Process Measurement

&

Control Applications

Labs

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1.1 Instrumentation and Control Principles

Objectives

After studying this module, you should :

1. For a given process, be able to identify the controlled and manipulated variables.
2. By sketching a simple block diagramm be able to indicate the following: setpoint, measurement, error, output and disturbances.
3. Be able to state, in writing, the difference between open and closed loop control.
4. Be able to state, in writing, the basic differences between feedback and feedforward control.

Basic Control Principles

A typical process control system consists of the following parts/components:

- An open tank which contains water supplies a prcess
- For control, it is necessary to measure the level of water
- A valve for inflow supply
- A pump at the outflow

A process has a number of variables. We must first identify the variables in our system. The two that we are most interested in our process:

- The controlled variable
- The manipulated variable

The tank will require a supply to maintain its level at a fixed predetermined point.

Control action is only necessary when a difference or error exists between the setpoint and the measured level.

Depending on whether this error is a positive or negative quantity, an appropriate control correction will be made in an attempt to restore the process to the setpoint.

Error = Setpoint - Measured Variable

or

$$e = SP - M$$

A process can be represented by a:

- open loop
- closed loop

Open Loop

If the controller is in manual, changes to the measured variable do not affect the output. An operator would have to manually change the controller output to provide corrective actions. This is termed open loop operation.

Closed Loop

The system output is monitored by a process sensor and the measurement signal is feedback to a comparator at the input of the system. The second input to the comparator is the setpoint signal; the comparator's output being the difference or error signal. The amplifier, at present just a "black box", will provide the appropriate correction to maintain the process at its setpoint despite disturbances that may occur.

<u>Feedback Control</u>

This concept justifies the use of the word negative in three ways:

- The negative aspect of feeding the measured signal backwards from the output to the input of the system. (Actual definition of negative feedback control).
- The control correction must be negative in that a correction rather than a compounding of error must occur.
- The fact that an error must occur before a correction can take place, i.e., retrospective or negative control action.

If we wish to control our process without an error first occurring, we must base our control on correction of the disturbances which will eventually cause a process error. This is termed Feedforward Control. This will be discussed fully in another module.

1.2 On/Off Control

Objectives

After studying this module, you should :

1. Given a process operating with ON/OFF control be able to briefly explain in writing, the general control operation.

2. Be able to briefly explain, in writing, why a process under ON/OFF control is not controllable at the setpoint.

3. Be able to briefly explain why ON/OFF control is suitable for slow responding processes. e.g., room heating.

There are different types of control schemes for operating a process. The most commonly used are:

- ON/OFF
- Proportional (P)
- Integral (I)
- Derivative (D)
- Combinations of PID

<u>ON/OFF Control</u>

The level in the tank changes about the setpoint from L1 to L2. The level can never stay at the setpoint since there must be a difference in the operating level L1 and L2. We will control with a "deadband" about the setpoint.

The periodic cycling is typical of ON/OFF control. If fine control is required a simple ON/OFF control system is inadequate.

Advantages:

- Simple system
- Few components

See Figure 1.1 for a practical application

ON/OFF Process

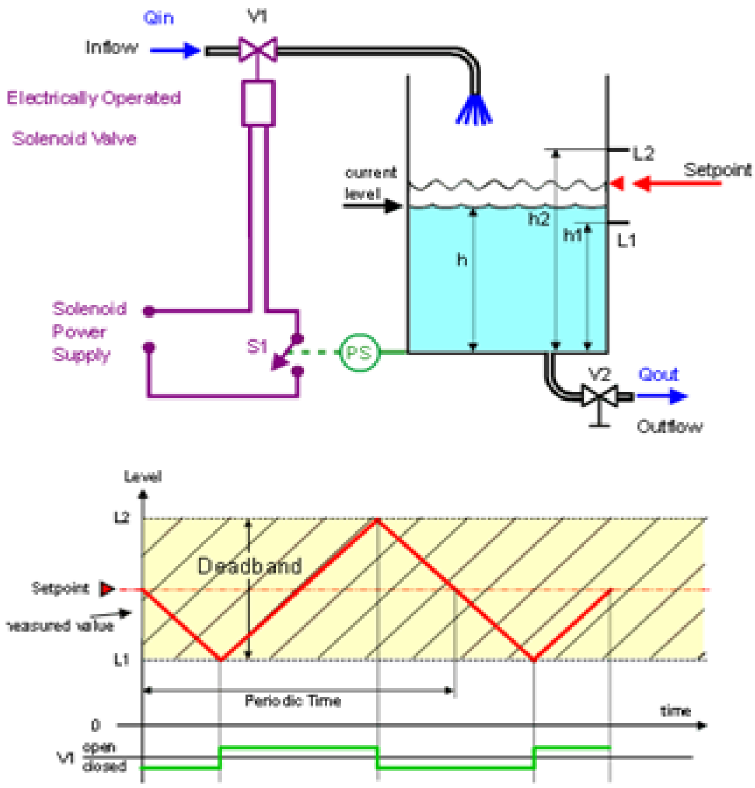


Figure 1.1 ON/OFF Process Control

Disadvantages:

- The control signal can be in one of two states only, ON/OFF, no intermediate status is possible.
- Set-point can never be maintained without a dead-band.
- Used only for large (sluggish) systems.

1.3 Proportional Controller

Objectives

After studying this module, you should :

1. Be able to explain the meaning of proportional control in terms of the relationship between the error signal and the control signal.

2. Be able to explain why OFFSET will occur in a control system, with proportional control only, which is subjected to a disturbance.

3. For a particular given equipment setup, be able to choose the controller action for corrective control.

4. Be able to convert values of PB in percentage to gain values and vice-versa.

5. For a given set of conditions, be able to determine the relative magnitude of offset with respect to the proportional band setting.

6. Be able to state the accepted system response, i.e., ¼ -decay curve, following a disturbance.

This chapter covers the basics of proportional control principles, as well as a series of terms.

In the example of on/off control it was seen that an "all or nothing" control correction was applied as the result of an error signal occurring.

It is an advantage when the control signal is proportional to the magnitude of error. This is the basis of proportional control and is the most frequently encountered control mode.

Proportional Control

A more practical proportional control scheme can be achieved by inserting a controller LIC between the level transmitter LT and the control valve V1.

To achieve the necessary control action on a falling tank level, it is necessary to convert the decreasing output of the level transmitter to an increasing control valve input signal.

The level controller will perform this function and is termed an Direct (↑↑) or Reverse acting (↑↓) controller.

Normally controllers are capable of performing either control action, Direct or Reverse, by a simple switching process.

The controller will also accept our desired input setpoint. Perform the comparison between setpoint and measurement, and calculate the errors in magnitude and direction.

In Instrumentation this adjustment of controller gain is referred to as:

Proportional Band (PB).

It is defined as the input signal span change, in percent, that will cause a hundred percent change in the output signal.

Gain can be defined as the ratio between change in output and change in input.

$$\text{gain} = \frac{\%\ \Delta\ \text{output}}{\%\ \Delta\ \text{input}}$$

Proportional Band, PB, is the reciprocal of gain, expressed as a percentage.

$$\text{gain} = \frac{100\%}{\text{PB}} = \frac{100\%\ (\Delta\ \text{output})}{\Delta\ \text{input}}$$

Small values of PB (high gain) are usually referred to as narrow proportional band whilst low gain is termed wide proportional band.

Proportional Control Process

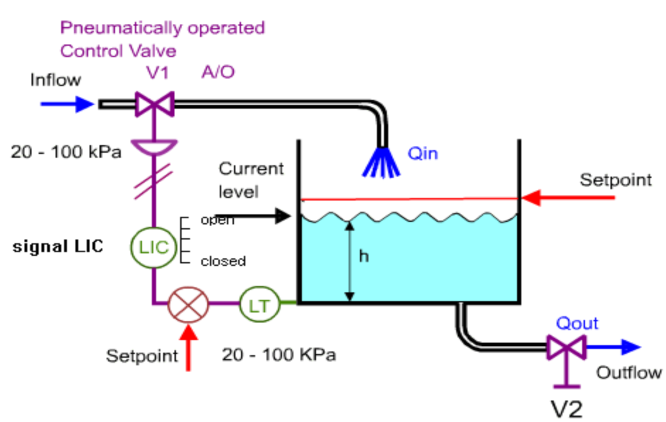


Figure 1.2 Open Tank Concept

The process response can take different shapes, the shapes depend on parameter such as Gain (PB) . The displays below show different results base on the settings.

