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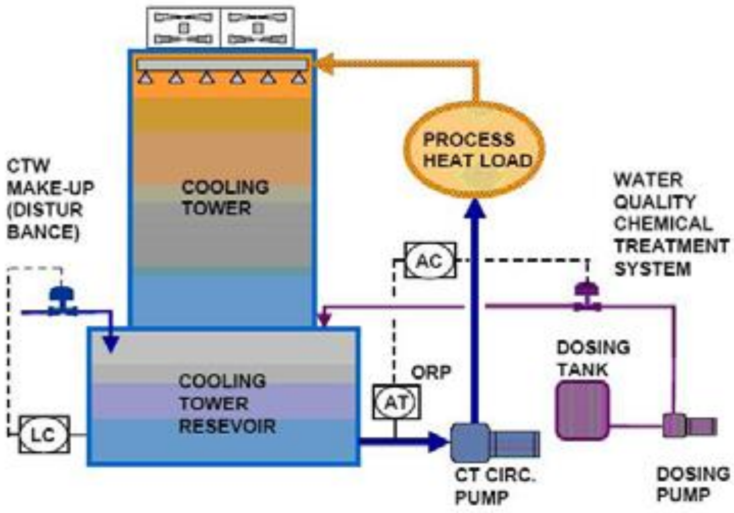
Department of Electrical and Electronics Skills

STUDENT HANDBOOK

Principles of Control

INCT 1427

2020



Prepared by

Industrial Instrumentation & Control Skills Team

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Unit 1: Introduction to Process Control

Lesson 1.1: Definition of Process Control

In simple term, control means methods to keep parameters in the environment to have specific values. These controls can be a simple one to keep the temperature in an oven to be at 80°C or as complex as sending a missile to a target.

The basic objective of a process control system is to maintain the value of some parameter like pressure ,temperature , flow ,level, PH value etc at some specific value. This specific value is called the desired value or reference value or set point.

We can therefore state that a control system is called a process control, when we use automatic control system to regulate the value of a certain variable to the desired value.

Process: Figure 1 shows a process in which a liquid is flowing to a tank at some rate and it is flowing out at some other rate. The objective is to regulate the level (h) of the liquid to some value H. It is a fact that the output flow rate of the liquid is proportional to the square root of the height of the liquid. That means if the height of the liquid is more, the flow rate output will be more.

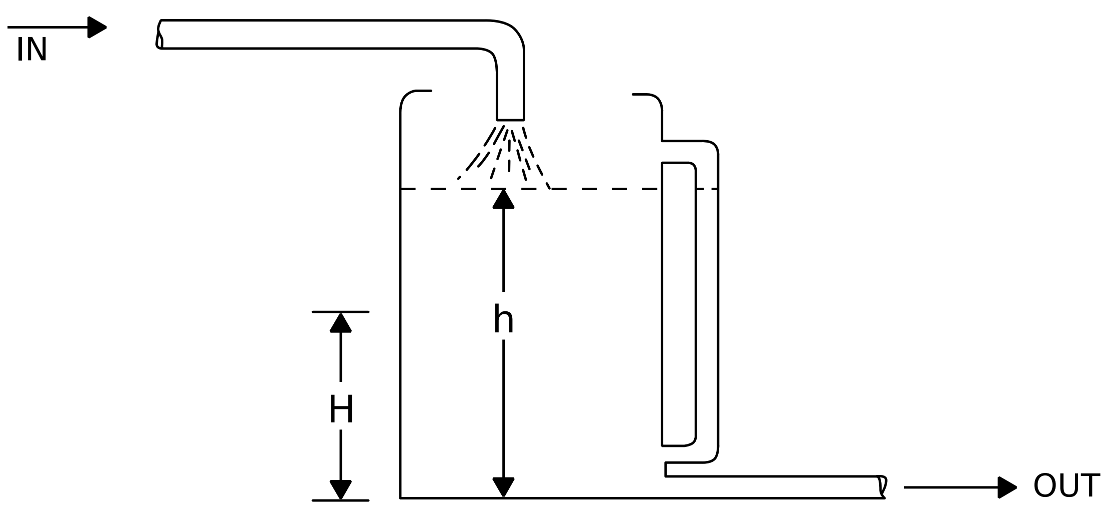


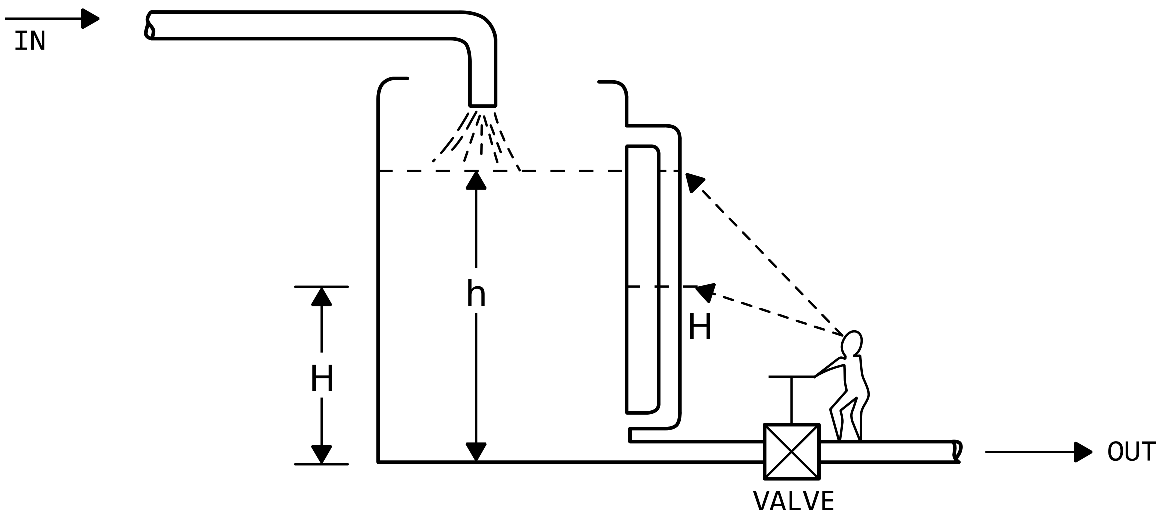
Figure :1

Self regulation:
When the liquid flows in and out of the tank, at one particular level of the liquid, the input flow rate will be equal to the output flow rate.This condition is called self regulation. It is a property of the process shown above."

Lesson 1.2: Manual Control & Automatic Control

<u>Manual Control:</u>

Let us see how to control the level of liquid in the tank to a particular level H, manually. Figure 2 below shows this



<u>Figure : 2</u>

The human can see the present level of liquid in the tank-by looking to the sight tube. He also knows what should be the required level to be maintained. There is also a valve attached to the output flow to control the output flow rate. In manual control, the human being looks to the sight tube, and compares the present level with the desired level and then he takes-a decision to open or close the valve. After a series of opening and closing of the valve he can finally bring the level required value. The level is now regulated. This is the principle of manual control.

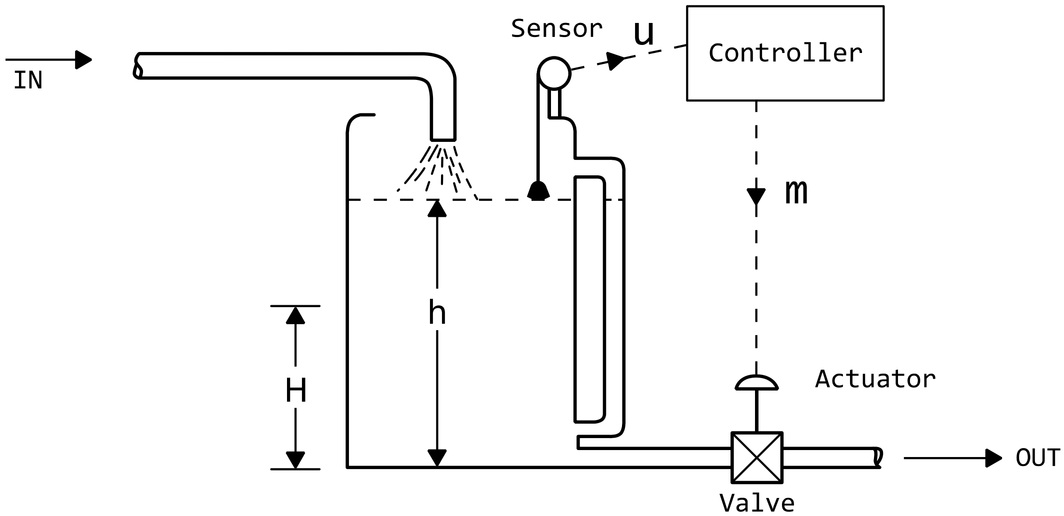


Figure: 3

Automatic Control

To get automatic control, we modify the manual control system as shown in figure 2. Here we have added a sensor which will detect the present level of liquid and sends a proportional signal ‘u’ to a controller. Here, the controller is doing the duty of the human being to compare the sensor output value and the required value to give an output signal ‘m’. This signal ‘m’ will change the opening and closing of the control valve with the help of an actuator connected to the valve and regulates the level to the desired value.

We can say that a control is called ***process control,*** when we use automatic control system to regulate the value of a certain variable to a desired value.

Lesson 1.3: Open Loop Control System

Control system can be classified as open loop systems and closed loop systems. In an open loop system, the control of the variable does not depend upon the present value of the process variable. That is the control is totally independent of the output. Because the control action is totally independent of the output, there is no need to measure the output. Therefore in an open loop system there is no measurement and hence no feed back signal.

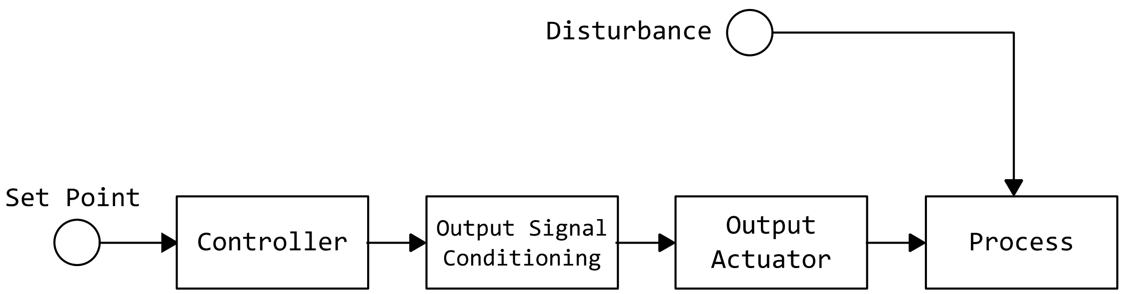


Figure 4: Open-Loop Control

Advantages and Disadvantages of open loop system:

Advantages:
Relatively simple
Inherently stable

Disadvantages:
External or internal changes Affects its operation
Not accurate as there is no corrective Action

Lesson 1.4: Closed Loop Control System

In a closed loop system the control of the process variable depends up on the present value of it. In other words we can say that, the control totally depends upon the output. Hence in a closed loop control we need to provide a mechanism to measure output and to feed it back to the controller to compare with the desired value of the output.

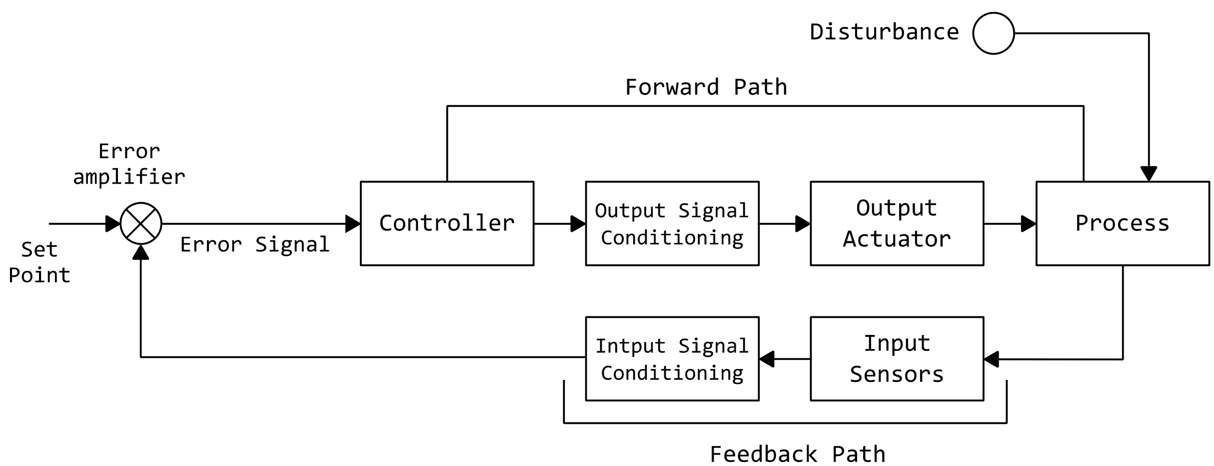


Figure 5: Closed-Loop Control System

Closed Loop Control System (Process Control Block Diagram):

A simple block diagram of a control loop is shown. Let us discuss each block with respect to the liquid level control system given in the figure.

1. **Process:** generally a process can consist of complex phenomena which relates to some manufacturing process. With regard to our example, the tank, the flow of liquid in and out and the liquid constitutes a process.

2. **Measurement:** A variable cannot be controlled without knowing the present information about it. That is, measurement is the means for getting information about a variable. In our example, the sensor performs the initial measurement and gives out a proportional analogue electrical signal or a pneumatic signal. The sensor can also be called a transducer because it involves transforming a physical variable from one form to another.

3. **Error Detector:** Before any control action can be taken to the controller, the difference between the actual value and the desired value must be known. This difference is called an error signal. The error signal has both

a magnitude and a direction. The device which calculates the difference is called an error detector.

4. **Controller:** the controller receives the error signal from the error detector and determines the action to be taken. Sometimes the error detector itself is shown as part of the controller. In that case the inputs to the controller are the measurement signal and the desired value. The basic function of a controller is to issue a control signal based on the error signal received so as to keep the process variable equal to the desired value (set point).

5. **Final Control Element:** this element receives the signal from the controller which will then perform a proportional operation to bring the controlled variable to the desired value. In our example, the final control element is the control valve.

6. **The Feedback Control Loop:** in the block diagram shown above, the signal flow makes a complete circuit through various elements starting from the process, the measurement, error detector, controller, and then the final control element. This loop is called a feedback control loop.

Advantages and Disadvantages of closed loop system:

Advantages:

No external disturbances internal changes can affect controlled variable
Accuracy is more than open loop system.

Disadvantage:

Because of the addition of feedback element ,and the mechanism, it is more complex than open loop.
Sometime closed loop system become unstable.

Unit 2: Introduction to Control Action

Lesson 2: Controller Operation and Description:

There are many different applications of process control in today's industries. Some of these applications are very complex, and some are relatively simple. Regardless of how simple or complex a process control system is, it usually contains **four basic elements:**

1. A primary element, which senses changes in the process;
2. A measuring element, which indicates the condition of the process variable;
3. A controlling element, which provides a controlling or corrective signal; and
4. A final control element, which acts to manipulate the process. The heart of any control system is the controlling element, which is usually a controller.

This training unit is designed to introduce instrument technicians to some of the basic control actions provided by different types of controllers. The material covered includes the definitions and basic control actions provided by two-position, proportional, reset, rate, and proportional-plus-reset-plus-rate controllers.

2.1: Controller Identification

A controller can be identified in several different ways: by its power source, by the process variable it controls, and by the kind of controlling action it provides.

Controllers that can be identified by their power source are typically either pneumatic controllers or electronic controllers. A pneumatic controller is powered by compressed air. Pneumatic controllers are rugged and durable, and they work well under a variety of adverse conditions. An electronic controller is powered by electricity. Electronic controllers can send signals over long distances in relatively short periods of time.

Some controllers that can be identified by the process variable they control are level controllers, pressure controllers, flow controllers, and temperature controllers. A level controller controls level conditions; a pressure controller controls pressure conditions; a flow controller controls flow conditions; and a temperature controller controls temperature conditions.

On occasion, some controllers in a plant are identified by both their power source and the process variables that they control. For example, a pneumatic level controller is a controller that is powered by compressed air to control level conditions.

The third way that a controller can be identified is by the kind of controlling action it provides. The types of controlling actions that can be provided are covered later in this section.

2.2: Controller Functions and Inputs

In general, controllers have four basic functions: **measuring, comparing, computing,** and **correcting.**

A controller <u>measures</u> a signal from the measuring element or transmitter, <u>compares</u> the measured value of that signal to set point, <u>computes</u> the difference between the measured value and set point, and produces a <u>correcting</u> signal that is transmitted to the final control element.

The signal that a controller receives from a measuring element represents the <u>value of a process variable.</u> The form that the signal takes can vary. For example, a controller can contain a primary sensing element, which allows the controller to be connected directly to the process it controls, or the controller may receive a signal from a transmitter. In a typical pneumatic system, the signal is in the form of air pressure that ranges from **3 to 15 psi**, or **3 to 27 psi,** or any of several other standard signal pressures. In a typical electronic system, the input signal is in the form of current that ranges from **4 to 20 mA** or **10 to 50 mA** or voltage that ranges from **1 to 5 volts** or **2 to 10 volts**. Other pneumatic or electronic signal ranges can be used, depending on the manufacturer and design of the system.

Since the input signal to the controller represents the value of a process variable, the input changes as the process variable changes. The ways that the input signal can change can be represented by four basic signal patterns, as shown in Figure 6

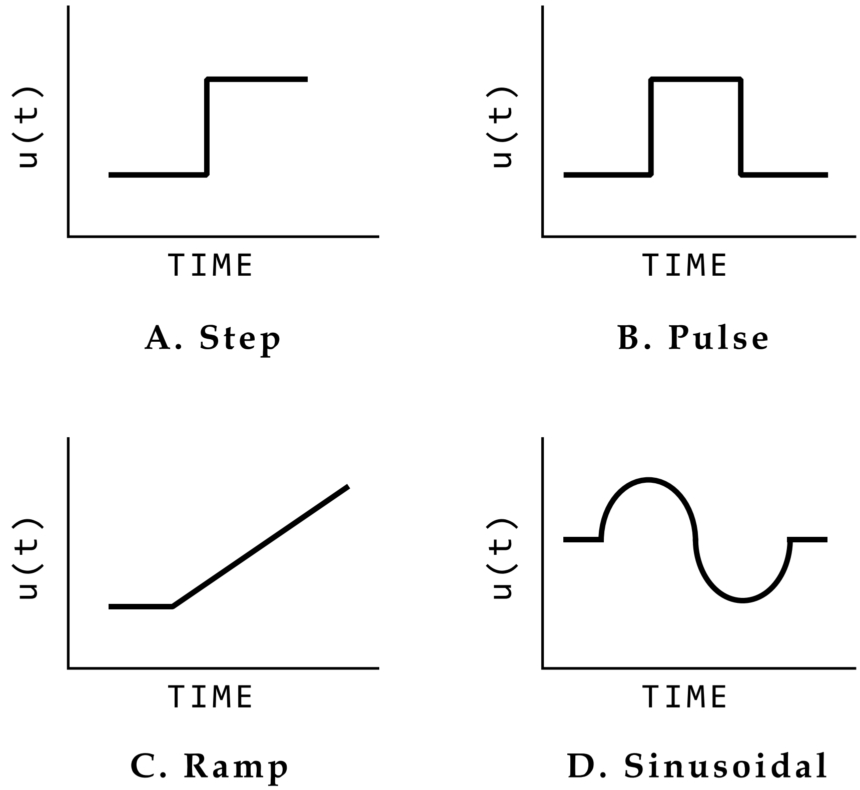


Figure: 6

2.3: Basic signal pattern

The signal pattern in Figure 6A is a "step" signal. It indicates an instant increase in the value of the process variable. The signal pattern in Figure 6B is a "pulse" signal. It indicates that the value of the process variable instantly increased; then, after a brief period of time, it instantly returned to its original value. The signal pattern in Figure 6C is a "ramp" signal. It indicates a gradual increase in the value of the process variable. The signal patterns in Figures 6A, 6B, and 6C represent increasing process values. Decreasing process values would be represented by signal patterns that decline rather than rise. The signal pattern in Figure 6D is a "sinusoidal" signal. It indicates that the value of the process variable is alternately increasing and decreasing.

When the controller receives any input signal from the measuring element, the controller measures the value of the signal, compares the value to set point, computes the difference, and produces a corrective output signal. The output signal from the controller can be any one of the signal patterns shown in Figure 6, or it can be a combination of two or more signal patterns. The signals actually generated in plant applications seldom look exactly like these, but they generally do resemble one or a combination of the four basic patterns.

2.4: Controller Modes

The output signal from a controller activates a final control element that in some way changes the value of the process variable. The kind of output signal generated in relation to an input signal change depends on the controller action. Controller actions are often referred to as control modes.

Control Mode can be defines as the way in which the controller reacts to error changes.

There are five basic types of control modes:

(1) Two-Position or ON/OFF Control.

(2) Proportional Control.

(3) Integral or reset Control.

(4) Derivative or rate Control.

(5) proportional-plus-reset-plus rate.

Unit 3: Two Position (on/off) Control Action

Lesson 3.1: Example of Two position (on/off) control action

Two-position control is used in industry to turn components (such as the sump pump shown in Figure below) on or off. Sump pumps are often used to maintain the level in a well, or sump, within defined limits by drawing water out of the sump when the level gets too high. or too low by the help of switch mechanism. This arm closes a set of contacts within the switch that energize an electrical circuit that starts the pump motor and opens the contacts, de-energizes the electrical circuit when level is high, and shuts off the pump motor.

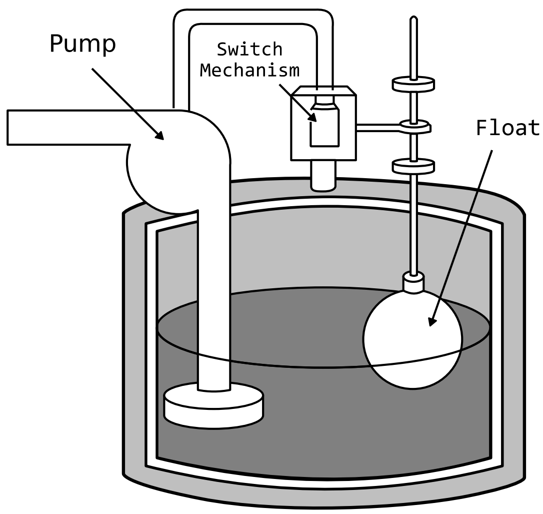


Figure: 7

The type of output produced by the action of turning a pump on and off is illustrated below. The "vertical' line between points A and B' represents the point at which the collar on the float rod tripped the electrical switch to turn the pump on. The vertical line between points C and D represents the point at which the other collar on the float rod tripped the electrical switch to turn the .pump off. The horizontal lines represent the time during which no change occurred in the operation of the pump: it stayed on or it stayed off. The lower horizontal lines represent the time during which the pump was off, and the upper horizontal lines represent the time during which the pump was on.

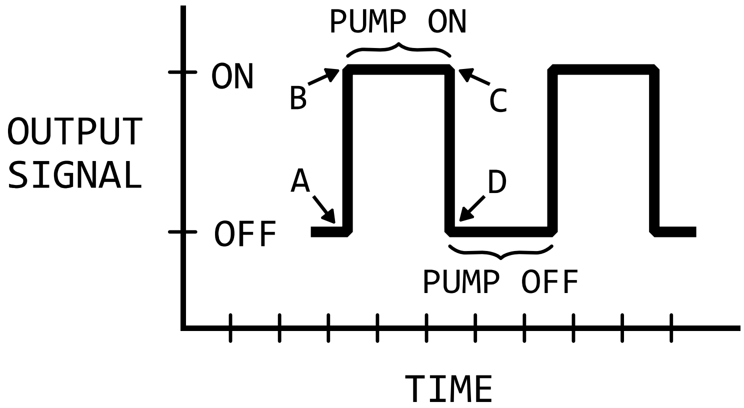


Figure: 8

Lesson 3.2: Dead Zone

The term "dead zone" refers to the amount of change that can occur in a process without triggering a control action. For example, in below Figure, the dead zone is the amount of level change it takes for the float rod to move up or down enough to turn the electrical switch on or off. The dead zone in that example could be reduced by moving the two collars on the float rod closer together. Then it would take a smaller change in level to cause the pump to turn on or off. If this were done, the sump could be maintained at a more constant level, but the pump would be turned on and off more frequently. This could cause the system's components to fail prematurely due to overuse.

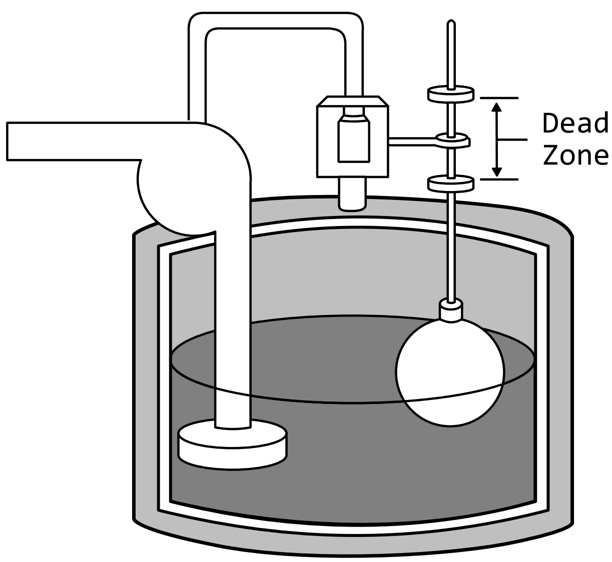


Figure: 9

Unit 4: Proportional Control Action

Proportional Control is control in which the output signal's characteristics are proportional to the input signal's characteristics. In other words, if the input to a proportional controller increases by a given amount, the controller's output will increase by a given amount; if the input decreases by a given amount, the output will decrease by a given amount. This control scheme is the simplest continuous mode in which the final control element maybe in any position within its operating range, whereas in On/off control, the final control element has only two positions- fully closed or fully open. In proportional control the final control element maybe 20% open, 75% open, ie. It is not limited to 0% or 100% as in the two-position control scheme (On/Off).

The controller output signal is given by the equation:

$$m = K_C e + C_0$$

Where **m** = controller output signal
K_C = controller gain
e = error (difference between set point and process variable)
C_0 = controller output when the error is zero. This is a constant value that can be adjusted to get the required output, usually at 50%

As the name implies, there is a continuous relation between the error signal and the position of the final control element.

Amount of proportional control:

The amount of PB (or gain) used in a certain control application depends upon the process characteristics. In other words, each process will have a specific value of PB by which the control woks efficiently and smoothly.

