual control.

2.2 To study the proportional control.

2.3 To study the Two mode (P+I) control.

2.4 To study the Two mode (P+D) control.

2.5 To study the Three mode (PID) control.

2.6 To study the tuning of controller (Open loop method) using Zeigler-Nichols method.

2.7 To study the stability of the system using the BODE PLOT.

2.8 To study the autotuning of controller.

3. INTRODUCTION :

Currently, the PID algorithm is the most common control algorithm used in industry. Often, people use PID control processes that include heating and cooling systems, fluid flow monitoring, flow control and temperature control. In PID control, you must specify a process variable and a set point. The process variable is the system parameter you want to control such as temperature, pressure and flow rate and the set point is the desired value for the parameter you are controlling. A PID controller determines a controller output value, such as the heater power or valve position. The controller applies the controller output value to the system, which in turn drives the process variable towards the set point value.

CONTROL SYSTEM:

The control system is that means by which any quantity of interest in a machine, mechanism or equipment is maintained or altered in accordance with a desired manner. Control system is of two types: -

OPEN LOOP CONTROL SYSTEM:

It is shown in figure1. Any physical system, which doesn't automatically correct for variation in its output, is called open loop system. In these systems, the output remains constant for a constant input signal provided the external; conditions remain unaltered. The output may be changed to any desired value by appropriately changing the input signal but variations in external or internal parameters of the system may cause the output to vary from the desired value in an uncontrolled fashion. The open loop control is, therefore, satisfactory only if such fluctuations can be tolerated or system components are designed and constructed so as to limit parameter variations and environmental conditions as well controlled.

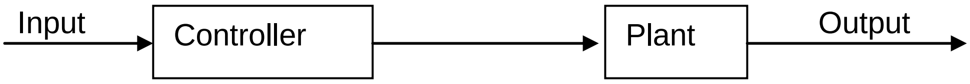


Fig. 1: Open Loop Control System

It is important to note that the fundamental difference between an open and closed loop control system is that of a feedback action. Consider, for example, traffic control system for regulating the flow of traffic at the crossing of two roads. The system will be termed open loop if red and green lights are put on by a timer mechanism set for predetermined fixed intervals of time. It is obvious that such an arrangement takes no account of varying rates of traffic flowing to the road crossing from the two directions. If on the other hand a scheme is introduced in which the rate of traffic flow along both directions are measured and are compared and the difference is used to control the timings of the red and green lights, a closed-loop system results. Thus, the concept of feedback can be usefully employed to traffic control.

Unfortunately, the feedback, which is the underlying principle of most control systems, introduces the possibility of undesirable system oscillations.

CLOSED LOOP CONTROL SYSTEM:

A closed loop control system consists of a process and a controller that automatically adjusts one of the inputs to the process in response to a signal feedback from the process output. The performance of the system can be judged by the transient response of the output to specific changes in the input. The change in the input may be a change in set point or a change in any one of the several load variables. If the purpose of the control system is to make the process follow changes in set point as closely as possible, the operation is called “servo-operation”. The term “regulator operation” is used when the main problem is to keep the output almost constant in spite of changes in load. The designer must be aware of the purpose of the control system, since the system that gives optimum servo-operation will generally not be the best for regulator operation.

CONTROLLED VARIABLE & MANIPULATED VARIABLE:

The controlled variable is the quantity or condition that is measured and controlled. The-manipulated variable is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable. Normally, the controlled variable is the output of the system. Control means measuring the value of the controlled variable of the system and applying the manipulated variable to the system to correct or limit deviation of the measured value from a desired value.

PLANT:

A plant may be a piece of equipment, perhaps just a set of machine parts functioning together, the purpose of which is to perform a particular operation.

PROCESSES:

A process may be defined as natural, progressively continuing operation or development marked by a series of gradual changes that succeed one another in relatively fixed way and leads toward a particular result or end; or an artificial or voluntary, progressively continuing operation that consists of a series of controlled actions or movements systematically directed towards a particular result.

SYSTEMS:

A system is a combination of components that act together and perform a certain objective. A system is not limited to physical ones. The concept of system can be applied to abstract, dynamic phenomena such as those encountered in economics. The word system should therefore, be interpreted to imply physical, biological, economic and the like systems.

DISTURBANCES:

A disturbance is a signal that tends to adversely affect the value of the output of a system. If a disturbance is generated within the system, it is called internal, while the external disturbance is generated outside the system and is an input.

FEEDBACK CONTROL:

Feedback control refers to an operation that, in the presence of disturbance tends to reduce the difference between the output of a system and some reference input and does so on the basis of this difference. Here only the unpredictable or known disturbances can always be compensated for within the system.

