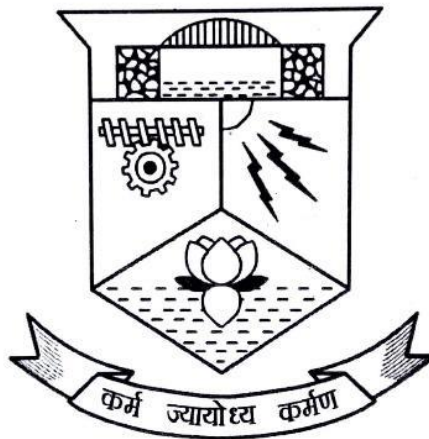


**DEPARTMENT OF ELECTRONICS & COMMUNICATION  
ENGINEERING  
COLLEGE OF ENGINEERING TRIVANDRUM**

*Laboratory Manual*

*of*

**AE332  
PROCESS CONTROL LAB  
(PART 1 of 2)**



**DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING  
COLLEGE OF ENGINEERING THIRUVANANTHAPURAM**



**CERTIFICATE**

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Course Code	Course Name	L-T-P Credits	Year of Introduction
AE332	PROCESS CONTROL LAB	0-0-3-1	2016
<b>Prerequisite:</b> AE302 Process Control			
<b>Course Objectives:</b> <ul style="list-style-type: none"> <li>To provide experience on control of various industrial processes using different control paradigms</li> <li>To provide experience in development of virtual instrumentation systems for industry applications</li> <li>To introduce few novel control strategies based on artificial neural networks, fuzzy logic, digital control algorithm, etc.</li> </ul>			
<b>LIST OF EXPERIMENTS:</b> (Minimum 12 Experiments are to be done) <ol style="list-style-type: none"> <li>ON-OFF Controller with a without neutral zone- level control, flow control</li> <li>Temperature Control using P, PI, PD and PID controllers- Study of output response</li> <li>Flow Control using P, PI, PD and PID controllers- Study of output response</li> <li>Liquid Level Control using P, PI, PD and PID controllers- Study of output response</li> <li>Pressure Control using P, PI, PD and PID controllers- Study of output response</li> <li>Control Valve characteristics</li> <li>Controller Tuning for various processes-using Ziegler Nichols rule</li> <li>Controller Tuning for various processes-using Cohen and Coon rule</li> <li>Controller Tuning - Simulation</li> <li>Block diagram simulation of a complex control system</li> <li>Study of Feed-forward control, cascade and ratio controls</li> <li>Data Logger</li> <li>PC based control of robotic actions</li> <li>Simulation of Artificial Neural Networks- use any software</li> <li>Simulation of Heat Exchanger Temperature Control</li> <li>Interface of DCS with PLC/ SCADA using protocol/ fieldbus</li> </ol>			
<b>Expected Outcome:</b> <ul style="list-style-type: none"> <li>At the end of the semester students will be familiar with the concepts of process controllers</li> </ul>			

Course Code	Course Name	L-T-P Credits	Year of Introduction
01EC6193	<b>INSTRUMENTATION AND CONTROL SYSTEM LAB</b>	<b>0-0-2-1</b>	<b>2015</b>
<b>Prerequisite: AE302 Process Control</b>			
<b>Course Objectives:</b> <ol style="list-style-type: none"> <li>1. Familiarizing various PLC software and ladder logic</li> <li>2. Familiarising GUI (Graphical User Interface) software like SCADA and LabVIEW.</li> <li>3. Implementing various Control Systems.</li> </ol>			
<b>LIST OF EXPERIMENTS:</b> <ol style="list-style-type: none"> <li>1. Data Acquisition and control using Lab VIEW.</li> <li>2. Controller tuning techniques</li> <li>3. Determining the non-linearity of a system.</li> <li>4. Distributed Control through PROFIBUS.</li> <li>5. SCADA.</li> <li>6. Control of Robotic arm.</li> <li>7. PLC.</li> <li>8. Cascade control.</li> <li>9. Feed forward control.</li> <li>10. Ratio Control</li> <li>11. Inferential Control</li> <li>12. Override Control</li> </ol>			
<b>Expected Outcome:</b> <ul style="list-style-type: none"> <li>• On completion of the LAB student will be capable doing PLC and SCADA programming in Industrial Level.</li> <li>• On completion of the LAB student will get a sound understanding of Control system in Industrial level.</li> </ul>			

## **AE332 PROCESS CONTROL LAB**

**(i) Course Outcomes (COs)**

<b>Course Outcome Designation</b>	<b>Course Outcome (CO) Description</b>
	<b>At the end of the course, the student should be able to:</b>
AE332/CO1	Realize various controllers for controlling temperature, pressure, level & flow
AE332/CO2	Realize of logic gates using PLC
AE332/CO3	Plot the characteristics of complex control schemes like ratio, cascade, etc.
AE332/CO4	Tune controllers using Ziegler- Nichols & Cohen- Coon techniques
AE332/CO5	Understand the working of data acquisition system & Virtual Instrument

**(ii) CO-PO/PSO matrix showing level of correlation (1-Low, 2-Medium, and 3-high)**

<b>Course: AE332 Process Control Lab</b>															
<b>Course Outcome Designation</b>	<b>CO-PO/PSO matrix showing level of correlation (1-Low, 2-Medium, and 3-High)</b>														
	<b>PO - 1</b>	<b>PO - 2</b>	<b>PO- 3</b>	<b>PO- 4</b>	<b>PO- 5</b>	<b>PO- 6</b>	<b>PO- 7</b>	<b>PO- 8</b>	<b>PO- 9</b>	<b>PO- 10</b>	<b>PO- 11</b>	<b>PO- 12</b>	<b>PS O- 1</b>	<b>PS O- 2</b>	<b>PS O- 3</b>
AE332/ CO1	3	2	3	2	3				3	3			3	3	
AE332/ CO2	3	2	3	3	3				3	3			3	3	
AE332/ CO3	3	2	3	3	3				3	3			3	3	
AE332/ CO4	3	2	3	3	3				3	3			3	3	
AE332/ CO5	3	2	3	1	3				3	3			3	3	3

**(ii) Course-PO/PSO matrix which is consistent with CO-PO/PSO mapping/matrix**

<b>Course: AE332 Process Control Lab</b>															
<b>Course Outcome Designation</b>	<b>CO-PO/PSO matrix showing level of correlation (1-Low, 2-Medium, and 3-High)</b>														
	<b>PO - 1</b>	<b>PO - 2</b>	<b>PO- 3</b>	<b>PO- 4</b>	<b>PO- 5</b>	<b>PO- 6</b>	<b>PO- 7</b>	<b>PO- 8</b>	<b>PO- 9</b>	<b>PO- 10</b>	<b>PO- 11</b>	<b>PO- 12</b>	<b>PS O- 1</b>	<b>PS O- 2</b>	<b>PS O- 3</b>
AE332/ CO1	3	2	3	2	3				3	3			3	3	3

## PROCESS CONTROL LAB

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7	Controller tuning for various processes – Using Ziegler-Nichols rule	44
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# **EXPERIMENT NO. 1**

## **ON-OFF CONTROLLER WITH AND WITHOUT NEUTRAL ZONE- TEMPERATURE CONTROL**

### **Aim**

To design and set up ON-OFF controller with and without neutral zone for the following specifications.

1. Design and test an ON-OFF controller for a heater, for a set point of 150°C.
2. Design an ON-OFF controller with neutral zone to control the temperature of water between 80°C and 100°C

### **Apparatus Required**

Temperature controller.

### **Theory**

An ON-OFF controller is the simplest form of a temperature control device. The output from the device is either on or off, with no state in between. An ON-OFF controller switches the output only when the temperature is below the set point, and off when the temperature is above the set point. The temperature keeps cycling continuously between these two stages. In cases where this cycling occurred rapidly, to prevent damage to contactors and valves, an on ON-OFF differential or 'hysteresis', is added to the controller operations. The temperature exceeds set point by a certain amount before the output will turn off or on again because of hysteresis. ON-OFF differential prevents the output from 'chattering' or making fast, continuous switching if the cycling above and below the set point occurs very rapidly.

ON-OFF control is usually used where a precise control is not necessary, in systems which cannot handle the energy of turning on and off frequently. Systems where the mass of the system is so great that temperature change extremely slowly, a temperature alarm, etc. can use ON-OFF controller. One special type of ON-OFF control used for alarm is a limit controller. This controller uses latching relay, which must be manually reset and is used to shut down a process when a temperature is reached.

When a controller operates in discontinuous mode around a set point (for example turning an air conditioner ON above a certain room temperature and turn OFF below that temperature) there can be frequent undesirable oscillations between on and off (sometimes referred to as 'chatter'), when the variable is close to the set point. To solve this problem a neutral zone (as shown in Fig.1.1), can be implemented between two set points (high and low) with the controller taking no action as long as the temperature is in the neutral zone.

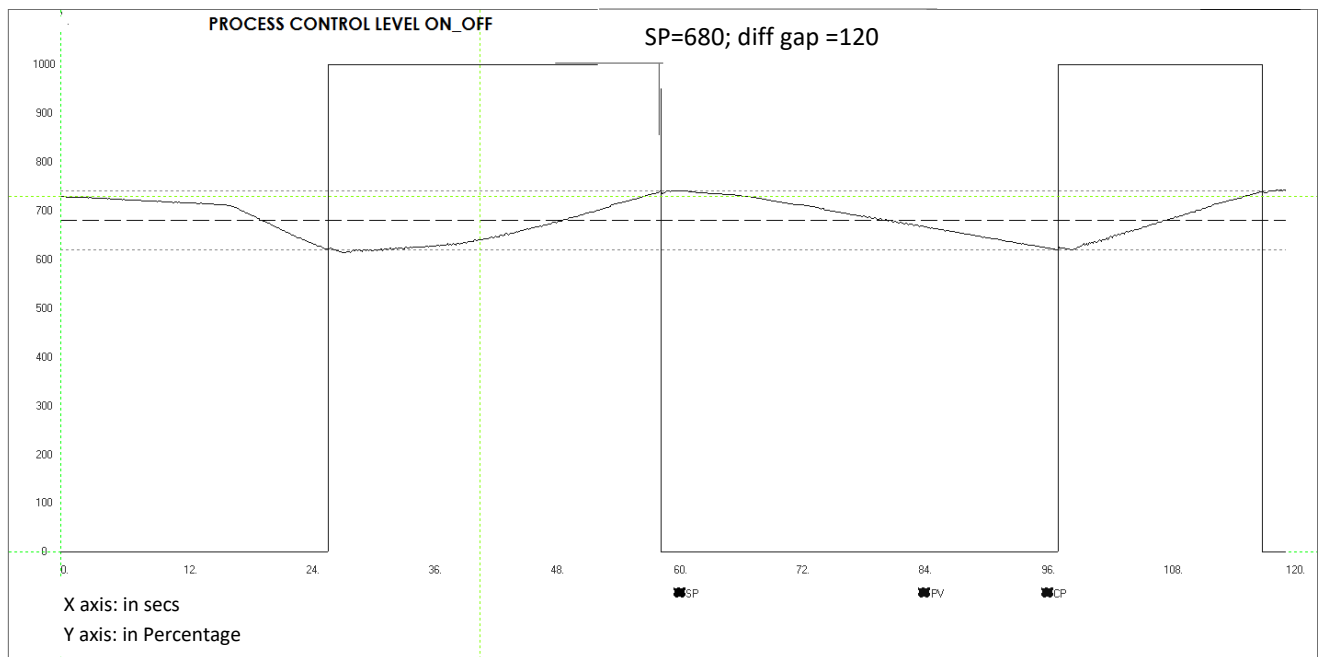


Fig. 1.1 ON-OFF control graph

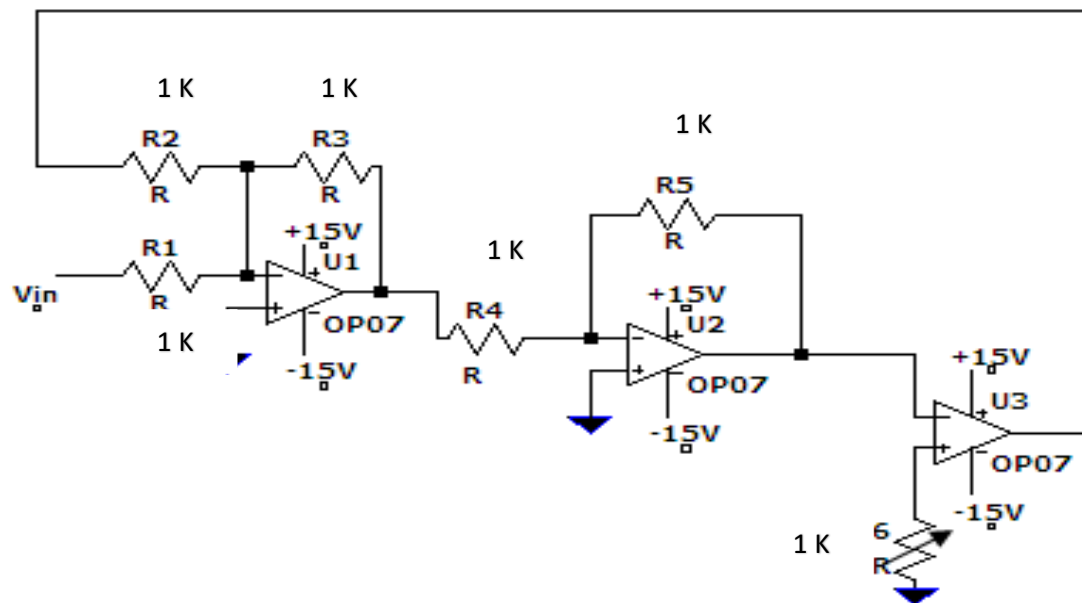


Fig. 1.2 ON-OFF Controller without neutral zone



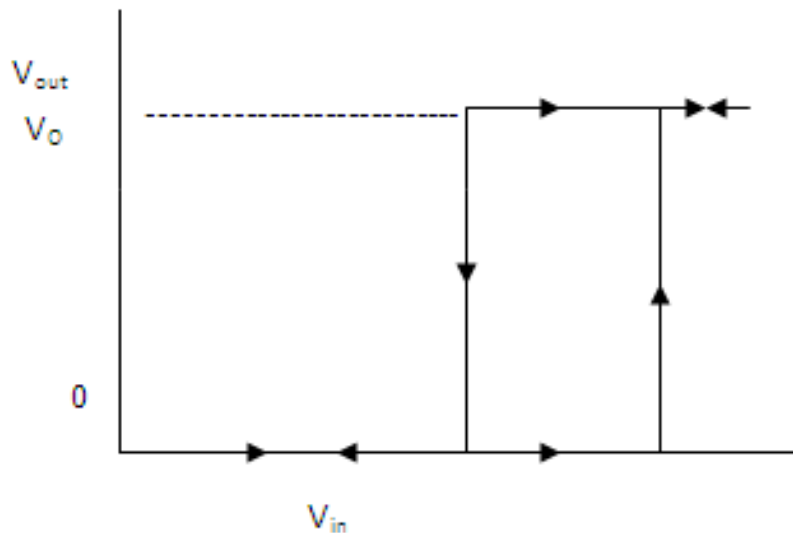


Fig. 1.3 Hysteresis curve of ON- OFF Control

#### ON-OFF controller without neutral zone

Select Pt100 as the sensing element. Pt100 has  $100\Omega$  at  $0^\circ\text{C}$  and a temperature coefficient,  $\alpha$  of  $.0036\ \Omega/^\circ\text{C}$ . Select the lower fixed resistance as  $150\ \Omega$  and the other as RTD measured value. For setting bridge performance, the upper arms are selected approximately 10 times as lower arms. The voltage across  $154\ \Omega$  is applied as the reference voltage to a comparator. The RTD voltage is applied at the non-inverting terminal. When the temperature just exceeds  $150^\circ\text{C}$ , output of the comparator switches to positive saturation. This will turn on the transistor as the normally closed terminals of relay are used, the heater turns off when the transistor switches on. When the temperature falls below  $150^\circ\text{C}$ , the output of the comparator switches to negative saturation and the heater is turned on again.