If the gain is large, we can say that the PB is narrow (because they are inversely proportional), and if the PB is narrow, a very small change in the error (plus or minus) will make the control valve move from full open to full closed and vice versa. This means that the valve is very sensitive to error changes. This condition is referred to as too much proportional control action.

This case is similar to On/Off control without a dead band in that any small change in the error makes the valve fully closed or fully open. Hence, we can say that if the PB is narrow (large gain), the process variable will oscillate continuously because the control valve will close and open continuously.

If PB is still lower than the above condition, the oscillations will increase and, as a result, the control system becomes unstable.

Now let's think of the opposite case, if PB is wide (low gain). This condition is called too low proportional control action. In this case, the full range of error change (plus or minus) would make the valve move only slightly. In other words, even if you apply 100% control signal, the control valve will not fully close or fully open. This means that the valve has very low sensitivity to error changes, and therefore, the control action will be corrected very slowly in temperature control applications as an example.

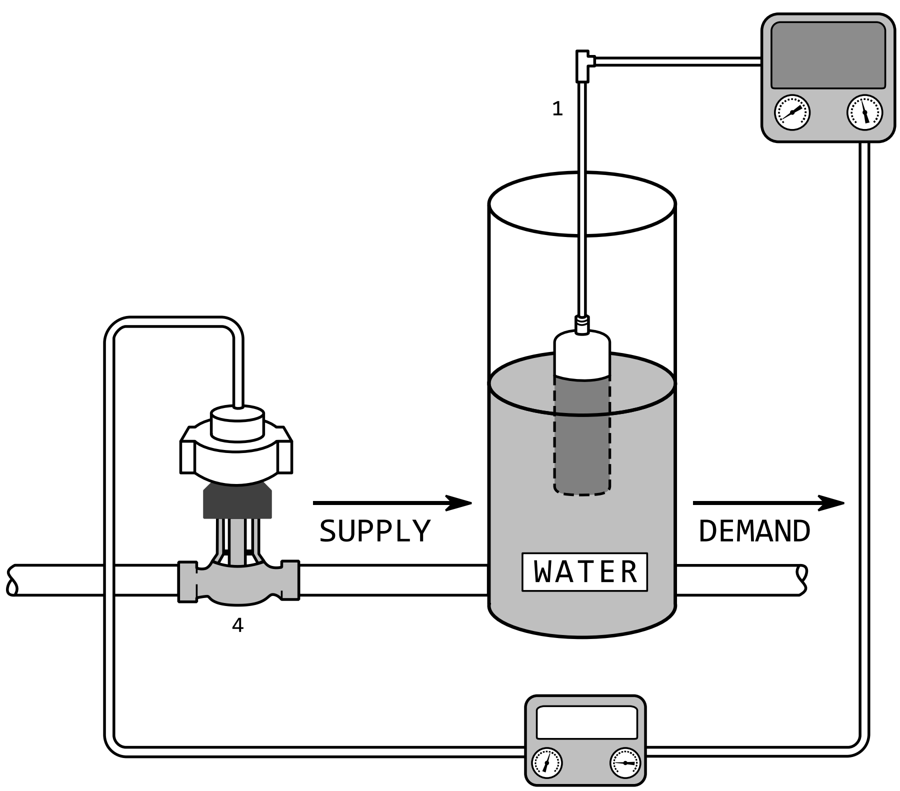


Figure:10

Lesson 4.1: Examples of Proportional Control Action

Proportional Control is control in which the output signal's characteristics are proportional to the input signal's characteristics. In other words, if the input to a proportional controller increases by a given amount, the controller's output will increase by a given amount; if the input decreases by a given amount, the output will decrease by a given amount.

For example, in proportional control, a step input signal change results in a step output signal change, or a ramp input signal results in a ramp output signal. In other words, in proportional control, the output signal is proportional to the input signal. This eliminates the dead zone characteristic of on/off control. Figure 10 is an illustration of a simple automatic control system that can be used to help explain the concept of proportional control.

In this example, when the level of water in the tank changes, the primary element (1) converts the change into mechanical motion. The motion is measured by the measuring element (2) and converted into a pneumatic signal. The pneumatic signal is sent to the controlling element (3), which measures the signal, compares it to set point, computes the difference, and produces a correcting signal that is transmitted to the final control element. The final control element responds to the signal from the controlling element by adjusting the flow of water to the tank.

In terms of proportional control, the points of interest are the input signal to the controlling element (from the measuring element) and the output signal from the controlling element, which is transmitted to the final control element. These signals can be illustrated on a simple graph, as shown in Figure 11, which illustrates input and output signals for a proportional controller with a temporary process disturbance.

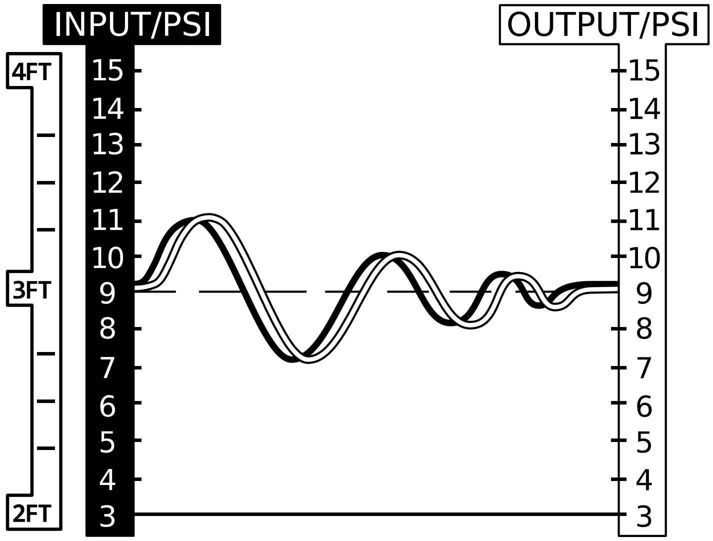


Figure: 11

The graph in Figure: 11 has two scales: one on the left for input and one on the right for output. Both scales are marked off in psi (pounds per square inch) for the pressure values of the pneumatic signals going into and out of the controller. (The process variable in this system is level, but the measuring element converts level changes to pneumatic signals.

The signal that the controller receives is a psi signal. The controller's output signal is also in psi). The dashed line across the graph represents set point, which, in this example, is 9 psi. When the level in the tank changes, the input signal to the controller also changes.

For example ,in Figure 11 ,an increase in level caused the input signal to the controller to increase from 9 psi to 11 psi. At the same time, the output of the controller also increased from 9 psi to 11 psi. The output in this example is directly proportional to the input: for every 1 psi change in the input signal there is a corresponding change of 1 psi in the output signal. (Normally, the input and output signals would change almost simultaneously. The two signals have been separated here to make them easier to compare.)

The change in the controller's output signal was sent to the final control element, which caused the water level in the tank to change. Then, both the input signal and the output signal cycled above and below set point until the water level returned to steady state at set point.

The graph illustrates the changing signals going into and out of a proportional controller as a result of a continual disturbance. In this example, when the level of water in the tank increased, the controller responded to correct the change in level. However, when the controller was able to stop the level from changing, the level was higher than it was originally. The input and output signals shown in Figure 11 are very similar to the signals shown in Figure 11, except that when the process settled out at steady state, it was at a control point that was higher than set point. The signals in

Figure 11, become steady at 11 psi rather than at 9 psi. This example illustrates the point that a proportional controller typically produces enough output to catch an error and bring it under control, but it may not be able to overcome a continual disturbance and return a process variable to set point.

Proportional Band :

Although *a* proportional controller may provide control that results in offset, there is a way that the controller can be adjusted to reduce the amount of offset. This adjustment is called "proportional band." Proportional band is the change in input required to produce a full range change in output; it is usually expressed as a percentage. Proportional band can be expressed in terms of the following formula:

$$\frac{Controller\ Input}{Controller\ Output} = PB$$

$$PB \times 100 = PB\%$$

Unit 5: Reset (or) Integral Control

Lesson 5.1: Characteristics of Reset Control

Reset control is the portion of controller output that responds to the amount of deviation from set point for the duration of time that the deviation exists. In simpler terms, as long as a process variable is away from set point, a reset controller will keep adjusting its output, based on the amount of process deviation from set point, or offset.

Reset control does not exist by itself; it is <u>always combined</u> with proportional control. With proportional control (or "P only" control, as it is sometimes referred to) when the input to the controller changes, the controller's output changes proportionally. In other words, if the input to a proportional controller increases by a given amount, the controller's output will increase by a given amount. When the input stops changing, the output also stops changing, frequently resulting in offset. When reset is added to proportional control, the controller continues to adjust its output until the process variable returns to set point. Reset control is actually proportional plus reset control; it adds a corrective action to the proportional action.

Lesson 5.2: Reset Control - Example

Figure 12 below is a representation of the simple automatic control system that was used earlier to explain the concept of proportional control. In this example, reset control has been added to the proportional controller.

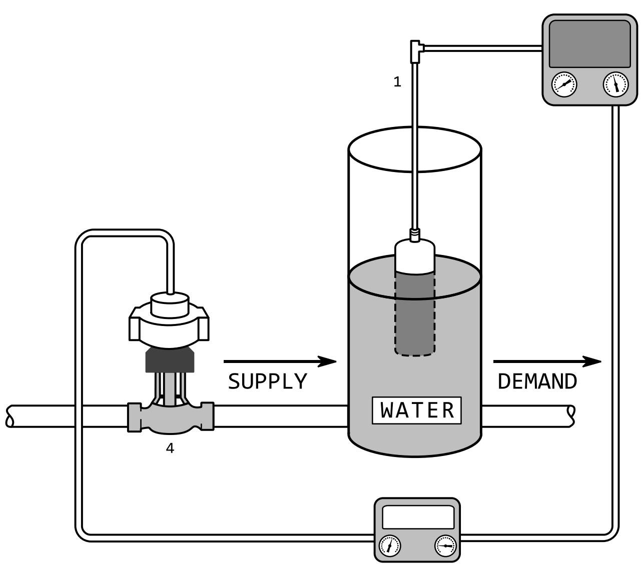


Figure :12

In this example, as in the example for proportional control, assume that a continual disturbance causes the flow of water to the tank to increase, and, therefore, the level of water in the tank rises. The signals that represent the changing water level and the reset controller output are shown in Figure:13 below.

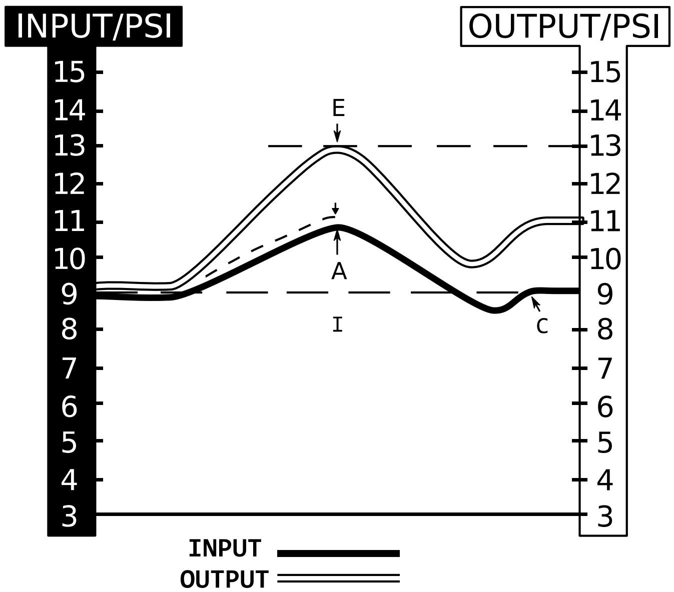


Figure:13

The increase in water level during the first minute is represented by the controller input signal from 0 to point A in Figure 13. A proportional only controller with a 100% proportional band would produce an output signal that matches the input signal at point A.

When reset is added, the output signal during the first minute is represented by the line from 0 to point B. This represents an increase over a proportional only output by an amount equal to 1 repeat per minute. The increase in the reset signal is 2 psi between points A and B, an amount equal to the proportional deviation from set point at point A.

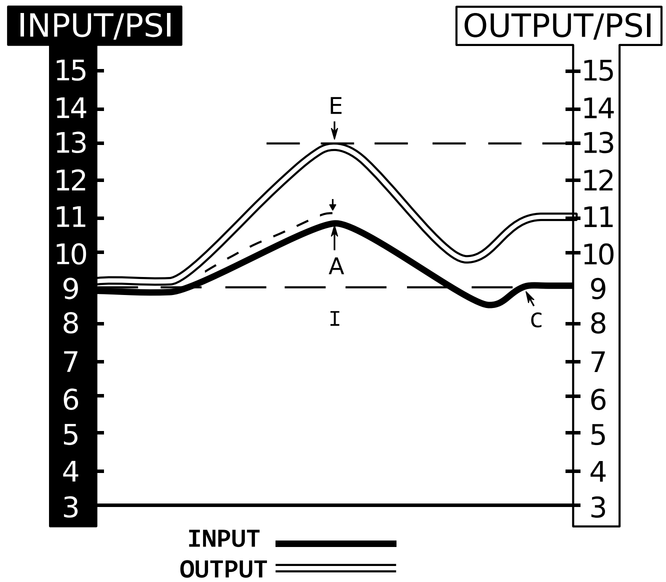


Figure: 14

The water level (as represented by the input signal in Figure 13 begins to drop after one minute as a result of the-reset controller output. The input signal continues to change until the water level settles out at steady state at set point (point C). The output signal also changes until it reaches steady state at a value of 11 psi, 2 psi above the set point of 9 psi. This does not represent offset, because the value of the process variable (the input signal) does not vary from set point. Since the input signal has returned to set point, there is no offset.

Figure 14 illustrates the input signal (water level) changes and the reset controller output with a reset of 2 repeats per minute. Notice that the amount of deviation at point A is less than the 2 psi deviation in Figure .Also notice that the reset output signal at point B represents an increase of 4 psi over the original proportional only output of 11 psi (at point A in Figure 2 This is equal to two repeats of the proportional output deviation of 2 psi, for a reset of 2 repeats per minute.

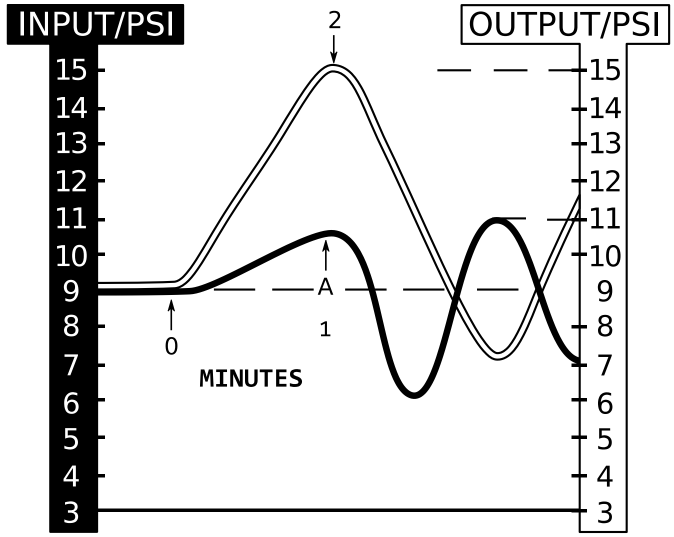


Figure: 15

A disadvantage of reset control is also shown in Figure 15 above. As the input and output signals continue, they appear to cycle out of control. Too much reset can sometimes cause a controller to overcorrect. As a result, the process variable changes too much and cycles out of control. It is important that an instrument technician have a basic idea of the type of output signal that will be provided by a controller in response to specific input changes. Generally, a reset controller will respond in a predictable manner to a specific input signal change.

Unit 6: Rate or Derivative Control Action

Lesson 6.1: Characteristics of Rate Control

Rate control the portion of controller output that responds to the speed of deviation from set point. If a process variable changes rapidly , a rate controller will respond with a greater amount of control action. If changes are slow, there is less control action. If there is no change, there is no control action.

As with reset control, rate control does not exist by itself: it is always combined with proportional control. With rate control added to a proportional controller, when input to the controller changes, the controller measures the speed of the change and produces an instant "boost" to the proportional output signal. In effect, this mode of control opposes changes in the input (the process variable) and tries to stop the changes as soon as they are detected. When the input stops changing, the rate part of the control action stops, leaving only the proportional part of the output.

Lesson 6.2: Rate Control - Example

The simple automatic level control system used earlier to explain the concepts of proportional and reset control can be used again to help illustrate the concept of rate control. In this example, rate control has been added to the proportional controller. The system is illustrated in Figure 16 below.

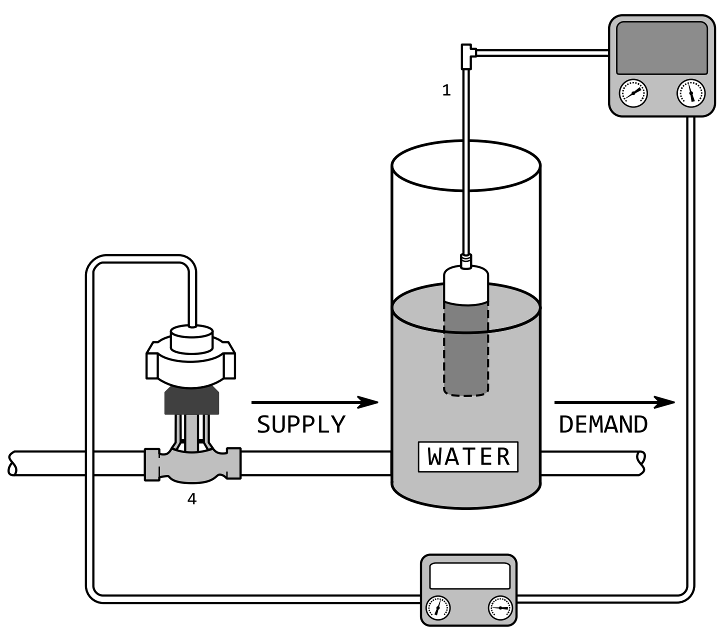


Figure : 16 (Simple Automatic Control System)

In this example, as in earlier examples using this system, a continual disturbance causes the level of the water in the tank to rise. The controller input signals shown in Figure below represent the changing water level as a result of three different control actions.

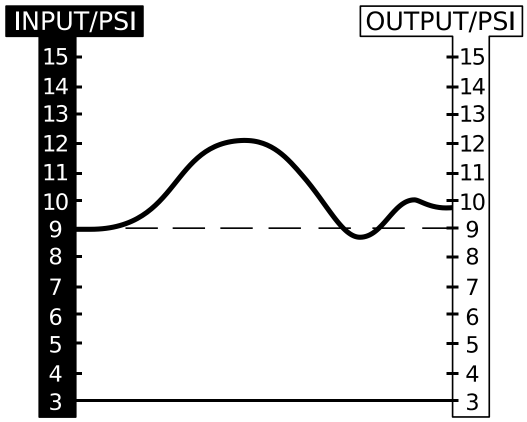


Figure: 17 (A. Proportional Control with a 100% Proportional Band)

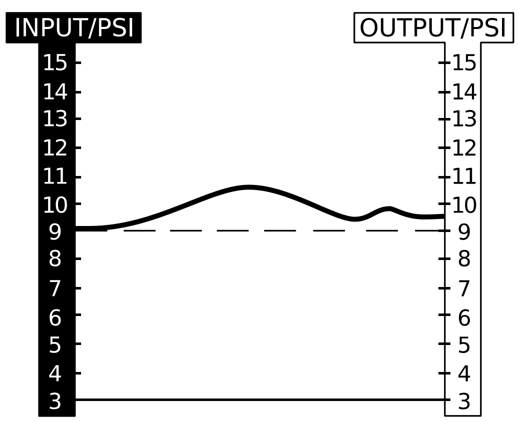


Figure: 18 (Proportional Plus Rate Control)

Figure:16 represents the level changes resulting, from the response of a proportional controller with a 100% proportional band..

Figure:17 above represents the level changes resulting from the response of a proportional plus rate controller to the same continual disturbance. The amount of offset is less than the offset for the proportional controller with a 100% proportional band, and the cycling action is less than the cycling from the controller with a narrow proportional band. In addition, the total amount of error in the water level allowed by rate control is less than the error allowed by the other two control actions.

The reason why the rate controller was able to minimize error, reduce cycling, and reduce offset is that when the level started to change, The rate controller projected what the change would be after one minute. Then, the controller instantly produced a correcting output signal reflecting that amount, as illustrated in Figure:18 . This boost stopped the level from changing sooner than the other two control actions were able to. It is this initial fast response that also keeps offset at a minimum.

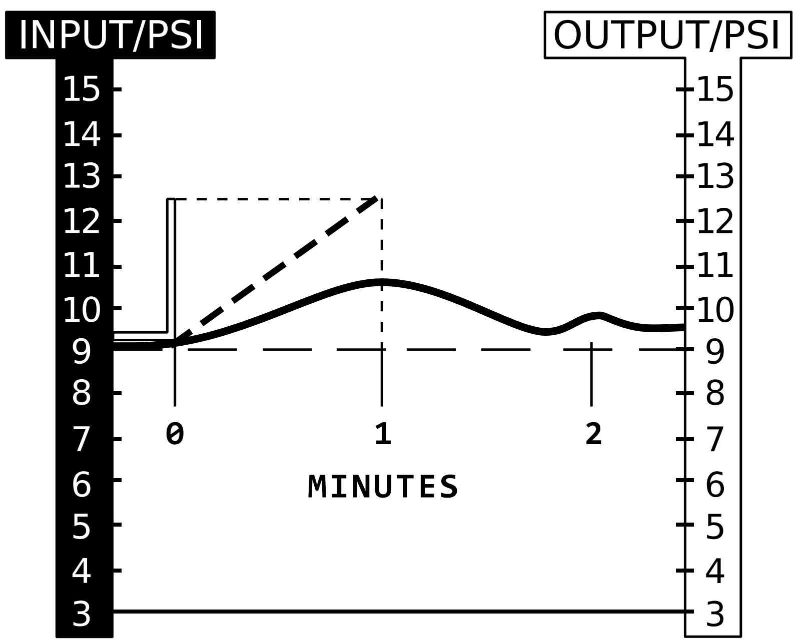


Figure: 19 (Derivative Time/Rate Control Response)

When the water level continued changing, as illustrated by line A in Figure:33 , the rate control action responded quickly to counteract the changes - both increases in level and decreases in level. In effect, the rate control output acted to oppose any change in the water level, either up or down. As a result, the rate controller did not allow the water level to cycle to any significant degree. However, rate control does allow offset, because it responds only to changes in the input. If the level is at steady state, even with offset, the rate controller provides no correcting output.

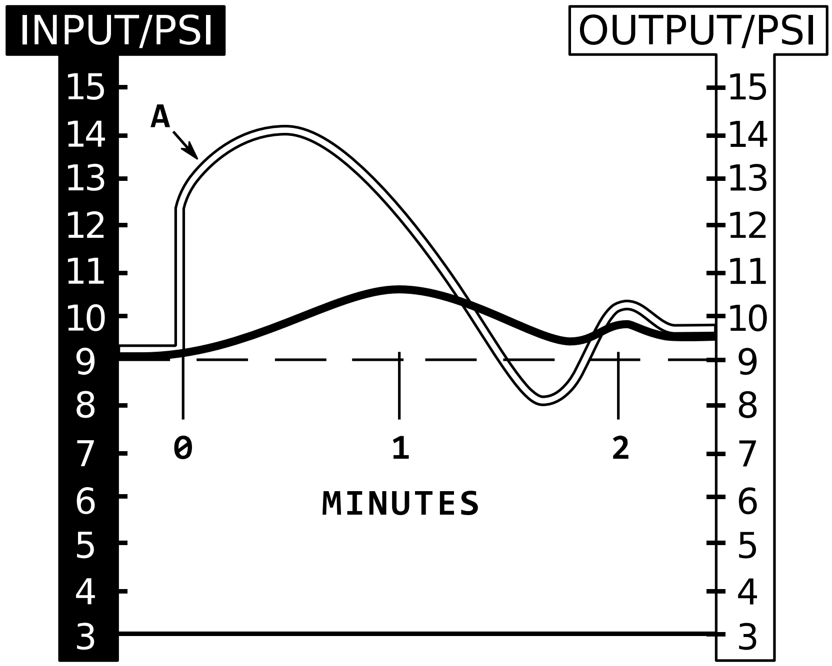


Figure :20 (Rate Control Output)

It is important that an instrument technician have a basic idea of the type of output signal that will be provided by a controller in response to specific input changes. Generally, a rate controller will respond in a predictable manner to a specific input signal change.

Unit 7: PID Control Action

Lesson 7.1: PID Control Action -Definition

Proportional plus reset plus rate control is the controller output that combines a proportional response with the precise response action of reset control and the fast response action of rate control. This kind of controller output provides a rapid control action that eliminates offset.

Proportional plus reset plus rate control is more frequently called PID control: P for proportional, 1 for integral (which is the same as reset), and D for derivative (which is the same as rate).

Proportional plus reset plus rate control is the controller output that combines a proportional response with the precise response action of reset control and the fast response action of rate control. This kind of controller output provides a rapid control action that eliminates offset.

Proportional plus reset plus rate control is more frequently called PID control: P for proportional, 1 for integral (which is the same as reset), and D for derivative (which is the same as rate).

Lesson 7.2: PID Control – Example

Figure below illustrates a process that requires the type of control response provided by PID controller. This illustration is of a gas-fired oil-heating furnace. Its function is to provide heated oil to another process. The controlled variable in the process is oil temperature. When the system is in operation, gas is supplied through a pipe to the inside of the furnace. As the gas is burned, the heat that is produced travels throughout the combustion chamber and is eventually transferred to oil that is transported through the combustion chamber by another pipe.