DELAY TIME:

It is the time required for the response to reach 50% of the final value in first attempt. It is represented by td. It is shown in figure 2.

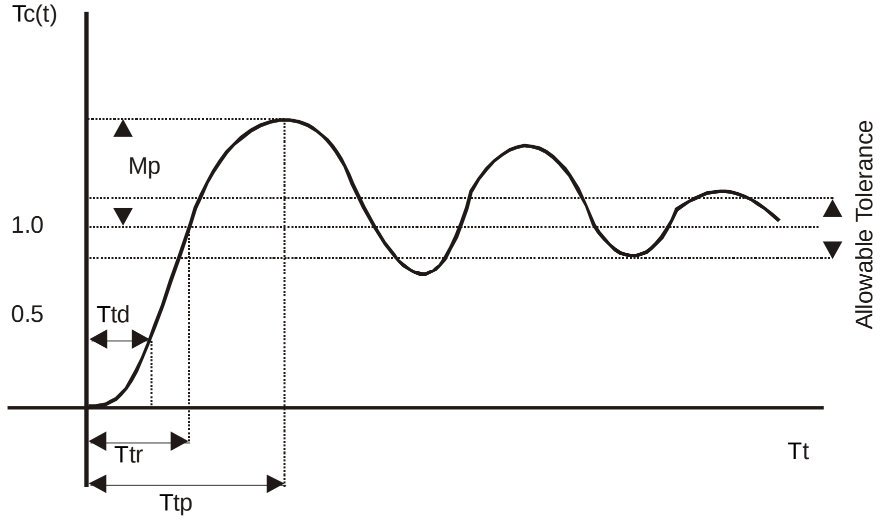


Figure : 2

RISE TIME:

It is the time required for the response to rise from 10% to 90% of the final value for over damped systems and 0 to 100% of the final value for under damped systems.

PEAK TIME:

It is the time required for the response to reach the peak of time response or the peak overshoot.

PEAK OVERSHOOT M_P:

It indicates the normalized difference between the time response peak and the steady output and is defined as:

Peak percent overshoot = [Ctp – C∞/C∞] x 100 (%)

SETTING TIME:

It is the time required for the response to reach and stay within a specified tolerance band (Usually 2% to 5%) of its final value.

THE CHARACTERISTICS OF P, I & D CONTROLLERS:

A proportional controller will have the effect of reducing the rise time and will reduce, but never eliminate, the steady state. An integral control will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers K_c, T_i, and T_d on a closed-loop system are summarized in the table shown below.

Controller Response	Rise Time	Overshoot	Settling Time	Steady-State Error
K_c	Decrease	Increase	Small Change	Decrease
T_i	Decrease	Increase	Increase	Eliminate
T_d	Small Change	Decrease	Decrease	Small Change

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

GENERAL TIPS FOR DESIGNING A P.I.D. CONTROLLER:

When you are designing a PID controller for a given system, follow the steps shown below to obtain a desired response.

- Obtain an open-loop response and determine what needs to be improved.
- Add a proportional control to improve the rise time.
- Add an integral control to eliminate the steady-state error.
- Add a derivative control to improve the overshoot.
- Adjust each of Kc, T_i, and T_d until you obtain a desired overall response.

Lastly, please keep in mind that you do not need to implement all three controllers (proportional, derivative, and integral) into a single system, if not necessary. For example, if a PI controller gives a good enough response, then you don't need to implement derivative controller to the system. Keep the controller as simple as possible to obtain the system with no overshoot, fast rise time, and no steady-state error.

4. THEORY:

PART-I: OPEN LOOP CONTROL SYSTEM

If the main variable is not used to adjust any of the inputs automatically, the system is an open loop control system. It is alternative method of control would be to regulate all the inputs to the process by the use of separate controller, metering pums or manually adjusted valves. With an open loop system, every input , variable must be kept constant to keep the output constant.

In these systems, the output remains constant for a constant input signal provided the external; conditions remain unaltered. The output may be changed to any desired value by appropriately changing the input signal but variations in external or internal parameters of the system may cause the output to vary from the desired value in an uncontrolled fashion. The open loop control is, therefore, satisfactory only if such fluctuations can be tolerated or system components are designed and constructed so as to limit parameter variations and environmental conditions as well as controlled, whereas in case of closed loop system, the controlled variable is measured and compared with reference input and the difference is used to control the elements.

Open loop control is used for some simple processes where close control is not needed or where the input variables do not change appreciably. At the other extreme, open-loop control may be used for complex process where feedback control is not good enough.