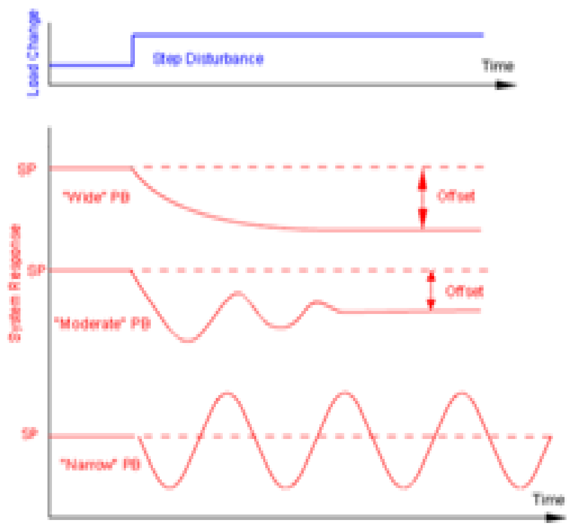
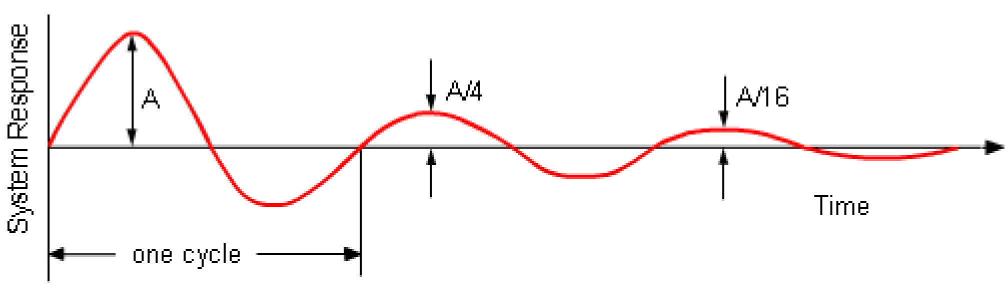


Figure1.3 Process Waveform

Quarter Decay Control Process

We previously found that neither a high or a low gain is the optimum for a controller. An optimum between highly stable and sluggish is the "1 quarter Method" (half by half)



Quarter Wave

Figure 1.4

Obviously there must be some optimum setting of PB which is a trade off between the highly stable but sluggish low gain system with large offset, and the fast acting, unstable on/off system with mean offset equal to zero. The accepted optimum setting is one that causes the process to decay in a 1/4 decay method"

The quarter decay curves show that the process returns to a steady state condition after three cycles of damped oscillation.

The output of a proportional controller is equal to:

$$m = k \bullet e$$

(m = control signal; k = controller; e = error signal = SP - M)

If the error is zero the control signal will be zero, an undesirable situation. We will need a bias value on the output to throttle the final control element when the error is zero.

Therefore, for proportional control, a constant term or bias must be added to provide a steady state control signal when the error is zero.

$$m = k \bullet e + b$$

(b = bias)

Usually= 50% added to output signal.

Advantages:

- Stabilizes an error
- Simple implementation
- Reduces offset

Disadvantages:

- Cannot eliminate offset
- Returns to ON/OFF control if gain too high
- Proper PB setting required

1.4 Reset or Integral Action

Objectives

After studying this module, you should :

1. Be able to briefly explain the reason for the use of Reset (Integral) control and its units.
2. Be able to sketch the open loop response curve for proportional plus reset control in response to a step disturbance.

3. Be able to state two general disadvantages of reset control with respect to overall loop stability and loop response if the control setting is incorrectly adjusted.

4. Be able to calculate the reset action in MPR or RPM given a control system's parameters.

This chapter explains the function of Reset (Integral) control.