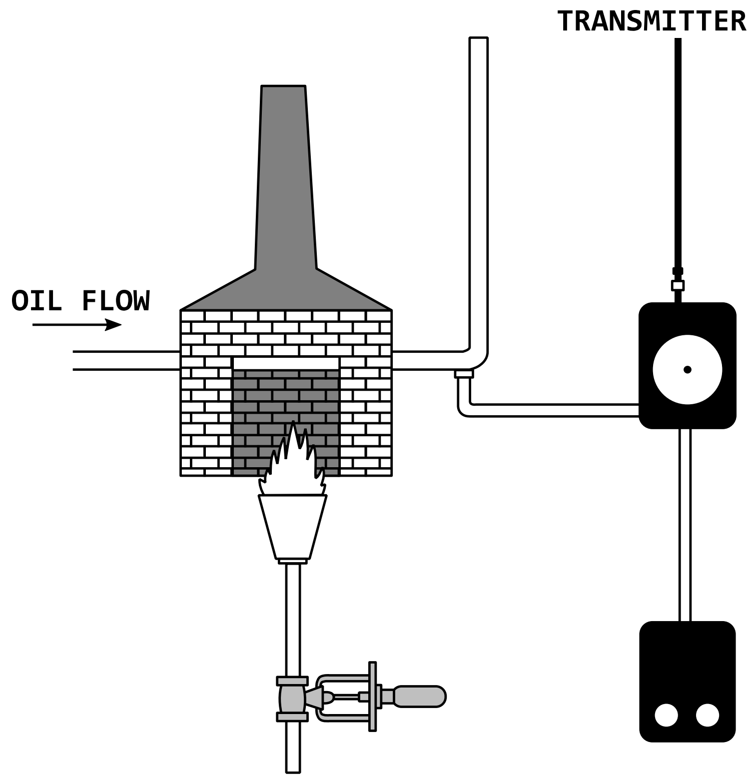


Figure :21

One of these delay characteristics is capacitance. The furnace has the capacity to store a lot of heat in its inner walls. This stored heat is transferred to the oil, but the transfer is not immediate. If the inner walls are heated too much, it will take a certain amount of time to lower their temperature - time during which the oil could also be overheated. If the inner walls are not heated enough, it will take a certain amount of time to raise their temperature - time during which the oil might not receive enough heat.

Another delay characteristic is the resistance of the oil pipe. The pipe resists the transfer of heat from outside the pipe to the oil inside the pipe.

The rate control portion of the PID controller helps to overcome these delay characteristics by providing an immediate boost of control action. The reset portion of the PID controller continually adjusts the output as long as there is offset, until the process variable returns to set point. As an example, Figure below illustrates the controller input and output signals that resulted from a demand change that reduced the flow of oil and caused the oil temperature to increase.

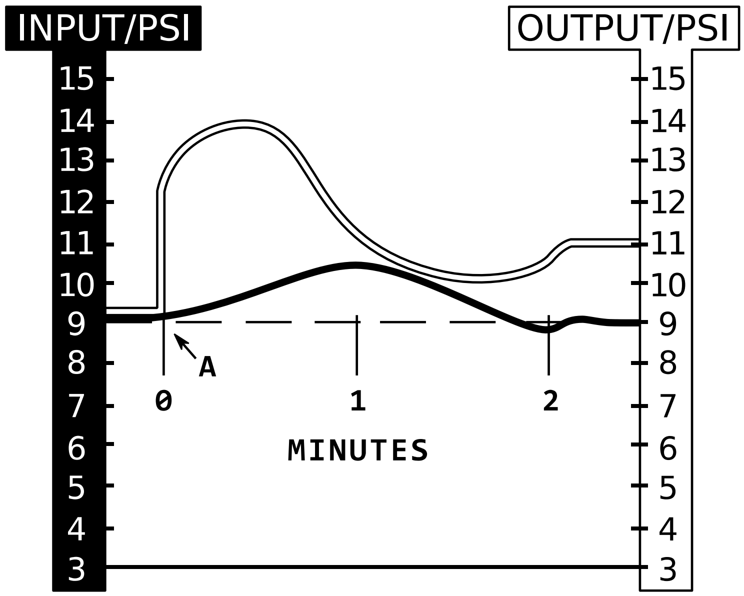


Figure :22: PID Controller

The input signal to the controller in this example represents the value of the oil temperature. As this illustration shows, when the temperature of the oil first began to change (point A, the controller projected what the amount of change would be after one minute and immediately produced a correcting output signal (point B) reflecting that amount. This boost of control action stopped the temperature from changing as rapidly as it would have without "rate" action. As the rate portion of the controller output worked to stabilize the oil temperature, the reset portion of the controller output worked to return the oil temperature to set point. Finally, the combined .PID controller output returned the oil temperature to set point and steady state (point C). The final output signal leveled off at a new value (point D) to ensure that the reduced demand for oil did not cause the oil temperature to change again. In summary, the PID controller minimized error in the process variable, limited cycling, and eliminated offset.

Unit 8: Controllers

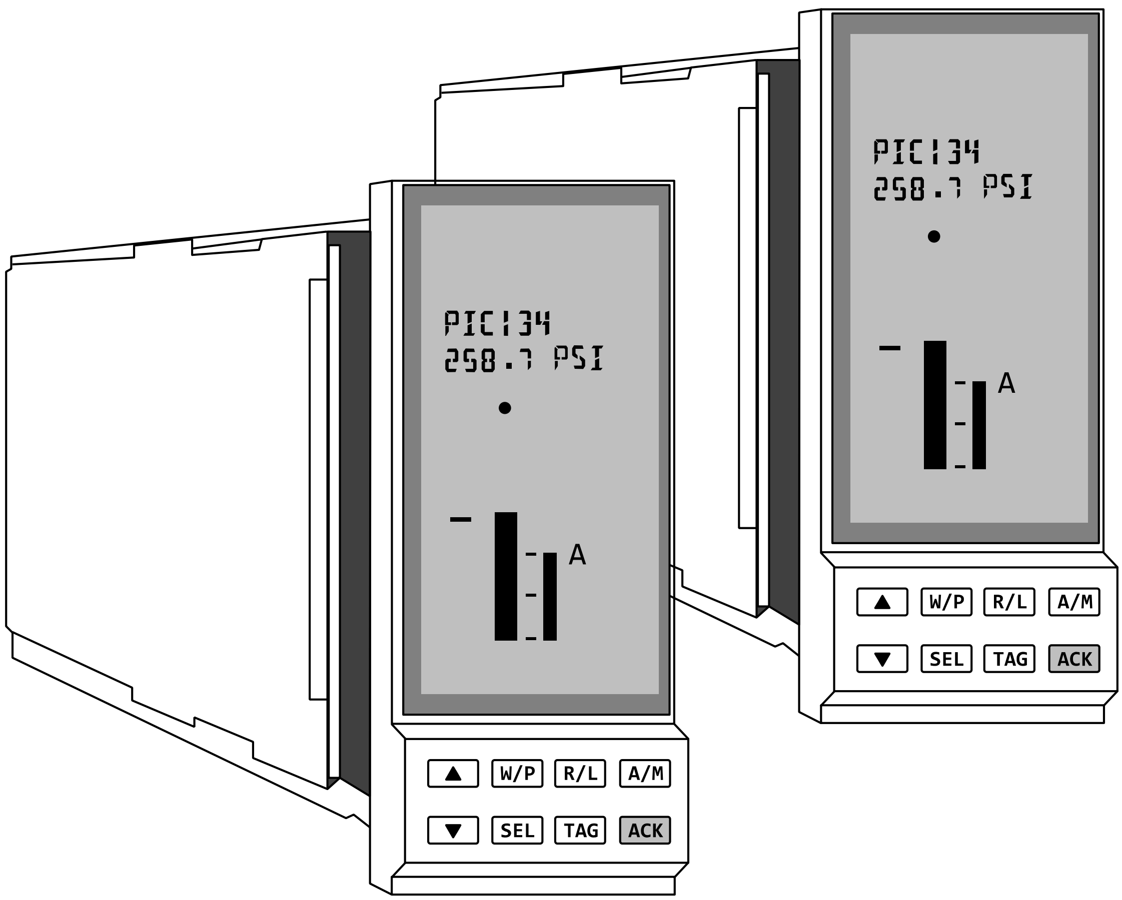


Figure: 23: Electronic Controllers

Lesson 8.1: Electronic Controller

This controller is a self-contained microprocessor based instrument capable of cascade control. It continuously monitors and controls a process in accordance with its configured algorithm. It has a Continuous bar graph display of up to two selected variables. In addition. the value and status of selected control parameters are readily available to the operator .All settings are made on the front of the controller. Thus, there is no need for the operator to withdraw the controller from the panel.

Modes of operation

The controller operates in one of three modes :

a) NORMAL
b) READ
c) SET

In Normal operation, the controller performs the usual controller function.

In the READ mode ,the operator can read the value or status of the various control parameters.

In SET mode, the operator can change those parameters that the configuration of the controller designates as operator adjustable.

Regardless of the mode that the controller is in ,it continually monitors and controls the process (except during SET Configuration, Calibration, or Test).

Operator adjustments and controls

The front panel contains all the operator adjustments and controls.

a) Alphanumeric display
b) Graphic display
c) Keypad

The alphanumeric display consists of two lines of nine characters (or space) each. The graphic display consists of three bar-graphs (each with a bar graph identifier dot and over range and under range indicators),an alarm indicator, three status indicators, and a controller fault indicator. The keypad consists of eight keys. Three are fixed-function status keys, and the remaining five keys are multi-function communication keys.

Lesson 8.2: Pneumatic Controller

Pneumatic process controller.

Process controllers play the major part of any control system. The controller must be selected to perform as it is expected by the system. Some control systems require on/off control and some others require continuous control. Most of the process industries use the continuous control in their control systems.

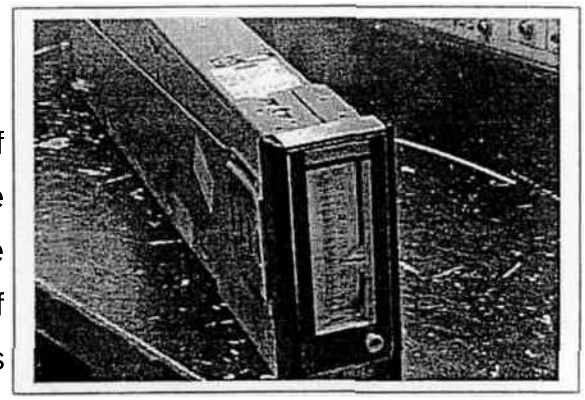


Figure: 24

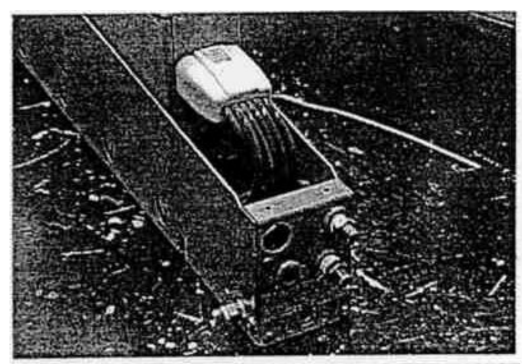


Figure : 25

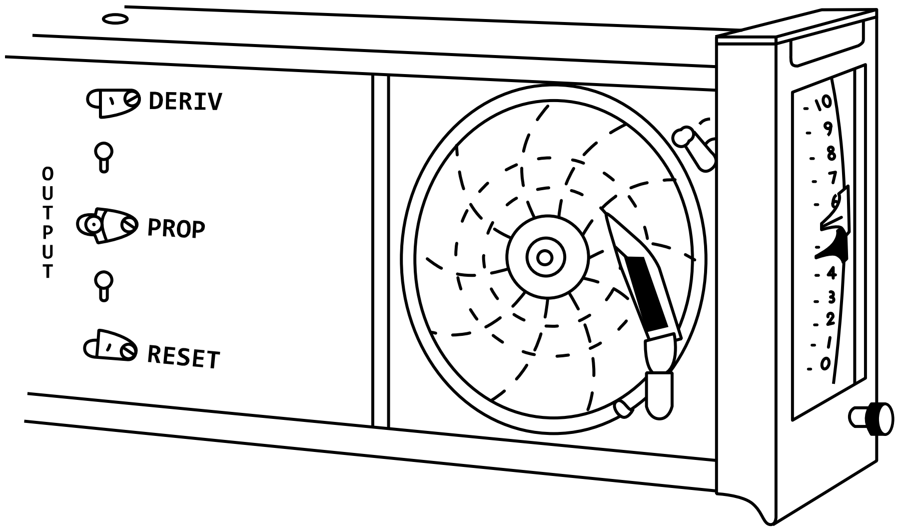


Figure :26 Pneumatic controller PID Settings

Unit 9: Practical Exercises

Exercise 1: Temperature Measurement using a Thermocouple

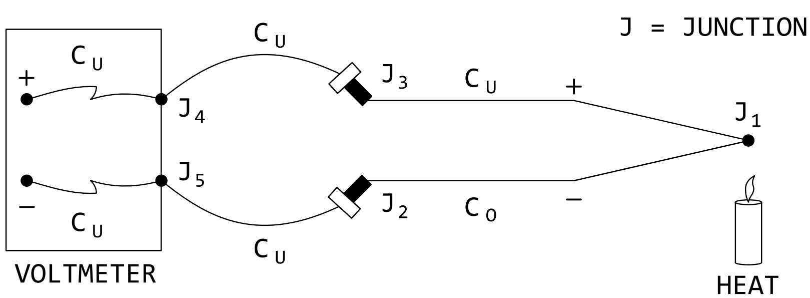
OBJECTIVES

At the completion of this project, you will be able to convert the millivolt output of a thermocouple to Its equivalent temperature.

DISCUSSION

A thermocouple, or thermoelectric couple, is a pair of wires composed of dissimilar metal which are joined at both ends. When one of the ends Is heated, a continuous current Is produced which flows In the thermoelectric circuit.

If this circuit is broken at one end, the net open circuit voltage (called the Seebeck voltage) is a function of the junction temperature and the composition of the two metals. It is difficult to measure this voltage directly because the voltmeter leads which are connected to the thermocouple create their own thermoelectric circuit.



The resultant voltmeter reading will be proportional to the temperature difference between J1 and J2 (J3 Is a Cu-Cu junction, which means that it creates no thermal emf). To find the temperature at J1 we must first find the temperature at J2.

One way to find the temperature at J2 is to maintain this reference junction at a known constant temperature, such as 0°C.

Thermocouple tables are used to convert the measured voltage to the measurement junction (J1) temperature. These tables assume that the reference junction temperature is O°C/32°F.

If the reference junction (J_2) is at any other temperature, the measured voltage must be adjusted by an amount proportional to this temperature difference before the Thermocouple Tables can be used to determine the actual measured temperature. This adjustment is referred to as the reference junction compensation.

PROCEDURAL NOTES

1. The thermocouple and thermometer must be placed close together to ensure that they are both at the same temperature. This will provide valid results in the procedure.

2. The actual oven temperatures and thermocouple temperatures (as read from the tables) are not the same. The thermocouple temperatures, when graphed, form a hysteresis loop.

3. The reference junction should be located close to the oven damper. This will allow the reference junction temperature to vary significantly and thus demonstrate the need for reference junction temperature compensation.

4. The thermocouple produces a voltage that is proportional to the difference between measurement junction temperature and reference junction temperature. The data recorded in Table 4-1, should be sufficient to prove the need for reference junction compensation.

5. The Law of Intermediate Temperatures: the sum of emf of Thermocouple X and emi generated by actual Thermocouple = emf produced by single Thermocouple with reference temperature at 0°C and measurement junction at temperature to be measured (call this Thermocouple Y). To determine the actual oven temperature, add the millivolts for TCX to actual TC, and look up millivolt value in Thermocouple Tables (type J).

EQUIPMENT LIST

Temperature Process Station 3504, including:

1. Type J Thermocouple (TE)
2. Digital Multimeter (from 3550 Cal Bench)
3. One Thermometer 0-200°C

PROCEDURE

CAUTION!

The Temperature Station Is hot!

1. Insert the thermocouple into the oven and close the main power switch.

2. Select the Relay position on Relay/Driver toggle switch. Turn the thermostat control fully clockwise on the oven.

3. Using J thermocouple wire, create a reference junction as shown in the Loop Diagram. The iron wire (+) is white and the constantan wire (-) is red.

   Connect the reference junction and the thermocouple to the voltmeter Install the reference junction close to the oven damper. Use the thermometer near the reference junction to measure the junction temperature, then insert the thermometer into the oven.

4. Record the reference junction temperatures and the thermocouple output voltages in Table 4-1 as the temperature increases to 150°C. When the temperature reaches 150°C, place the toggle switch in the Driver position, and open the main power switch.

5. As the temperature decreases from 150°C to 50°C, record the reference junction temperatures and thermocouple output voltages in Table 4-2.

   ***Note**: This exercise is easier to perform if a second thermometer is available.*

NOTES/CALCULATIONS

Actual Oven Temp. °C	Reference Junction Temp.	Referenc e Junction Voltage	Thermocouple (mV)	Reference mV + Thermocouple mV	Temp. From Thermocouple Tables
50					
75					
100					
125					
150					
125					
100					
75					
50					

J °C

TABLE 7 ***Type J Thermocouple*** — *thermoelectric voltage as a function of temperature (°C); reference junctions at 0 °C*

Thermoelectric Voltage in Millivolts

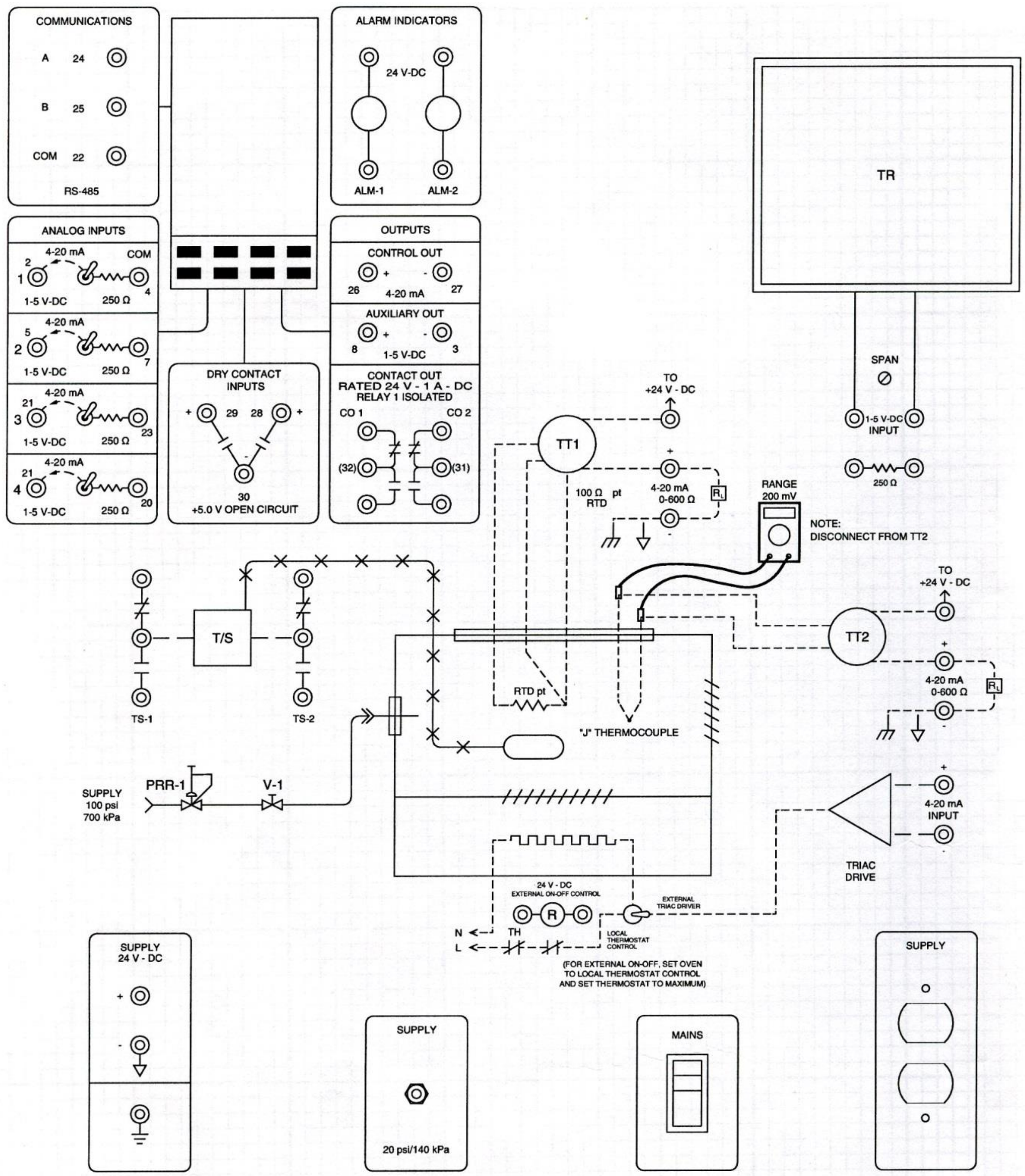
°C	0	1	2	3	4	5	6	7	8	9	10	°C
-210	-8.095											-210
-200	-7.890	-7.912	-7.934	-7.955	-7.976	-7.996	-8.017	-8.037	-8.057	-8.076	-8.095	-200
-190	-7.659	-7.683	-7.707	-7.731	-7.755	-7.778	-7.801	-7.824	-7.846	-7.868	-7.890	-190
-180	-7.403	-7.429	-7.456	-7.482	-7.508	-7.534	-7.559	-7.585	-7.610	-7.634	-7.659	-180
-170	-7.123	-7.152	-7.181	-7.209	-7.237	-7.265	-7.293	-7.321	-7.348	-7.376	-7.403	-170
-160	-6.821	-6.853	-6.883	-6.914	-6.944	-6.975	-7.005	-7.035	-7.064	-7.094	-7.123	-160
-150	-6.500	-6.533	-6.566	-6.598	-6.631	-6.663	-6.695	-6.727	-6.759	-6.790	-6.821	-150
-140	-6.159	-6.194	-6.229	-6.263	-6.298	-6.332	-6.366	-6.400	-6.433	-6.467	-6.500	-140
-130	-5.801	-5.838	-5.874	-5.910	-5.946	-5.982	-6.018	-6.054	-6.089	-6.124	-6.159	-130
-120	-5.426	-5.465	-5.503	-5.541	-5.578	-5.616	-5.653	-5.690	-5.727	-5.764	-5.801	-120
-110	-5.037	-5.076	-5.116	-5.155	-5.194	-5.233	-5.272	-5.311	-5.350	-5.388	-5.426	-110
-100	-4.633	-4.674	-4.714	-4.755	-4.796	-4.836	-4.877	-4.917	-4.957	-4.997	-5.037	-100
-90	-4.215	-4.257	-4.300	-4.342	-4.384	-4.425	-4.467	-4.509	-4.550	-4.591	-4.633	-90
-80	-3.786	-3.829	-3.872	-3.916	-3.959	-4.002	-4.045	-4.088	-4.130	-4.173	-4.215	-80
-70	-3.344	-3.389	-3.434	-3.478	-3.522	-3.566	-3.610	-3.654	-3.698	-3.742	-3.786	-70
-60	-2.893	-2.938	-2.984	-3.029	-3.075	-3.120	-3.165	-3.210	-3.255	-3.300	-3.344	-60
-50	-2.431	-2.478	-2.524	-2.571	-2.617	-2.663	-2.709	-2.755	-2.801	-2.847	-2.893	-50
-40	-1.961	-2.008	-2.055	-2.103	-2.150	-2.197	-2.244	-2.291	-2.338	-2.385	-2.431	-40
-30	-1.482	-1.530	-1.578	-1.626	-1.674	-1.722	-1.770	-1.818	-1.865	-1.913	-1.961	-30
-20	-0.995	-1.044	-1.093	-1.142	-1.190	-1.239	-1.288	-1.336	-1.385	-1.433	-1.482	-20
-10	-0.501	-0.550	-0.600	-0.650	-0.699	-0.749	-0.798	-0.847	-0.896	-0.946	-0.995	-10
0	0.000	-0.050	-0.101	-0.151	-0.201	-0.251	-0.301	-0.351	-0.401	-0.451	-0.501	0
0	0.000	0.050	0.101	0.151	0.202	0.253	0.303	0.354	0.405	0.456	0.507	0
10	0.507	0.558	0.609	0.660	0.711	0.762	0.814	0.865	0.916	0.968	1.019	10
20	1.019	1.071	1.122	1.174	1.226	1.277	1.329	1.381	1.433	1.485	1.537	20
30	1.537	1.589	1.641	1.693	1.745	1.797	1.849	1.902	1.954	2.006	2.059	30
40	2.059	2.111	2.164	2.216	2.269	2.322	2.374	2.427	2.480	2.532	2.585	40
50	2.585	2.638	2.691	2.744	2.797	2.850	2.903	2.956	3.009	3.062	3.116	50
60	3.116	3.169	3.222	3.275	3.329	3.382	3.436	3.489	3.543	3.596	3.650	60
70	3.650	3.703	3.757	3.810	3.864	3.918	3.971	4.025	4.079	4.133	4.187	70
80	4.187	4.240	4.294	4.348	4.402	4.456	4.510	4.564	4.618	4.672	4.726	80
90	4.726	4.781	4.835	4.889	4.943	4.997	5.052	5.106	5.160	5.215	5.269	90
100	5.269	5.323	5.378	5.432	5.487	5.541	5.595	5.650	5.705	5.759	5.814	100
110	5.814	5.868	5.923	5.977	6.032	6.087	6.141	6.196	6.251	6.306	6.360	110
120	6.360	6.415	6.470	6.525	6.579	6.634	6.689	6.744	6.799	6.854	6.909	120
130	6.909	6.964	7.019	7.074	7.129	7.184	7.239	7.294	7.349	7.404	7.459	130
140	7.459	7.514	7.569	7.624	7.679	7.734	7.789	7.844	7.900	7.955	8.010	140
150	8.010	8.065	8.120	8.175	8.231	8.286	8.341	8.396	8.452	8.507	8.562	150
160	8.562	8.618	8.673	8.728	8.783	8.839	8.894	8.949	9.005	9.060	9.115	160
170	9.115	9.171	9.226	9.282	9.337	9.392	9.448	9.503	9.559	9.614	9.669	170
180	9.669	9.725	9.780	9.836	9.891	9.947	10.002	10.057	10.113	10.168	10.224	180
190	10.224	10.279	10.335	10.390	10.446	10.501	10.557	10.612	10.668	10.723	10.779	190
200	10.779	10.834	10.890	10.945	11.001	11.056	11.112	11.167	11.223	11.278	11.334	200
210	11.334	11.389	11.445	11.501	11.556	11.612	11.667	11.723	11.778	11.834	11.889	210
220	11.889	11.945	12.000	12.056	12.111	12.167	12.222	12.278	12.334	12.389	12.445	220
230	12.445	12.500	12.556	12.611	12.667	12.722	12.778	12.833	12.889	12.944	13.000	230
240	13.000	13.056	13.111	13.167	13.222	13.278	13.333	13.389	13.444	13.500	13.555	240
°C	0	1	2	3	4	5	6	7	8	9	10	°C

K°C

TABLE 9 ***Type K Thermocouple*** — *thermoelectric voltage as a function of temperature (°C); reference junctions at 0 °C*