PART-II: PROPORTIONAL CONTROL

The proportional controller produces an output signal that is proportional to the error e. This action may be expressed as:

$$P = K_C \times e + P_S \qquad \text{------------------------(1)}$$

In order to get steady operation when the disturbances are absent, the controlled variable must be a continuous function of error. With proportional control, the most widely used type; the controller output is a linear function of the error signal. The controller gain is the fractional change in output divided by the fractional change in input.

Where P is output signal from controller, K_C is proportional gain, e is error and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In a controller having adjustable gain, the value of the gain K_C can be varied by moving knob in the controller. The value of p_s is the value of the output signal when e is zero, and in most controller p_s can be adjusted to obtain the required output signal when the control system is at steady state and e = 0.

PART-III: TWO MODE (PROPORTIONAL+INTEGRAL) CONTROL

This mode of control is described by the following relationship:

$$P = K_C \times e + \frac{K_C}{T_i}\int edt + P_S \qquad \text{-------------------------(1)}$$

Where P is output signal from controller, K_C is gain, e is error, T_i is time integral and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e, another term that is proportional to the integral of the error. The value of K_C and T_i may be varied by two knob in the controller.

There is no offset with the integral control, since the output keeps changing as long as any error persists. However, the initial response to an error is slow and proportional control is ordinarily used with integral control. The integral action corrects for the offset that usually occurs with proportional control only, and the effect is similar to manual adjustment or resetting of the set point after each load change. The terms “reset action” and “reset time” are widely used to characterize the integral action of a proportional – integral controller.

$$P = K_C \left(e + \frac{1}{T_i}\int edt\right) \quad \text{-------------------------(2)}$$

A small reset time corresponds to an increase in the integral action. With P action the measured value will not necessarily become equal to the set point and a deviation will usually be present. The control algorithm that applies changes in output as long as deviation exits, so as to bring the deviation to zero is called integral action. With integral action the parameters that determines how fast the output will change in corresponding to some amount.

PART-IV: TWO MODE (PROPORTIONAL+DERIVATIVE) CONTROL

This mode of control may be represented by following expression:

$$P = K_C \times e + K_C T_d \frac{de}{dt} + P_S \quad \text{-------------------------(1)}$$

Where P is output signal from controller, K_C is gain, e is error, T_d is derivative time and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e to the another term that is proportional to the derivative of the error. The value of K_C and T_d may be varied by two knob in the controller.

Derivative action is often added to proportional control to improve the response of slow systems. By increasing the output when the error is changing rapidly, derivative action anticipates the effect of large load changes and reduces the maximum error.

Larger the derivative time larger is the action. Smaller is the proportional band the larger is the derivative action.

PART-V: THREE MODE (PROPORTIONAL+INTEGRAL+DERIVATIVE) CONTROL

This mode of control is described by the following relationship

$$P = K_C \times e + \frac{K_C}{T_i}\int edt + K_C \times eT_d \frac{de}{dt} + P_S \qquad \text{---------------------} \quad (1)$$

Where P is output signal from controller, K_C is gain, e is error, T_i is time integral, T_d is derivative time and p_s is a constant.

The error e, which is the difference between the set point and the signal from the measuring element, may be in any suitable units. However, the units of set point and measured variable must be the same, since the error is the difference between these quantities.

e = SP-PV

Where SP is set point and PV is process variable.

In this case, we have added to the proportional action term, K_C*e to the another two term that is proportional to the derivative of the error and integral of the error. The value of K_C T_i and T_d may be varied by three knob in the controller.

There is no offset with the integral control, since the output keeps changing as long as any error persists. However, the initial response to an error is slow and proportional control is ordinarily used with integral control.

Derivative action is often added to proportional control to improve the response of slow systems. By increasing the output when the error is changing rapidly, derivative action anticipates the effect of large load changes and reduces the maximum error.

PART-VI: TUNING OF CONTROLLER (OPEN LOOP METHOD)

This method is basically used to calculate the value of P, I, D using the open loop or manual control method. The values of P, I, D are selected in such a way that the error or the difference between the SP and PV should become equal to zero.

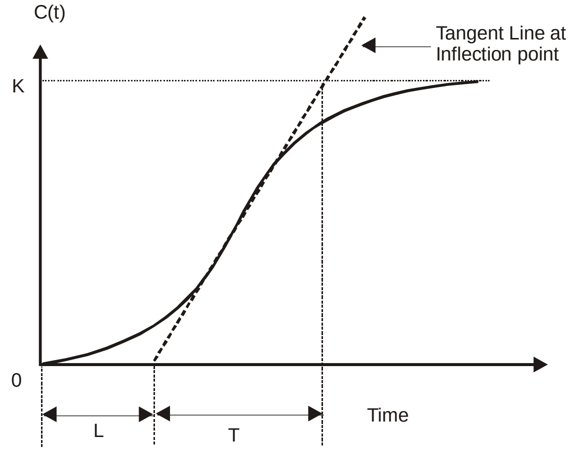


Figure : 7

S Shaped Response Curve

Since we are not given with the plant equation. So the process is assumed to be of first order with steady state gain Kc, integral time T_i and derivative time T_d. The step response i.e. process reaction curve, allows to obtain the approximate values of each parameter. With the feedback loop open, a step response is applied to manipulated variable and the values of P, I and D are estimated.