#### ON-OFF controller with neutral zone

In Fig.1.2, if the input voltage  $V_{in}$  from the sensor processing circuits output reaches a value  $V$

### **DESIGN**

#### 1. ON-OFF controller without neutral zone

$$R_{150} = R_0 (1 + \alpha T) = 100(1 + 0.0036 \times 150) = 154\Omega \text{ (select } 150\Omega\text{)}$$

Select upper arms as  $1\text{k}\ \Omega$ . At positive saturation, output of comparator =  $15\text{V}$

$$\text{Relay needs a current} = \frac{12\text{V}}{200\Omega} = 60\text{ mA}$$

Select transistor with  $I_C$  more than  $60\text{ mA}$ .

$$I_b = I_c / \beta = 60\text{mA}/100 = 0.6 \text{ mA.}$$

$$R_b = \frac{15-.7}{.0006} = 22k$$

## 2. ON-OFF controller with neutral zone

For Pt100 RTD,  $R_0 = 100\Omega$

$$R_T = R_0(1 + \alpha T) = 100(1 + .0036 \times 100) = 136\Omega$$

At  $80^\circ\text{C}$  the difference O/P of the bridge =  $.567 - .454 = .113\text{V}$

At  $100^\circ\text{C}$  the diff. O/P of bridge =  $((5 \times 136)/(1000 + 136)) - .454 = .144\text{V}$

Set the gain of the diff. amplifier, such that the voltage will be changing from 1.13V to 1.44V when the temperature changes from  $80^\circ\text{C}$  to  $100^\circ\text{C}$

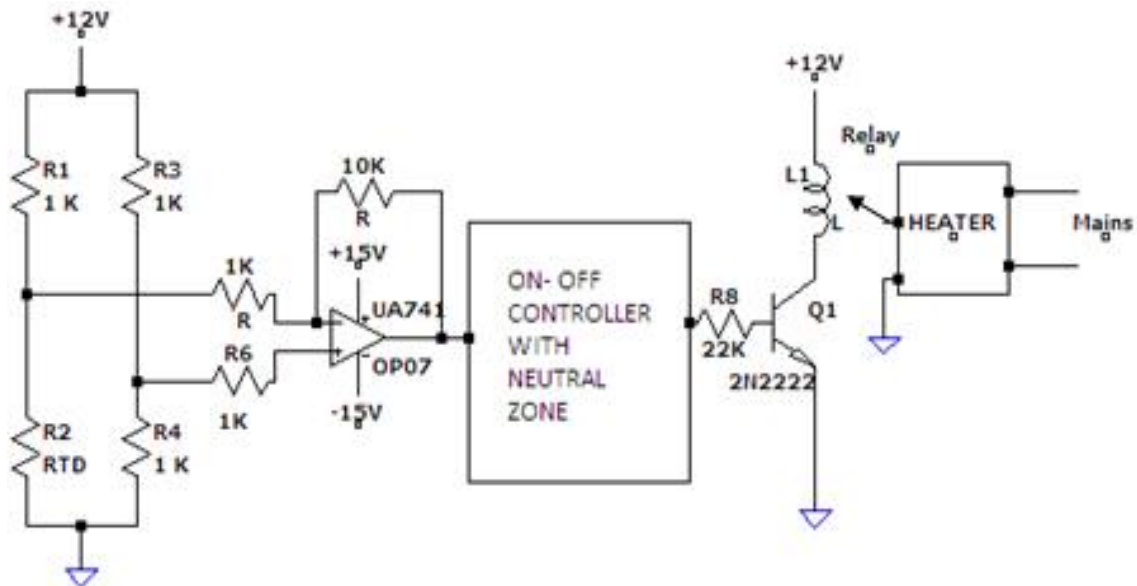


Fig. 1.4 ON-OFF Controller with neutral zone

Therefore, set  $V_{sp} = V_H 1.44 \text{ V}$  by adjusting the pot 'p'. Put R of the inverter as 1K

$$tV_1 = V_{SP} - \left(\frac{R_1}{R_2}\right) \times V_O = 1.13\text{V}$$

$$V_1 = 1.44 - \left(\frac{R_1}{R_2}\right) (V_{\text{sat of the comparator}})$$

Take  $R_1$  &  $R_2$  which satisfies the above condition.

## **Procedure**

### **Without neutral zone**

- Place the overall system in the on-off mode.
- Give a value set point.
- Observe the process output Vs time.

### **With neutral zone**

- Place the overall system in the on-off mode.
- Give the upper limit and lower limit of set point.
- Observe the process output versus time.

## **Result**

ON-OFF controller, with and without neutral zone using a temperature controller was studied.

## **EXPERIMENT NO. 2**

### **TEMPERATURE CONTROL USING P, PI, PD AND PID CONTROLLERS- STUDY OF OUTPUT RESPONSE**

#### **Aim**

To study the performance of P, PI, PD and PID controllers in a temperature control system.

#### **Apparatus required**

Temperature Control System trainer kit

#### **Theory**

Fig 2.1 shows the block diagram of a closed loop control system. The function of the controller is to receive the measured output signal, which is to be compared with the set point to produce the actuating signal in such a way as to bring the output to the desired value. The input to the controller is the error signal which is defined as the difference between the measured output signal and set point. The basic feedback controllers are explained below.

#### **1. Proportional controller**

Proportional controller produces a signal that is proportional to the error  $e(t)$ . This action may be expressed as,  $P(t) = K_C e(t) + P_s$ , where  $P_s$  is controller bias signal which is a constant,  $K_C$  is gain,  $p(t)$  is output and  $e(t)$  is error. The P controller is described by  $K_C$  or equivalently by proportional band (PB), where  $PB = 100/K_C$ . P controller produces an oscillatory response with overshoot which always produces offset.

#### **2. Proportional- Derivative controller**

Proportional Derivative Controller is represented as

Controller O/P,  $P(t) = K_C e(t) + K_C \tau_d \frac{de(t)}{dt} + P_s$ , where  $\tau_d$  is the derivative time constant and 'e' and 'P' are functions of time. Here the response exhibits a smaller overshoot and smaller oscillations compared to P controller. The offset is also less than that of P controller.

#### **3. Proportional- Integral Controller**

This mode of controller is represented as

Controller O/P,  $P(t) = K_C e(t) + \frac{K_C}{\tau_I} \int_0^t e(t) dt + P_s$ , where  $\tau_I$  is the integral time constant and 'e' and 'P' are functions of time. PI controller eliminates offset. The peak overshoot is same as that of P controller and the settling time is relatively large.

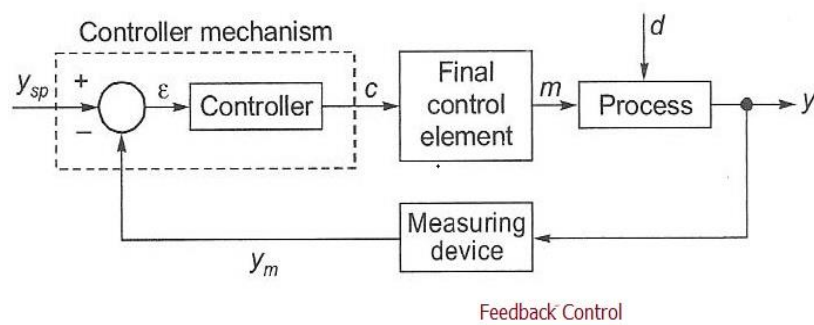


Fig. 2.1 Block Diagram of a closed loop control system

Note: For component specific problems refer Components' Manuals

Problems	Possible causes / remedies
Temperature does not rise	<ul style="list-style-type: none"> <li>• Low electric supply voltage</li> <li>• Burnt heater coil. Replace the heater</li> <li>• Faulty Solid State Relay</li> </ul>
No communication with computer	<ul style="list-style-type: none"> <li>• Check communication settings for IP addresses of computer and controller. Default setting computer 192.168.1.2 and controller 192.168.1.11</li> </ul>

Table 2.1 Troubleshooting

Product	Temperature control trainer
Product code	311A
Temperature sensor	Make Radix, Type Pt100, Sheath Dia.6mmX110mmL, SS316, Connection 1/4"BSP(M) adjustable compression fitting
Digital indicating controller	Make Yokogawa, Model UT35A-002-11-00 with Ethernet communication
Heating control (SSR)	Make Unison, Model UNI 701 PHT 24 25 420 (Back To Back SCR), Input 4-20 mA, O/P 230VAC with Heat sink, Rating: 25Amp. (765+89)
Heater	Type - 3.0 kw, 2 coil, industrial, Size - 1.25 " BSPx10 " L, Input 230VAC
Rotameter	Make Eureka, Model MG 10, Range 6 -60 lph, connection 1/4" back, screwed, packing PTFE + Silicon

Table 2.2 Details of Equipment Used

#### 4. Proportional- Integral- Derivative Controller

PID Controller is represented as

Controller O/P,  $P(t) = K_c e(t) + \frac{K_c}{\tau_I} \int_0^t e(t) dt + K_C \tau_d \frac{de(t)}{dt} + P_s$ , where 'e' and 'P' are functions of time. The response has lower overshoot and returns to set point more quickly.

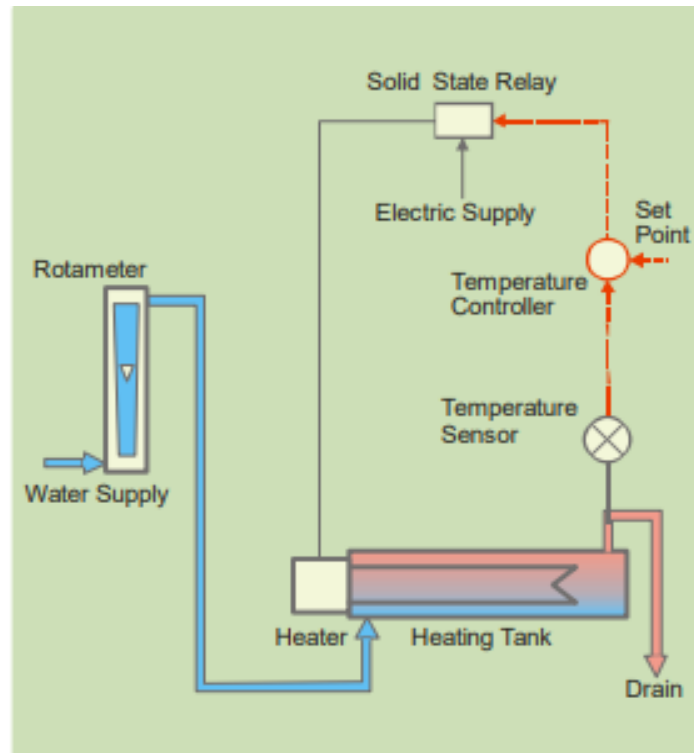


Fig. 2.2 Temperature Control of heating tank system diagram

#### Trainer Kit Description

Temperature control trainer is designed for understanding the basic temperature control principles. The process setup consists of heating tank fitted with SSR controlled heater for on- line heating of the water. The flow of water can be manipulated and measured by rotameter. Temperature sensor (RTD) is used for temperature sensing. The process parameter (Temperature) is controlled by microprocessor based digital indicating controller which manipulates heat input to the process. These units along with necessary piping and fitting are mounted on support frame designed for tabletop mounting. The controller can be connected to computer through Ethernet port for monitoring the process in SCADA mode.

<b>Product</b>	Temperature control trainer
<b>Product code</b>	311A
<b>Type of control</b>	SCADA
<b>Control unit</b>	Digital indicating controller with Ethernet communication
<b>Communication</b>	Ethernet
<b>Temperature sensor</b>	Type RTD, PT100
<b>Heating control</b>	Proportional power controller (SSR), Input 4-20 mA, Capacity 50 A.
<b>Heater</b>	Type Electrical 2 coil, Capacity 3 KW
<b>Rotameter</b>	6-60 LPH
<b>Process tank</b>	SS304, Capacity 0.5 lit, insulated
<b>Overall dimensions</b>	550Wx480Dx525H mm

Table 2.3 Specifications

## **Procedure**

### **1. Study of open loop response (Manual Control)**

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at
- @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Temperature Control Trainer (311A)
- Select Yokogawa (UT35A)
- Click Continue
- Click Connect
- Click on Select Experiment.
- Select Open Loop and click Start
- Decrease the controller output to 0%. Note down steady state process value.
- Apply the step change by 10% to controller output and wait for process value to reach the steady state value.
- Repeat the above step until the controller output reaches to maximum, i.e., 100% and for each change, note steady state process value.

Set the output of the controller to the noted value and at steady state, apply the load change to the process. Load change can be given by slightly varying the drain valve. Observe new steady state Process value.

### Observations (Manual Mode)

Controller output (in %)	Process Value (%)

- From the above data, note the output required for maintaining the temperature at desired set points.

### Observations (P Mode)

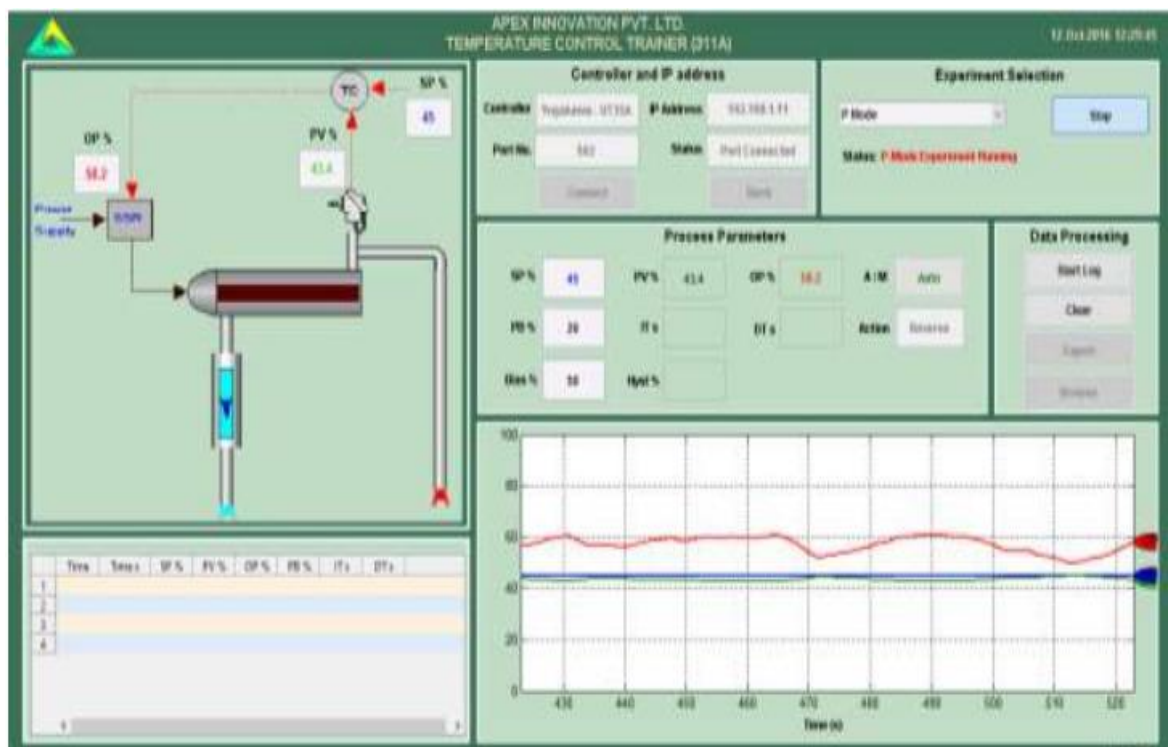


Fig. 2.3 P response

- Observe steady state error decreases as proportional band decreases.
- Observe the effect of very low proportional band values (system works in oscillatory mode).