Thermoelectric Voltage in Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-270	-6.458											-270
-260	-6.411	-6.444	-6.446	-6.448	-6.450	-6.452	-6.453	-6.455	-6.456	-6.457	-6.458	-260
-250	-6.404	-6.408	-6.413	-6.417	-6.421	-6.425	-6.429	-6.432	-6.435	-6.438	-6.441	-250
-240	-6.344	-6.351	-6.358	-6.364	-6.370	-6.377	-6.382	-6.388	-6.393	-6.399	-6.404	-240
-230	-6.262	-6.271	-6.280	-6.289	-6.297	-6.306	-6.314	-6.322	-6.329	-6.337	-6.344	-230
-220	-6.158	-6.170	-6.181	-6.192	-6.202	-6.213	-6.223	-6.233	-6.243	-6.252	-6.262	-220
-210	-6.035	-6.048	-6.061	-6.074	-6.087	-6.099	-6.111	-6.123	-6.135	-6.147	-6.158	-210
-200	-5.891	-5.907	-5.922	-5.936	-5.951	-5.965	-5.980	-5.994	-6.007	-6.021	-6.035	-200
-190	-5.730	-5.747	-5.763	-5.780	-5.797	-5.813	-5.829	-5.845	-5.861	-5.876	-5.891	-190
-180	-5.550	-5.569	-5.588	-5.606	-5.624	-5.642	-5.660	-5.678	-5.695	-5.713	-5.730	-180
-170	-5.354	-5.374	-5.395	-5.415	-5.435	-5.454	-5.474	-5.493	-5.512	-5.531	-5.550	-170
-160	-5.141	-5.163	-5.185	-5.207	-5.228	-5.250	-5.271	-5.292	-5.313	-5.333	-5.354	-160
-150	-4.913	-4.936	-4.960	-4.983	-5.006	-5.029	-5.052	-5.074	-5.097	-5.119	-5.141	-150
-140	-4.669	-4.694	-4.719	-4.744	-4.768	-4.793	-4.817	-4.841	-4.865	-4.889	-4.913	-140
-130	-4.411	-4.437	-4.463	-4.490	-4.516	-4.542	-4.567	-4.593	-4.618	-4.644	-4.669	-130
-120	-4.138	-4.166	-4.194	-4.221	-4.249	-4.276	-4.303	-4.330	-4.357	-4.384	-4.411	-120
-110	-3.852	-3.882	-3.911	-3.939	-3.968	-3.997	-4.025	-4.054	-4.082	-4.110	-4.138	-110
-100	-3.554	-3.584	-3.614	-3.645	-3.675	-3.705	-3.734	-3.764	-3.794	-3.823	-3.852	-100
-90	-3.243	-3.274	-3.306	-3.337	-3.368	-3.400	-3.431	-3.462	-3.492	-3.523	-3.554	-90
-80	-2.920	-2.953	-2.986	-3.018	-3.050	-3.083	-3.115	-3.147	-3.179	-3.211	-3.243	-80
-70	-2.587	-2.620	-2.654	-2.688	-2.721	-2.755	-2.788	-2.821	-2.854	-2.887	-2.920	-70
-60	-2.243	-2.278	-2.312	-2.347	-2.382	-2.416	-2.450	-2.485	-2.519	-2.553	-2.587	-60
-50	-1.889	-1.925	-1.961	-1.996	-2.032	-2.067	-2.103	-2.138	-2.173	-2.208	-2.243	-50
-40	-1.527	-1.564	-1.600	-1.637	-1.673	-1.709	-1.745	-1.782	-1.818	-1.854	-1.889	-40
-30	-1.156	-1.194	-1.231	-1.268	-1.305	-1.343	-1.380	-1.417	-1.453	-1.490	-1.527	-30
-20	-0.778	-0.816	-0.854	-0.892	-0.930	-0.968	-1.006	-1.043	-1.081	-1.119	-1.156	-20
-10	-0.392	-0.431	-0.470	-0.508	-0.547	-0.586	-0.624	-0.663	-0.701	-0.739	-0.778	-10
0	0.000	-0.039	-0.079	-0.118	-0.157	-0.197	-0.236	-0.275	-0.314	-0.353	-0.392	0
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203	20
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612	30
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023	40
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436	50
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851	60
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267	70
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682	80
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096	90
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509	100
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920	110
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328	120
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735	130
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138	140
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	6.540	150
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	6.941	160
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	7.340	170
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	7.739	180
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	8.138	190
°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**°C**



Loop diagram

REVIEW QUESTIONS

1. If the measurement junction temperature is held constant, what effect does an increase in reference junction temperature have on the millivolt output of a thermocouple circuit?

Mention two applications of using a thermocouple?

Exercise 2: Temperature Measurement using an RTD

OBJECTIVES

At the completion of this project, you will be able to measure the resistance of an RTD and convert the readings to an equivalent temperature.

DISCUSSION

The resistance temperature detector (RTD), in this exercise is a platinum probe which is used to measure temperature. An RTD is based upon the inherent characteristic of metals to change electrical resistance when they undergo a change in temperature. As the temperature increases, the resistance of an RTD probe will increase.

Although all metals share this characteristic, the most common RTD’s are made of platinum, nickel or nickel alloy. While nickel RTDs are less expensive than platinum, nickel is useful over a more limited temperature range, is quite non-linear, and tends to drift with time. Platinum wire is used because it can withstand high temperatures, while maintaining excellent stability. As a noble metal, platinum shows limited susceptibility to contamination. The response of a platinum RTD probe is nearly linear over the entire operating range of the applied temperature.

The resistance temperature coefficient is a measure of the magnitude of the change in RTD resistance for a given change in temperature, with respect to its resistance at a reference temperature. As with a thermocouple, the reference temperature is assumed to be 0°C/32°F. At this temperature, the resistance of a loo ohm platinum RTD is 100 ohms, and the resistance of a 10 ohm RTD is 10 ohms. The resistance temperature coefficient is the fractional change (fraction of the RTD resistance at the base temperature) in resistance per °C/°F change in temperature from the reference temperature. RTD resistance at any temperature is normally determined from a table because the resistance temperature coefficient is not constant.

The RTD is a more linear temperature device than the thermocouple, but it still requires curve-fitting.

Due to its construction, the RTD probe is more fragile than the thermocouple, so precautions must be taken to protect it.

EQUIPMENT LIST

Temperature Process Station 3504, including:

1. Resistance Temperature Detector, 100 ohm Platinum (TE)
2. Digital Multimeter (From 3550 Calibration Bench)
3. Thermometer 00 200°C Range (or larger)

PROCEDURE

CAUTION!

The Temperature Station is hot!

1. Insert the RTD into the oven.
2. Insert the thermometer into the oven.
3. Connect the red lead of the RTD to the "+" terminal of the DMM and the black lead to the "-" terminal as per the loop diagram. (Note: do not connect the RTD to the transmitter).
4. Turn the mains switch on, turn the oven thermostat fully clockwise and place the Relay/Driver toggle switch in the Relay position.
5. Record the RTD resistance values in Table 5-1 as the temperature increases to 150°C. When the oven reaches 150°C turn the station off.
6. As the temperature decreases from 150°C to 50°C, record the RTD resistance values in Table 5-1.

NOTES/CALCULATIONS

ACTUAL OVEN TEMP. °C	RTD RESISTANCE (Ω)	RTD TEMPERATURE
50		
75		
100		
125		
150		
125		
100		
75		

TEMPERATURE VS RESISTANCE TABLE

°C	Ohm Ω	°C	Ohm Ω	°C	Ohm Ω	°C	Ohm Ω
±0	100.00	+62	124.01	124	147.56	+186	170.68
+2	100.78	64	124.77	126	148.32	188	171.42
4	101.56	66	125.54	128	149.07	190	172.16
6	102.34	68	156.30	130	149.82	192	172.90
8	103.12	70	127.07	132	150.57	194	173.63
10	103.90	72	127.83	134	151.32	196	174.37
12	104.68	74	128.60	136	152.07	198	175.10
14	105.46	76	129.36	138	152.82	200	175.84
16	106.23	78	130.13	140	153.57		
18	107.01	80	130.89	142	154.32		
20	107.79	82	131.65	144	155.07		
22	108.57	84	132.41	146	155.82		
24	109.34	86	133.18	148	156.57		
26	110.12	88	133.94	150	157.32		
28	110.89	90	134.70	152	158.07		
30	111.67	92	135.46	154	158.81		
32	112.44	94	136.22	156	159.56		
34	113.22	96	136.98	158	160.30		
36	113.99	98	137.74	160	161.05		
38	114.77	100	138.50	162	161.79		
40	115.54	102	139.26	164	162.53		
42	116.31	104	140.01	166	163.28		
44	117.08	106	140.77	168	164.02		
46	117.86	108	141.52	170	164.76		
48	118.63	110	142.28	172	165.50		
50	119.40	112	143.04	174	166.24		
52	120.17	114	143.79	176	166.99		
54	120.94	116	144.55	178	167.73		
56	121.70	118	145.30	180	168.47		
58	122.47	120	146.06	182	169.21		
60	123.24	122	146.81	184	169.95		

Temperature Measurement using an RTD

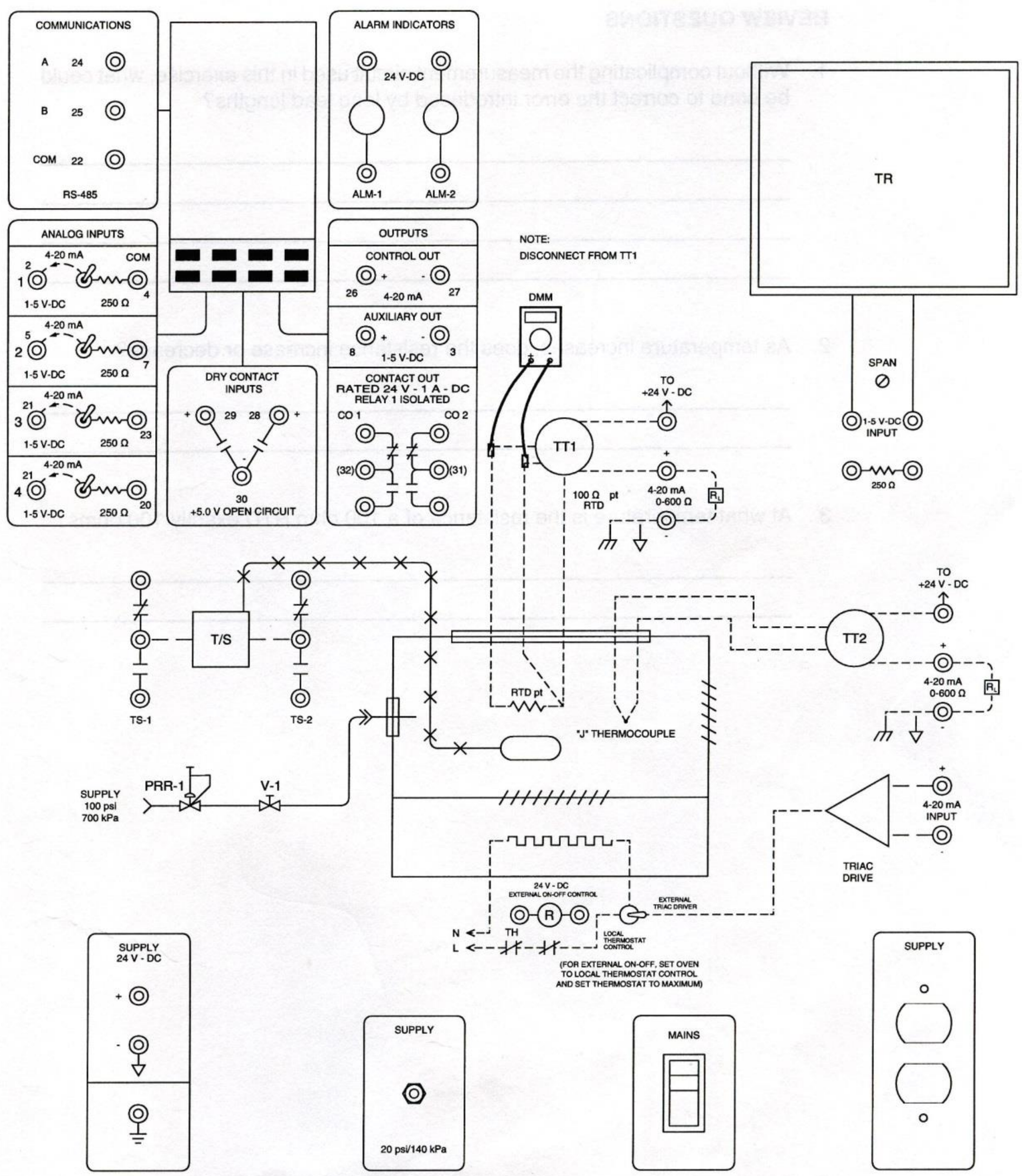


Figure 5-1. Loop Diagram.

REVIEW QUESTIONS

1. Without complicating the measurement circuit used in this exercise, what could be done to correct the error introduced by long lead lengths?

2. As temperature increases, does the resistance increase or decrease?

3. At what temperature is the resistance of a 100 ohm RTD exactly 100 ohms?

Exercise 3: On-Off Temperature Control

OBJECTIVES

At the completion of this laboratory exercise, you will be familiar with the operational characteristics of controlling a temperature process with a two-position controller.

DISCUSSION

A controller is an instrument that generates an output signal dependent upon the error or deviation between the process measurement input signal it receives, and the desired value or setpoint of the controller. The output signal is sent to the final control element which regulates the process to eliminate this error.

A two-position controller has only two operating states: either completely on or completely off. It is therefore also referred to as an ON/OFF Controller, or as a Switch - in this case a Temperature Switch.

Two-position controllers are very popular in the process industry because they are simple, inexpensive and reliable. The major limitation to controlling a process with a two-position controller is the inherent characteristic of continuous cycling. This characteristic makes ON/OFF Controllers more suitable to a “slow” process such as temperature since a “fast” process will cause extreme wear on the instrument. To compensate for this some two-position controllers have an adjustable differential which can be used to reduce the rate of cycling.

EQUIPMENT LIST

Temperature Process Station 3504, including:

1. On/Off Controller (TS)
2. Thermometer (TI)

INSTRUMENT DATA

1. On/Off Temperature Controller 0-400°F

PROCEDURE

CAUTION!

The Temperature Station is hot!

1. Insert the capillary bulb of the On/Off controller in to the oven.

2. Connect the leads from the On/Off controller to the patch panel on the side of the station. The leads on the left hand side of the controller are for TS-i.

3. Open the main air supply. Turn the mains power on. Turn the oven switch on. Open PRR-l and use Vito set a low rate of air flow through the air injector. Open the oven damper. Set the oven thermostat to approximately the midpoint. (Note: thermostat scale does not correspond to °F or °C. It is an arbitrary scale to assist in reproducing any setting.)

4. Allow the oven temperature to stabilize. Read the oven temperature with the thermometer.

5. Remove the cover of the controller. Use a screwdriver to adjust the setpoint of controller #1 to the oven temperature. Turn the calibration adjust screw until you hear the snap-acting switch click. Repeat for controller #2.

6. Turn the oven thermostat to maximum. Connect the leads as per the loop diagram.

7. Adjust the controller setpoint and check with the thermometer that the oven is maintaining the desired temperature.

8. Increase the pressure through the air injector and note any change in the on/off cycle time.

9. Repeat steps 6 to 8 to check the calibration of controller #2.

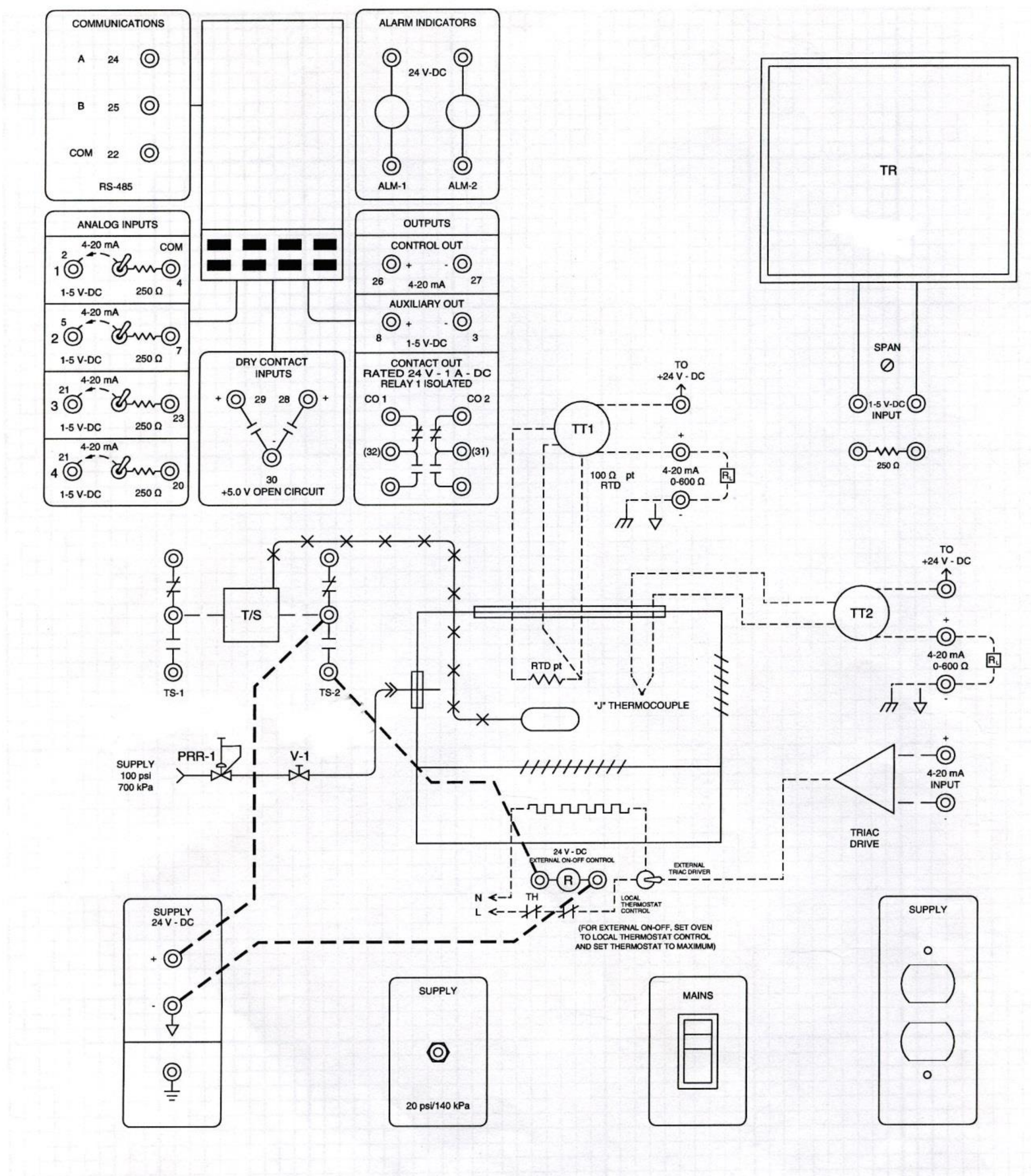


Figure 6-2. Loop Diagram.

REVIEW QUESTIONS

1. Why does the temperature process continuously cycle when being controlled by a Two-Position Controller?

____

____

____

____

____

____

2. When you increased the “load” on the process by increasing the air pressure applied to the air injector, why did the heater ON and heater OFF cycle times change?

____

____

____

____

____

____

Exercise 4: Temperature Process Proportional Control

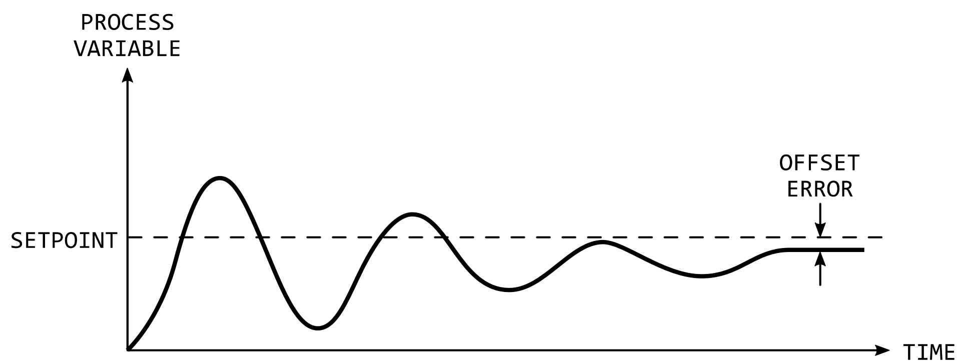
OBJECTIVES

At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoínt changes on a proportional controller.

DISCUSSION

Understanding how a controlled process responds to a setpoint change or demand disturbances is important to the individual who must calibrate the instruments used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

A setnoint is chosen, representing the desired value of the controlled variable. The controller inputs the result of a measurement of the controlled variable and determines an appropriate output for the final control element according to the magnitude of deviation from the setpoint, and how the operator has set, or tuned, the instrument. The results of different settings can be observed from the strip chart obtained from the recorder.



PROPORTIONAL CONTROL

A proportional controller functions to maintain the process within specified band of control. It gives an output to input relationship which is linear. Proportional band is the range of error signals that will give a controller output in this linear range. Gain, the ratio of output to input of any section of a controlled system, is inversely related to proportional band.

$$Proportional\ Band = \frac{\%\ Change\ in\ input}{\%\ Change\ in\ output} \times 100\%$$

$$Gain = \frac{Output\ Change}{Input\ Change}$$

With a lower gain, a larger change ¡n the input signal is required to cause the output to change from 0-100%. Within the proportional band, the controller output is proportional to the input signal, and the gain factor determines the proportional relationship. The magnitude of the offset error is directly related to the proportional band, higher gain settings result in reduced offset error, but increased instability.

EQUIPMENT LIST

Temperature Process Station 3504, including:

1. Microprocessor Controller (TIC)
2. Temperature Transmitter (TT)
3. J Thermocouple (TE)
4. Strip Chart Recorder (TR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
TT			0-200°C/4-20 mA
TR			1-5 V dc/4-20 mA

CONTROLLER CONFIGURATION

1. Modes=P
2. Gain = 1 (Prop. Band = 100%)
3. Action = Reverse (inc/dec)

PROCEDURE

CAUTION!
The Temperature Station is hot!

1. Set up and connect equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller as per the controller configuration.

3. Set the Relay/Driver toggle switch to the Driver position. Open the oven damper. Open PRR-1 a few turns and open V-1 approximately 1/4 turn.

4. With the controller in manual, increase the output until the measured variable equals setpoint. Place the controller in automatic and allow the process to stabilize. **After that calculate the error ___________%.**

5. Load change disturbance to process:

   (a) start the recorder

   (b) increase the pressure on the air injector by opening Vi another 1/4 turn

   (c) stop the recorder when the process stabilizes.

   (d) **calculate the error ___________%.**

6. Increasing gain in response to load change:

   (a) increase the gain to 4% (____%PB)

   (b) stabilize the process at 50% and repeat step 6 (a) and

   (c) Reset Vi to 1/4 turn open.

   (d) **calculate the error after the process stabilize ___________%.**

7. Effect of original gain in response to setpoint change:

   (a) adjust the gain to 1 (100% Prop. band)

   (b) stabilize the process at 50%

   (c) start the recorder and increase the setpoint to 70%

   (d) stop the recorder when the process stabilizes **calculate the error ___________%.**

8. Increasing gain in response to setpoint change:

   (a) adjust the gain to 10% (________% PB)

   (b) repeat step 8 (b) to (d).

Temperature Process Proportional Control

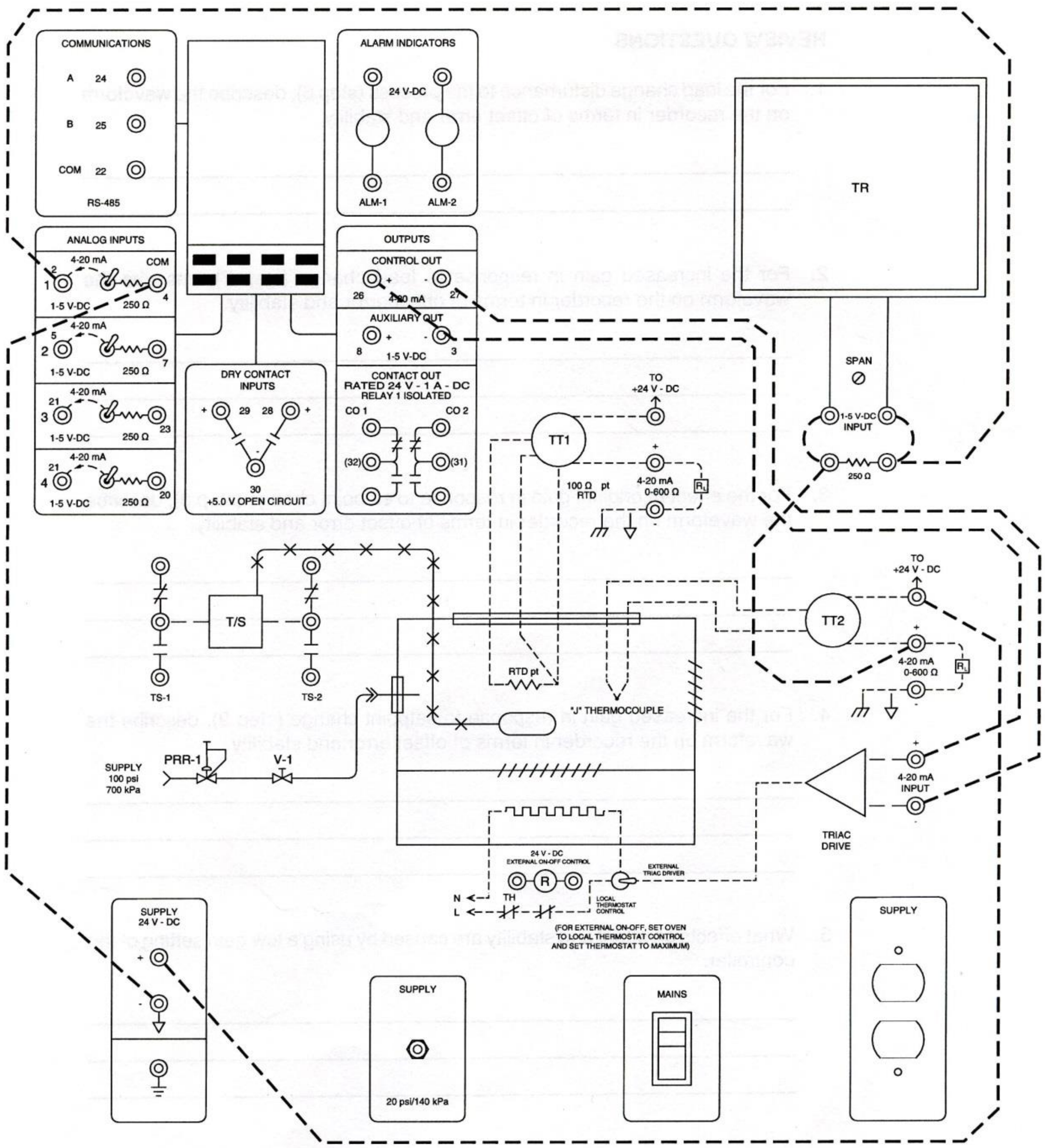


Figure 7-3. Loop Diagram.