The delay time T and time constant T_P are determined by drawing a tangent line at the inflection point of a S-shaped curve and determining the intersections of the tangent line with the time axis and line c (t) = K as shown in the figure obtained by performing the experiment.

For P, PI and PID controller the parameters are calculated as follows:

Mode	**K_C**	**T_i**	**T_d**
P	T_P/T	INFINITY	0
P+I	$0.9T_P/T$	T/0.3	0
P+I+D	$1.2T_P/T$	2T	0.5T

PART-VII: STABILITY OF SYSTEM (BODE PLOT)

For our purposes, a stable system will be defined as one for which the output response is bounded for all bounded inputs. A system exhibiting an unbounded response to a bounded input is unstable. This definition, although some what loose is adequate for most of the linear systems and simple inputs that we shall study.

Abounded input function is a function of time that always falls within certain bounds during the course of time. For example the step function and sinusoidal functions are bounded inputs.

The Bode diagrams constitute a convenient way to represent the frequency response characteristics of a system. As we can see from the amplitude ratio and the phase shift of the ultimate response of a system are functions of the frequency ω.The Bode diagram consists of a pair of plots showing;

a. How the logarithm of the amplitude ratio varies with frequency.
b. How the phase shift varies with frequency.

In order o cover a large range of frequencies, we use a logarithmic scale for the frequencies.

For first order system:

For a first order system we have seen that

Amplitude ratio $A.R. = \frac{K_p}{\sqrt{1+\omega^2\tau^2}}$

Phase lag $\phi = \tan^{-1}(-\tau\omega)$

For convenience, since τ is constant, regard $\tau\omega$ as the independent variable instead of ω. The plot of log AR versus log $\tau\omega$ and plot of ϕ versus $\tau\omega$ is known as Bode plot.

In case of Bode plot, the crossover frequency at which the phase lag is 180^0, is noted as w_{CO} on the Bode diagram. At this frequency AR is A. If A exceed unity, we know from the Bode criterion that the system is unstable.

If A is less than unity then the system is stable.

PART-VIII: AUTOTUNING OF CONTROLLER

Auto-tuning is automatic tuning of controller parameter in one experiment. It is common that commercial controllers offer auto-tuning. The operator starts the auto-tuning via some button or menu choice on the controller. The controller then executes automatically a pre-planned experiment on the uncontrolled process or on the control system depending on the auto-tuning method implemented.

Auto-tuning based on relay tuning:

The relay method for tuning PID controllers is used as the basis of auto-tuning in some commercial controllers. The principle of this method is as follows:

When the auto-tuning phase is started, a relay controller is used as controller in the control loop. This controller creates automatically sustained oscillations in control loop, and forms the amplitude and the period of these oscillations proper PID controller parameters are calculated by an algorithm in the controller.

Use auto-tuning to improve performance. Often many controllers are poorly tuned. As a result some controllers are too aggressive and some are too sluggish. PID controllers are difficult to tune, when you do not know the process dynamics or disturbance. In this case use auto-tuning.

For most systems the nonlinear relay characteristic generates a limiting cycle from which the auto-tuning algorithm identifies the relevant information needed for PID tuning. If the existing controller is proportional only the auto-tuning algorithm identifies the ultimate gain K_u and ultimate period P_u. If the existing model is PI or PID the auto-tuning algorithm identifies the dead time T and time constant T_P, which are two parameters in the integral plus dead time models.

Here we use Ziegler-Nichols heuristic method for determining the parameters of a PID controller. When you auto-tune select one of the following three types of loop performance:

- Fast (1/4 damping ratio)
- Normal (some overshoot)
- Slow (Little overshoot)

Tuning formula under P-only control (fast)			
Mode	**K_C**	**T_i**	**T_d**
P	0.5 K_u		
P+I	0.45 K_u	P_u/1.2	
P+I+D	0.6 K_u	P_u/2	P_u/8

Tuning formula under P-only control (normal)			
Mode	**K_C**	**T_i**	**T_d**
P	0.2 K_u		
P+I	0.18 K_u	0.8 P_u	
P+I+D	0.25 K_u	0.5 P_u	0.12 P_u