## 2. Study of Proportional Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Temperature Control Trainer (311A)
- Select Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select P Mode and click Start
- Keep the set point to 40%. (Set point should be 10% more than inlet water temperature) Change output mode to Manual. Adjust output value so as to match the process value with set point and apply this output value as bias value to the controller. Adjust the proportional band to 50%.
- Switch the controller to auto mode.
- Apply step change to set point, step change should be of 2 to 3 % and observe the response.
- Switch the controller to Manual mode. Decrease proportional band to half of the previous value & then shift controller to Auto mode. With each decrease, obtain a new response of the step change. Ensure that the set point changes are around the same operating point (@ 2-3% only).
- Using trial and error approach find a value of proportional band so that the response to a step change has at most one overshoot and one undershoot.
- Set the controller to the settings obtained in the above step and wait for the system to reach at steady state.

## 3. Study of Proportional- Integral controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex Process Trainers icon on the desktop.
- Select product Temperature Control Trainer (311A)
- Select Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PI Mode and click Start
- Adjust the process value by changing the output of controller in manual mode to a particular pressure (set point =40%).
- Set the proportional band estimated in Proportional control. Set derivative time to 0 sec and integral time 1000 sec, which will cut off the derivative action and widen the effect of integral action.
- Allow the process to reach at steady state. Record the steady state error.
- Switch the controller to manual mode. Reduce the integral time to 2 -3% of the previous value.
- Switch to Auto mode and apply step change to the set point. Note the response of the system.
- Using trial and error, find out an integral time, which gives satisfactory response to the step change in set point.

## Observations (PI Mode)

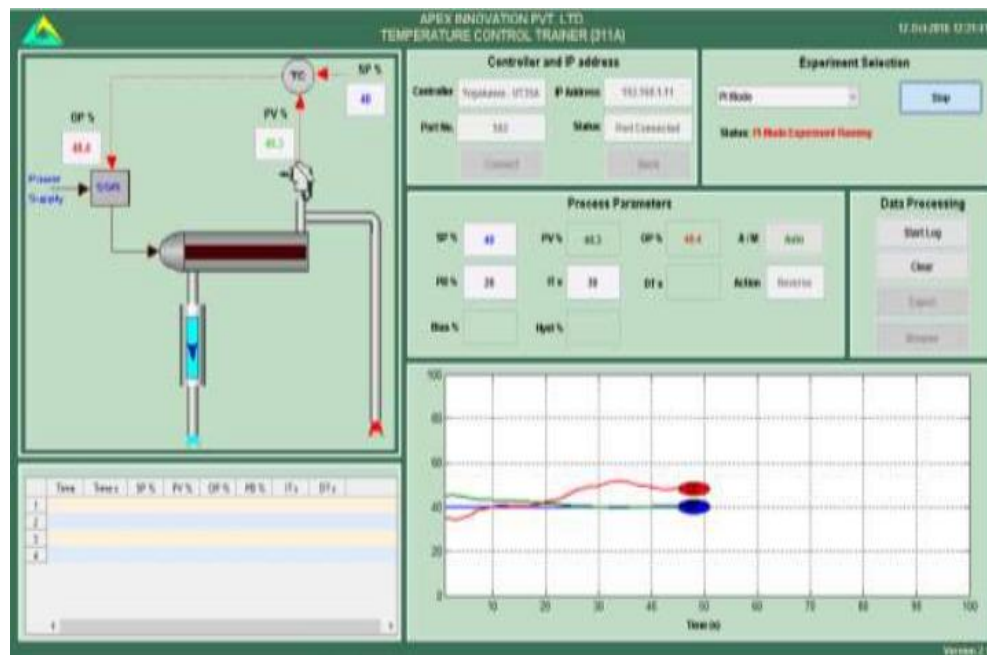


Fig. 2.4 PI response

## Observations (PD Mode)

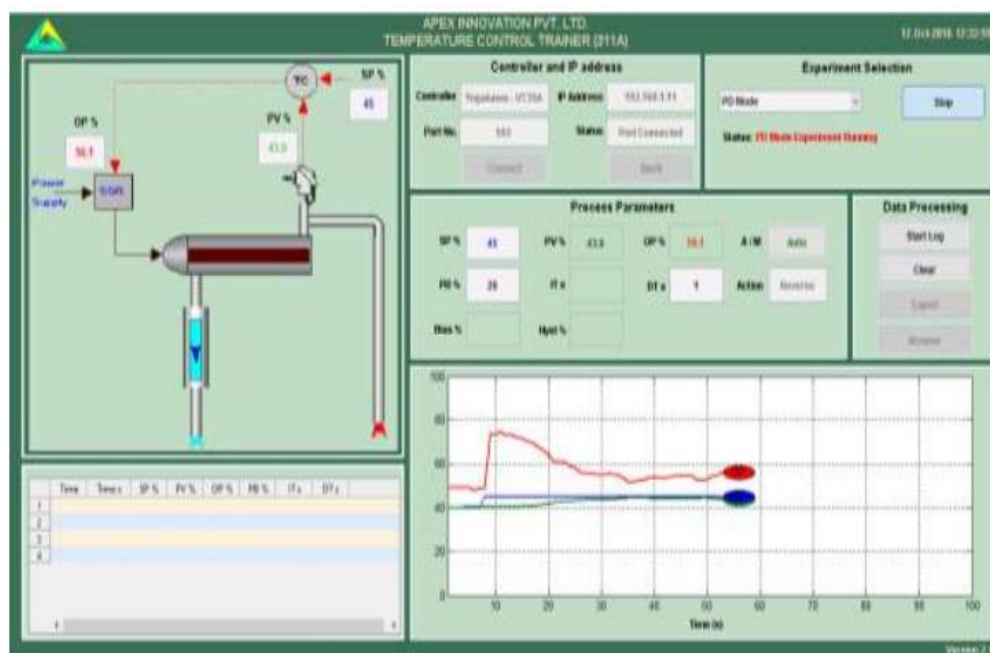


Fig. 2.5 PD response

#### **4. Study of proportional derivative controller**

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer >> Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Temperature Control Trainer (311A)>>Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PD Mode and click Start
- Select PD controller. Set the proportional band estimated from Proportional control (P only). Start with derivative time=0 and integral time=6000 sec., which will cut off the derivative action and widen the effect of integral action.
- Set the set point to desired value (@40%). Allow the process to reach at steady state. Note the response of the system.
- Switch the controller to manual mode Increase the derivative time by 1 sec. Switch to Auto mode and apply step change to the set point by 2 to 3%. Note the response of the system.
- Increase the derivative time gradually and observe the process response for step change.

#### **5. Study of proportional integral derivative controller**

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Temperature Control Trainer (311A)>> Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PID Mode and click Start
- Switch the controller to manual mode.
- Change the proportional band to the value that estimated in proportional controller. Set integral time and derivative time based on the responses in previous experiments.
- Change the controller to Auto mode. Apply step change by 2 to 3% to the set point and observe the response of the process
- Change the proportional band, integral time, derivative time and observe the response of the process for step change for each change in setting.

## Observations (PID Mode)

Compare the steady state response of the PID controller with P, PI and PD controller obtained in the above experiment.

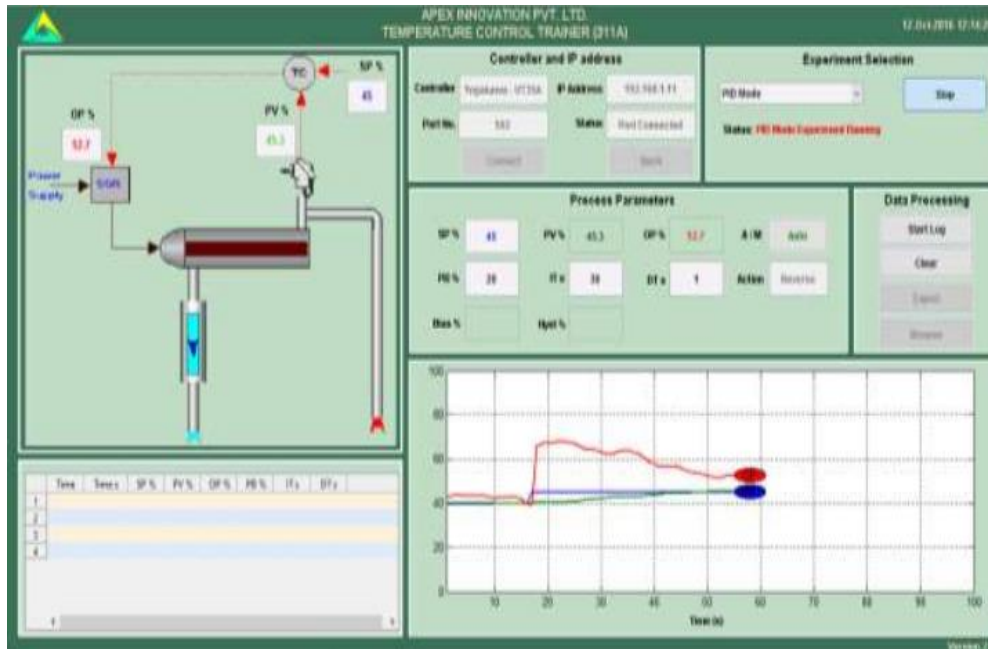


Fig. 2.6 PID response

## Result

The performance of P, PI, PD and PID controllers are studied for temperature control and the response curves are plotted.

# EXPERIMENT NO. 3

## FLOW CONTROL USING P, PI, PD AND PID CONTROLLERS-

### STUDY OF OUTPUT RESPONSE

#### Aim

To study the performance of P, PI, PD and PID controllers in a Flow control system.

#### Apparatus required

Flow Control trainer

#### Theory

Fig. 3.1 shows the block diagram of a closed loop control system. The function of the controller is to receive the measured output signal, which is to be compared with the set point to produce the actuating signal in such a way as to bring the output to the desired value. The input to the controller is the error signal which is defined as the difference between the measured output signal and set point. The basic feedback controllers are given below.

#### **1. Proportional controller**

Proportional controller produces a signal that is proportional to the error  $e(t)$ . This action may be expressed as,  $P(t) = K_C e(t) + P_s$ , where  $P_s$  is controller bias signal which is a constant,  $K_C$  is gain,  $p(t)$  is output and  $e(t)$  is error. The P controller is described by  $K_C$  or equivalently by proportional band (PB), where  $PB = 100/K_C$ . P controller produces an oscillatory response with overshoot which always produces offset.

#### **2. Proportional- Derivative controller**

Proportional Derivative Controller is represented as

Controller O/P,  $P(t) = K_C e(t) + K_C \tau_d \frac{de(t)}{dt} + P_s$ , where  $\tau_d$  is the derivative time constant and 'e' and 'P' are functions of time. Here the response exhibits a smaller overshoot and smaller oscillations compared to P controller. The offset is also less than that of P controller.

#### **3. Proportional- Integral Controller**

This mode of controller is represented as

Controller O/P,  $P(t) = K_C e(t) + \frac{K_C}{\tau_I} \int_0^t e(t) dt + P_s$ , where  $\tau_I$  is the integral time constant and 'e' and 'P' are functions of time. PI controller eliminates offset. The peak overshoot is same as that of P controller and the settling time is relatively large.

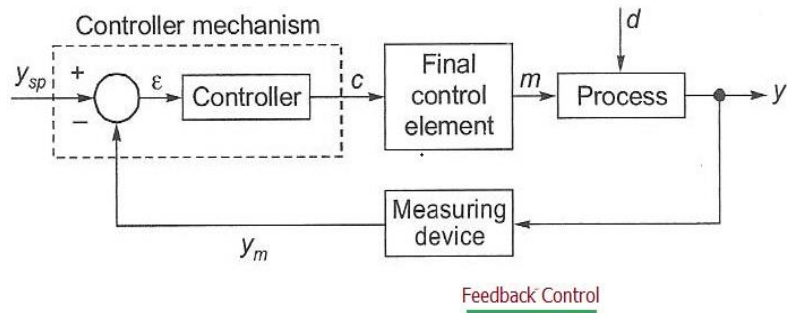


Fig. 3.1 Block Diagram of a closed loop control system

Note: For component specific problems refer Components' Manual

Problems	Possible causes / remedies
Incorrect flow reading	<ul style="list-style-type: none"> <li>• Air trap in pressure signal line to flow transmitter</li> <li>• Choked pressure signal connections from orifice to flow transmitter due to scaling in water.</li> <li>• Reversed High-Low pressure signal connections from orifice to the flow transmitter</li> </ul>
Control valve does not operate	<ul style="list-style-type: none"> <li>• Valve diaphragm leakage/breakage</li> <li>• Faulty I/P converter</li> <li>• No output from Controller</li> </ul>
I/P converter does not work	<ul style="list-style-type: none"> <li>• Insufficient supply air pressure</li> <li>• Faulty electrical input signal</li> <li>• Clogged orifice</li> </ul>
No communication with computer	<ul style="list-style-type: none"> <li>• Check communication settings for IP addresses of computer and controller. Default setting computer 192.168.1.2 and controller 192.168.1.12</li> </ul>

Table 3.1 Troubleshooting

Product	Flow control trainer
Product code	312A
Differential pressure transmitter	Make Yokogawa, Model EJA110E-JM55J-912NN, Calibration range 0-200 (SQ RT) mm H <sub>2</sub> O, Output square root
Digital indicating controller	Make Yokogawa, Model UT35A-002-11-00 with Ethernet communication
I/P converter	Make Control air inc, Type T500-AC, Input 4-20 mA DC, output 3-15 psig, end connection 1/4 NPT
Control valve	Make Pneucn, Type globe 2 way, Model 119, size 1/2"x1/8", Screwed end(F), Body CCS, Trim SS, Travel 14.3, CV=0.63, Air to CLOSE, Spring range 0.2-1, actuator 12 sq inch.
Rotameter	Make Eureka, Model MG 11, Range 10-100 lph, Connection 1/4" BSP back, screwed, Packing PTFE + Silicon
Pump	Model HQB 4500, Head max. 4.5m, Output 5000 lph, Watts 100, Volts 220-240 AC, 50Hz.
Air filter regulator	Make Airmatic, Model MB10-02-1-PAP-PD ( Alu body, Polycarbonate bowl, G1/4 BSP, Range 0-2 Kg/cm <sup>2</sup> , Relieving, 25M Plastic element, Bunan diaphragm.
Pressure gauge	Make Wika, Dia.2.5", Gly. filled, Brass internls, S.S. casing, Range 0-2.5 Kg/cm <sup>2</sup> and 0-35 PSI, 1/4" BSP (M) back connection without bracket.
Pressure gauge	Make Wika, Dia.2.5", Gly. filled, Brass internls, S.S. casing, Range 0-7 Kg/cm <sup>2</sup> and 0-100PSI, 1/4" BSP (M) back connection without bracket.

Table 3.2 Details of Equipment Used

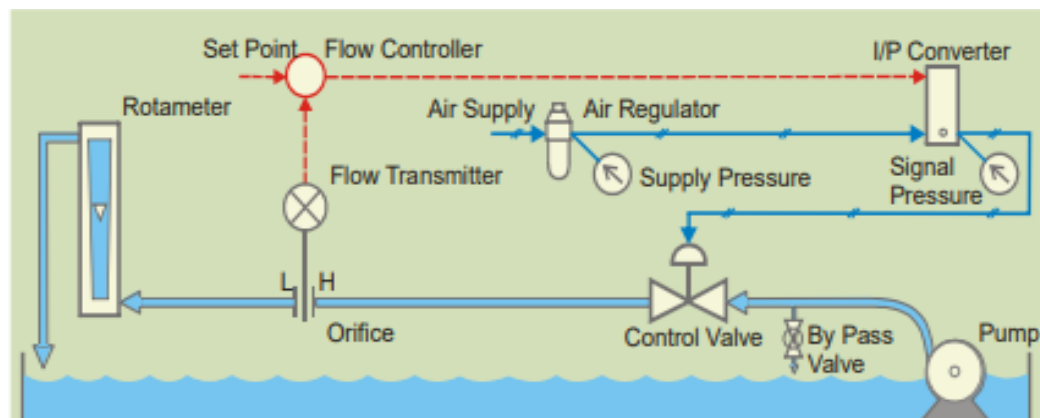


Fig. 3.2 Flow Control System Diagram

#### 4. Proportional- Integral- Derivative Controller

PID Controller is represented as

Controller O/P,  $P(t) = K_c e(t) + \frac{K_c}{\tau_I} \int_0^t e(t) dt + K_c \tau_d \frac{de(t)}{dt} + P_s$ , where 'e' and 'P' are functions of time. The response has lower overshoot and returns to set point more quickly.