REVIEW QUESTIONS

1. For the load change disturbance to the process (step 6), describe the waveform on the recorder in terms of offset error and stability.

   ____

   ____

2. For the increased gain in response to load change (step 7), describe the waveform on the recorder in terms of offset error and stability.

   ____

   ____

   ____

3. For the effect of original gain in response to setpoint change (step 8), describe the waveform on the recorder in terms of offset error and stability.

   ____

   ____

   ____

4. For the increased gain in response to setpoint change (step 9), describe the waveform on the recorder in terms of offset error and stability.

   ____

   ____

   ____

5. What effects on offset and stability are caused by using a low gain setting of the controller?

   ____

   ____

   ____

Exercise 5: Temperature Process Proportional Plus Integral Control

OBJECTIVES

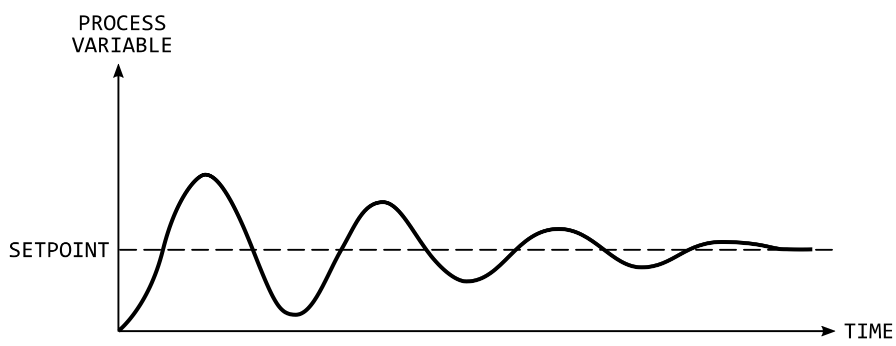
At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of setpoint disturbances on a proportional plus integral controller.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instrument used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

The addition of Integral action, also called Reset Action, to a proportional controller results in the elimination of offset error.

The main advantage of the integral control mode is that the controller output continues to reposition the final control element until the error is reduced to zero, within system design limitations.



P + I CONTROL

The main disadvantage of the integral control mode is that the controller output does not immediately direct the final control element to a new position in response to an error signal. The controller output changes at a defined rate of change, and time is needed for the final control element to be gradually repositioned.

The addition of integral action to proportional control automatically performs the gain resetting that was manually accomplished. For this reason, proportional plus integral controllers are sometimes referred to as proportional plus automatic reset, or simply proportional plus reset controllers.

Higher gain settings result in increased instability. An increase in Reset (Repeats Per Minute) will cause the process to return to the setpoint value faster, but also produces instability if adjusted too high.

EQUIPMENT LIST

Temperature Process Station 3504, including:

1. Microprocessor Controller (TIC)
2. Temperature Transmitter (TT)
3. J Thermocouple (TE)
4. Chart Recorder (TR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
TT			0-200°C (0-400°F)/4-20 mA
TR			1-5 Vdc/4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint = 50%
3. Modes = PI (Proportional + Integral)
4. Gain = 5 (Prop. Band = 20%)
5. Reset = 0.06 repeats/minute
6. Action = Reverse (inc/dec)

PROCEDURE

CAUTION!
The Temperature Station is hot!

1. Set up and connect equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller as per the CONTROLLER CONFIGURATION.

3. Open the oven damper, and set the air injector to approximately 5 psi.

4. Set Relay/Driver toggle switch to Driver position.

5. Manually increase the controller output to raise the oven temperature until the measured variable equals the setpoint. Place controller in Automatic and allow the process to stabilize. **After that calculate the error ___________%.**

6. Setpoint change disturbance into process; increase the setpoint to 75%, and allow process to stabilize and then **calculate the error ___________%.**

7. Increasing integral action in response to setpoint change:

   (a) increase the integral adjustment to **__1__** repeats/minute.

   (b) decrease the setpoint to 50% and allow the process to stabilize and after that **calculate the error ___________%.**

8. Further increasing integral action in response to setpoint change:

   (a) increase the integral adjustment to **__5__** repeats/minute.

   (b) increase the setpoint to 75%, allow the process to stabilize and then **calculate the error ___________%.**.

9. Place the controller in Manual. Open the Main Power Switch.

10. Answer the questions at the end of the exercise.

Temperature Process Proportional Plus Integral Control

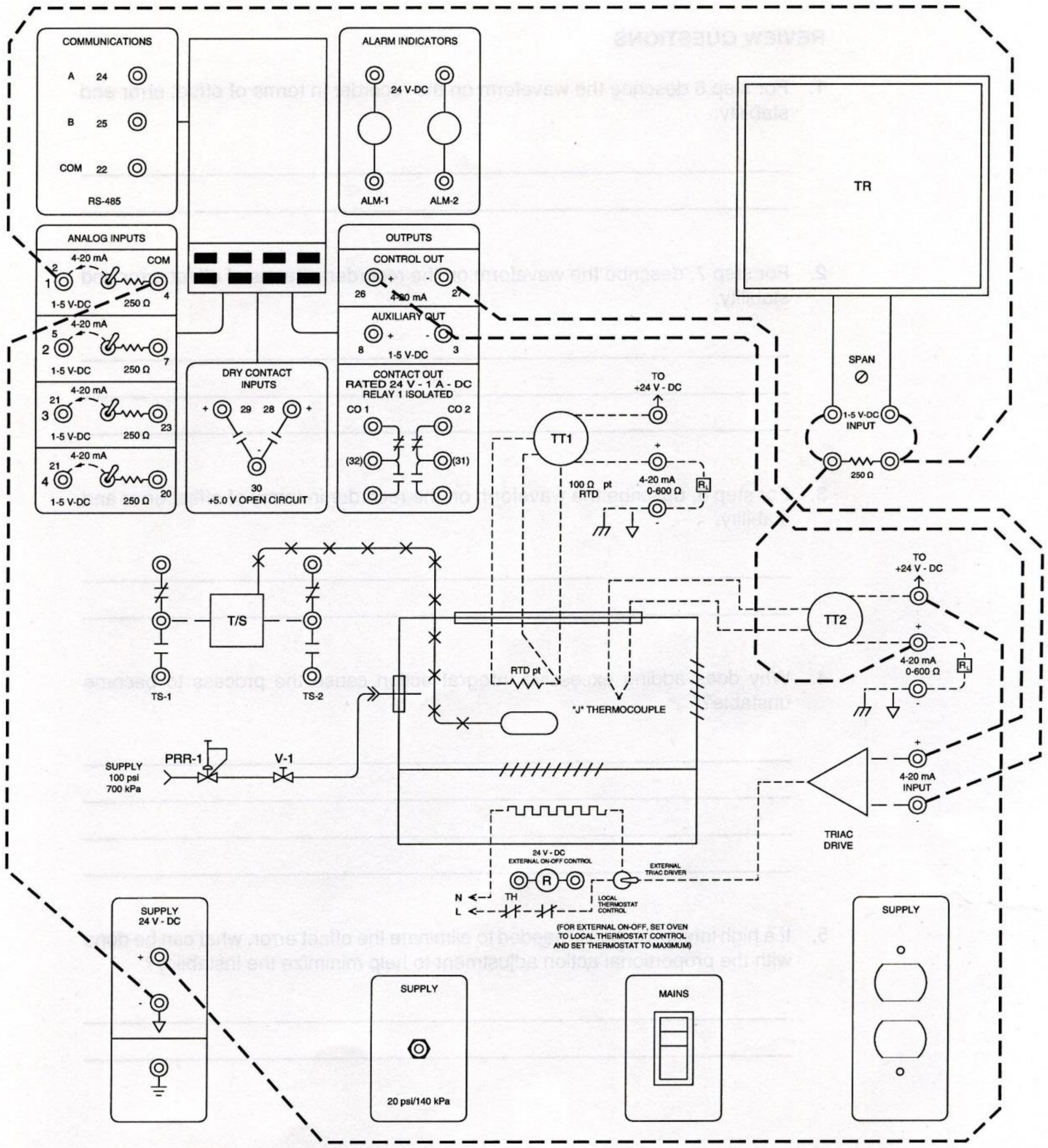


Figure 8-3. Loop Diagram.

REVIEW QUESTIONS

1. For step 6 describe the waveform on the recorder in terms of offset error and stability.

2. For step 7, describe the waveform on the recorder in terms of offset error and stability.

3. For step 8, describe the waveform on the recorder in terms of offset error and stability.

4. Why does adding excessive integral action cause the process to become unstable?

5. If a high integral action is needed to eliminate the offset error, what can be done with the proportional action adjustment to help minimize the instability?

Exercise 6: Temperature Process Proportional Plus Integral Plus Derivative Control

OBJECTIVES

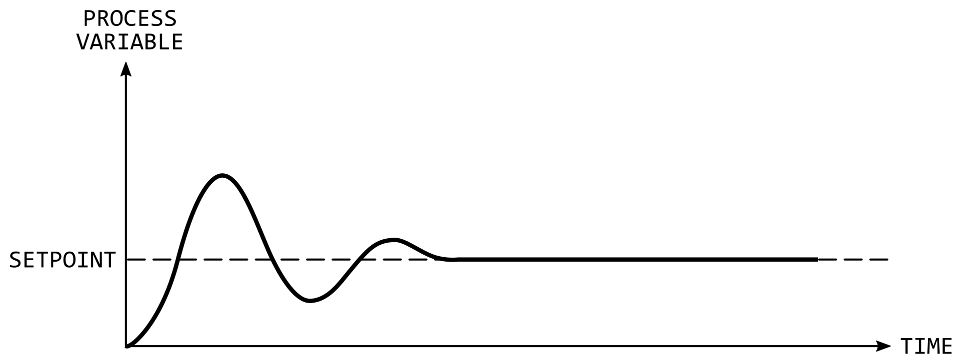
At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoint changes on a proportional plus integral plus derivative controller used in a temperature process.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instruments used for controlling process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

For processes that cannot tolerate continuous cycling, a proportional controller is used. For processes that cannot tolerate continuous cycling or offset error, a proportional plus integral controller is used.

For processes that need improved stability and can tolerate offset error, a proportional plus derivative controller is used. (Derivative control is rarely used with Proportional Control only. PD control is desirable in processes where there are several different lag times).



PID CONTROL

Some processes cannot tolerate offset error, yet need good stability. In this case a control mode that combines the advantages of proportional, integral and derivative (PID) control is used.

Derivative action causes the proportional output to be advanced which provides an output signal to the final control element sooner. As the error signal rate of change increases, the initial controller output is large. This helps the controller anticipate large error amplitudes that are a result of rapidly changing error signals.

Derivative action is not usually used with fast responding processes such as flow control or with noisy processes, because the derivative action responds to any rate of change in the error signal, including noise.

Derivative control is used in process control systems where the lag time (the time it takes a change to be measured) is large. Derivative control is considered difficult to implement and adjust; therefore, it is only used when the amount of lag time is extensive. It is typically used as PID control for temperature control and other slow applications.

EQUIPMENT LIST

Temperature Process Station 3504, including:
1. Microprocessor PID Controller (TIC)
2. Temperature Transmitter (TT)
3. J Thermocouple (TE)
4. Strip Chart Recorder (TR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
TT			0-200°C (0-400°F)/4-20 mA
TR			1-5 V dc/4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint=50%
3. Action = Reverse
4. Modes = PID
5. Gain = 1 (Prop. Band = 100%)
6. Reset = 0.02 rep/minutes
7. Derivative = 0.02 minutes

PROCEDURE

CAUTION!
The Temperature Station is hot!

1. Set up and connect equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller as per the **CONTROLLER CONFIGURATION** data.

3. Set the Relay/Driver toggle switch to Driver. Open the oven damper and set a small cooling load from the air injector.

4. Manually adjust the controller output until the measured variable equals the setpoint. Place the controller in Automatic and allow the process to stabilize. **After that calculate the error ___________%.**

5. Load change disturbance to process:

   (a) start the recorder

   (b) increase the pressure on the air injector line

   (c) stop the recorder when the process stabilizes

   (d) reduce the pressure on the air injector line and allow the process to stabilize and then **calculate the error ___________%.**

6. Increasing gain in response to load change:

   (a) increase gain to **_2_** (_____% PB)

   (b) repeat step 6 (a) to (d).

   (c) when the process stabilizes, **calculate the error ___________%.**

7. Increasing integral action in response to load change:

    (a) increase the Reset to **__1__** rep/min

    (b) repeat step 6 (a) to (d).

    (c) when the process stabilizes, **calculate the error ___________%.**

8. Increasing derivative action in response to load change:

    (a) set Derivative to **__2__** minutes

    (b) repeat step 6 (a) to (d).

    (d) Adjust the Gain to 1 (100% prop. band), Reset to 0.02 rep/min and when the process stabilizes, **calculate the error ___________%.**

9. Change the Derivative to 0.05 minutes

    (a) start the recorder, rapidly decrease the setpoint to 20%
    (b) stop the recorder when the process stabilizes, adjust the setpoint to 50% and after that, **calculate the error ___________%.**

10. Increasing gain in response to setpoint change:

    (a) adjust the Gain to **_10_** (____% PB)

    (b) repeat step (b) and (c).
    (c) when the process stabilizes, **calculate the error ___________%.**

11. Increasing integral action in response to setpoint change:

    (a) adjust the Reset to **_5_** rep/min

    (b) repeat step 10 (b) and (c).
    (c) when the process stabilizes, **calculate the error ___________%.**

12. Increasing derivative action in response to setpoint change:

    (a) adjust the Derivative to **_10__** minutes

    (b) repeat step 10 (b) and (c).
    (c) when the process stabilizes, **calculate the error ___________%.**

Temperature Process Proportional Plus Integral Plus Derivative Contorl

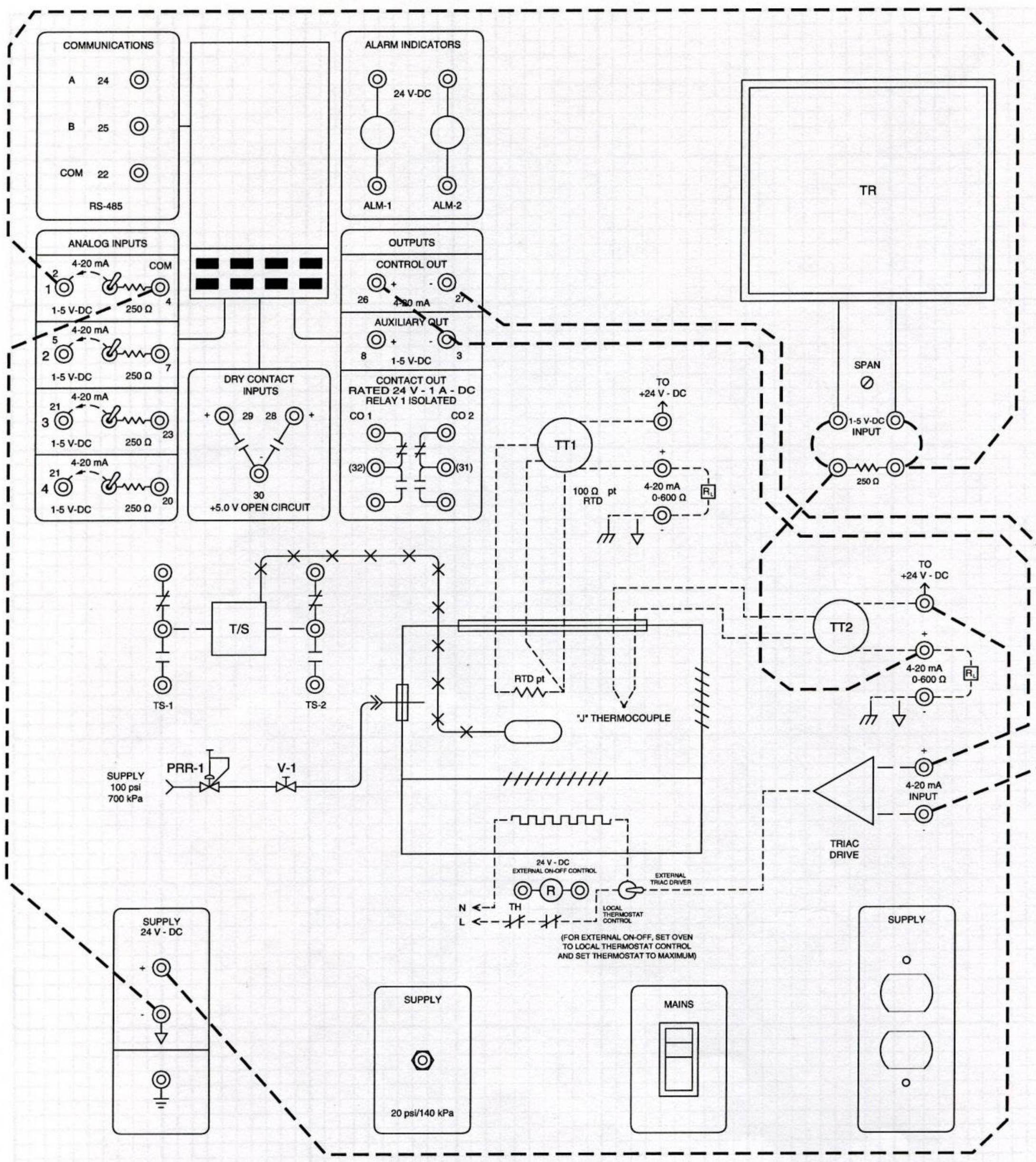


Figure 9-3. Loop Diagram.

REVIEW QUESTIONS

1. For step 6, describe the waveform on the recorder in terms of offset error and stability.

2. For step 7, describe the waveform on the recorder in terms of offset error and stability.

3. For step 8, describe the waveform on the recorder in terms of offset error and stability.

4. For step 9, describe the waveform on the recorder in terms of offset error and stability.

5. For step 10, describe the waveform on the recorder in terms of offset error and stability.

6. For step 11, describe the waveform on the recorder in terms of offset error and stability.

7. For step 12, describe the waveform on the recorder in terms of offset error and stability.

8. For step 13, describe the waveform on the recorder in terms of offset error and stability.

9. What are the advantages to using a proportional plus integral plus derivative controller?

10. With the same integral and derivative settings, what is the change in the integral and derivative action caused by increasing the gain of the controller?

11. Is the integral action of the PID Controller affected by adjusting the derivative setting?

Exercise 7: Level Process Proportional Control

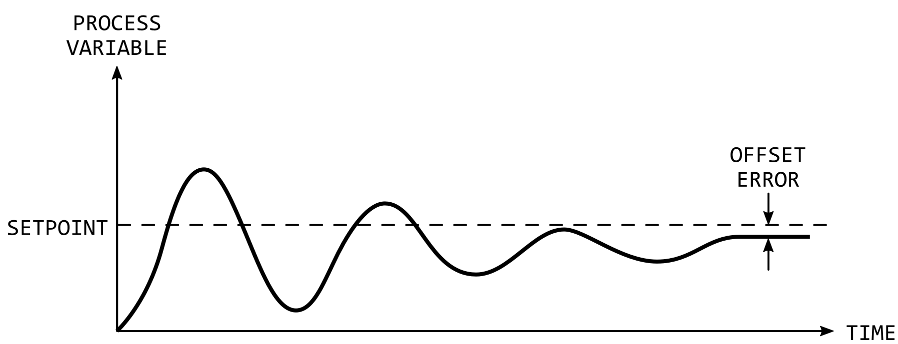
OBJECTIVES

At the completion of this project, you will be able to use standard process instrumentation to observe and analyze proportional control.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important forthe individual who must calibrate the instruments used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

A setpoint is chosen, representing the desired value of the controlled variable. The controller inputs the result of a measurement of a controlled variable and determines an appropriate output for the final control element according to the magnitude of deviation from setpoint, and how the operator has set, or tuned, the instrument. The results of different settings can be observed from the strip chart obtained from the recorder.



PROPORTIONAL CONTROL

A proportional controller functions to maintain the process within a specified band of control. It gives an output to input relationship which is linear.

$$Proportional\ Band = \frac{\%\ Change\ in\ input}{\%\ Change\ in\ output} \times 100\%$$

Gain, the ratio of output to input of any section of a controlled system, ¡s inversely related to proportional band.

$$Gain = \frac{Ouput\ Change}{Input\ Change}$$

With a lower gain, a larger change in the input signal is required to cause the output to change from 0-100%. Within the proportional band, the controller output is proportional to the input signal, and the gain factor determines the proportional relationship. The magnitude of the offset error is directly related to the proportional band. Higher gain settings result in reduced offset error, but increased instability.

EQUIPMENT LIST

Level Process Station 3503, including:
1. Microprocessor PID Controller (LIC)
2. Differential Pressure Transmitter (LT)
3. Current to Pressure Converter (I/P)
4. Chart Recorder (LR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
LT			0-30” WC/4-20 mA
I/P			4-20 mA/3-15 psi
LR			1-5 V dc/4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual Manual
2. Setpoint = 50%
3. Gain = 1 (Prop. Band = 100%)

PROCEDURE

1. Set up and connect the equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller as per the CONTROLLER CONFIGURATION.

3. Start the recorder and place the controller in Automatic. Manually adjust the controller output until the measured variable equals the setpoint and

when the process stabilizes, **calculate the error** ___________**%.**

4. Effect of original gain in response to setpoint changes.

   (a) Rapidly increase the setpoint to 75%,

   (b) Stop the recorder when the process stabilizes,

   (c) Adjust the setpoint to 50% and allow the process to stabilize. After that, **calculate the error** ___________**%.**

5. Decreasing gain in response to setpoint change:

   (a) Adjust the gain to **__0.25___** (**______** % PB)

   (b) Start the recorder.

   (c) Rapidly increase the setpoint to 75%, stop the recorder when the process stabilizes.

   (d) Adjust the setpoint to 50% and allow the process to stabilize. After that, **calculate the error** ___________**%.**

6. Increasing gain in response to setpoint change:

   (a) Increase the gain to **__4___** (**______** %PB)

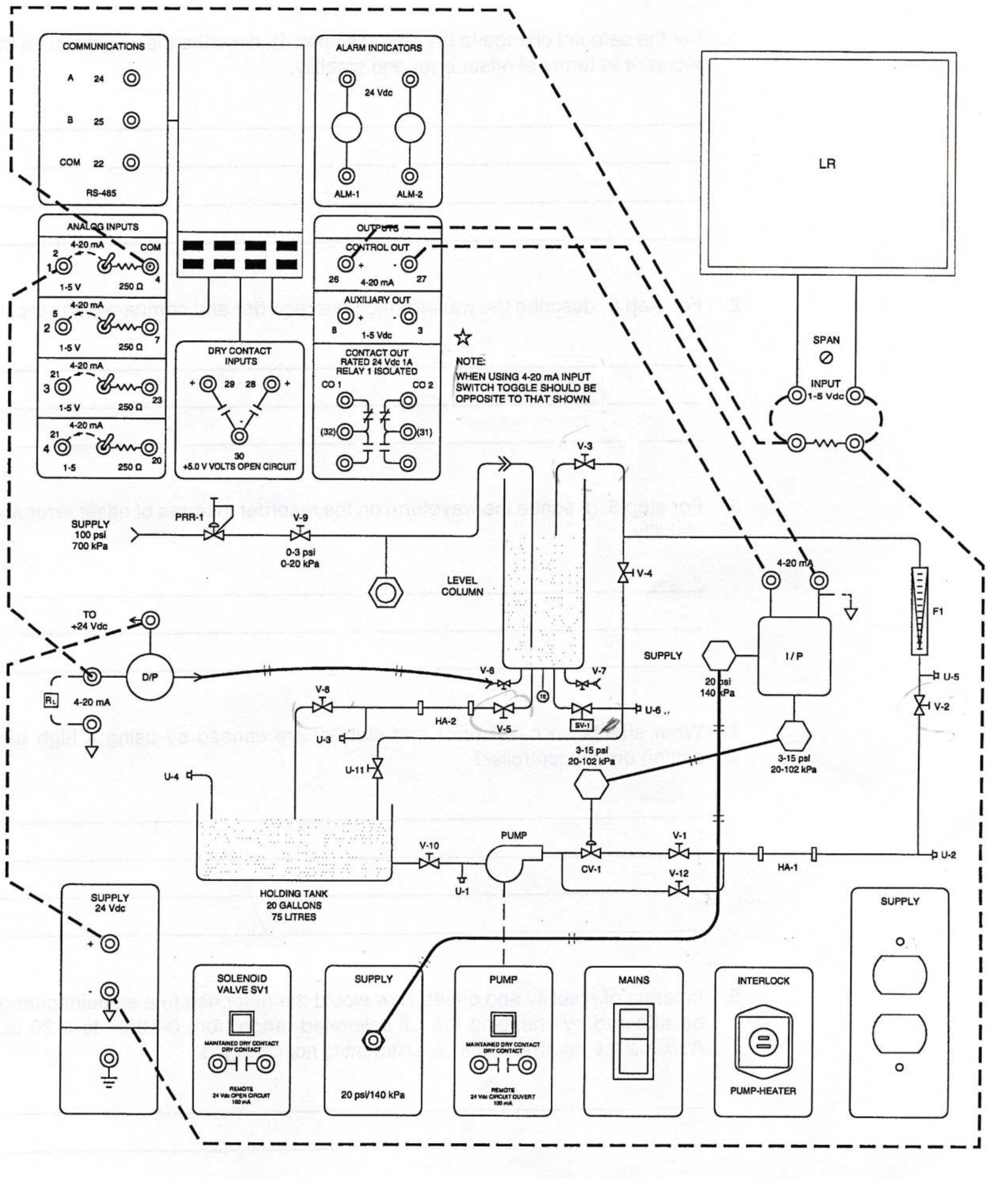
   (b) Repeat step 5 (b), (c) and (d).

   (c) When the process stabilizes, **calculate the error** ___________**%.**

7. If you have time, repeat steps 4-6 using a load change instead of a setpoint change. To make a small load change restrict valve V2. To cause a large change, completely close valve V3 and hold it closed for several seconds before reopening it. If your station has solenoid valve SV-1 and valve V11, use them to configure an alternate flow path from the process column to effect a load change.