If we wish to restore the process to the setpoint after a disturbance then proportional action alone will be insufficient. Integral is most often used in addition to proportional.To restore the process to the setpoint, we must increase the inflow over and above that required to restore a mass balance. The additional inflow must replace the lost volume and then revert to a mass balance situation to maintain the level at the setpoint. To achieve this additional inflow we need an additional control signal, it must be present until the error signal is once again zero. The combination of proportional plus reset action is usually referrred to as PI control.

A very slow reset rate will ramp the control signal up very slowly. Eventually the process will be returned to the setpoint. The control will be very sluggish and if the system is subjected to frequent disturbances the process may not ever be fully restored to the setpoint!

If a very fast reset rate is used, the control signal will increase very quickly.

Reset action is defined as either reset rate in:

Repeats per Minute (RPM)

or reset time in

Minutes per Repeat (MPR).

<u>Dynamic P+I Response</u>

Reset time too slow

A very slow reset rate will ramp the control signal very slowly. Eventually the process will be returned to the set-point. The control will be very sluggish. If the system is subjected to frequent disturbances, it may never be fully restored. Reset rate needs to increase.

Reset time optimal

With a proper reset time and correct proportional band setting, the process will stabilize within three cycles or less.

1.5 Rate or Derivate Action

Objectives

After studying this module, you should :

1. Be able to state, briefly in writing, the purpose of Rate or Derivative control.
2. Be able to state the units of Derivative control.
3. Be able to justify the use of Rate control on slow responding processes such as heat exchangers.
4. Using a flow loop as an example, be able to briefly explain why Rate control is not used on fast responding processes.
5. For a control system with proportional plus derivative control modes, be able to sketch the open loop response curve.

This chapter explains the purpose of Rate or Derivative Control.

Consider a control system where we will introduce a disturbance that causes the error to increase in a ramped manner. We need to provide some extra control signal related to the rate of change of the error signal. This is termed rate or derivative action and is usually incorporated with proportional control.

Rate action is an anticipatory control that provides a large initial control signal to limit the final deviation. Derivative action is a leading control and, therefore, tends to reduce the overall lag in the system, resulting in a somewhat more stable system.

Rate or Derivative Action

Flow is a fast acting process. Use of derivative would be very unstable.

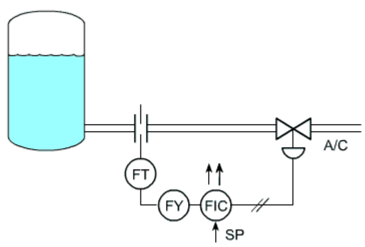


Figure 1.5 Rate or Derivative Action

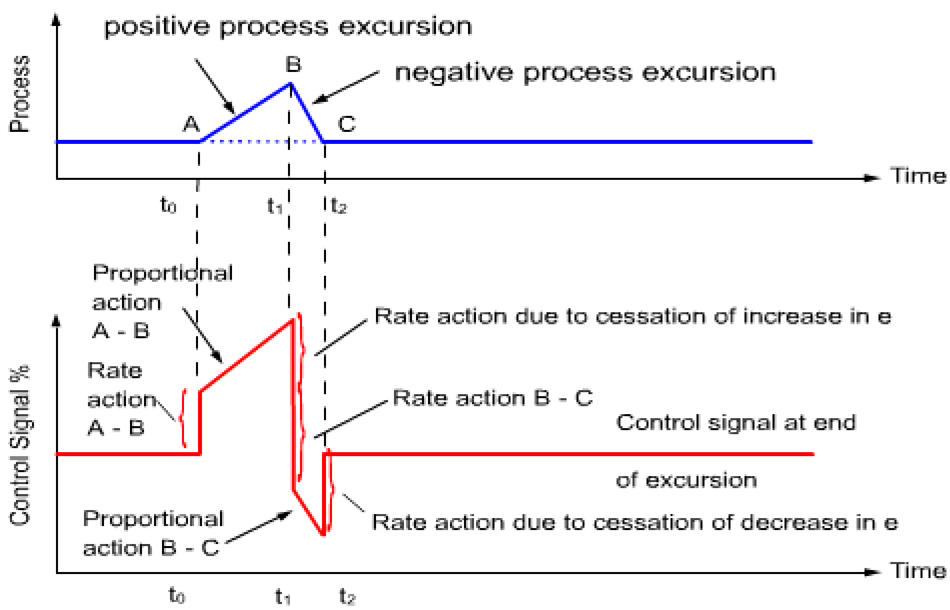


Figure 1.6 The process signal versus control signal

1.6 Multiple Control Modes

Objectives

After studying this module, you should :