Tuning formula under P-only control (slow)			
Mode	**K_C**	**T_i**	**T_d**
P	0.13 K_u		
P+I	0.13 K_u	0.8 P_u	
P+I+D	0.15 K_u	0.5 P_u	0.12 P_u

Tuning formula under PI or PID control (fast)			
Mode	K_C	T_i	T_d
P	T_P/T		
P+I	0.9 T_P/T	0.33 T	
P+I+D	1.1 T_P/T	2.0 T	0.5 T

Tuning formula under PI or PID control (normal)			
Mode	K_C	T_i	T_d
P	0.44 T_P/T		
P+I	0.4 T_P/T	5.33 T	
P+I+D	0.53 T_P/T	4.0 T	0.8 T

Tuning formula under PI or PID control (slow)			
Mode	K_C	T_i	T_d
P	0.26 T_P/T		
P+I	0.24 T_P/T	5.33 T	
P+I+D	0.32 T_P/T	4.0 T	0.8 T

5. DESCRIPTION:

The set-up consists of process tank. Temperature transmitter is given to transmit the temperature. Heater is provided to rise the temperature. Rotameter is given for flow control of water. Micro-processer controller with PID setting, auto tuning, and fully programmable with serial communications is provided. Software is provided with facility of data logging, trend plot and offfline analysis & printing.

6. UTILITIES REQUIRED:

6.1 Water Supply: Continuous @ 2 LPM.

6.2 Electricity Supply: Single Phase, 220V AC, 50Hz, 5-15 Amp combined socket with earth connection.

6.3 Computer: Pentium IV with CD drive, Windows XP version and MS office XP pre-loaded. One RS 232 serial communication port free for interfacing unit.

6.4 Table for set-up support.

7. Experimental Procedure:

7.a Start Up:

7.a.a Close all the valves V_1-V_2.

7.a.b Ensure that switches given on the panel are at OFF positions.

7.a.c Connect water inlet and outlet to apparatus.

7.a.d Open the valve V_1 and set the flow rate of water.

7.a.e Switch ON the power supply.

7.a.f Switch ON the computer and the interfacing unit.

7.a.g Select the Auto mode to perform the experiment automatically and in Manual mode to change the values manually.

7.b Shut Down:

7.b.a Exit from the software.

7.b.b Switch OFF the interfacing unit.

7.b.c Switch OFF the power supply.

7.b.d Drain the process tank by open the valve V_2.

7.a.1 Starting Procedure (For Open Loop Control):

7.a.1.1 Start up the setup as mentioned above.

7.a.1.2 Select the manual mode.

7.a.1.3 Set the controller output to 100%.

7.a.1.4 Apply a change to the controller output and wait for the process variable to reach the steady state.

7.a.1.5 Record the set point and process variable.

7.a.1.6 Repeat the experiment for different value of controller output and measure the process variable at steady state.

7.b.1 Closing Procedure (For Open Loop Control):

7.b.1.1 When experiment is over shut down the apparatus as mentioned in the starting.

7.a.2 Starting Procedure (For Proportional Controller):

7.a.2.1 Start up the set up as mentioned previously.

7.a.2.2 Select the controller in AUTO mode.

7.a.2.3 Set the value of K_C as high as possible.

7.a.2.4 Observe the process and the output response.

7.a.2.5 If output response doesn't shows cycling, adjust the value of K_C to half of its previous value.

7.a.2.6 Repeat the above steps until cycling is observed.

7.a.2.7 Then increase the value of K_C to twice its value and observe the Output response.

7.a.2.8 Repeat the above step until cycling is observed.

7.a.2.9 Record the value of K_C at which you observe the oscillations and record the overshoot.

7.a.2.10 Now increase the value of K_C in steps and observe the corresponding overshoots.

7.a.2.11 Compare the relative overshoot with the value of K_C.

7.b.2 Closing Procedure (For Proportional Controller):

7.b.2.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.3 Starting Procedure (For Proportional+ Integral Controller):

7.a.3.1 Start up the setup as mentioned previously.

7.a.3.2 Select the controller in AUTO mode.

7.a.3.3 Select a value of set point.

7.a.3.4 Select a value of K_C and T_i as high as possible.

7.a.3.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the corresponding values of K_C or T_i so as to make PV equal to SP.

7.a.3.6 Then observe the output response curve.

7.b.3 Closing Procedure (For Proportional+ Integral Controller):

7.b.3.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.4 Starting Procedure (For Proportional + Derivative Controller):

7.a.4.1 Start up the setup as mentioned previously.

7.a.4.2 Select the controller in AUTO mode.

7.a.4.3 Select a value of set point.