8. Answer the questions.

LOOP DIAGRAM



QUESTIONS

1. For the setpoint change to the process (step 4), describe the waveform on the recorder in terms of offset error and stability.

2. For step 5, describe the waveform on the recorder and compare with step 4.

3. For step 6, describe the waveform on the recorder in terms of offset error and stability.

4. What effects on offset error and stability are caused by using a high gain setting on the controller?

5. In terms of stability and offset, how would the response to a setpoint change be affected by changing the LT calibrated range from 0-30 in to 0-20 in.? Assume the controller gain adjustment is not changed.

Exercise 8: Level Process Proportional Plus Integral Control

OBJECTIVES

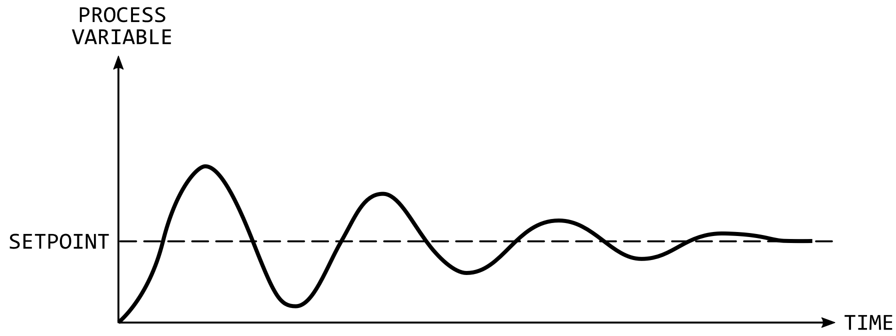
At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoint changes on a proportional plus integral controller used in a level process.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instrument used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

The addition of integral action, also called RESET action, to a proportional controller results in the elimination of offset error.

The main advantage of the integral control mode is that the controller output continues to reposition the final control element until the error is reduced to zero, within system design limitations.



P + I CONTROL

The main disadvantage of the integral control mode is that the controller output does not immediately direct the final control element to a new position in response to an error signal.

The controller output changes at a defined rate of change, and time is needed for the final control element to be gradually repositioned.

The addition of integral action to proportional control automatically performs the gain resetting that was manually accomplished. For this reason, proportional plus integral controllers are sometimes referred to as proportional plus automatic reset, or simply proportional plus reset controllers.

Higher gain settings result in increased instability. An increase in RESET (Repeats per Minute) will cause the process to return to the setpoint value faster, but also produces instability if adjusted too high.

EQUIPMENT LIST

Level Process Station 3503, including:

1. Microprocessor PID Controller (LIC)
2. Differential Pressure Transmitter (LT)
3. Current to Pressure Converter (lIP)
4. Chart Recorder (LR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
LT			0-30” WC/4-20 mA
I/P			4-20 mA/3-15 psi
LR			1-5 V dc/4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint=50%
3. Gain = 1 (Prop. Band = 100%)
4. Reset = 0.1 rep/mm

PROCEDURE

1. Set up and connect the equipment as per the loop diagram.

2. Turn On the main power switch and Manually adjust the controller output to approximately 50%. Turn the pump on, open V1, fill tank to 15 in. (38 cm), and vent the HP side of the transmitter.

3. Set the controller as per the Controller Configuration. Start the recorder and place the controller in Automatic.

4. Load change disturbance to process: close valve V3 for 2 to 3 seconds, then fully open valve V3 and allow the process to stabilize.(Or open valve V11 and then open SV-1 for approximately 3 seconds). Stop the recorder

when the process stabilizes, **calculate the error** ___________**%.**

5. Increasing gain in response to load change:

   a. increase the gain to __**4**____ (______% P.B.),

   b. start the recorder,

   c. when the process stabilizes, **calculate the error** ___________**%.**

6. Increasing integral action in response to load change:

   a. increase the reset to ___5____ rep/min

   b. start the recorder, (c) repeat step 5.

   c. when the process stabilizes, **calculate the error** ___________**%.**

7. Effect of original settings in response to setpoint change:

   a. Set gain to 1 (100% P.B.),

   b. start the recorder and rapidly decrease the setpoint to 20%,

   c. stop the recorder when the process stabilizes, adjust the setpoint to 50% and after the process stabilizes, **calculate the error** ___________**%.**

8. Increasing gain in response to setpoint change:

   a. adjust the gain to ___**10**___ (______ % P.B.),

   b. repeat step 7 (b)-(c).

   c. when the process stabilizes, **calculate the error** ___________**%.**

9. Increasing integral action in response to setpoint change:

   a. adjust the reset to __10_____ repeats/min

   b. repeat step 7 (b)-(c).

   c. when the process stabilizes, **calculate the error** ___________**%.**

10. Answer the questions at the end of the exercise.

LOOP DIAGRAM

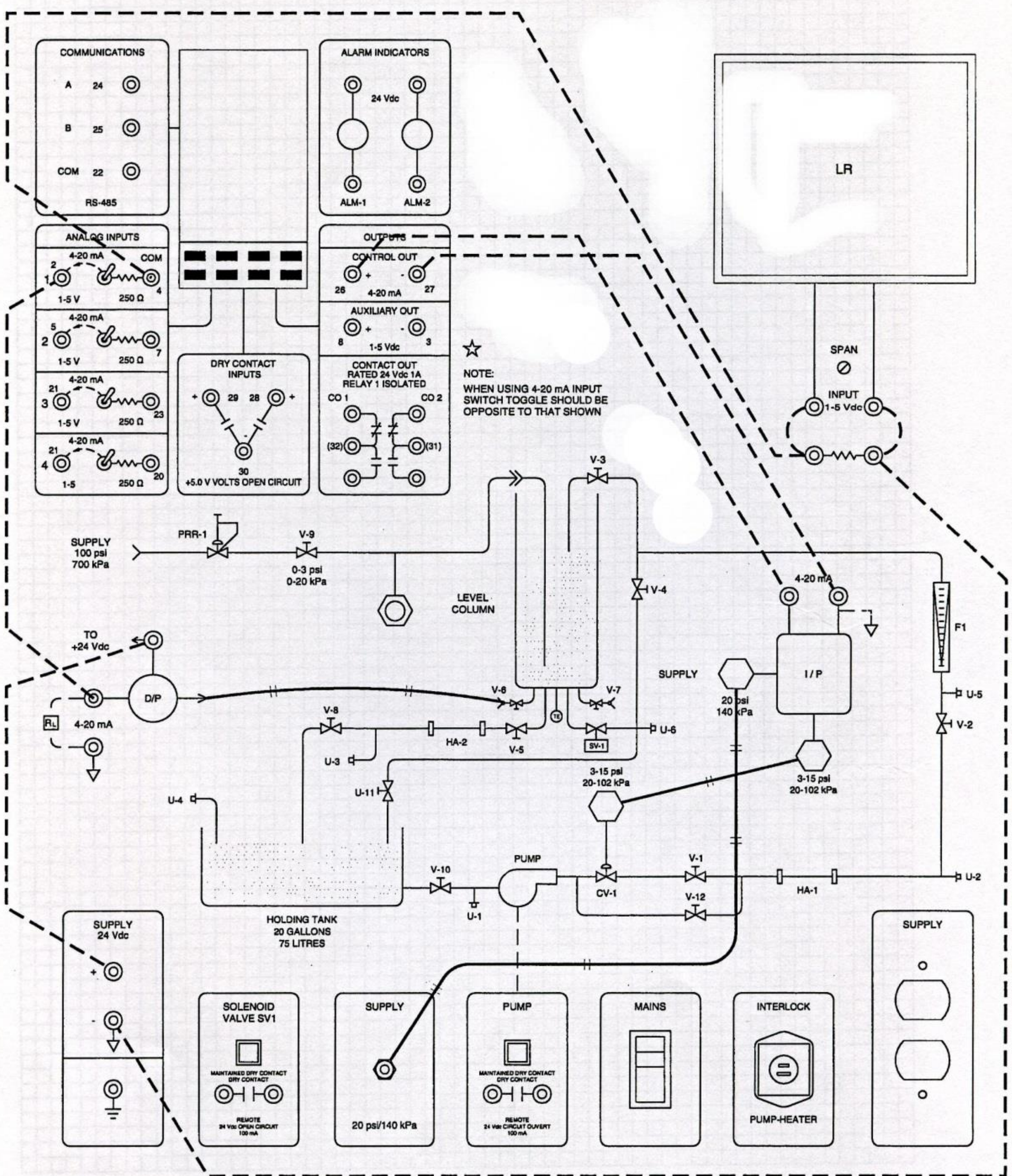


Figure 9-2.

QUESTIONS

1. For step 5, describe the waveform on the recorder in terms of offset error and stability.

2. For step 6, describe waveform on the recorder in terms of offset error & stability.

3. For step 7, describe the waveform on the recorder in terms of offset error & stability.

4. For step 8, describe the waveform on the recorder in terms of offset error & stability.

5. For step 9, describe the waveform on the recorder in terms of offset error & stability.

6. For step 10, describe the waveform on the recorder in terms of offset error & stability.

7. What advantage is obtained by adding integral action to a proportional controller?

8. Could a change in the process occur resulting in such a large offset error that even high amounts of integral action could not eliminate it? Explain.

9. How would the control channel respond if the controller was configured to Direct Action (inc/inc)?

Exercise 9: Level Process Proportional Plus Integral Plus Derivative Control

OBJECTIVES

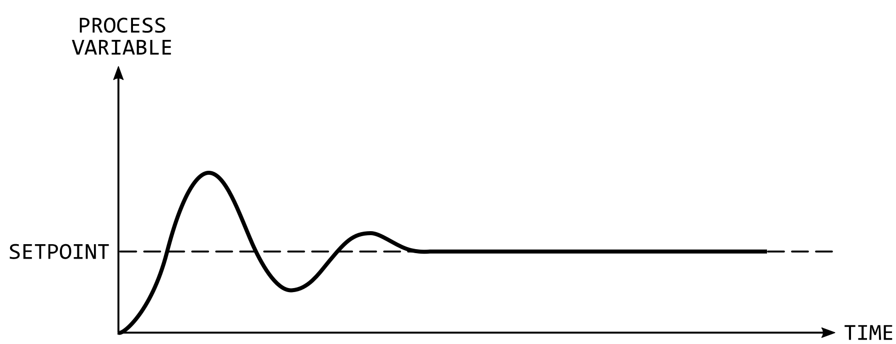
At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoint changes on a proportional plus integral plus derivative controller used in a level process.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instrument used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

For processes that cannot tolerate continuous cycling, a proportional controller is used. For processes that cannot tolerate continuous cycling or offset error, a proportional plus integral controller is used.

For processes that need improved stability and can tolerate offset error, a proportional plus derivative controller is used.



PID CONTROL

Derivative control is rarely used with Proportional Control only. PD control is desirable in processes where there are several different lag times.

Some processes cannot tolerate offset error, yet need good stability. In this case a control mode that combines the advantages of proportional, integral, and derivative (P ID) control is used.
Derivative action causes the proportional output to be advanced which provides an output signal to the final control element sooner. As the error signal rate of change increases, the initial controller output is larger. This helps the controller

anticipate large error amplitudes that are a result of rapidly changing error signals.

Derivative action is not usually used with fast responding processes such as flow control, or with noisy processes, because the derivative action responds to any rate of change in the error signal, including noise.

Derivative control is used in process control systems where the lag time (the time it takes a change to be measured) is large. Derivative control is considered difficult to implement and adjust; therefore, it is only used when the amount of lag time is extensive. It is typically used as PID control for temperature control and other slow applications.

EQUIPMENT LIST

Level Process Station 3503, including:

1. Microprocessor PID Controller (LIC)
2. Differential Pressure Transmitter (LT)
3. Current to Pressure Converter (lIP)
4. Chart Recorder (LR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
LT			0-30” WC/4-20 mA
I/P			4-20 mA/3-15 psi
LR			1-5 V dc/4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint = 50%
3. Gain = 1 (Prop. Band = 100%)
4. Reset = 0.1 rep./min
5. Derivative = 0.05 min.

PROCEDURE

1. Set up and connect the equipment as per the loop diagram.

2. Turn On the main power switch and Manually adjust the controller output to approximately 50%. Turn the pump on, open V1, fill tank to 15 in. (38 cm), and vent the HP side of the transmitter.

3. Set the controller as per the Controller Configuration. Start the recorder and place the controller in Automatic.

4. Load change disturbance to process: close valve V3 for 2 to 3 seconds, then fully open valve V3 and allow the process to stabilize.(Or open valve V11 and then open SV-1 for approximately 3 seconds). Stop the recorder when the process stabilizes, **calculate the error** ___________**%.**

5. Increasing gain in response to load change:

   a. increase the gain to **___4___** (**______** %P.B.),

   b. start the recorder,

   c. when the process stabilizes, **calculate the error** ___________**%.**

6. Increasing integral action in response to load change:

   a. increase the reset to **___2____** rep/min

   b. start the recorder,

   c. repeat step 4 and when the process stabilizes, **calculate the error** ___________**%.**

7. Increasing derivative action in response to load change:

   a. set the derivative to **__2____** minutes,

   b. start the recorder,

   c. repeat step 5 and when the process stabilizes, **calculate the error** ___________**%.**

8. Effect of original settings in response to setpoint change:

    a. Set P and I to the original settings

    b. start the recorder and rapidly decrease the setpoint to 20%,

    c. stop the recorder when the process stabilizes, adjust the setpoint to 50% and then, **calculate the error ___________%.**

9. Increasing gain in response to setpoint change:

    a. adjust the gain to **__8____** (**_______** % P.B.),

    b. repeat step 8 (b)-(c).
    c.
    d. when the process stabilizes, **calculate the error** ___________**%.**

10. Increasing integral action in response to setpoint change:

    a. adjust the reset to **___4____** repeats/min

    b. repeat step 8 (b)-(c).

    c. when the process stabilizes, **calculate the error** ___________**%.**

11. Increasing derivative action in response to setpoint change:

    a. adjust the derivative to **___4____** minutes,

    b. repeat step 8 (b)-(c), and turn off pump.

    c. when the process stabilizes, **calculate the error** ___________**%.**

12. Answer the questions.

Level Process Proportional Plus Integral Plus Derivative Control

LOOP DIAGRAM

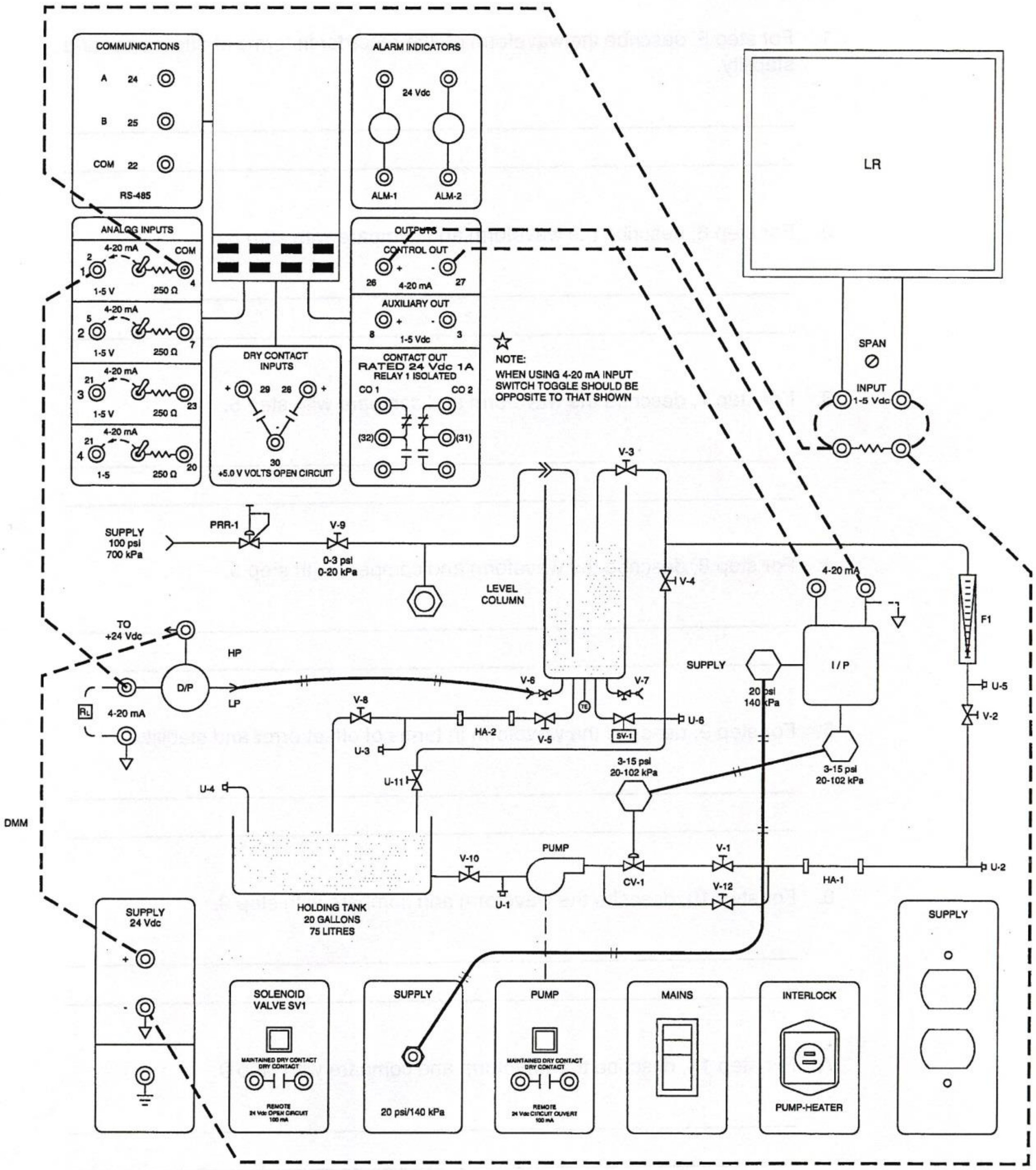


Figure 10-2.

QUESTIONS

1. For step 5, describe the waveform on the recorder in terms of offset error and stability.

2. For step 6, describe the waveform and compare with step 5.

3. For step 7, describe the waveform and compare with step 5.

4. For step 8, describe the waveform and compare with step 5.

5. For step 9, describe the waveform in terms of offset error and stability.

6. For step 10, describe the waveform and compare with step 9.

7. For step 11, describe the waveform and compare with step 9.

8. For step 12, describe the waveform and compare with step 9.

9. In the level process, what would be the result of high derivative settings?

10. With the same settings of integral and derivative control, what is the change in the integral and derivative action, caused by increasing the gain of the controller?

11. Is the integral action of the PID controller affected by adjusting the derivative action?

Exercise 10: Flow Process Proportional Control

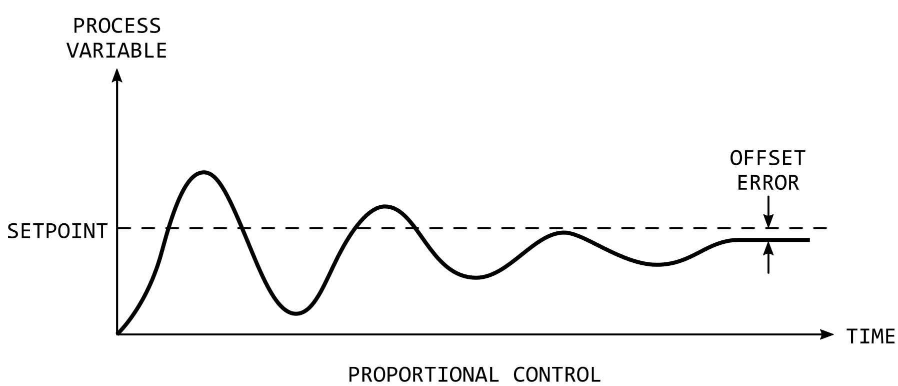
OBJECTIVES

At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoint changes on a proportional controller.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instruments used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

A setpoint is chosen, representing the desired value of the controlled variable. The controller inputs the result of a measurement of the controlled variable and determines an appropriate output for the final control element according to the magnitude of deviation from setpoint, and how the operator has set, or tuned, the instrument. The results of different settings can be observed from the strip chart obtained from the recorder.



A proportional controller functions to maintain the process within a specified band of control points. It gives an output to input relationship which is linear.

$$Proportional\ Band = \frac{\%\ Change\ in\ input}{\%\ Change\ in\ output} \times 100\%$$

Gain, the ratio of output to input of any section of a controlled system, is inversely related to proportional band.

$$Gain = \frac{Ouput\ Change}{Input\ Change}$$

With a lower gain, a larger change in the input signal is required to cause the output to change from 0-100%. Within the proportional band, the controller output is proportional to the input signal, and the gain factor determines the proportional relationship. The magnitude of the offset error is directly related to the proportional band. Higher gain settings result in reduced offset error, but increased instability.

EQUIPMENT LIST

Flow Process Station 3502, including:

1. Microprocessor PID Controller (FIC)
2. Differential Pressure Transmitter (FT)
3. Chart Recorder (FR)
4. Variable Area Flowmeter (FI)
5. Venturi Flow Element (FE)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
FT			0-50” H_2O/4-20 mA
FR			1-5 V dc/4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual: = Manual
2. Setpoint = 50%
3. Modes = P (Proportional only)
4. Measurement: Format = SQR (Square Root)
5. Output 2 = Process Measurement
6. Gain = 1 (PB = 100%)

PROCEDURE

1. Set up and connect equipment as per the loop diagram.

2. Turn On the main power switch and Open V1, V2, V3, V4. With the pump drive on Manual, increase the flow until there is sufficient pressure to vent the HP and LP sides of the flow transmitter. Set the pump drive to Drive

Signal.

3. Configure the controller as per the CONTROLLER CONFIGURATION.

4. Manually adjust the output until the measured variable equals the setpoint.

5. Start the recorder and place the controller in Automatic and when the process stabilizes, **calculate the error** ___________**%.**

6. Effect of original gain in response to setpoint changes:

    a. Adjust gain to 1 (100% prop. band).

    b. Rapidly decrease the setpoint to 30%.

    c. Stop the recorder when the process stabilizes.

    d. Adjust the setpoint to 50% and allow the process to stabilize, after that, **calculate the error** ___________**%.**

7. Decreasing gain in response to setpoint change:

    a. Adjust gain to **__0.25___** (**_____** % PB)

    b. Start the recorder.

    c. Rapidly decrease the setpoint to 30%.

    d. Stop the recorder when the process stabilizes.

    e. Adjust the setpoint to 50% and allow the process to stabilize and then, **calculate the error** ___________**%.**

8. Increasing gain in response to setpoint change:

    a. Adjust gain to __4___ (**_____** %PB)

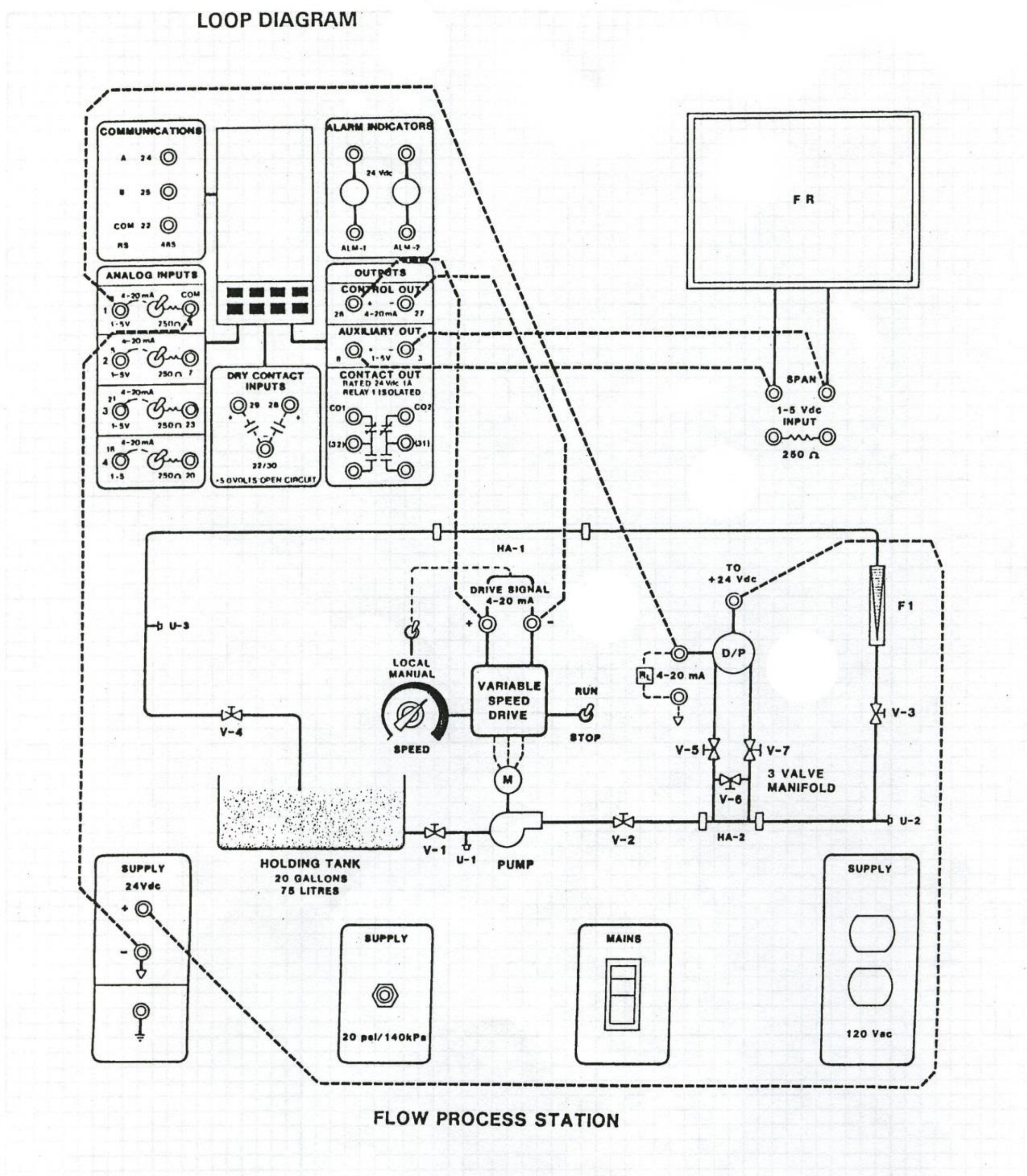
    b. Rapidly decrease the setpoint to 30%.

    c. Stop the recorder when the process stabilizes, **calculate the error** ___________**%.**

    d. Turn the pump off.