#### Trainer Kit Description

Flow control trainer is designed for understanding the basic principles of flow control. The process setup consists of supply water tank fitted with pump for water circulation. A DP transmitter is used for flow sensing which measures differential pressure across orifice meter. The process parameter (flow) is controlled by microprocessor based digital indicating controller which manipulates pneumatic control valve through I to P converter. The control valve is fitted in water flow line. These units along with necessary piping are fitted on support housing designed for tabletop mounting. The controller can be connected to computer through Ethernet port for monitoring the process in SCADA mode.

<b>Product</b>	Flow control trainer
<b>Product code</b>	312A
<b>Type of control</b>	SCADA
<b>Control unit</b>	Digital indicating controller with Ethernet communication
<b>Communication</b>	Ethernet
<b>Differential pressure transmitter</b>	Type Capacitance, two wire, Range 0–200 mm, Output 4–20 mA sq.root
<b>I/P converter</b>	Input 4-20mA, Output 3-15 psig, make Control Air
<b>Control valve</b>	Type: Pneumatic; Size: 1/4", Input: 3–15 psig, Air to close
<b>Rotameter</b>	10-100 LPH
<b>Pump</b>	Fractional horse power, type submersible
<b>Supply tank</b>	SS304
<b>Flow measurement</b>	Orifice meter
<b>Air filter regulator</b>	Range 0-2.5 kg/cm <sup>2</sup>
<b>Pressure gauge</b>	Range 0-2.5 kg/cm <sup>2</sup> (1No), Range 0-7 kg/cm <sup>2</sup> (1No)
<b>Overall dimensions</b>	550Wx480Dx525H mm
<b>Optional</b>	Mini Compressor

Table 3.3 Specifications



## **Procedure**

### **1. Study of open loop response (Manual Control)**

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Flow Control Trainer (312A)
- Select Yokogawa (UT35A)
- Click Continue
- Click Connect
- Click on Select Experiment.
- Select Open Loop and click Start
- Close the control valve by increasing the controller output to 100%.
- Apply the step change by 10% to controller output and wait for process value to reach the steady state value.
- Repeat the above step until the controller output reaches to minimum 0%.
- From the above data, note the output required for maintaining the flow at desired set points.

### **2. Study of Proportional Controller**

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Flow Control Trainer (312A)
- Select Yokogawa (UT35A)
- First click Continue, then Connect and then click on Select Experiment
- Select P Mode and click Start
- Adjust the process value by switching the controller to manual mode to a particular flow (say 50 %) on the screen and apply output of the controller as bias value. Change the proportional band to 100%.
- Switch the controller to auto mode and apply step change of 10% to set point.
- Compare the steady state response of the PD controller with PI controller obtained in the previous experiment. Note the effect of noisy flow measurement on the derivative action
- Switch the controller to manual mode. Decrease proportional band to half of the previous value. With each decrease, obtain a new response of the step change. Ensure that the set point changes are around the same operating point (Say 50%).
- Using trial and error approach find a value of proportional band so that the response to a step change has at most one overshoot and one undershoot.
- Set the controller to the settings obtained in the above step and wait for the system to reach at steady state.

### Observations (Manual Mode)

Controller output (in %)	Process Value (%)

### Observations (P Mode)

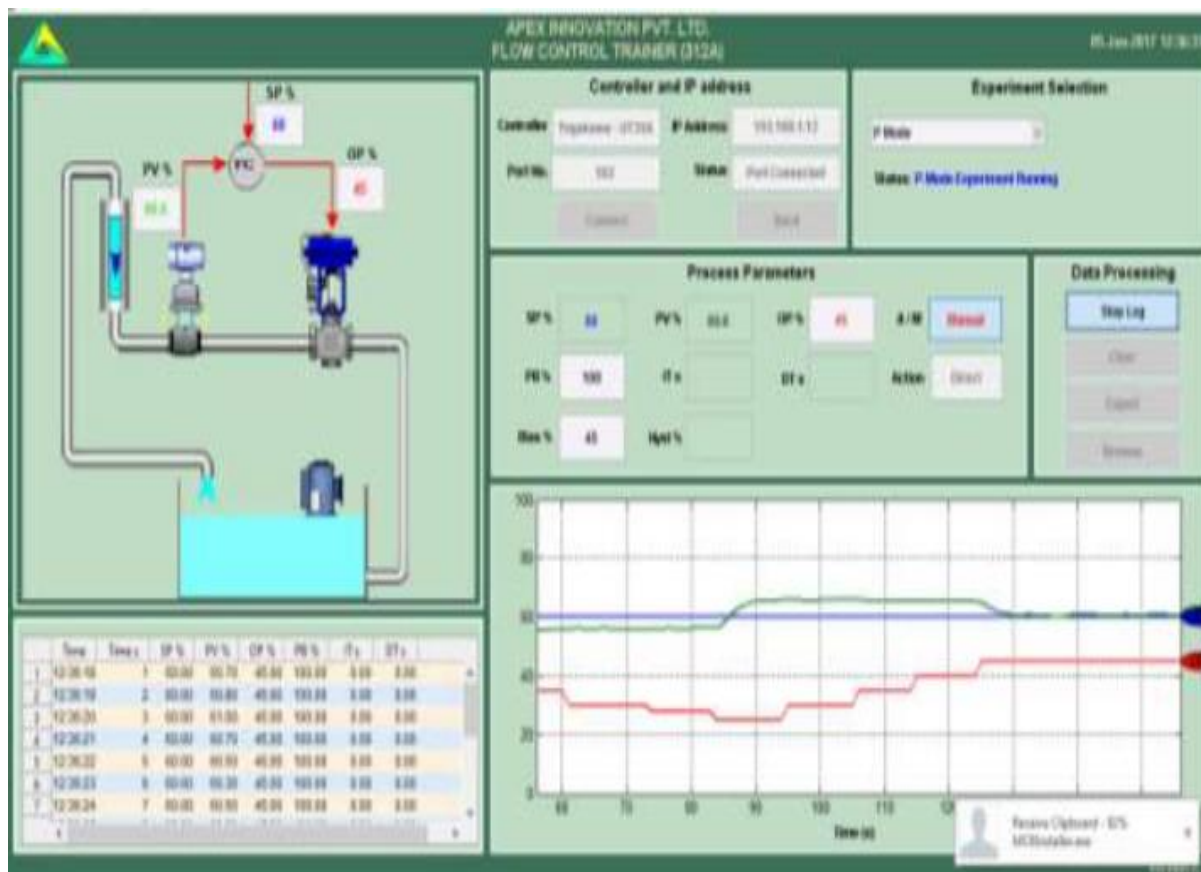


Fig 3.3 P response

- Observe steady state error decreases as proportional band decreases.
- Observe the effect of very low proportional band values (system works as on-off control).
- Observe the response of the system at load change. Load change can be given by slightly varying the flow rate with the help of rotameter manually.

### Observations (PI Mode)

Observe the effect of reducing integral time on offset and on the response of the process

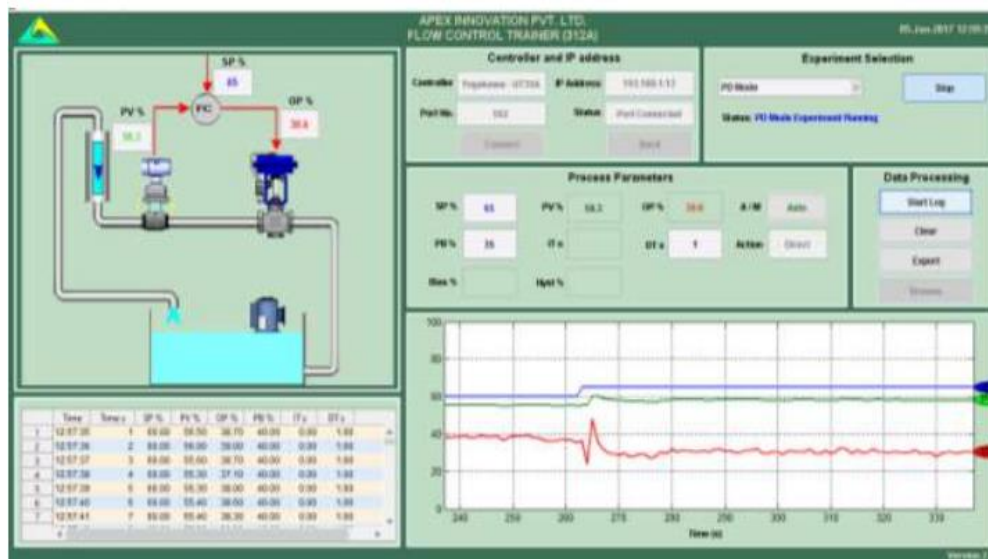


Fig. 3.4 PI response

### Observations (PD Mode)

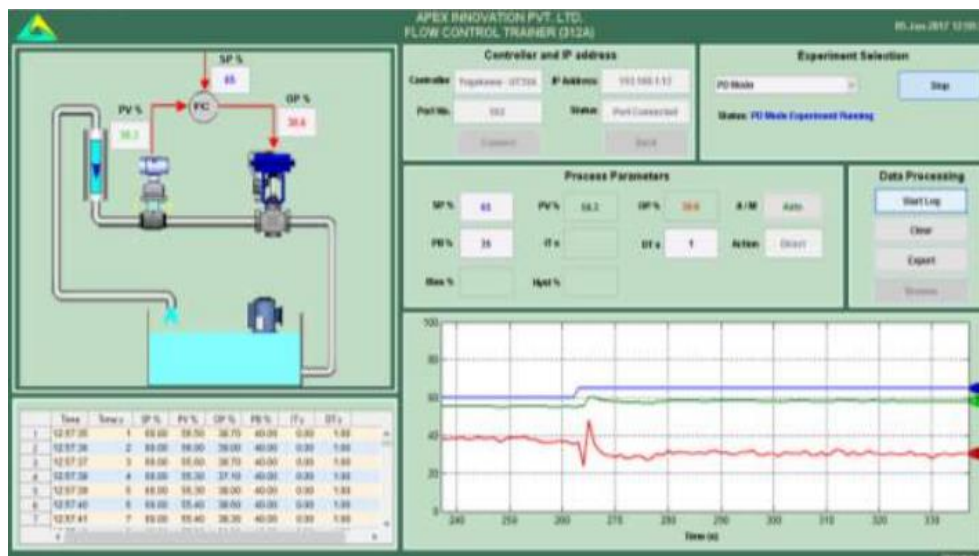


Fig. 3.5 PD response

Compare the steady state response of the PD controller with PI controller obtained in the previous experiment. Note the effect of noisy flow measurement on the derivative action.

### 3. Study of Proportional Integral Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Flow Control Trainer (312A)
- Select Yokogawa (UT35A)
- Click Continue
- Click Connect
- Click on Select Experiment
- Select PI Mode and click Start
- Set the proportional band estimated in Proportional control. Set derivative time to 0 sec and integral time 6000 sec, which will cut off the derivative action and widen the effect of integral action.
- Set the set point to desired flow value (@70%). Allow the process to reach at steady state. Record the steady state error.
- Switch the controller to manual mode. Reduce the integral time to half of the previous value. Switch to Auto mode and apply step change (+/- 10%) to the set point. Note the response of the system.
- Repeat above step to observe the effect of changes in Integral setting.

### 4. Study of Proportional Derivative Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Flow Control Trainer (312A)
- Select Yokogawa (UT35A)
- Click Continue >> Click Connect >> Click on Select Experiment
- Select PD Mode and click Start
- Set the proportional band estimated from Proportional control (P only) Set derivative time to 0 and integral time=6000 sec.
- Set the set point to desired value (@70%). Allow the process to reach at steady state. Note the response of the system.
- Switch the controller to manual mode Increase the derivative time by 1 sec. Switch to Auto mode and apply step change to the set point by 5 to 10%. Note the response of the system.
- Increase the derivative time gradually and observe the process response for step change.

### 5. Study of proportional integral derivative controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.

- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Flow Control Trainer (312A)
- Select Yokogawa (UT35A)
- Click Continue >> Click Connect >> Click on Select Experiment
- Select PID Mode and click Start
- Switch the controller to manual mode.
- Change the proportional band to the value that estimated in proportional controller. Set integral time and derivative time based on the responses in previous experiments.
- Adjust the set point to @ 50 %. Switch the controller to auto mode. Apply step change of 10%. Observe the process response.
- Change the proportional band, integral time, derivative time and observe the response of the process for step change for each change in setting.

### **Observations (PID Mode)**

Compare the steady state response of the PID controller with P, PI and PD controller obtained in the above experiment.

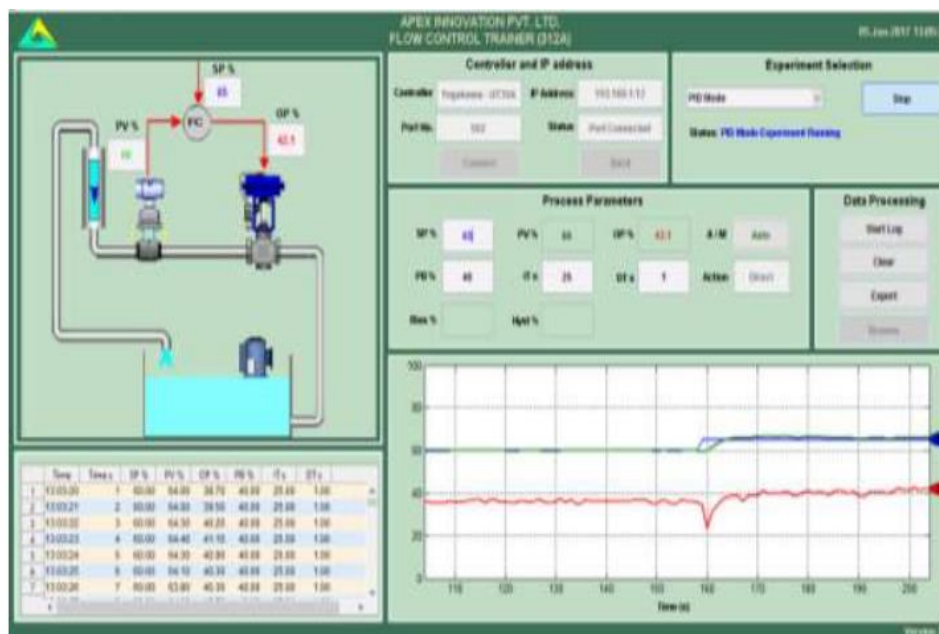


Fig. 3.6 PID response

### **Result**

The performance of P, PI, PD and PID controllers are studied for flow control and the response curves are plotted.

## **EXPERIMENT NO. 4**

### **LEVEL CONTROL USING P, PI, PD AND PID CONTROLLERS- STUDY OF OUTPUT RESPONSE**

#### **Aim**

To study the performance of P, PI, PD and PID controllers in a level control system.

#### **Apparatus required**

Level Control trainer

#### **Theory**

Fig 4.1 shows the block diagram of a closed loop control system. The function of the controller is to receive the measured output signal, which is to be compared with the set point to produce the actuating signal in such a way as to bring the output to the desired value. The input to the controller is the error signal which is defined as the difference between the measured output signal and set point. The basic feedback controllers are given below.