7.a.4.4 Select some value of K_C and the value of T_d to the minimum value.

7.a.4.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the value of T_d to make PV equal to SP.

7.a.4.6 Then observe the output response curve.

7.b.4 Closing Procedure (For Proportional+ Derivative Controller):

7.b.4.1 After experimentation, shut down the apparatus as mentioned previously.

7.a.5 Starting Procedure (For Pid Controller):

7.a.5.1 Start up the setup as mentioned previously.

7.a.5.2 Select the controller in AUTO mode.

7.a.5.3 Select a value of set point.

7.a.5.4 Select some value of K_C, T_i and T_d.

7.a.5.5 Observe the response of the system. If over damped oscillations are occurring, then increase or decrease the corresponding values of K_C, T_i and T_d so as to make PV equal to SP.

7.a.5.6 Using trial and error method by select the proportional gain and integral time, which gives a satisfactory response to step change in set point.

7.a.5.7 Set the derivative time to a non-zero value and carry out the above steps for different derivative time values.

7.b.5 Closing Procedure (For Pid Controller):

7.b.5.1 After experimentation shut down the setup as mentioned earlier.

7.a.6 Starting Procedure (For Tuning Of Controller (Open Loop Method)):

7.a.6.1 Start up the set up as mentioned.

7.a.6.2 Select open loop option for control.

7.a.6.3 Select the value of the set point to some desired value.

7.a.6.4 Apply a 20-30% change to controller output. Record the step response. Wait for the steady state.

7.a.6.5 Start data logging and from the readings draw a step response curve.

7.a.6.6 Calculate the value of T and T_p.

7.a.6.7 From this, calculate the values of PID controller settings from the table.

7.b.6 Closing Procedure (For Tuning Of Controller (Open Loop Method)):

7.b.6.1 After experimentation, shut down the set up.

7.a.7 Starting Procedure (For Stability Of System (Bode Plot)):

7.a.7.1 Rewrite the sinusoidal transfer function in the time constant form.

7.a.7.2 Identify the corner frequencies associated with each factor of the transfer function.

7.a.7.3 Knowing the corner frequency, draw the asymptotic magnitude plot. This plot consists of a straight line segments with the line slope changing at each corner frequency by +20 db/decade for a zero and –20 db/decade for a pole For a complex conjugate zero or pole the slope changes by +/- 40 db/decade.

7.a.7.4 Draw a smooth curve through the corrected point such that it is asymptotic to the straight-line segments. This gives the actual log-magnitude plot.

7.a.7.5 Draw the phase angle curve for each factor and add them algebraically to get the phase plot.

7.a.7.6 The ultimate gain value i.e. Wco is that value when the phase angle curve crosses the 180 degree line and the corresponding gain value is called the ultimate gain i.e. Ku.

7.a.7.7 By using these two gains the other parameters that are the values of P, I and D are calculated from the table given in the theory part of the Zeigler's closed loop method.

7.b.7 Closing Procedure (For Stability Of System (Bode Plot)):

7.b.7.1 After experimentation, shut down the set up.

7.a.8 Starting Procedure (For Autotuning):

7.a.8.1 Start up the set up as mentioned previously.

7.a.8.2 Select close loop option for control.

7.a.8.3 Select a value of proportional gain disturbs the system and observe the transient response.

7.a.8.4 Continue increasing the gain in small steps until the response first exhibits a sustained oscillation.

7.a.8.5 Record the time of oscillation and gain.

7.b.8 Closing Procedure (For Autotuning Control):

7.b.8.1 After experimentation, shut down the set up.

8. Observations & Calculations:

Observation Table (For Open Loop Control System):

S.No.	SP (%)	PV (%)

Observation Table (For Proportional Control):

S.No.	K_C	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table (For Proportional+ Integral Control):

S.No.	K_C	T_i (min)	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table For Proportional+ Derivative Control):

S.No.	K_C	T_d (min)	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table (For Proportional+Integral+ Derivative Control):

S.No.	K_C	T_i (min)	T_d (min)	t (sec)	SP (%)	PV (%)	OP (%)

Observation Table (For Tuning Of Control (Open Loop Method)):

S.No.	t (sec)	PV (%)

Observation Table (For Stability Of System (Bode Plot)):

S.No.	K_C	t (sec)	w (rad/sec)

OBSERVATION TABLE (FOR AUTOTUNING OF CONTROL):				
S.No.	P_u (min)	K_u	T (min)	T_P (min)

CALCULATIONS:

(FOR OPEN LOOP CONTROL SYSTEM):

$$e = SP - PV \ (\%)$$

(FOR PROPORTIONAL CONTROL):

$$e = SP - PV \ (\%)$$

$$P_B = \frac{1}{K_C} \times 100 \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+INTEGRAL CONTROL):

$$e = SP - PV \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+DERIVATIVE CONTROL):

$$e = SP - PV \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR PROPORTIONAL+INTEGRAL+DERIVATIVE CONTROL):

$$e = SP - PV \ (\%)$$

Plot the graph of e vs t.