1. Be able to state which combinations of the control modes discussed so far, i.e., Proportional, Proportional plus Reset, Proportional plus Integral plus Derivative, will most likely be found in typical control schemes.

This chapter explains combinations of the control modes i.e., Proportional, Proportional plus Reset, Proportional plus Integral plus Derivative.

The more common combinations are:

- P
- P + I
- P + D
- P + I + D

<u>Proportional only (P)</u>

An application of proportional only control in a Candu system is in the Liquid Zone Level Control System. The controlled variable is not level but neutron flux. The manipulated variable is the flow into the tank, therefore offset is not important as the level is manipulated to provide the required neutron flux.

<u>Proportional plus Reset Integral (P + I)</u>

The majority of control loops will use this combination. Most loops are reasonably fast acting and have no large deadtimes. Integral will return the loop to setpoint after a disturbance.

<u>Proportional plus Derivative Rate (P + D)</u>

An example is a triplicated controller scheme where the median signal controls and the low or high output signals are a backup. TS pressure control and pressurizer level control are examples in the stations. If these controllers had an integral mode, the two backup controllers would windup their outputs and not be available for proper operation on loss of the median signal.

Proportional plus Integral plus Derivative (P + I + D)

Frequently heat exchanger temperature controllers will incorporate three mode control (P + I +D). Mathematically Proportional (P) plus Intergral (I) plus Derivative (D) control is

$$m = k\left(e + \frac{1}{T_R}\int e\,dt + T_D\frac{de}{dt}\right) + b$$

expressed as (P+I+D):

1.7 Typical Control Schemes

Objectives

After studying this module, you should :

1. Be able to sketch, using standard symbology, typical control schemes for level, pressure, flow and temperature applications.

This chapter explains standard symbology, typical control schemes for level, pressure, flow and temperature applications.

Open Tank Installation

Assuming the control valve is on the inflow, the best failure mode for the valve would be to fail closed, i.e., Air to Open (A/O) valve. The pressure sensed at the base of the tank will decrease. I.e.: controller input. The valve must open more, to replenish the tank, requiring an increasing signal. The controller must be reverse acting and will usually have P + I modes.

Air to Open (A/O)

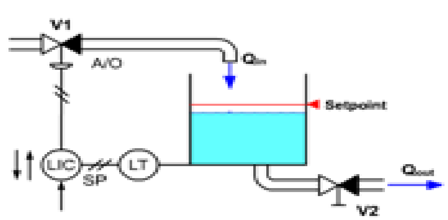


Figure 1.7 Air to Open (A/O)

If it is necessary to mount the valve in the outflow, the best failure mode would probably be to fail open (A/C). This valve action would require an increasing signal to halt a falling tank level, again a reverse acting (P + I) controller is necessary.

Air to Close

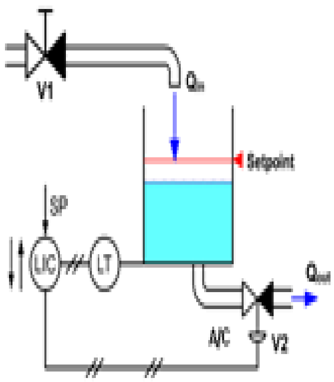


Figure 1.8 Air to Close

Flow Control

A typical flow control system requires some form of restriction to provide a pressure differential proportional to flow (e.g., orifice plate) plus a square root extractor to provide a linear signal. If an air to open valve is chosen then controller action should be reverse as an increase in flow must be countered by a decrease in valve opening. For an air to close valve the action must of course be direct. The control modes will be proportional plus integral, hence derivative on a flow control loop is never used.