#### **1. Proportional controller**

Proportional controller produces a signal that is proportional to the error  $e(t)$ . This action may be expressed as,  $P(t) = K_C e(t) + P_S$ , where  $P_S$  is controller bias signal which is a constant,  $K_C$  is gain,  $P(t)$  is output and  $e(t)$  is error. The P controller is described by  $K_C$  or equivalently by proportional band (PB), where  $PB = 100/K_C$ . P controller produces an oscillatory response with overshoot which always produces offset.

#### **2. Proportional- Derivative controller**

Proportional Derivative Controller is represented as

Controller O/P,  $P(t) = K_C e(t) + K_C \tau_d \frac{de(t)}{dt} + P_S$ , where  $\tau_d$  is the derivative time constant and 'e' and 'P' are functions of time. Here the response exhibits a smaller overshoot and smaller oscillations compared to P controller. The offset is also less than that of P controller.

#### **3. Proportional- Integral Controller**

This mode of controller is represented as

Controller O/P,  $P(t) = K_C e(t) + \frac{K_C}{\tau_I} \int_0^t e(t) dt + P_S$ , where  $\tau_I$  is the integral time constant and 'e' and 'P' are functions of time. PI controller eliminates offset. The peak overshoot is same as that of P controller and the settling time is relatively large.

#### **4. Proportional- Integral- Derivative Controller**

PID Controller is represented as

Controller O/P,  $P(t) = K_C e(t) + \frac{K_C}{\tau_I} \int_0^t e(t) dt + K_C \tau_d \frac{de(t)}{dt} + P_S$ , where 'e' and 'P' are functions of time. The response has lower overshoot and returns to set point more quickly.

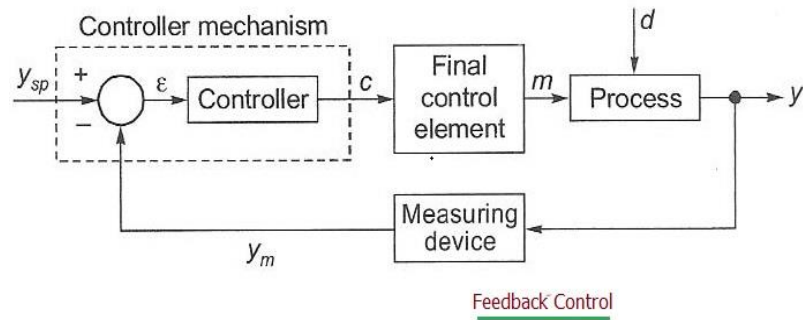


Fig. 4.1 Block Diagram of a closed loop control system

Note: For component specific problems refer Components' Manuals

Problems	Possible causes / remedies
Control valve does not operate	<ul style="list-style-type: none"> <li>Valve diaphragm leakage/breakage</li> <li>Faulty I/P converter</li> <li>No output from Controller</li> </ul>
I/P converter does not work	<ul style="list-style-type: none"> <li>Insufficient supply air pressure</li> <li>Faulty electrical input signal</li> <li>Clogged orifice</li> </ul>
No communication with computer	<ul style="list-style-type: none"> <li>Check communication settings for IP addresses of computer and controller. Default setting computer 192.168.1.2 and controller 192.168.1.13</li> </ul>

Table 4.1 Troubleshooting

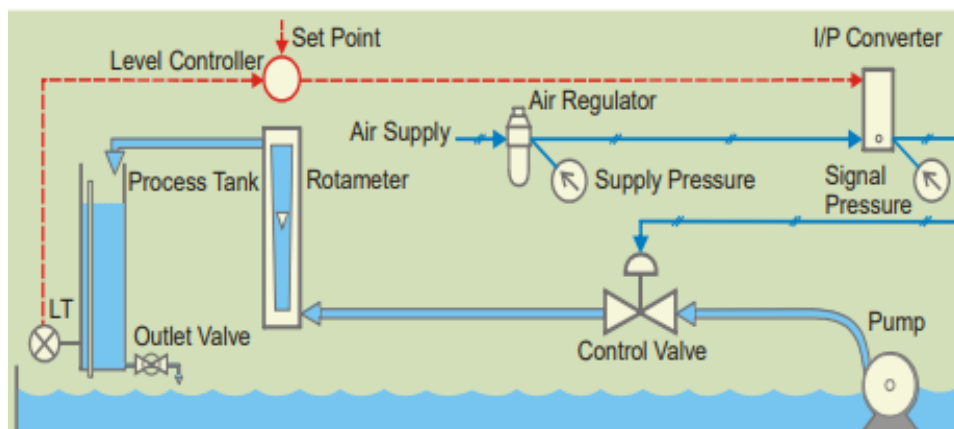


Fig. 4.2 Level Control System

Product	Level control trainer
Product code	313A
Level transmitter	Make WIKA, Model SL-1-A-MAG-ND-ZA4Z-ZZZ and output 4-20 mA, supply 10-30 VDC, conn. 1/2"NPT (M), Range 0-25 mbar.
Digital indicating controller	Make Yokogawa, Model UT35A-002-11-00 with Ethernet communication
I/P converter	Make Control air inc, Type T500-AC, Input 4-20 mA DC, output 3-15 psig, end connection 1/4 NPT
Control valve	Make Pneucn, Type globe 2 way, Model 119, size 1/2"x1/8", Screwed end(F), Body CCS, Trim SS, Travel 14.3, CV=0.63, Air to CLOSE, Spring range 0.2-1, actuator 12 sq inch.
Rotameter	Make Eureka, Model MG 11, Range 10-100 lph, Connection 1/4" BSP back, screwed, Packing PTFE + Silicon
Pump	Model HQB 4500, Head max. 4.5m, Output 5000 lph, Watts 100, Volts 220-240 AC, 50Hz.
Air filter regulator	Make Airmatic, Model MB10-02-1-PAP-PD( Alu body, Polycarbonate bowl, G1/4 BSP, Range 0-2 Kg/cm <sup>2</sup> , Relieving, 25M Plastic element, Bunan diaphragm.
Pressure gauge	Make Wika, Dia.2.5", Gly. filled, Brass internals, S.S. casing, Range 0-2.5 Kg/cm <sup>2</sup> and 0-35 PSI, 1/4"BSP (M) back connection without bracket.
Pressure gauge	Make Wika, Dia.2.5", Gly. filled, Brass internals, S.S. casing, Range 0-7 Kg/cm <sup>2</sup> and 0-100PSI, 1/4"BSP (M) back connection without bracket.

Table 4.2 Details of Equipment Used

### Trainer Kit Description

Level control trainer is designed for understanding the basic principles of level control. The process setup consists of supply water tank fitted with pump for water circulation. The level transmitter used for level sensing is fitted on transparent process tank. The process parameter (level) is controlled by microprocessor based digital indicating controller which manipulates pneumatic control valve through I to P converter. A pneumatic control valve adjusts the water flow in to the tank. These units along with necessary piping are fitted on support housing designed for table-top mounting. The controller can be connected to computer through Ethernet port for monitoring the process in SCADA mode.



<b>Product</b>	Level control trainer
<b>Product code</b>	313A
<b>Type of control</b>	SCADA
<b>Control unit</b>	Digital indicating controller with Ethernet communication
<b>Communication</b>	Ethernet
<b>Level transmitter</b>	Type Electronic, two wire, Range 0–250 mm, Output 4–20mA
<b>I/P converter</b>	Input 4-20mA, Output 3-15 psig
<b>Control valve</b>	Type: Pneumatic; Size: 1/4", Input: 3–15 psig, Air to close, Characteristics: linear
<b>Rotameter</b>	10-100 LPH
<b>Pump</b>	Fractional horse power, type submersible
<b>Process tank</b>	Transparent, Acrylic, with 0-100% graduated scale
<b>Supply tank</b>	SS304
<b>Air filter regulator</b>	Range 0-2.5 kg/cm <sup>2</sup>
<b>Pressure gauge</b>	Range 0-2.5 kg/cm <sup>2</sup> (1No), Range 0-7 kg/cm <sup>2</sup> (1No)

Table 4.3 Specifications

## **Procedure**

### **1. Study of open loop response (Manual Control)**

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Level Control Trainer (313A) and select Yokogawa (UT35A)
- Click Continue>>Click Connect >> Select Experiment.
- Select Open Loop and click Start
- Open the control valve fully by decreasing the controller output to 0%. (Click on Auto, change it to Man then change OP to 0%)
- Adjust the tank drain valve such that the tank level shall remain between 90 and 100% Change the controller to Auto mode
- Close the control valve by increasing the controller output to 100%.
- Apply the step change by 10% to controller output and wait for process value to reach the steady state value.
- Repeat the above step until the controller output reaches to minimum 0%.
- From the above data, note the output required for maintaining the Level at desired set points.

### Observations (Manual Mode)

Controller output (in %)	Process Value (%)

Set the output of the controller to the noted value and at steady state, apply the load change to the process. Load change can be given by slightly varying the drain valve. Observe new steady state process value.

### Observations (P Mode)

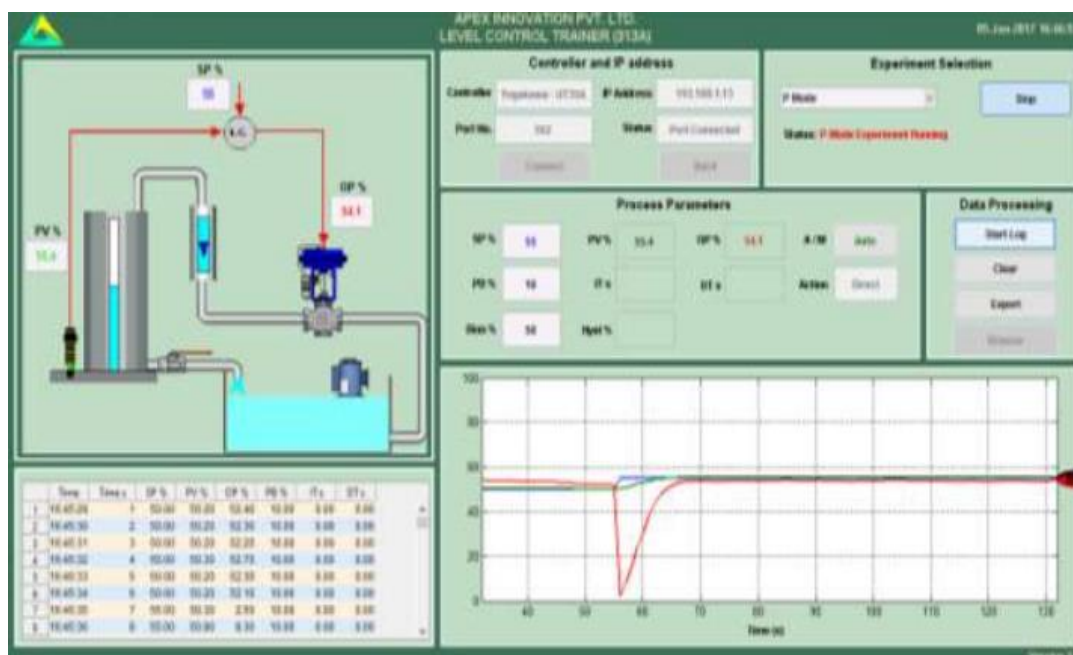


Fig. 4.3 P response

Observe the effect of very low proportional band values (system works as ON- OFF control)

## 2. Study of Proportional Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @  $2 \text{ kg/cm}^2$  >>Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Level Control Trainer (313A)>>Select Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment. Select P Mode and click Start
- Open the control valve fully by decreasing the controller output to 0%. (Click on Auto, change it to Manual then change OP to 0%)
- Adjust the tank drain valve such that the tank level shall remain between 90 and 100% Change the controller to Auto mode.
- Adjust the process value by switching the controller to manual mode to a particular flow (say 50 %) on the screen and apply output of the controller as bias value. Change the proportional band to 100%.
- Switch the controller to auto mode and apply step change of 10% to set point.
- Switch the controller to manual mode. Decrease proportional band to half of the previous value. With each decrease, obtain a new response of the step change. Ensure that the set point changes are around the same operating point (Say 50%).
- Using trial and error approach find a value of proportional band so that the response to a step change has at most one overshoot and one undershoot.
- Set the controller to the settings obtained in the above step and wait for the system to reach at steady state.

## 3. Study of Proportional- Integral Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @  $2 \text{ kg/cm}^2$
- Switch on the computer and double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Level Control Trainer (313A) and select Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PI Mode and click Start
- Open the control valve fully by decreasing the controller output to 0%. (Click on Auto, change it to Man then change OP to 0%)
- Adjust the tank drain valve such that the tank level shall remain between 90 and 100% Change the controller to Auto mode
- Set the proportional band estimated in Proportional control. Set derivative time to 0 sec and integral time 6000 sec, which will cut off the derivative action and widen the effect of integral action.
- Set the set point to desired flow value (@50%). Allow the process to reach at steady state. Record the steady state error.
- Switch the controller to manual mode. Reduce the integral time to half of the previous value. Switch to Auto mode and apply step change (+/- 10%) to the set point. Note the response of the system.
- Repeat above step to observe the effect of changes in Integral setting.

## Observations (PI Mode)

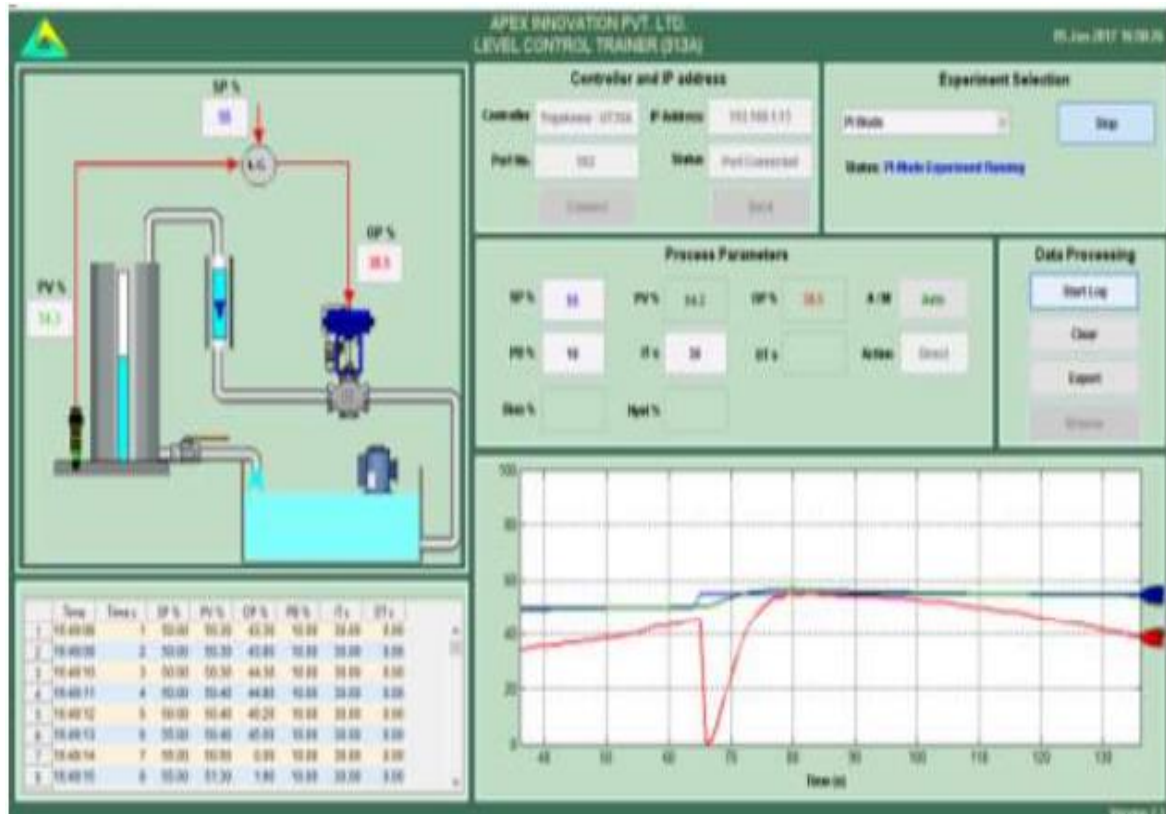


Fig. 4.4 PI response

Observe the effect of reducing integral time on the response of the process.