Plot the graph of PV vs t.

(FOR TUNING OF CONTROLLER (OPEN LOOP METHOD)):

T = ____________(min) **[Refer theory Part-VI]**

T_P = ____________ (min) **[Refer theory Part-VI]**

For P controller

$$K_C = \frac{T_P}{T}$$

For PI controller

$$K_C = 0.9\frac{T_P}{T}$$

$$T_i = \frac{T}{0.3} \text{ (min)}$$

For PID controller

$$K_C = 1.2\frac{T_P}{T}$$

$$T_i = 2T \text{ (min)}$$

$$T_d = 0.5T \text{ (min)}$$

(FOR STABILITY OF SYSTEM):

$$AR = \frac{K_C}{\sqrt{1 + w^2 t^2}}$$

$$\phi = \tan^{-1}(-tw)$$

CALCULATION TABLE:		
S.No.	**AR**	ϕ

Plot the graph of AR vs w on semi log co-ordinates.

Plot the graph of ϕ Vs w on semi log co-ordinates.

$w_{CO} =$ ___________ [at $\phi = 180^0$]

$A = AR$ [at w_{CO}]

(FOR AUTOTUNING OF CONTROLLER):

For P-only control (fast)

For P controller

$K_C = 0.5K_u$

For PI controller

$K_C = 0.4K_u$

$Ti = 0.8P_u$ (min)

For PID controller

$K_C = 0.6K_u$

$T_i = 0.5P_u$ (min)

$T_d = 0.12P_u$ (min)

For P-only control (normal)

For P controller

$K_C = 0.2K_u$

For PI controller

$K_C = 0.18 K_u$

$T_i = 0.8 P_u$ (min)

For PID controller

$K_C = 0.25 K_u$

$T_i = 0.5 P_u$ (min)

$T_d = 0.12 P_u$ (min)

For P-only control (slow)

For P controller

$K_C = 0.13 K_u$

For PI controller

$K_C = 0.13 K_u$

$T_i = 0.8 P_u$ (min)

For PID controller

$K_C = 0.15 K_u$

$T_i = 0.5 P_u$ (min)

$T_d = 0.12 P_u$ (min)

For PI and PID control (fast)

For P controller

$$K_C = \frac{T_P}{T}$$

For PI controller

$$K_C = 0.9 \frac{T_P}{T}$$

$T_i = 0.33 T$ (min)

For PID controller

$$K_C = 1.1\frac{T_P}{T}$$

$T_i = 2.0T$ (min)

$T_d = 0.5T$ (min)

For PI and PID control (normal)

For P controller

$$K_C = 0.44\frac{T_P}{T}$$

For PI controller

$$K_C = 0.4\frac{T_P}{T}$$

$T_i = 4.0T$ (min)

For PID controller

$$K_C = 0.32\frac{T_P}{T}$$

$T_i = 4.0T$ (min)

$T_d = 0.8T$ (min

For PI and PID control (slow)

For P controller

$$K_C = 0.26\frac{T_P}{T}$$

For PI controller

$$K_C = 0.24\frac{T_P}{T}$$

$T_i = 5.33T$ (min)

For PID controller

$$K_C = 0.32\frac{T_P}{T}$$

$$T_i = 4.0T \text{ (min)}$$

$$T_d = 0.8T \text{ (min)}$$

9. NOMENCLATURE:

Nom	Column Headings	Units	Type
SP	Set point	%	Measured
PV	Process variable	%	Measured
e	Error	%	Calculated
K_C	Controller gain	*	Measured
t	Time	sec	Measured
P_B	Proportional band	%	Calculated
OP	Output	%	Measured
T_i	Integral time	min	Measured
T_d	Derivative time	min	Measured
K_u	Ultimate gain	*	Measured
P_u	Ultimate period	min	Measured
w	Frequency	*	Measured
AR	Amplitude ratio	*	Calculated
ϕ	Phase angle	*	Calculated
A	Amplitude ratio	*	Calculated
w_{CO}	Cross over frequency	*	Calculated
T	Dead time	min	Measured
T_P	Time constant	min	Measured

* Symbols represent unitless quantity.