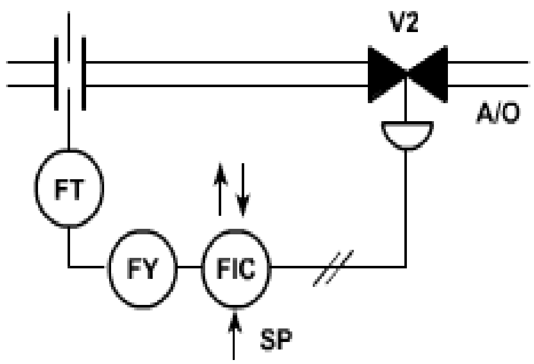


Figure 1.19 Flow Control System

1.8 Control Loop:

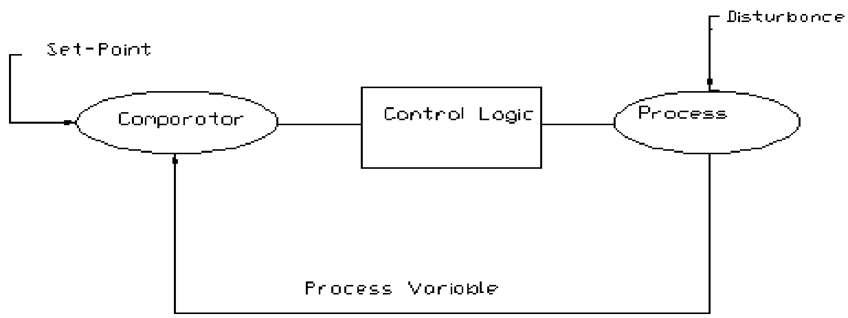


Figure 1.10 Process Control Loop

The set point: Sets the controller signal that is used to determine the value of the controlled variable. In addition the set point value will be changed from time to time by the control operator.

The comparator: Compares the set point value to the control variable value to create an error signal.

Control logic: Is the control mode that acts on the error signal to produce the desired control action.

Manipulated variable: Is the variable that is manipulated by the controller to hold the set point near the control variable. For example, in a heat exchanger, the manipulated variable is the steam.

Disturbances: A typical example of disturbance, would be a sudden change in the load (hot water) demand in a heat exchanger. This will also cause a sudden change in cold water input. In addition, any interference with the process will result in disturbance.

Process:

Steady state gain or process gain (K) = $\frac{\text{Change in output}}{\text{Change in Input (steam valve position)}}$

Change is defined as going from one steady state position to another.

Dead Time: The length of time the signal takes to travel from the input to the output.

Proportional Integral Derivative (PID) Controller

(1) Proportional is the simplest mode of control. The occurrence of a load disturbance will create an error signal, this signal will move the control valve to new position. The magnitude of the valve movement is directly proportional to the error. This method of control always leaves an offset as long as the load change persists.

(2) Integral is action more complicated; it moves the control valve as long as an error exists. Integral action works to eliminate the offset created by the proportional action.

(3) Derivative is more difficult to analyze; it moves the control valve as long as the error is changing. As soon as the error stops changing the derivative action will disappear. The amount of derivative action is set by the derivative time. Please note, derivative action should not be applied to noisy process. Furthermore, for most applications derivative is set to zero.

Process Data:

The term proportional band is quite often used to describe the characteristic of the controller. The proportional band can be thought of as the percentage full-scale change in input signal, that would cause a 100 percent change in output signal. A controller with a 20 % PB would require a 20 % change in input signal to affect a 100 % change in output signal, while a controller with a 200 % PB would change its output only 50 % if the input were changed 100 %. A PB of 20 % represents a gain of 5, while a PB of 200 % represents a gain of 0 .5.

Offset can be reduced by decreasing the proportional band of the controller [increasing the gain]. However, the limit as to how much the proportional band [gain] can be decreased depends on the dynamic characteristics of the process.