## 4. Study of Proportional- Derivative controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer >> Double- click on Apex\_Process\_Trainers icon on the desktop.
- Select product Level Control Trainer (313A) >> Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PD Mode and click Start
- Open the control valve fully by decreasing the controller output to 0%. (Click on Auto, change it to Man then, change OP to 0%)
- Adjust the tank drain valve such that the tank level shall remain between 90 and 100% Change the controller to Auto mode

## Observations (PD Mode)

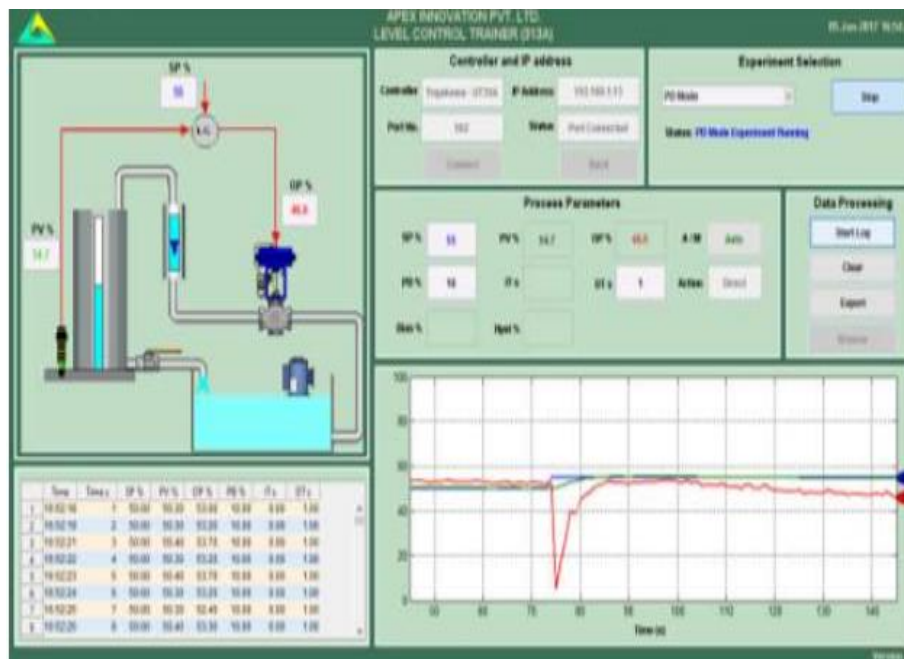


Fig. 4.5 PD response

## 5. Study of Proportional- Integral- Derivative Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Level Control Trainer (313A) >> Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PID Mode and click Start
- Open the control valve fully by decreasing the controller output to 0%. (Click on Auto, change it to Man then change OP to 0%)
- Adjust the tank drain valve such that the tank level shall remain between 90 and 100% Change the controller to Auto mode
- Switch the controller to manual mode.
- Change the proportional band to the value that estimated in proportional controller. Set integral time and derivative time based on the responses in previous experiments.
- Adjust the set point to @ 50 %. Switch the controller to auto mode. Apply step change of 10%. Observe the process response.
- Change the proportional band, integral time, derivative time and observe the response of the process for step change for each change in setting.

## Observations (PID Mode)

Compare the steady state response of the PID controller with P, PI and PD controller obtained in the above experiment.

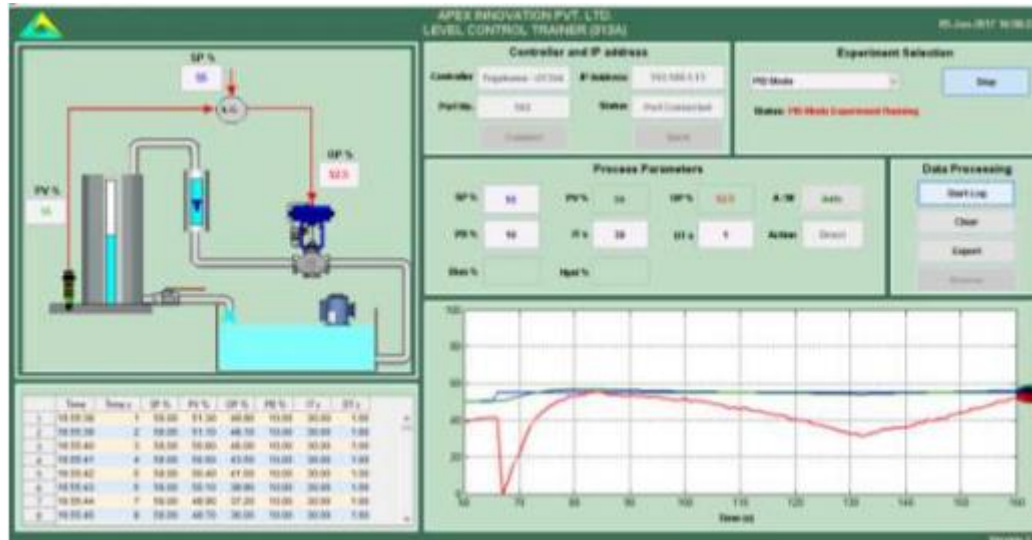


Fig. 4.6 PID response

- Set the proportional band estimated from Proportional control (P only). Set derivative time to 0 and integral time=6000 sec.
- Set the set point to desired value (@70%). Allow the process to reach at steady state. Note the response of the system.
- Switch the controller to manual mode Increase the derivative time by 1 sec. Switch to Auto mode and apply step change to the set point by 5 to 10%. Note the response of the system.
- Increase the derivative time gradually and observe the process response for step change.

## Result

The performance of P, PI, PD and PID controllers are studied for level control and the response curves are plotted.

## **EXPERIMENT NO. 5**

### **PRESSURE CONTROL USING P, PI, PD AND PID CONTROLLERS- STUDY OF OUTPUT RESPONSE**

#### **Aim**

To study the performance of P, PI, PD and PID controllers in a pressure control system.

#### **Apparatus Required**

Pressure Control System trainer kit

#### **Theory**

Fig 5.1 shows the block diagram of a closed loop control system. The function of the controller is to receive the measured output signal, which is to be compared with the set point to produce the actuating signal in such a way as to bring the output to the desired value. The input to the controller is the error signal which is defined as the difference between the measured output signal and set point. The basic feedback controllers are given below.

##### **1. Proportional controller**

Proportional controller produces a signal that is proportional to the error  $e(t)$ . This action may be expressed as,  $P(t) = K_C e(t) + P_s$ , where  $P_s$  is controller bias signal which is a constant,  $K_C$  is gain,  $P(t)$  is output and  $e(t)$  is error. The P controller is described by  $K_C$  or equivalently by proportional band (PB), where  $PB = 100/K_C$ . P controller produces an oscillatory response with overshoot which always produces offset.

##### **2. Proportional- Derivative controller**

Proportional Derivative Controller is represented as

Controller O/P,  $P(t) = K_C e(t) + K_C \tau_d \frac{de(t)}{dt} + P_s$ , where  $\tau_d$  is the derivative time constant and 'e' and 'P' are functions of time. Here the response exhibits a smaller overshoot and smaller oscillations compared to P controller. The offset is also less than that of P controller.

##### **3. Proportional- Integral Controller**

This mode of controller is represented as

Controller O/P,  $P(t) = K_C e(t) + \frac{K_C}{\tau_i} \int_0^t e(t) dt + P_s$ , where  $\tau_i$  is the integral time constant and 'e' and 'P' are functions of time. PI controller eliminates offset. The peak overshoot is same as that of P controller and the settling time is relatively large.

##### **4. Proportional- Integral- Derivative Controller**

PID Controller is represented as

Controller O/P,  $P(t) = K_C e(t) + \frac{K_C}{\tau_i} \int_0^t e(t) dt + K_C \tau_d \frac{de(t)}{dt} + P_s$ , where 'e' and 'P' are functions of time. The response has lower overshoot and returns to set point more quickly.

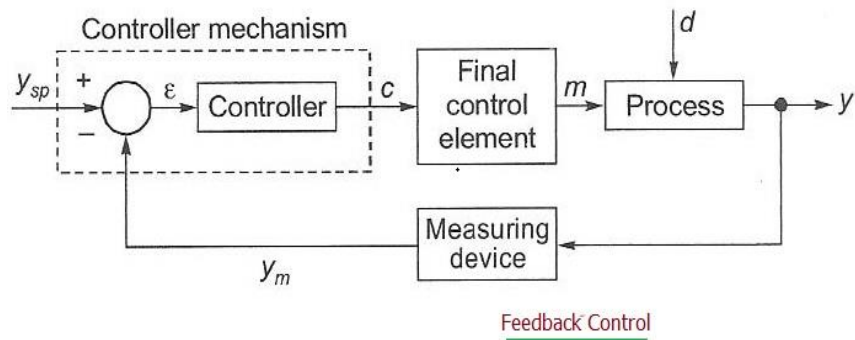


Fig 5.1 Block Diagram of a closed loop control system

Note: For component specific problems refer components' manual

Problems	Possible causes / remedies
Control valve does not operate	<ul style="list-style-type: none"> <li>Faulty I/P converter</li> <li>No output from Controller</li> </ul>
I/P converter does not work	<ul style="list-style-type: none"> <li>Insufficient supply air pressure</li> <li>Faulty electrical input signal</li> </ul>
No communication with computer	<ul style="list-style-type: none"> <li>Check communication settings for IP addresses of computer and controller. Default setting computer 192.168.1.2 and controller 192.168.1.14</li> </ul>

Table 5.1 Troubleshooting

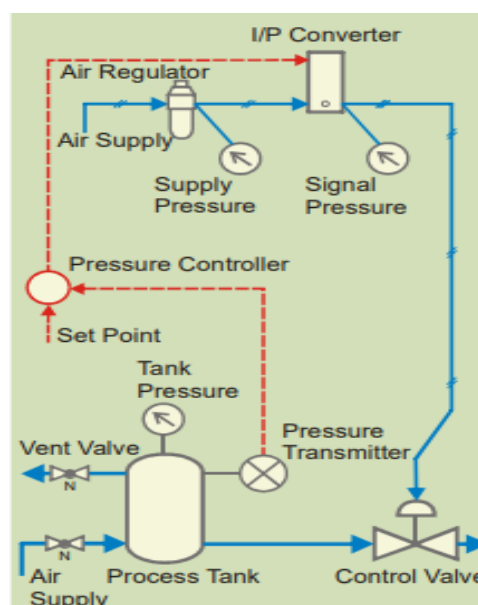


Fig. 5.2 Pressure Control system



Product	Pressure control trainer
Product code	314A
Pressure Transmitter	Make Wika, model Eco, Output 4-20mA (2 wire), Supply 24VDC, range 0-2.5 bar, process conn. 1/4"BSP(male)
Digital indicating controller	Make Yokogawa, Model UT35A-002-11-00 with Ethernet communication
I/P converter	Make Control air inc, Type T500-AC, Input 4-20 mA DC, output 3-15 psig, end connection 1/4 NPT
Control valve	Make Pneucn, Type globe 2 way, Model 119, size 1/2"x1/8", Screwed end(F), Body CCS, Trim SS, Travel 14.3, CV=0.1, Air to CLOSE, Spring range 0.2-1, actuator 12 sq inch.
Air filter regulator	Make Airmatic, Model MB10-02-1-PAP-PD ( Alu body, Polycarbonate bowl, G1/4 BSP, Range 0-2 Kg/cm <sup>2</sup> , Relieving, 25M Plastic element, Bunan diaphragm.
Pressure relief valve	Make Airmatic, Model MRV-022, Range 0-3.5Kg/cm <sup>2</sup> , Size G1/4, Alluminium.
Pressure gauge	Make Wika, Dia.2.5", Gly. filled, Brass internals, S.S. casing, Range 0-2.5 Kg/cm <sup>2</sup> and 0-35 PSI, 1/4"BSP (M) back connection without bracket.
Pressure gauge	Make Wika, Dia.2.5", Gly. filled, Brass internals, S.S. casing, Range 0-7 Kg/cm <sup>2</sup> and 0-100PSI, 1/4"BSP (M) back connection without bracket.

Table 5.2 Details of Equipment Used

### Trainer Kit Description

Pressure control trainer is designed for understanding the basic principles of pressure control. The process set up consists of pressure vessel fitted with pneumatic control valve. Pressure transmitter is used for pressure sensing. The process parameter (Pressure) is controlled by microprocessor based digital indicating controller which manipulates pneumatic control valve fitted at outlet of pressure tank outlet through I/P converter. These units along with necessary piping are fitted on support housing designed for tabletop mounting. The controller can be connected to computer through Ethernet port for monitoring the process in SCADA mode.

<b>Product</b>	Pressure control trainer
<b>Product code</b>	314A
<b>Type of control</b>	SCADA
<b>Control unit</b>	Digital indicating controller with Ethernet communication
<b>Communication</b>	Ethernet
<b>Pressure Transmitter</b>	Type Two wire, Range 0–2.5 bar, Output 4–20 mA
<b>I/P converter</b>	Input 4-20mA, Output 3-15 psig
<b>Control valve</b>	Type: Pneumatic; Size: 1/4", Input: 3–15 psig, Air to close, Characteristics: linear
<b>Process tank</b>	Pressure vessel, MS
<b>Air filter regulator</b>	Range 0-2.5 kg/cm <sup>2</sup>
<b>Pressure gauge</b>	Range 0-2.5 kg/cm <sup>2</sup> (1No), Range 0-7 kg/cm <sup>2</sup> (2Nos)

Table 5.3 Specifications

## **Procedure**

### **1. Study of open loop response (Manual Control)**

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop, select pro Pressure Control Trainer (314A)
- Select Yokogawa (UT35A)
- Click Continue
- Click Connect
- Click on Select Experiment.
- Select Open Loop and click Start
- Close the control valve by increasing the controller output to 100%.
- Apply the step change by 10% to controller output and wait for process value to reach the steady state value.
- Repeat the above step until the controller output reaches to minimum 0%.

### **Observations (Manual Mode)**

Controller output (in %)	Process Value (%)

From the above data, note the output required for maintaining the process at desired set points. (For particular vent valve opening).

Set the output of the controller to the noted value and at steady state apply the load change to the process. Load change can be given by slightly varying the vent valve. Observe new steady state process value.

## **2. Study of Proportional Controller**

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Pressure Control Trainer (314A) and select Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select P Mode and click Start
- Open the control valve fully by decreasing the controller output to 0%. (Click on Auto, change it to Manual, then change OP to 0%)
- Adjust the tank drain valve such that the tank level shall remain between 90 and 100% Change the controller to Auto mode.
- Keep the set point to 60%. Change output mode to Manual. Adjust output value so as to match the process value with set point and apply this output value as bias value to the controller. Adjust the proportional band to 50%
- Switch the controller to auto mode and apply step change of 10% to set point.
- Switch the controller to Manual mode. Decrease proportional band to half of the previous value & then shift controller to Auto mode. With each decrease, obtain a new response of the step change. Ensure that the set point changes are around the same operating point (@ 5-10% only).
- Using trial and error approach find a value of proportional band so that the response to a step change has at most one overshoot and one undershoot.
- Set the controller to the settings obtained in the above step and wait for the system to reach at steady state.