10. PRECAUTIONS & MENTAINENCE:

10.1 Flow should not be disturb during the experiment.

10.2 Do not switch OFF the power during experiment.

11. TROUBLESHOOTING:

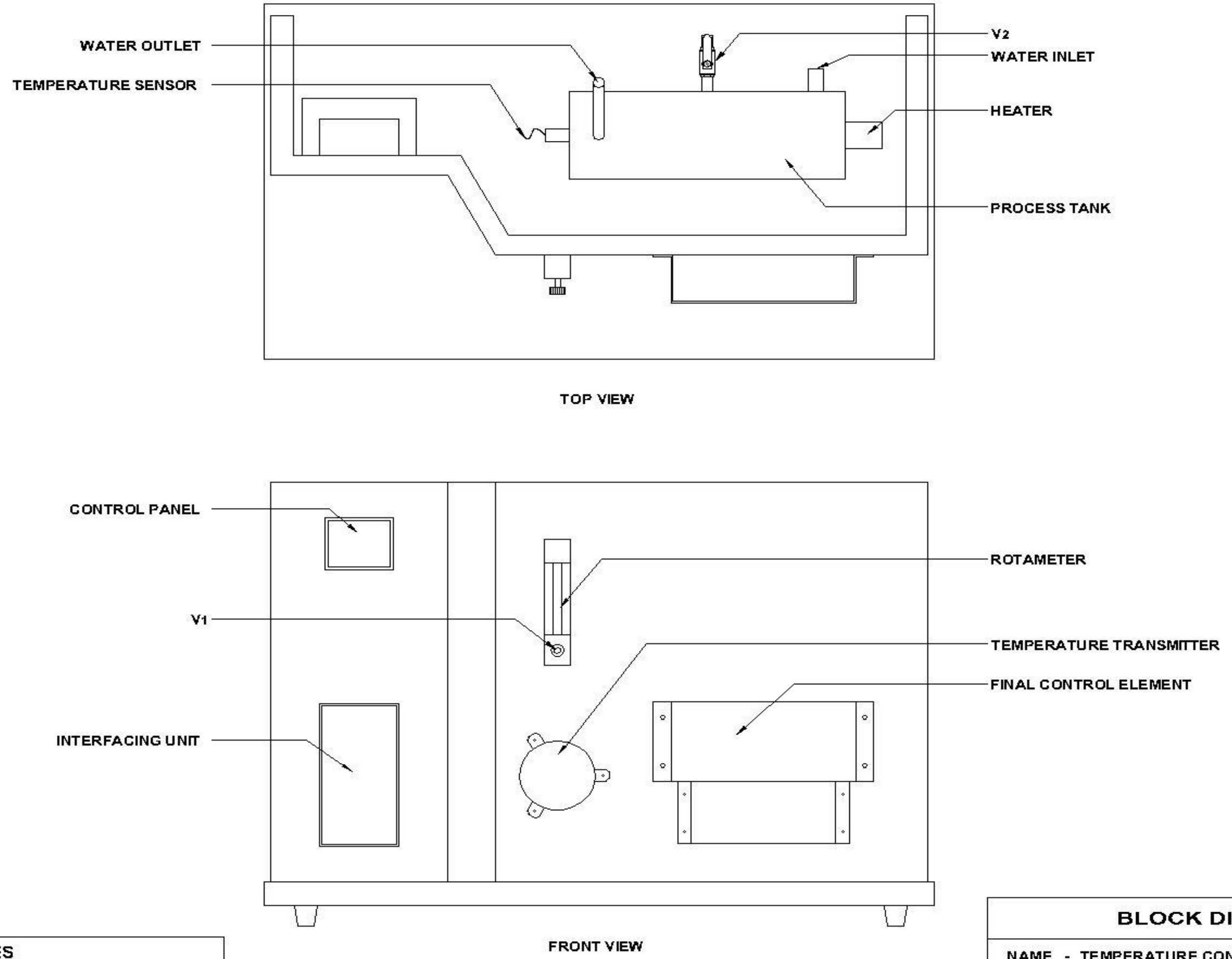
11.1 If rotameter fluctuating more than average then tight the control knob properly.

12. REFERENCES:

12.1 Coughanowr, Donald R. (1991). *Process Systems Analysis and Control.* 2nd Ed. ND: Mc Graw-hill International. pp 128-133, 164-165, 227-230.

12.2 Stephanopoulos, George (2006). *Chemical Process Control*. 1st Ed. ND: Prentice Hall of India Pvt. Ltd. p 243.

13. BLOCK DIAGRAM:



VALVES
1. V1 - FLOW CONTROL VALVE FOR WATER
2. V2 - DRAIN VALVE OF PROCESS TANK

BLOCK DIAGRAM
NAME - TEMPERATURE CONTROL TRAINER
CODE - PC-103