9. Answer the questions at the end of this exercise.

Flow Process Proportional Control



QUESTIONS

1. For the effect of original gain in response to setpoint change (step 6), describe the waveform on the recorder in terms of offset error and stability.

2. For the decreased gain in response to setpoint change (step 7) describe the waveform on the recorder in terms of offset error and stability.

3. For the increased gain in response to setpoint change (step 8) describe the waveform on the recorder in terms of offset error and stability.

4. What effects on offset and stability are caused by using a low gain setting on the controller?

5. After a setpoint change to a process, how could the offset error be removed?

Exercise 11: Flow Process Proportional Plus Integral Control

OBJECTIVES

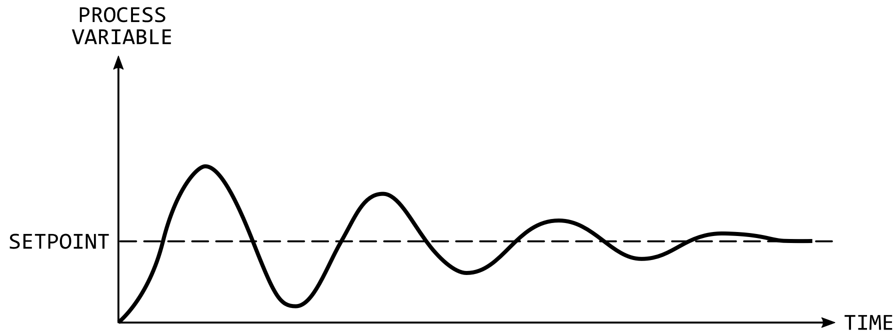
At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoint changes on a proportional plus integral controller used in a flow process.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instrument used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

The addition of integral action, also called RESET action, to a proportional controller results in the elimination of offset error.

The main advantage of the integral control mode is that the controller output continues to reposition the final control element until the error is reduced to zero, within system design limitations.



P + I CONTROL

The main disadvantage of the integral control mode is that the controller output does not immediately direct the final control element to a new position in response to an error signal.

The controller output changes at a defined rate of change, and time is needed for the final control element to be gradually repositioned.

The addition of integral action to proportional control automatically performs the gain resetting that was manually accomplished. For this reason, proportional plus integral controllers are sometimes referred to as proportional plus automatic reset, or simply proportional plus reset controllers.

Higher gain settings result in increased instability. An increase in RESET (Repeats per Minute) will cause the process to return to the setpoint value faster, but also produces instability if adjusted too high.

EQUIPMENT LIST

Flow Process Station 3502, including:

1. Microprocessor PID Controller (FIG)
2. Differential Pressure Transmitter (ET)
3. Chart Recorder (FR)
4. Variable Area Flowmeter (FI)
5. Venturi Flow Element (FE)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
FT			0-50" H_2O/4-20 mA
FR			1-5 V dc/4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint = 50%
3. Modes = PI (Proportional + Integral)
4. Output 2 = Process Measurement
5. Gain = 1 (Prop. Band = 100%)
6. Reset = 10 rep/mm.

PROCEDURE

1. Set up and connect equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller according to the Instrument Data.

3. Open V1, V2, V3, and V4. Vent the HP & LP sides of the flow transmitter.

4. Manually adjust the output until the measured variable equals the setpoint. Start the recorder and place the controller in Automatic, after that, **calculate the error ___________%.**

5. Effect of original gain in response to setpoint changes:

   a. Set the gain to 1(100% PB), set reset to 10 rep/mm (0.1 mm/rep).

   b. Rapidly decrease the setpoint to 30%,

   c. Stop the recorder when the process stabilizes.

   d. Adjust the setpoint to 50% and allow the process to stabilize and then **calculate the error ___________%.**

6. Increasing gain in response to setpoint change:

   a. adjust the gain to ___**2**___ (______ % PB),

   b. repeat step 5 (b), (c) and (d), after that **calculate the error _______%.**

7. Increasing integral action and original gain in response to setpoint change:

   a. adjust the gain to 1 (100% PB), and increase the reset to __**20**___ rep/min

   b. repeat step 5 (b), (c) and (d), after that **calculate the error _______%.**

8. Increasing gain and increasing reset in response to setpoint change:

   a. adjust the gain to ___4___ (______% PB), and adjust the reset to ___**30**___ min/rep.

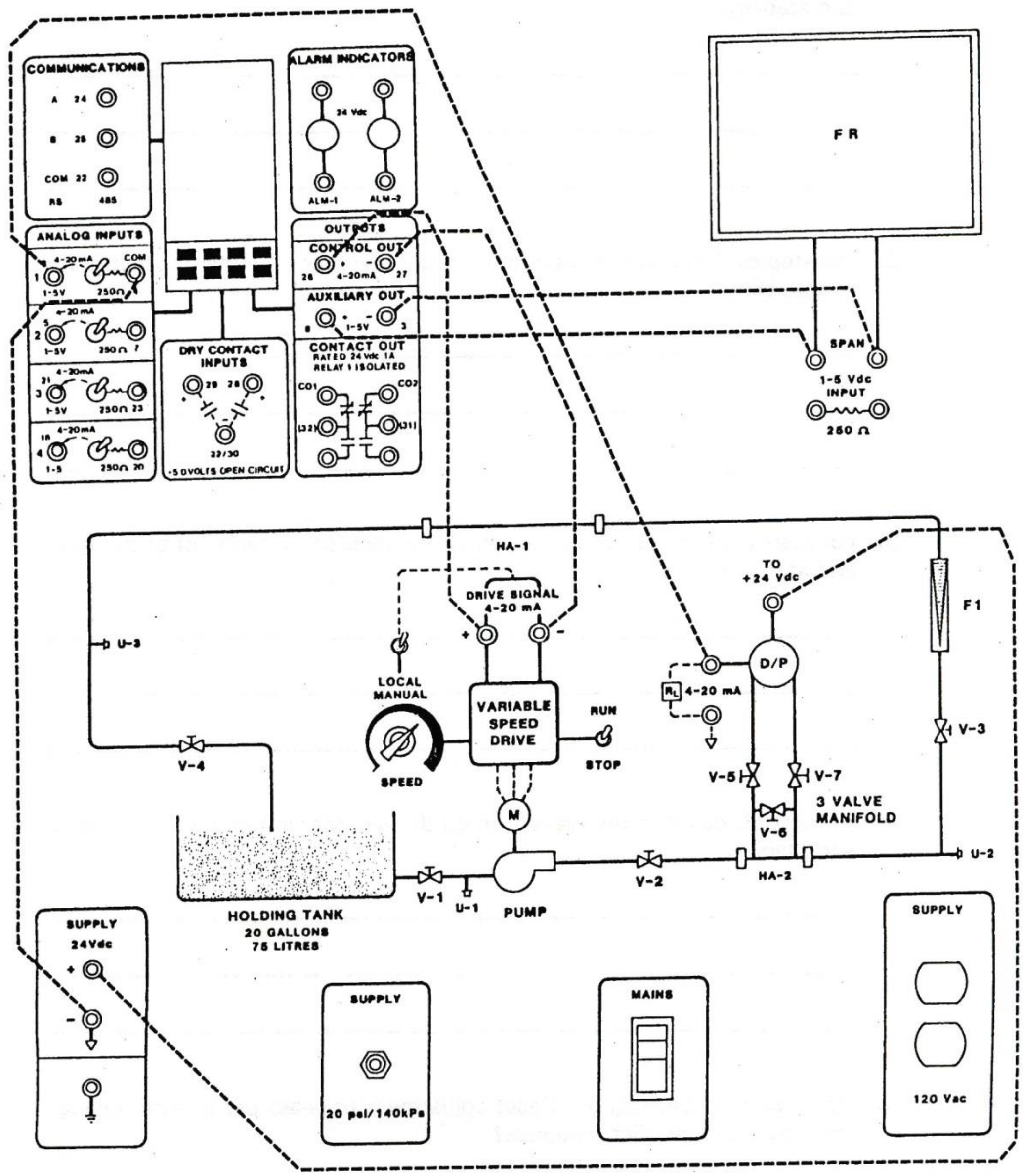
   b. repeat step 5 (b), (c) and (d), after that **calculate the error _______%.**

9. Stop the recorder and turn the pump off.

10. Answer the questions.

Flow Process Proportional Plus Integral Control

LOOP DIAGRAM



FLOW PROCESS STATION

QUESTIONS

1. For step 5, describe the waveform on the recorder in terms of offset error and stability.

2. For step 6, describe the waveform on the recorder in terms of offset error and stability.

3. For step 7, describe the waveform on the recorder in terms of offset error and stability.

4. For step 8, describe the waveform on the recorder in terms of offset error and stability.

5. How would increasing the Reset adjustment (repeats per minute) change the way the controller responds?

6. What effect on the integral action occurs when the gain of the proportional plus integral controller is increased?

7. Describe the effect on controller output to a setpoint disturbance caused by adding integral action to a proportional controller.

Exercise 12: Flow Process Proportional Plus Integral Plus Derivative Control

OBJECTIVES

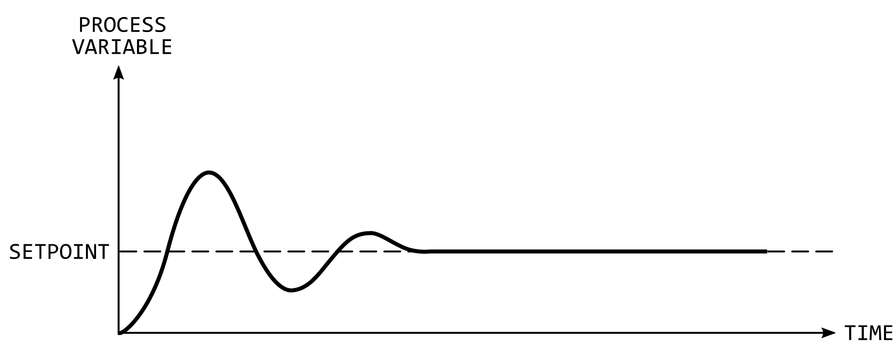
At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoint changes on a proportional plus integral plus derivative controller in a flow process.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instrument used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

For processes that cannot tolerate continuous cycling, a proportional controller is used. For processes that cannot tolerate continuous cycling or offset error, a proportional plus integral controller is used.

For processes that need improved stability and can tolerate offset error, a proportional plus derivative controller is used.



PID CONTROL

Derivative control is rarely used with Proportional Control only. PD control is desirable in processes where there are several different lag times.

Some processes cannot tolerate offset error, yet need good stability. In this case a control mode that combines the advantages of proportional, integral, and derivative (PID) control is used.

Derivative action causes the proportional output to be advanced which provides an output signal to the final control element sooner. As the error signal rate of change increases, the initial controller output is larger. This helps the controller anticipate large error amplitudes that are a result of rapidly changing error signals.

Derivative action is not usually used with fast responding processes such as flow control, or with noisy processes, because the derivative action responds to any rate of change in the error signal, including noise.

Derivative control is used in process control systems where the lag time (the time it takes a change to be measured) is large. Derivative control is considered difficult to implement and adjust; therefore, it is only used when the amount of lag time is extensive. It is typically used as PID control for temperature control and other slow applications.

EQUIPMENT LIST

Flow Process Station 3502, including:

1. Microprocessor PID Controller (FIC)
2. Differential Pressure Transmitter (FT)
3. Chart Recorder (FR)
4. Variable Area Flowmeter (FI)
5. Venturi Tube Flow Assembly (FE)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
FT			0-50” H_2O/4-20 mA
FR			1-5 V dc/4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint = 50%
3. Modes = PID
4. Gain = 1 (Prop. Band = 100%)
5. Reset = 10 rep/min
6. Derivative = 0.05 Min.

PROCEDURE

1. Set up and connect equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller according to the Instrument Data.

3. Open V1, V2, V3, and V4. Vent the HP & LP sides of the flow transmitter.

4. Manually adjust the output until the measured variable equals the setpoint. Start the recorder and place the controller in Automatic, after that **calculate the error ___________%.**

5.
   a) Set the gain to 1(100% PB), set reset to 10 rep/mm, (set derivative to 0.05 minutes,

   b) Rapidly decrease the setpoint to 30%.

   c) Stop the recorder when the process stabilizes.

   d) Adjust the setpoint to 50% and allow the process to stabilize and then **calculate the error ___________%.**

6. Increasing gain in response to setpoint change:

   a) adjust the gain to **___4___** (______ % PB).

   b) repeat step 5 (b), (c) and (d), after that **calculate the error _______%.**

7. Increasing integral and decreasing gain in response to setpoint change:

   a) Adjust the gain to 0.3 (333% PB), and reset to **___20___** rep/min.

   b) repeat step 5 (b), (c) and (d), after that **calculate the error _______%.**

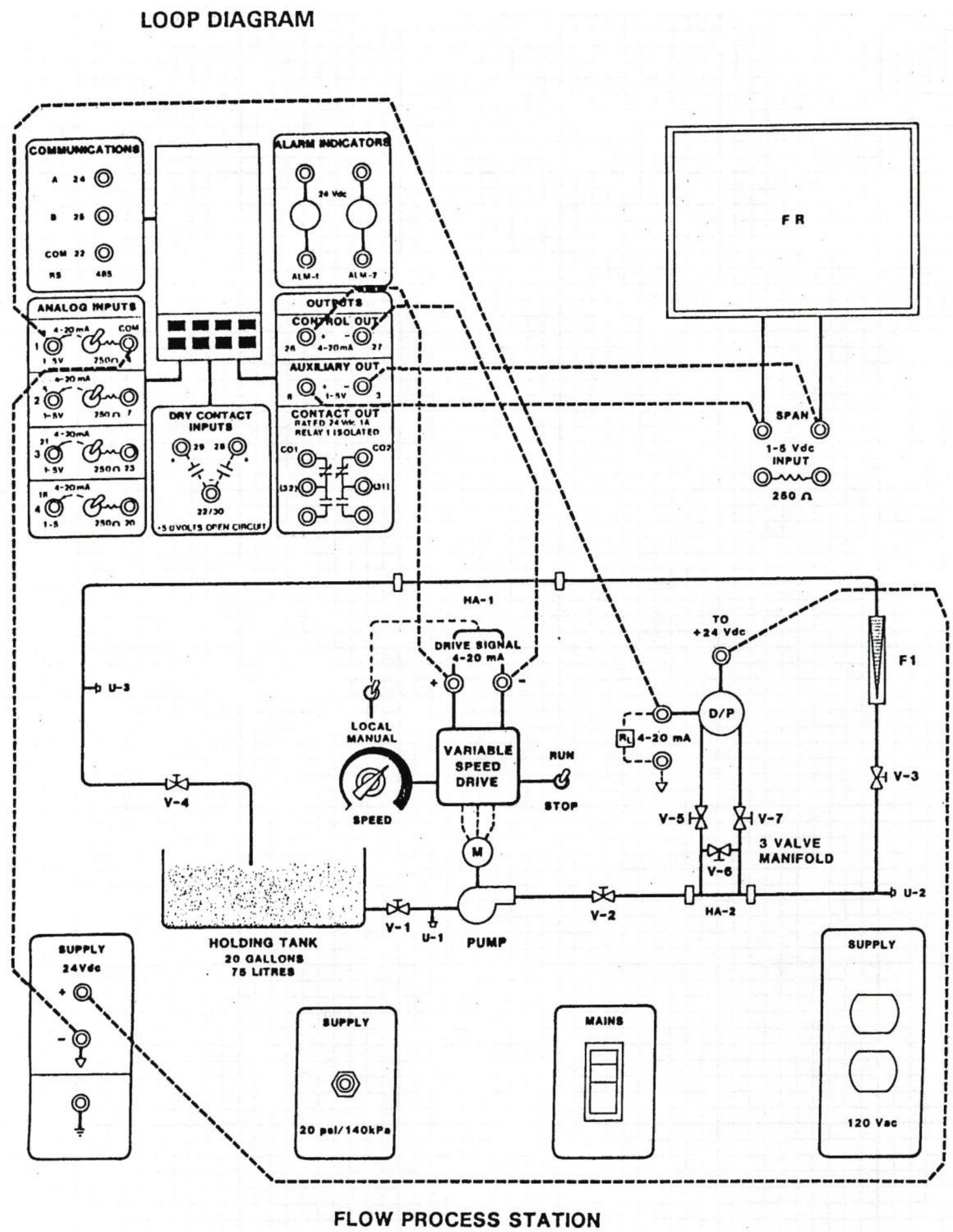
8. Increasing derivative action and decreasing integral action in response to setpoint change:

   a) Adjust the reset to 10 rep./min and derivative to **__10___** min.

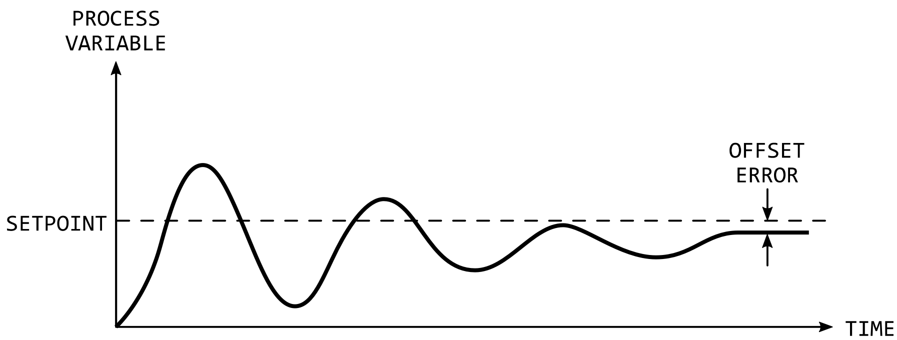
   c) repeat step 5 (b), (c) and (d), after that **calculate the error _______%.**

9. Turn the pump off.

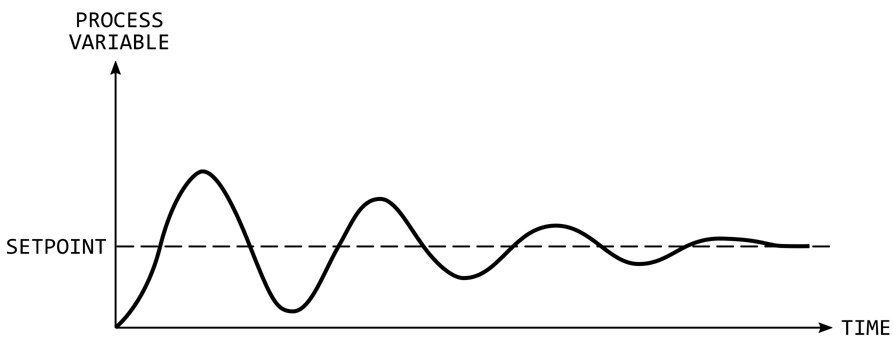
Flow Process Proportional Plus Integral Plus Derivative Control



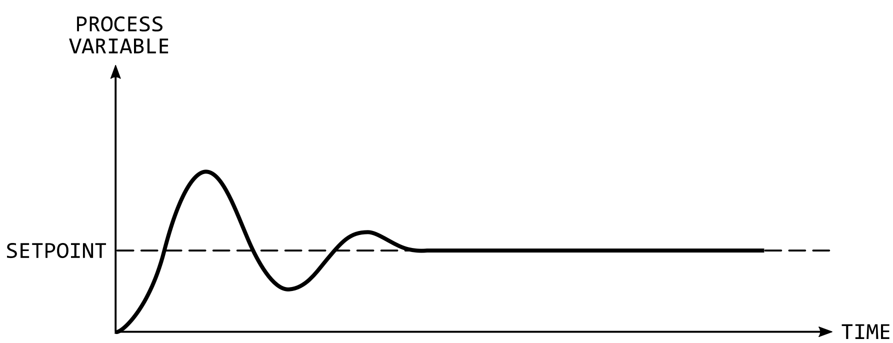
COMPARISON OF CONTROL MODES



PROPORTIONAL CONTROL



P + I CONTROL



PID CONTROL

QUESTIONS

1. For step 5, describe the waveform on the recorder in terms of offset error and stability.

2. For step 6, describe the waveform and compare with step 5.

3. For step 7, describe the waveform and compare with step 5.

4. For step 8, describe the waveform and compare with step 5.

5. In the flow process, what would be the result of high derivative settings?

6. Is the integral action of the PID controller affected by adjusting the derivative setting? Explain.

Exercise 13: Pressure Process Proportional Control

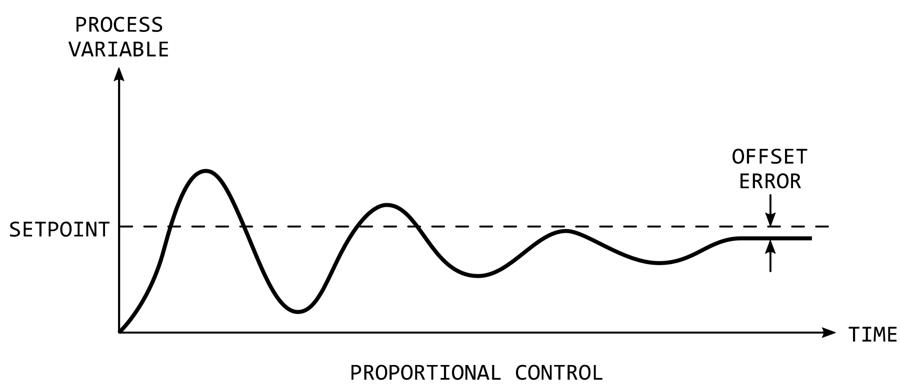
OBJECTIVES

At the completion of this project, you will be able to use standard process instrumentation to observe and analyze proportional control.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instruments used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

A setpoint is chosen, representing the desired value of the controlled variable. The controller inputs the result of a measurement of a controlled variable and determines an appropriate output for the final control element according to the magnitude of deviation from setpoint, and how the operator has set, or tuned, the instrument. The results of different settings can be observed from the strip chart obtained from the recorder.



A proportional controller functions to maintain the process within a specified band of control. It gives an output to input relationship which is linear.

$$Proportional\ Band = \frac{\%\ Change\ in\ input}{\%\ Change\ in\ output} \times 100\%$$

Gain, the ratio of output to input of any section of a controlled system, is inversely related to proportional band.

$$Gain = \frac{Ouput\ Change}{Input\ Change}$$

With a lower gain, a larger change in the input signal is required to cause the output to change from O-100%. Within the proportional band, the controller output is proportional to the input signal, and the gain factor determines the proportional relationship. The magnitude of the offset error is directly related to the proportional band. Higher gain settings result in reduced offset error, but increased instability.

EQUIPMENT LIST

Pressure Process Station 3501, including:

1. Microprocessor PID Controller (PIC)
2. Electronic Pressure Transmitter (PT)
3. Current to Pressure Converter (lIP)
4. Chart Recorder (PR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
PT			0-100 psi / 4-20 mA
I/P			4-20 mA / 3-15 psi
PR			1-5 V dc / 4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint = 50%
3. Modes = P
4. Gain = 1 (Proportional Band = 100%)

PROCEDURE

1. Set up and connect the equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller as per the Controller Configuration.

3. Plug the port between V4 and V5. Fully open V4, close V5, and partially open V3 to introduce a process load.

4. With the controller in Manual, adjust the output until the measured variable equals the setpoint. Start the recorder and place the controller in

automatic and when the process stabilizes, **calculate the error ______%.**

5. Effect of original gain in response to a load change

   a) fully open V5

   b) stop the recorder when the process stabilizes

   c) close V5, and allow the process to stabilize and **calculate the error ___________%.**

6. Increasing gain in response to load change:

   a) increase the gain to **__2__** (**_____** % PB)

   b) start the recorder

   c) repeat step 5 (a), (b) and (c) and when the process stabilizes, **calculate the error __________%.**

7. Effect of original gain in response to setpoint change

   a) adjust the gain to 1 (100% P.B.)

   b) start the recorder, rapidly decrease the setpoint to 20%

   c) stop the recorder when the process stabilizes, adjust the setpoint to 50% and allow the process to stabilize, after that **calculate the error __________%.**

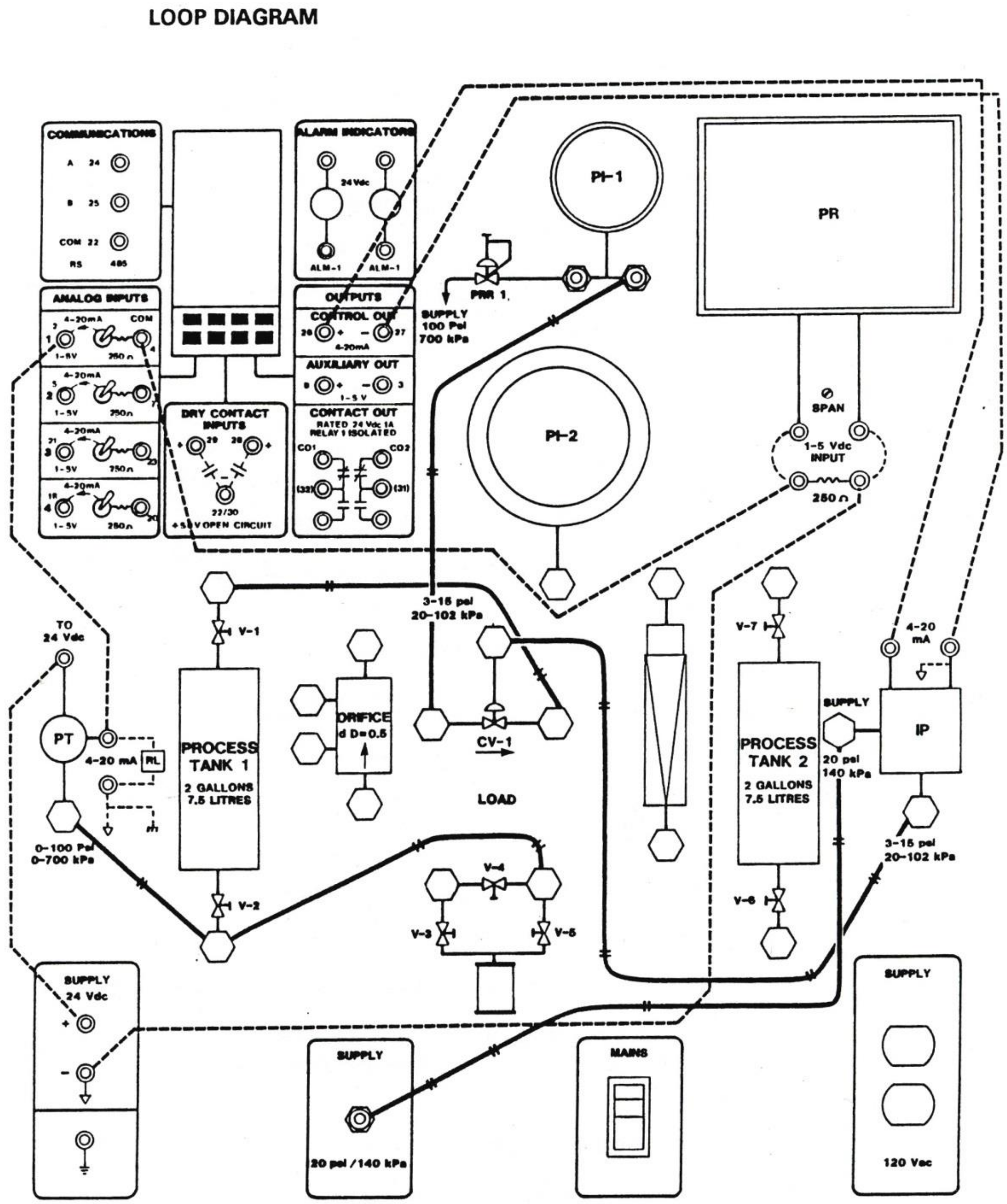
8. Increasing gain in response to setpoint change:

   a) adjust gain to **__4___** (**_____** % P.B.)

   b) start the recorder and rapidly decrease the setpoint to 20%

   c) stop the recorder when the process stabilizes, **calculate the error __________%.** Switch off the power.