## Observations (P Mode)

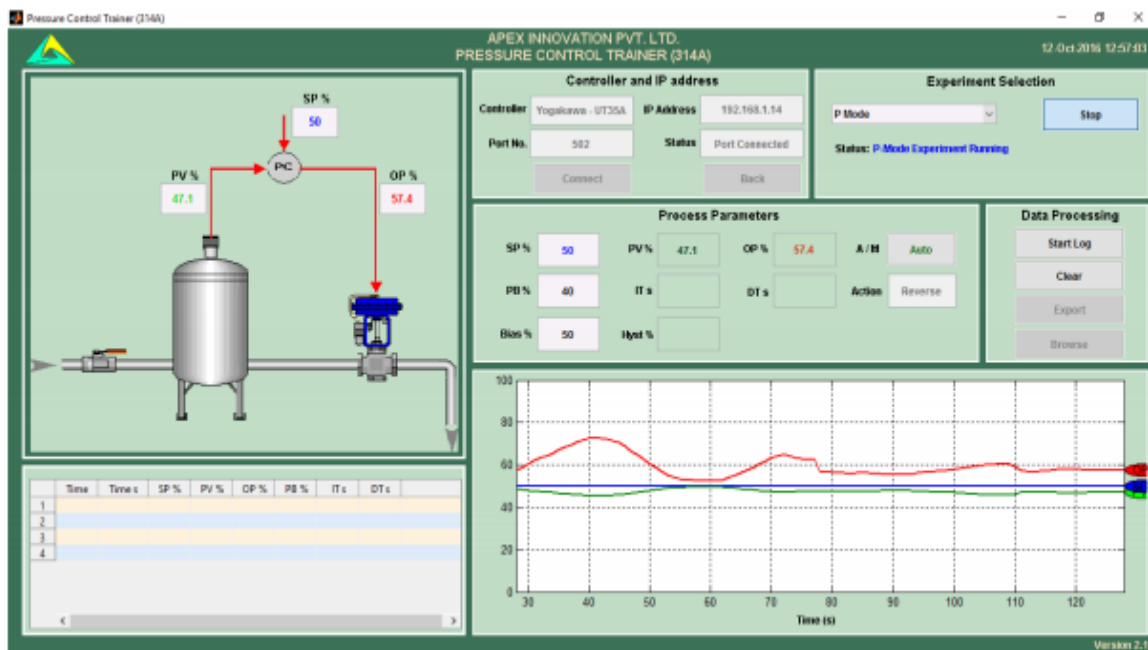


Fig. 5.3 P response

Observe steady state error decreases as proportional band decreases.

Observe the effect of very low proportional band values (system works in oscillatory mode).

### 3. Study of Proportional- Integral Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Pressure Control Trainer (314A) and select Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PI Mode and click Start
- Adjust the process value by changing the output of controller in manual mode to a particular pressure (set point =60%).
- Set the proportional band estimated in Proportional control. Set derivative time to 0 sec and integral time 1000 sec, which will cut off the derivative action and widen the effect of integral action.
- Set the set point to desired flow value (@60%). Allow the process to reach at steady state. Record the steady state error.
- Switch on the controller to manual mode. Reduce the integral time to half of the previous value. Switch to Auto mode and apply step change to the set point by 2 to 3%. Note the response of the system.
- Using trial and error, find out an integral time, which gives satisfactory response to the step change in set point.

## Observations (PI Mode)

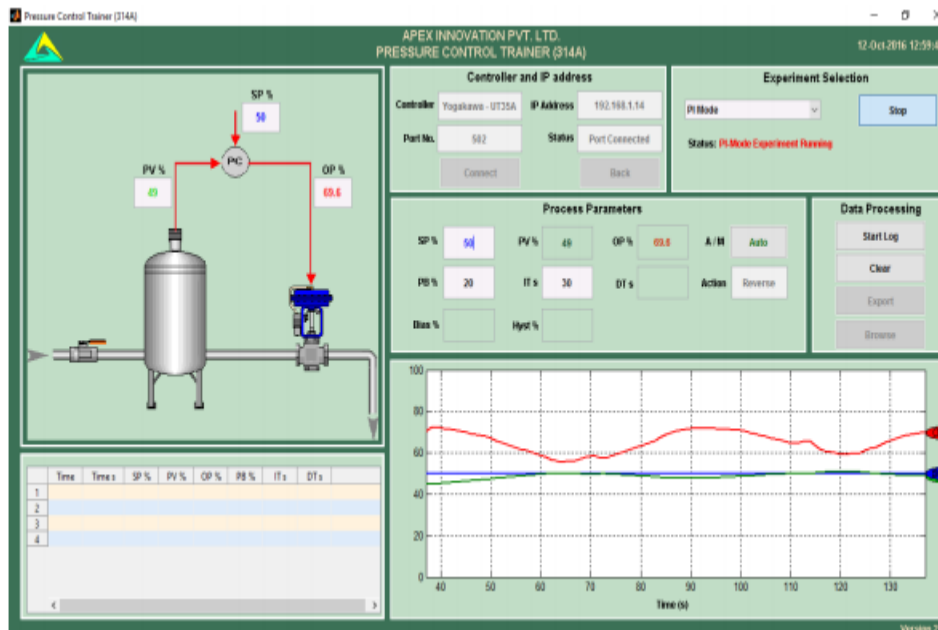


Fig. 5.4 PI response

Observe the effect of reducing integral time on the response of the process

## 4. Study of Proportional- Derivative Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer >> Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Pressure Control Trainer (314A)>> Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PD Mode and click Start
- Select PD controller. Set the proportional band estimated from Proportional control (P only). Start with derivative time=0 and integral time=6000 sec., which will cut off the derivative action and widen the effect of integral action.
- Set the set point to desired value (@60%). Allow the process to reach at steady state. Note the response of the system.
- Switch the controller to manual mode Increase the derivative time by 1 sec. Switch to Auto mode and apply step change to the set point by 2 to 3%. Note the response of the system.
- Increase the derivative time gradually and observe the process response for step change.

## Observations (PD Mode)

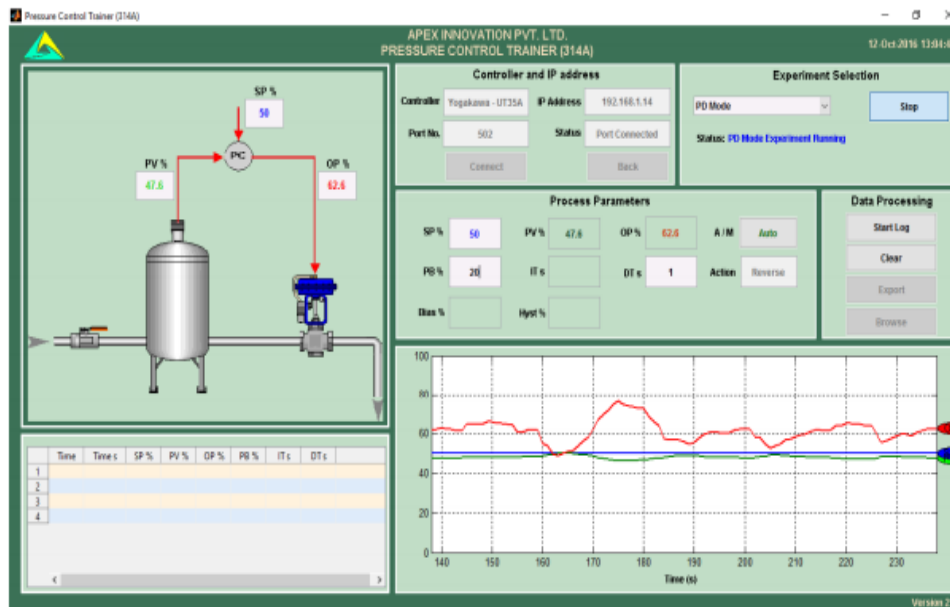


Fig. 5.5 PD response

Observe the effect of increasing derivative time. Also note that the process may show offset as effect of integral action is cut off.

## 5. Study of Proportional- Integral- Derivative Controller

- Switch on electric supply. Switch on Mains.
- Switch on the pump and adjust the bypass valve to set rotameter flow at 100 LPH.
- Switch on the compressed air source and adjust the air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>
- Switch on the computer.
- Double click on Apex\_Process\_Trainers icon on the desktop.
- Select product Pressure Control Trainer (314A) >> Yokogawa (UT35A)
- Click Continue >> Connect >> Select Experiment
- Select PID Mode and click Start
- Switch the controller to manual mode.
- Change the proportional band to the value that estimated in proportional controller. Set integral time and derivative time based on the responses in previous experiments.
- Change the controller to Auto mode. Apply step change by 2 to 3% to the set point and observe the response of the process.
- Change the proportional band, integral time, derivative time and observe the response of the process for step change for each change in setting.

## Observations (PID Mode)

Compare the steady state response of the PID controller with P, PI and PD controller obtained in the above experiment.

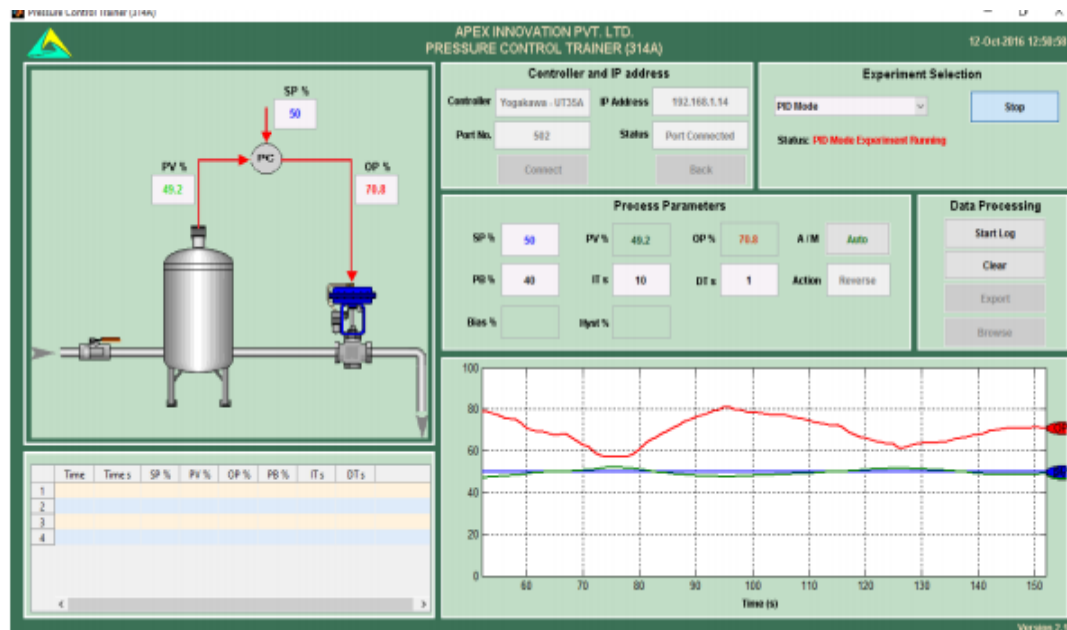


Fig. 5.6 PID response

## Result

The performance of P, PI, PD and PID controllers are studied for Pressure control and the response curves are plotted.

## **EXPERIMENT NO. 6**

### **CONTROL VALVE CHARACTERISTICS**

#### **Aim**

To study the quick opening, linear and equal percentage valve characteristics and to calculate gain at various conditions.

#### **Apparatus Required**

Control valve trainer, Compressor, air regulator

#### **Theory**

The flow characteristics of control valve define the relative flow variations with respect to percentage valve opening for a constant pressure drop across the valve. Following types of characteristics are common in control valves.

##### **(I) Linear valve characteristics**

The flow is directly proportional to valve opening for a constant pressure drop. The relationship can be represented by a straight line

##### **(II) Equal percentage characteristics**

According to the property of equal percentage characteristics, equal opening of valve produces equal percentage change in flow, at constant pressure drop base just before change mode.

##### **(III) Quick opening (ON-OFF) characteristics**

In this type, the relation between the flow and valve opening is approximately linear up to 68% to 70% of the valve opening. After this time, the flow does not change rapidly with valve opening.

#### **Procedure**

- Hand valve HV<sub>1</sub>, HV<sub>2</sub> and HV<sub>3</sub> are open and others are closed.
- Air regulator to give 15 psi output.
- The unit is switched on and pump speed is adjusted for maximum flow.
- Hand valve H<sub>1</sub> is adjusted to give maximum flow through actual valve.
- HV<sub>1</sub>, HV<sub>2</sub> are adjusted to fix some constant pressure in gauge.
- Flow through rotameter and step positions are noted.



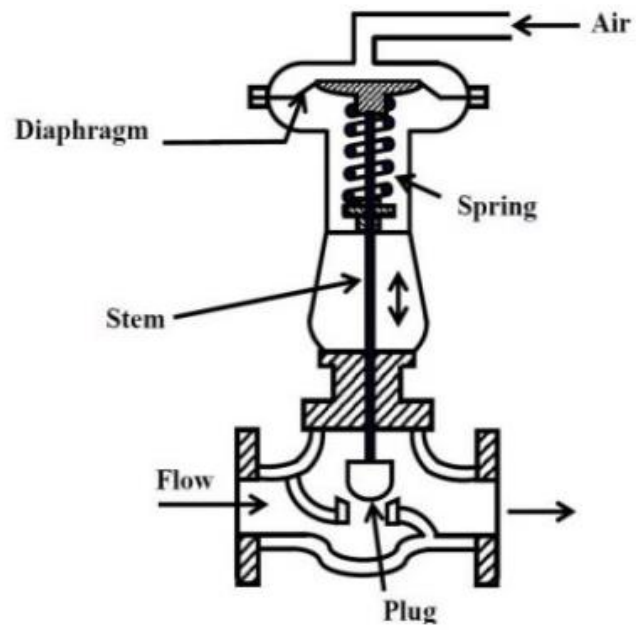


Fig. 6.1 Control valve components

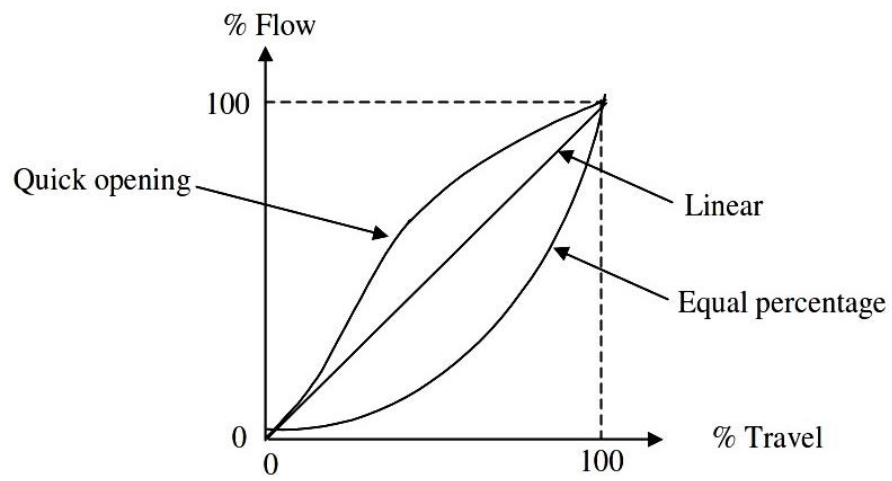


Fig. 6.2 Valve Characteristics

- Air regulated output is decreased, constant pressure across the valve is maintained by adjusting HV<sub>1</sub>.
- Previous steps are repeated for different pressures and readings are tabulated.
- Gain of control valve at operating pressure is calculated using the formula
- $\text{Gain} = \left(\frac{Q}{Q_{\max}}\right) / \left(\frac{S}{S_{\max}}\right)$
- Plot the graph by  $\frac{S}{S_{\max}}$  as abscissa and  $\frac{Q}{Q_{\max}}$  as ordinate to get quick opening characteristics.
- To get equal percentage characteristics, repeat previous steps replacing HV<sub>2</sub> and HV<sub>5</sub> with HV<sub>3</sub> and HV<sub>6</sub>.
- To get linear characteristics, repeat steps 1 to 10 by replacing HV<sub>2</sub> and HV<sub>5</sub> with HV<sub>4</sub> and HV<sub>7</sub>.