Pressure Process Proportional Control



PRESSURE PROCESS STATION

QUESTIONS

1. For the load change disturbance to the process (step 6), describe the waveform on the recorder in terms of offset error and stability.

2. For the increased gain in response to load change (step 7), describe the waveform on the recorder in terms of offset error and stability. Compare with step 6.

3. For the effect of original gain in response to setpoint change (step 8), describe the waveform on the recorder in terms of offset error and stability.

4. For the increased gain in response to setpoint change (step 9), describe the waveform on the recorder in terms of offset error and stability.

5. To increase the stability of the response of the process using a proportional controller, would you increase or decrease the gain setting? Explain.

Exercise 14: Pressure Process Proportional Plus Integral Control

OBJECTIVES

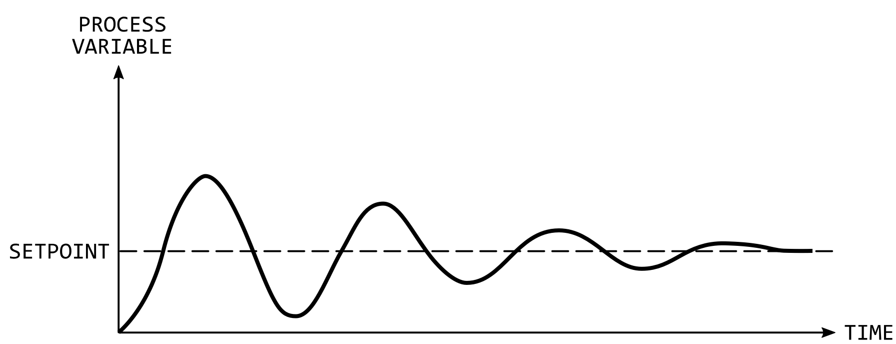
At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoint changes on a proportional plus integral controller used in a pressure process.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instrument used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

The addition of integral action, also called RESET action, to a proportional controller results in the elimination of offset error.

The main advantage of the integral control mode is that the controller output continues to reposition the final control element until the error is reduced to zero, within system design



P + I CONTROL

The main disadvantage of the integral control mode is that the controller output does not immediately direct the final control element to a new position in response to an error signal.

The controller output changes at a defined rate of change, and time is needed for the final control element to be gradually repositioned.

The addition of integral action to proportional control automatically performs the gain resetting that was manually accomplished. For this reason, proportional plus integral controllers are sometimes referred to as proportional plus automatic reset, or simply proportional plus reset controllers.

Higher gain settings result in increased instability. An increase in RESET (Repeats per Minute) will cause the process to return to the setpoint value faster, but also produces instability if adjusted too high.

EQUIPMENT LIST

Pressure Process Station 3501, including:

1. Microprocessor PID Controller (PIC)
2. Electronic Pressure Transmitter (PT)
3. Current to Pressure Converter (I/P)
4. Chart Recorder (PR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
PT			0-100 psi / 4-20 mA
I/P			4-20 mA / 3-15 psi
PR			1-5 V dc / 4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint 50%
3. Modes = PI
4. Gain = 1 (Prop. Band = 100%)
5. Reset = 10 Rep/min

PROCEDURE

1. Set up and connect the equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller as per the Controller Configuration.

3. Manually adjust the controller output until the measured variable equals the setpoint. Start the recorder.

4. Place the controller in Automatic, and when the process stabilizes, **calculate the error __________%.**

5. Plug the port between V4 and V5. Fully open V4, close V5, and partially open V3 to introduce a process load.

6. Load change disturbance to process:

   a) fully open V5 and stop the recorder when the process stabilizes

   b) close V5, and allow process to stabilize and then **calculate the error __________%.**

7. Increasing gain in response to load change:

   a) increase the gain to **__4___** (_____ % PB)

   b) repeat step 6 (a), (b) and (c), and when the process stabilizes, **calculate the error __________%.**

8. Increasing integral action in response to load change:

   a) set the Reset to **__20___** repeats/minute.

   b) repeat step 7 (a), (b) and (c), and when the process stabilizes, **calculate the error __________%.**

9. Effect of original gain and integral action in response to setpoint change:

   a) adjust the gain to 1 (100% PB) and Reset to 10 rep/min

   b) start the recorder, rapidly decrease the setpoint to 20%

   c) stop the recorder when the process stabilizes

   d) adjust the setpoint to 50% and allow the process to stabilize and then **calculate the error __________%.**

10. Increasing gain in response to setpoint change:

    a) adjust the gain to **__4___** (_____ % PB)

    b) repeat step 9 (b), (c) and (d), and allow the process to stabilize and then **calculate the error __________%.**

11. Increasing integral action in response to setpoint change:

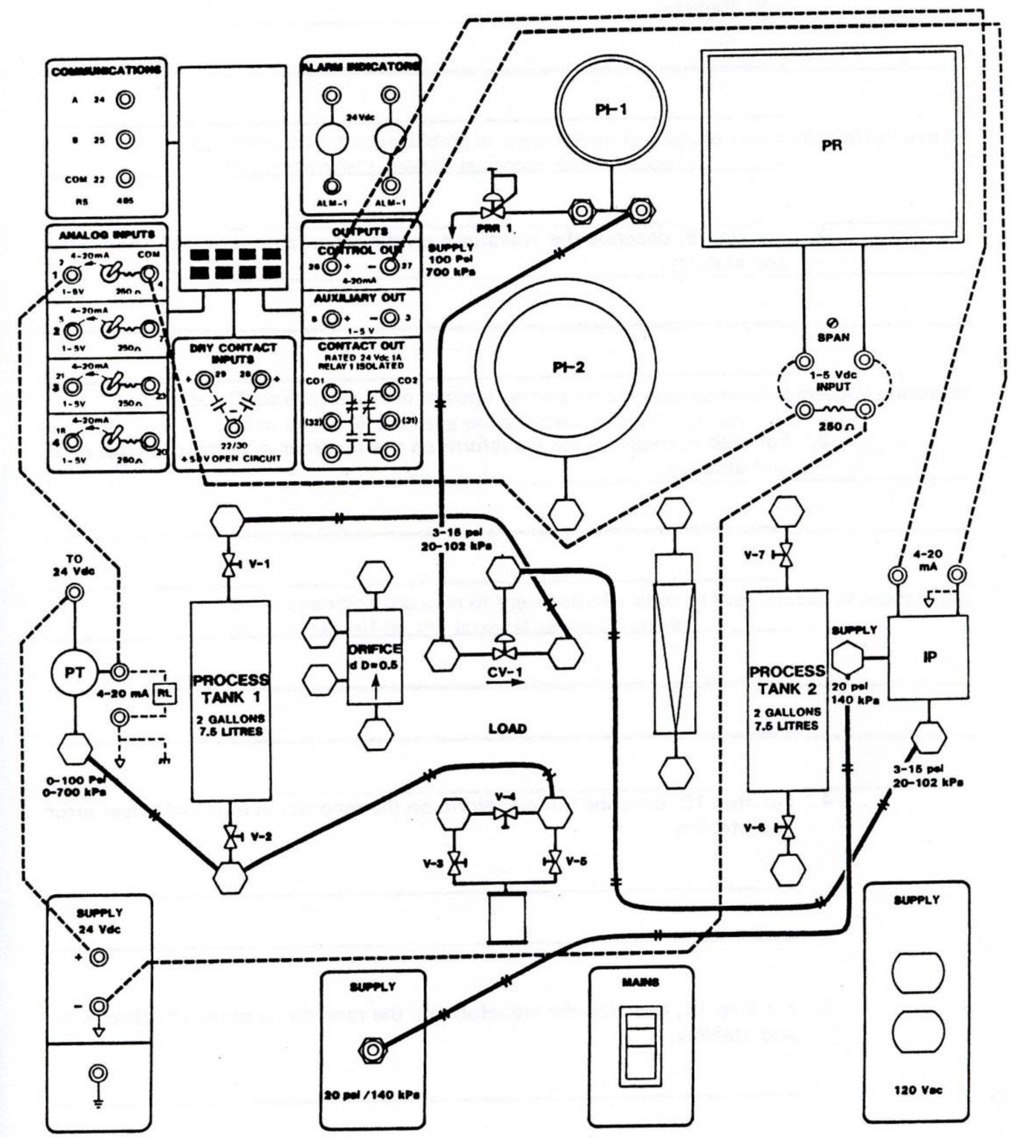
    a) adjust the Reset to **__20___** rep/min.

    b) repeat step 10 (b), (c) and (d), and allow the process to stabilize and then **calculate the error __________%.**

Exercise 14

Pressure Process Proportional Plus Integral Control

LOOP DIAGRAM



PRESSURE PROCESS STATION

QUESTIONS

1. For step 7, describe the waveform on the recorder in terms of offset error and stability.

2. For step 8, describe the waveform on the recorder in terms of offset error and stability.

3. For step 9, describe the waveform on the recorder in terms of offset error and stability.

4. For step 10, describe the waveform on the recorder in terms of offset error and stability.

5. For step 11, describe the waveform on the recorder in terms of offset error and stability.

Exercise 15: Pressure Process Proportional Plus Integral Plus Derivative Control

OBJECTIVES

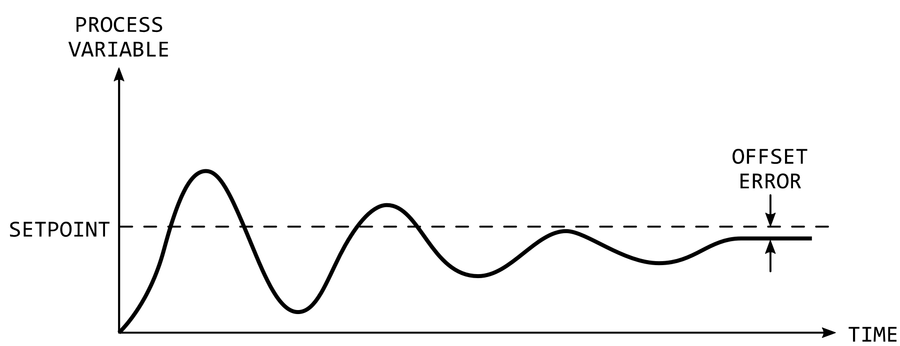
At the completion of this project, you will be able to use standard process instrumentation to observe and analyze the effects of demand and setpoint changes on a proportional plus integral plus derivative controller in a pressure process.

DISCUSSION

Understanding how a controlled process responds to supply or demand disturbances is important for the individual who must calibrate the instrument used for controlling the process. An easy method for observing how the controller adjustments affect the characteristics of a process is by intentionally disturbing the process and then monitoring the reaction on a multi-speed recorder.

For processes that cannot tolerate continuous cycling, a proportional controller is used. For processes that cannot tolerate continuous cycling or offset error, a proportional plus integral controller is used.

For processes that need improved stability and can tolerate offset error, a proportional plus derivative controller is used.



PROPORTIONAL CONTROL

Derivative control is rarely used with Proportional Control only. PD control is desirable in processes where there are several different lag times.

Some processes cannot tolerate offset error, yet need good stability. In this case a control mode that combines the advantages of proportional, integral, and derivative (PID) control is used.

Derivative action causes the proportional output to be advanced which provides an output signal to the final control element sooner. As the error signal rate of change increases, the initial controller output is larger. This helps the controller anticipate large error amplitudes that are a result of rapidly changing error signals.

Derivative action is not usually used with fast responding processes such as flow control, or with noisy processes, because the derivative action responds to any rate of change in the error signal, including noise.

Derivative control is used in process control systems where the lag time (the time it takes a change to be measured) is large. Derivative control is considered difficult to implement and adjust; therefore, it is only used when the amount of lag time is extensive. It is typically used as PID control for temperature control and other slow applications.

EQUIPMENT LIST

Pressure Process Station 3501, including:

1. Microprocessor PID Controller (PIC)
2. Electronic Pressure Transmitter (PT)
3. Current to Pressure Converter (IIP)
4. Chart Recorder (PR)

INSTRUMENT DATA

DEVICE	MODEL	SERIAL NO.	CALIBRATED
PT			0-100 psi / 4-20 mA
I/P			4-20 mA / 3-15 psi
PR			1-5 V dc / 4-20 mA

CONTROLLER CONFIGURATION

1. Auto/Manual = Manual
2. Setpoint = 50%
3. Modes = PI
4. Gain = 1 (Prop. Band = 100%)
5. Reset = 10 Rep/min
6. Derivative = 0.06 Min.

PROCEDURE

1. Set up and connect the equipment as per the loop diagram.

2. Turn On the main power switch and Set the controller as per the CONTROLLER CONFIGURATION.

3. With the controller in Manual, adjust the output until the measured variable equals the setpoint. Start the recorder.

4. Place controller in Automatic, and when the process stabilizes, **calculate the error __________%.**

5. Plug the port between V4 and V5. Fully open V4, close V5, and partially open V3 to introduce a process load.

6. Load change disturbance to process:

   a) fully open V5

   b) stop the recorder when the process stabilizes

   c) close V5, and allow the process to stabilize, after that **calculate the error __________%.**

7. Increasing gain in response to load change:

   a) increase the gain to **__4___** (**_____** % PB)

   b) start the recorder

   c) repeat step 6 (a), (b) and (c), and when the process stabilizes, **calculate the error __________%.**

8. Increasing integral action in response to load change:

   a) increase the Reset to **__20___** rep/min.

   b) start the recorder

   c) repeat step 6 (a), (b) and (c) , and when the process stabilizes, **calculate the error __________%.**

9. Increasing derivative action in response to load change:

   a) set the Derivative adjustment to **__2___** minutes

   b) start the recorder

   c) repeat step 6 (a), (b) and (c), and when the process stabilizes, **calculate the error __________%.**

10. Set the Gain to 1, Reset to 10 rep/mm, and Derivative to 0.06 minutes.

11. Start the recorder and rapidly decrease the setpoint to 20%. Stop the recorder when the process stabilizes, adjust setpoint to 50% and **calculate the error __________%.**

12. Increasing gain in response to setpoint change:

   a) adjust the Gain to **__4___** (**_____** % PB)

   b) repeat step 11, , and when the process stabilizes, **calculate the error __________%.**

13. Increasing integral action in response to setpoint change:

   a) adjust the Reset to **__20___** rep/min

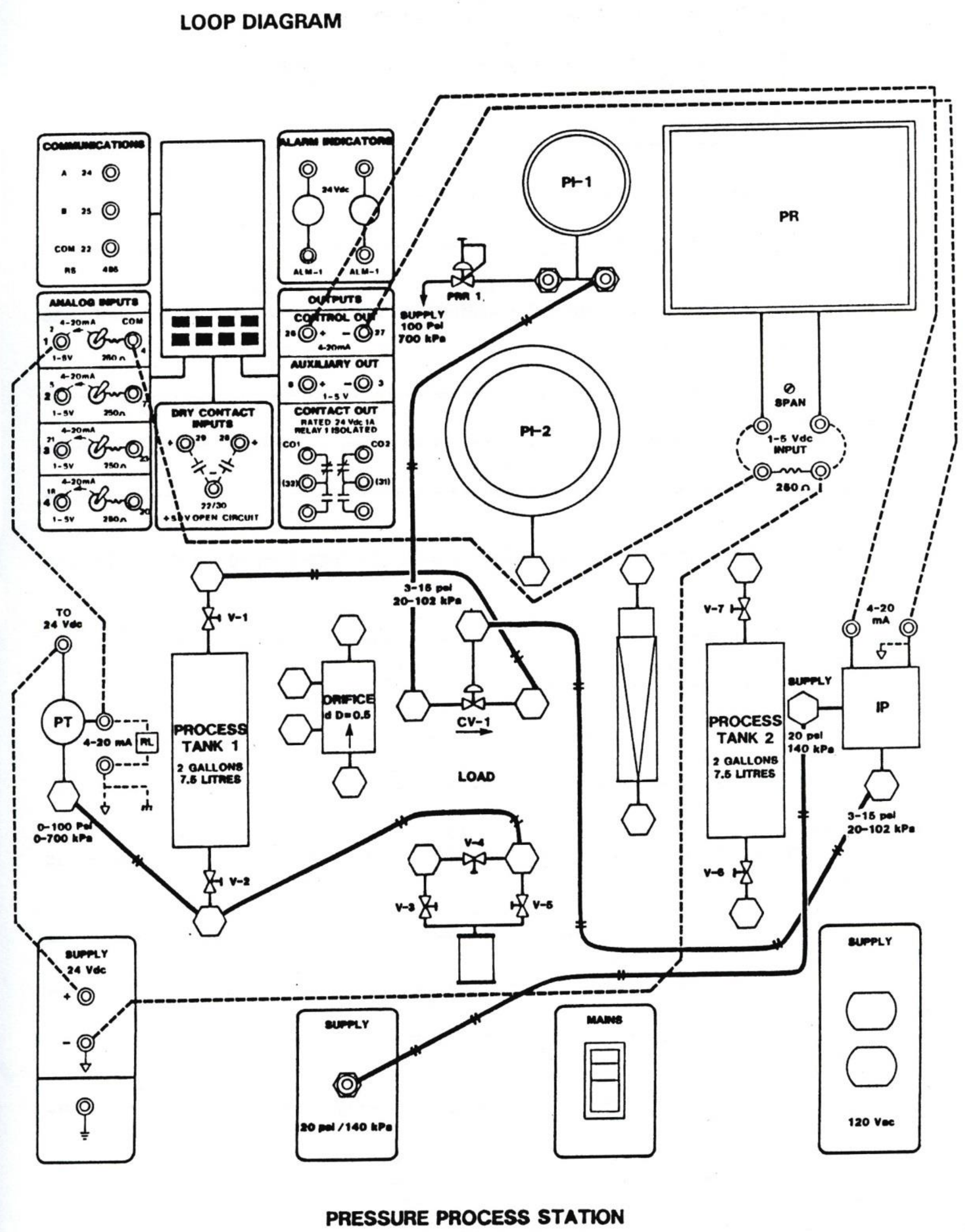
   b) repeat step 11, and when the process stabilizes, **calculate the error __________%.**

14. D 15. Increasing derivative action in response to setpoint change:

   a) adjust the Derivative to **__2___** minutes

   b) repeat step 11, and when the process stabilizes, **calculate the error __________%.**

Pressure Process Proportional Plus Integral Plus Derivative Control



QUESTIONS

1. For step 7, describe the waveform on the recorder in terms of offset error and stability.

2. For step 8, describe the waveform on the recorder and compare with step 7.

3. For step 9, describe the waveform on the recorder and compare with step 8.

4. For step lo, describe the waveform on the recorder and compare with step 9.

5. For step 11 and 12, describe the waveform in terms of offset error and stability.

6. For step 13, describe the waveform and compare with step 12.

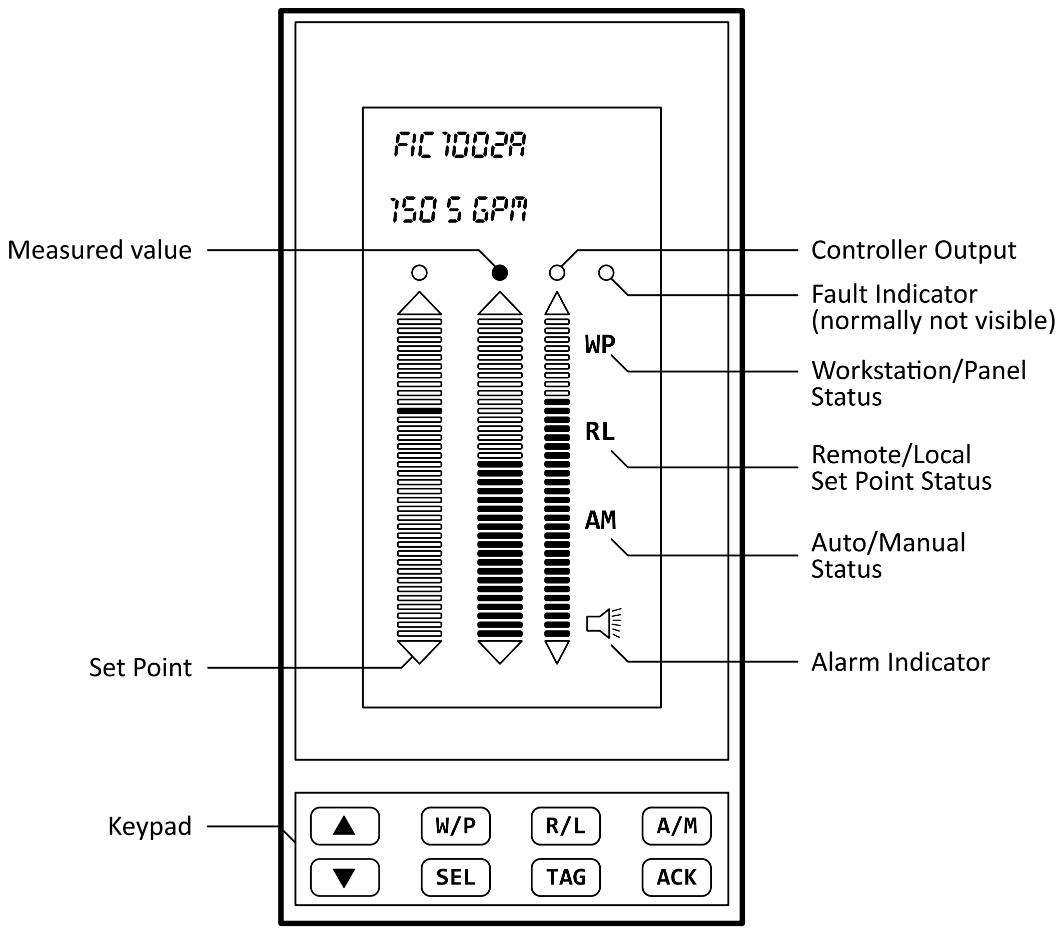
7. For step 14, describe the waveform and compare with step 13.

8. For step 1 5, describe the waveform and compare with step 14.

9. What are the advantages of using a proportional plus integral plus derivative controller?

Appendix A: Controller Description

Display Functions



The alphanumeric display at the top of the front panel has two lines of nine characters each. The graphics display consists of three bargraphs, each having 50 segments (each 2% of full scale) plus a triangular pointer on top and bottom to indicate when the variable is either above or below the range of the display.
The position of the bargraph indicator or “dot” identifies which variable is currently displayed on the Lower Digital Display. To move the indicator to the next position, press (short press) the SEL button.

Keypad Functions

Key	Function
	Pressing these keys moves you forward and backward through menu items and functions, and permits you to adjust parameter values. Also use these keys to increase and decrease set point and manual output values.
W/P	When W/P is configured, pressing this key toggles between

	Workstation and Panel mode. In Workstation mode, the controller is supervised from a remote workstation via the serial communication port. In the Panel mode, the controller is locally supervised. This key is disabled when the unit is configured for workstation priority and when W/P is routed to any selection from the Gate Input List.
R/L	When R/L is configured, pressing this switch toggles between Remote (R) and Local (L) set point operation. This key is disabled when the controller is in the W mode and when R/L is routed to any selection from the Gate Input List.
A/M	Pressing this key toggles between Auto (A) and Manual (M) operation. When transferring from A to M, the bargraph indicator light automatically selects the Output Bargraph for alphanumeric display. When transferring from M to A, it selects the Measurement Bargraph. This key is disabled when the controller is in the W mode and when A/M is routed to any selection from the Gate Input List.
SEL (Short press)	A short press (200 to 300 ms) selects the next variable for display on the Lower Digital Display (alphanumeric). Also provides access to remote set point, ratio, and totalized count, when so configured.
SEL (Long press)	A long press (≥300 ms) toggles between Faceplates 1 and 2, provided they are configured and active. If only one faceplate is configured, the key performs the same functions as a short press.
TAG	Pressing this key causes the controller to exit from the faceplate display and enter the User Interface. If the controller is in W mode, this key is disabled.
ACK	In NORMAL mode, pressing this key acknowledges an alarm condition, causing the indicator to change from flashing to steady. This key is functional in both W and P modes.

Setting a P-Only Controller

1. Press the TAG button
2. “READ” will be shown on the display. Press the down ▼ button
3. When “SET” is shown, press the ACK buttons four times
4. You should see “PF” displayed at the top of the screen
5. Use the up ▲ and down ▼ arrow keys to set the desired proportional band value. Press ACK to confirm the value
6. Finally, press TAG to return the controller into operation

Setting a PI Controller

1. Press the TAG button
2. “READ” will be shown on the display. Press the down ▼ button
3. When “SET” is shown, press the ACK buttons four times
4. You should see “PF” displayed at the top of the screen
5. Use the up ▲ and down ▼ arrow keys to set the desired proportional band value. Press ACK to confirm the value
6. Press ACK again to set the controller’s integral value
7. Use the up ▲ and down ▼ arrow keys to set the desired integral value. Press ACK to confirm it
8. Finally, press TAG to return the controller into operation

Setting a PID Controller

1. Press the TAG button
2. “READ” will be shown on the display. Press the down ▼ button
3. When “SET” is shown, press the ACK buttons four times
4. You should see “PF” displayed at the top of the screen
5. Use the up ▲ and down ▼ arrow keys to set the desired proportional band value. Press ACK to confirm the value
6. Press ACK again to set the controller’s integral value
7. Use the up ▲ and down ▼ arrow keys to set the desired integral value. Press ACK to confirm it
8. Press ACK again to access the derivative setting
9. Use the up ▲ and down ▼ arrow keys to set the desired derivative value. Press ACK to confirm it
10. Finally, press TAG to return the controller into operation