### **Observations**

Sl No	$\frac{S}{S_{\max}}$	$\frac{Q}{Q_{\max}}$

### **Result**

The characteristics and working of pneumatic control valve were studied.

## EXPERIMENT NO. 7

### CONTROLLER TUNING FOR VARIOUS PROCESSES USING ZIEGLER- NICHOLS RULE

#### Aim

To study and tune the parameters pressure, flow, level and temperature process stations using Ziegler Nichols method.

#### Apparatus Required

Flow, Level, Temperature, Pressure Process System Trainer kit

#### Theory

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller. It was developed by John G. Ziegler and Nathaniel B. Nichols. It is performed by setting the I (integral) and D (derivative) gains to zero. The "P" (proportional) gain, is then increased (from zero) until it reaches the ultimate gain, at which the output of the control loop has stable and consistent oscillations and the oscillation period is used to set the P, I and D gains depending on the type of controller used.

These 3 parameters are used to establish the correction  $u(t)$  from the error  $e(t)$  via the equation:

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

where,

$K_p$ - Proportional Gain

$K_i$ - Integral Gain

$K_d$ — Derivative Gain

$T_i$ - Reset Time or Integral time

$T_d$ - Rate time or derivative time

The proportional term in the controller generally helps in establishing system stability and improving the transient response while the derivative term is often used when it is necessary to improve the closed loop response speed even further. Conceptually the effect of the derivative term is to feed information in the rate of change of the measured variable into the controller action. The most important term in the controller is the integral term that introduces a pole at  $s=0$  in the forward loop of the process. Ziegler Nichols Method is also called the **ultimate cycle method**. It is based on adjusting a closed loop until steady state oscillation occurred. Controller settings are then based on the conditions that generate cycling steps for tuning.

# CHARACTRISTICS-ULTIMATE GAIN METHOD

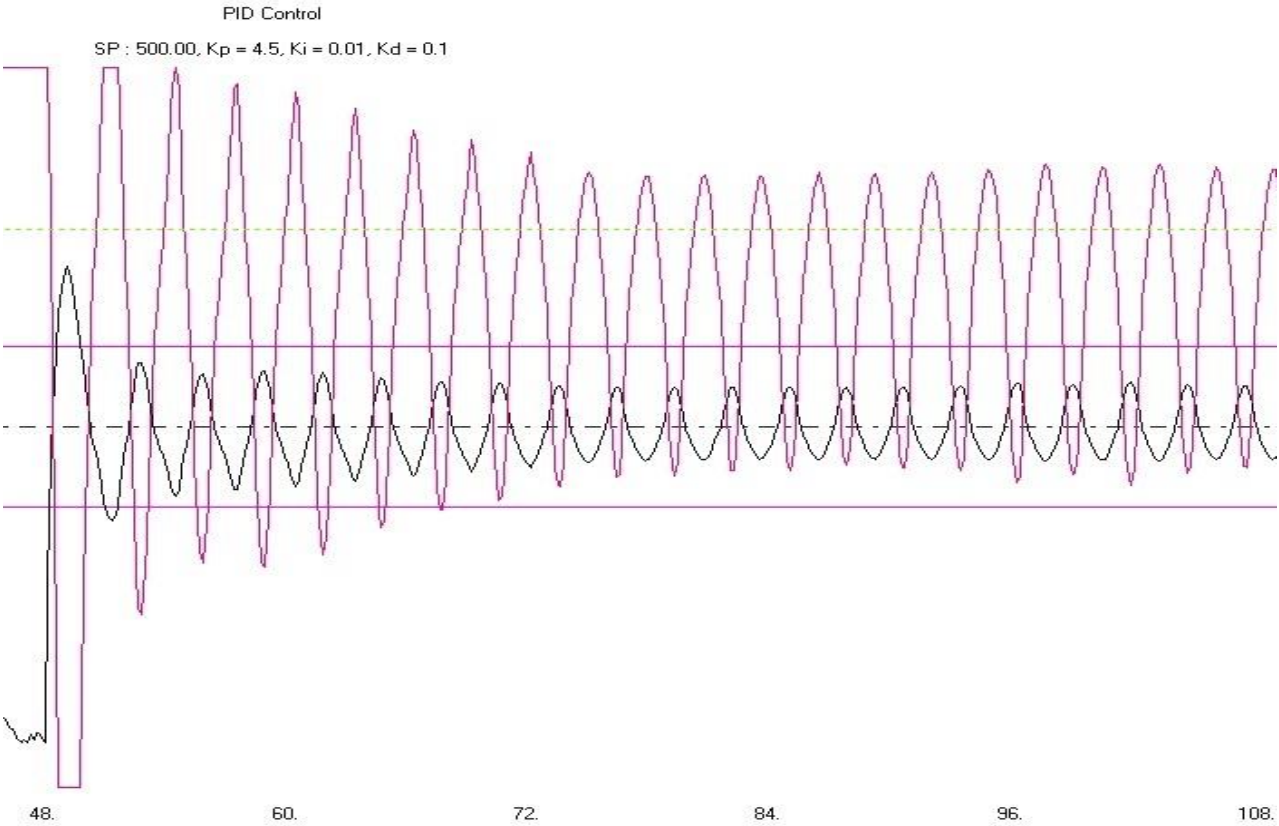


Fig. 7.1 Verge of instability indicated by sustained oscillations in ultimate gain method

## TABLE OF ULTIMATE GAIN AND TIME PERIOD

Ziegler–Nichols method			
Control Type	$K_p$	$T_i$	$T_d$
$P$	$0.5K_u$	-	-
$PI$	$0.45K_u$	$T_u/1.2$	-
$PD$	$0.8K_u$	-	$T_u/8$
$PID$	$0.6K_u$	$T_u/2$	$T_u/8$

Fig. 7.2 Tuned values

## Procedure

- Switch on Mains.
- Switch on the compressed air source and adjust the Air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>. >> Switch on computer
- Double click on Apex\_Process\_Trainers icon on the desktop
- Select product Pressure Control Trainer (314A) >>Select Yokogawa (UT35A)
- (Procedure is same for any systems, select product accordingly i.e., 311A, 312A, 313A for Temperature, Flow, Level Trainer system respectively.)
- Click Continue >>Click Connect >> Click Select Experiment
- Select Close Loop and click Start
- Set the proportional band value to maximum (Say 100). Set the controller to manual mode and adjust the output so that the process is nearly at set point (60%).
- Set controller to auto mode and impose step on the process by moving the set point for a few seconds & then return to its original value (or apply the step change to the set point of 5%). Wait for some time & observe the response.
- Decrease the proportional band to the half of previous and impose step on the process as mentioned above. Wait for some time & observe the response.
- Repeat the above procedure and find out correct value of proportional band for which the system just goes unstable i.e., continuous oscillations are observed in the output of controller.
- Record the ultimate proportional band and ultimate period from the response.
- Calculate the PID values from the table. Select the PID controller and apply the parameter values obtained from the above steps. Observe the response of the process to a step change with these settings

## Observations

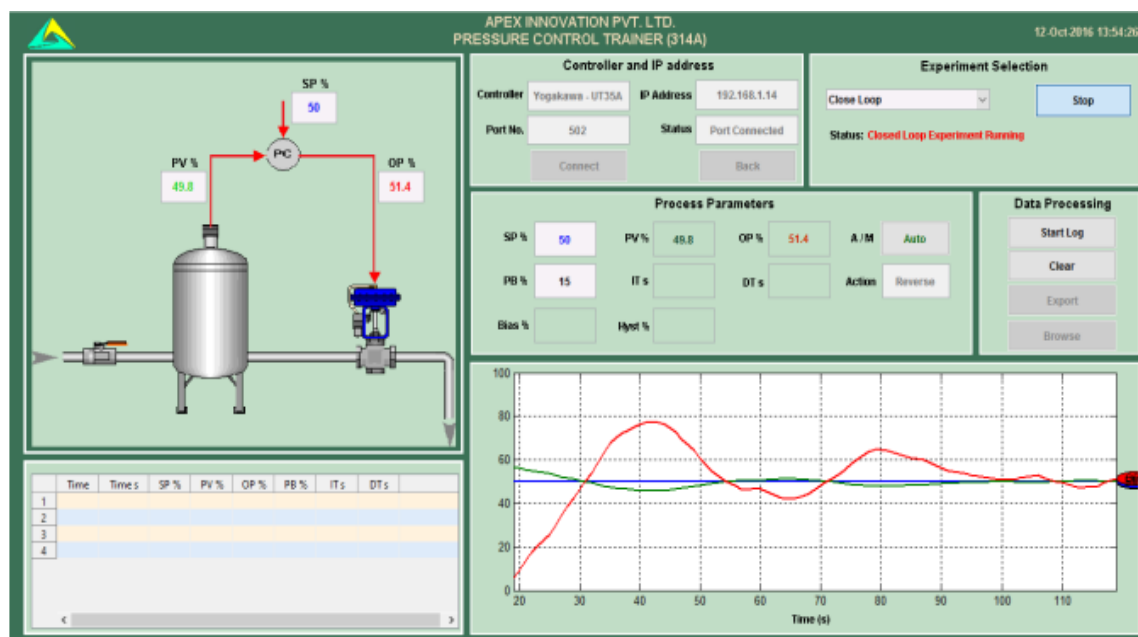


Fig 7.3 PID response; Zeigler Nichols Tuning

- Record the ultimate proportional band ( $Pb_u$ ) and ultimate period ( $T_u$ ) from above experiment.
- Calculate PID values by referring theory part for different control actions.
- Observe the process response for these settings.
- Compare the values obtained with open loop response method.

### **Result**

Studied the tuned parameters  $K_p$ ,  $K_i$  and  $K_d$  using Ziegler Nichols method.

## **EXPERIMENT NO. 8**

### **CONTROLLER TUNING FOR VARIOUS PROCESSES- USING COHEN AND COON RULE**

#### **Aim**

To study the Cohen-Coon method of tuning for process stations.

#### **Apparatus Required**

Flow, Level, Temperature or Pressure Process System Trainer kit

#### **Theory**

The Cohen- Coon tuning rules are suited for a wide variety of processes than the Ziegler-Nichols rules, which work well only on processes where the dead time is less than half the length of the time constant. The Cohen-Coon tuning rules work well on processes where the dead time is less than two times the length of the time constant.

Like the Ziegler-Nichols tuning rules, the Cohen-Coon rules aim for a quarter amplitude damping response. Although quarter-amplitude damping type of tuning provides very fast disturbance rejection, it tends to be very oscillatory and frequently interacts with similarly tuned loops. Quarter amplitude damping-type tuning also leaves the loop vulnerable to going unstable if the process gain or dead time doubles in value. The Cohen-Coon tuning rules use three process characteristics: process gain ( $g_p$ ), dead time ( $t_d$ ) and time constant ( $\tau$ ).

#### **Procedure**

- Assuming the controller loop is linear and the final control element is in good working order, tuning the controller can be done. These are determined by doing a step test and analyzing the results.
- Switch on Mains.
- Switch on the compressed air source and adjust the Air regulator to set supply air pressure at @ 2 kg/cm<sup>2</sup>.
- Switch on computer
- Double click on Apex\_Process\_Trainers icon on the desktop
- Select product Pressure Control Trainer (314A)
- Select Yokogawa (UT35A)
- Click Continue >> Click Connect >> Click Select Experiment
- Select Process Reaction and click Start
- Place the controller in manual mode and wait for the process to settle out.
- Make a step change of a few percent in the controller output (CO) and wait for the process variable (PV) to settle out at a new value.
  
- Calculate process gain,

$$g_p = \% \text{ change in PV} / \% \text{ change in CO}$$

- Measure the dead time ( $t_d$ ) as follows:  
 $t_d$  = Time difference between the change in CO and the intersection of the tangential line and the original PV level.
- Calculate the value of the PV at 63% of its total change. On the PV reaction curve, find the time value at which the PV reaches this level.
- If you get vastly different numbers every time, do even more step tests until you have a few step tests that produce similar value.
- Note  $t_d$ ,  $g_p$  and  $\tau$ , then apply the values according to the table mentioned above and find the tuned values of  $K_C$ ,  $T_i$  and  $T_D$ .
- Calculate P, PI, and PID setting from above values.
- Observe response of the system for different PID settings.

## Observations

### CHARACTERISTICS OF STEP INPUT ANALYSIS – COHEN & COON RULE

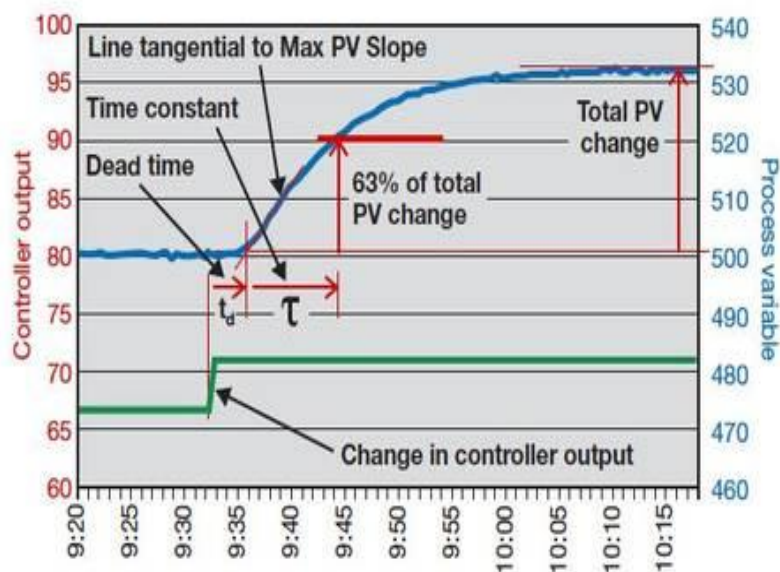


Fig. 8.1 Step response



Controller	Controller gain	Integral Time	Derivative time
P	$K_C = \frac{1.03}{g_p} \left( \frac{\tau}{t_d} + 0.34 \right)$		
PI	$K_C = \frac{0.9}{g_p} \left( \frac{\tau}{t_d} + 0.092 \right)$	$T_i = \frac{\tau + 0.092t_d}{\tau + 2.22t_d} (3.33t_d)$	
PD	$K_C = \frac{1.24}{g_p} \left( \frac{\tau}{t_d} + 0.129 \right)$		$T_D = \frac{\tau - 0.324t_d}{\tau + 0.129t_d} (0.27t_d)$
PID	$K_C = \frac{1.35}{g_p} \left( \frac{\tau}{t_d} + 0.185 \right)$	$T_i = \frac{\tau + 0.185t_d}{\tau + 0.611t_d} (2.5t_d)$	$T_D = \frac{\tau}{\tau + 0.185t_d} (0.37t_d)$

Fig. 8.2 Tuned Values

### **Result**

Studied the tuned parameters  $K_C$ ,  $T_i$  and  $T_D$  using Cohen and Coon rule.

### Program Outcomes (POs)

<b>Program Outcomes (POs) of the undergraduate Engineering programme</b>		
<b>PO</b>	<b>PO type</b>	<b>Engineering graduates will be able to</b>
PO-1	Engineering Knowledge	Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.
PO-2	Problem Analysis	Identify, formulate, review research literature and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.
PO-3	Design/Development of Solutions	Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal and environmental considerations.
PO-4	Conduct Investigations of Complex Problems	Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
PO-5	Modern Tool Usage	Create, select and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
PO-6	The Engineer and Society	Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
PO-7	Environment and Sustainability	Understand the impact of professional engineering solutions in societal and environmental contexts, and demonstrate knowledge of, and need for sustainable development.
PO-8	Ethics	Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO-9	Individual and Team work	Function effectively as an individual, and as a member or leader in diverse teams, and in multi-disciplinary settings.
PO-10	Communication	Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
PO-11	Project Management and Finance	Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
PO-12	Life-long Learning	Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.