The Figure 1.11 below shows a practical approach loop control

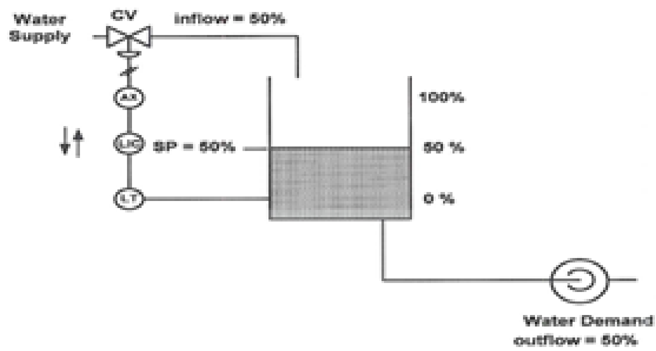


Figure 1.11

1.9 Tuning PID with Ziegler Nichols Techniques

A Pseudo analytical approach to controller tuning is to use the Ziegler- Nichols open and close loop techniques to generate the proper controller settings.

The close loop procedure is given below:

(1) Place the controller in manual mode

(2) Set the integral time (IT) to infinity (or as close as you can get to it)

(3) Set the derivative time to zero second

(4) Set the controller to auto mode and disturb the process as the proportional band is decreased until the process exhibits an oscillatory behaviour.

(5) Note the ultimate proportional band (UPB) and the ultimate period (P) of the oscillations. The period is defined as the time interval between two consecutive peaks

(6) Now you can calculate the controller settings using the relationships below

Setting the Parameters

PB: Is the proportional band

IT: Is the integral time

DT: Is the derivative time

PB = 1.7 UPB, where UPB is the ultimate proportional band

IT = 0.5 P where P is the ultimate period

DT = 0.125 P where P is the ultimate period

Process lab data used to create an ultimate cycle

Example:

Process Time Constant -1	=	100
Process Gain -1	=	1.5
process Time Constant -2	=	0
process Gain - 2	=	1
Process Dead Time	=	10 SEC.
Disturbance Time Constant	=	0 SEC.

Controller Data:

Select Auto (A) or Manual (M)

Set Point (%)	=	50
Proportional Band (%)	=	200
Integral (SEC/RPT)	=	9999
Derivative (SEC)	=	0

Process Oscillation

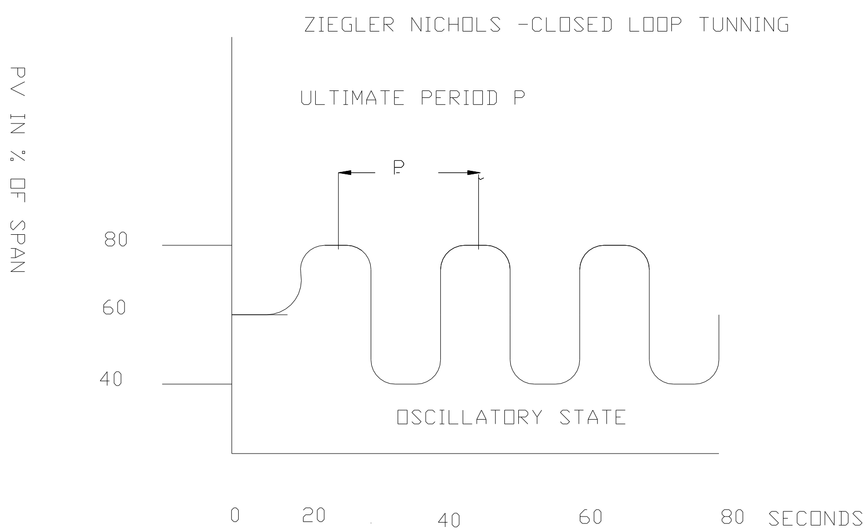


Figure 1.12 The Ultimate Cycle

1.10 Three of the most frequently used Process controllers are:

(1) Adaptive Control

(2) Feedforward

(3) Cascade Control

Adaptive controller adapts to changes in the process, and then makes the necessary changes in proportional integral and derivative (PID) to adapt to the new process. A change in process will create a dead time. Therefore, a change in the control parameters is necessary to adjust the controller to the process. The typical operation of this model is to introduce a step change in the set-point. The response from the step change will allow be observed by the controller, and a self learning process will allow the controller to repeat the process until all the adjustments meet the process requirement.

Adaptive Control

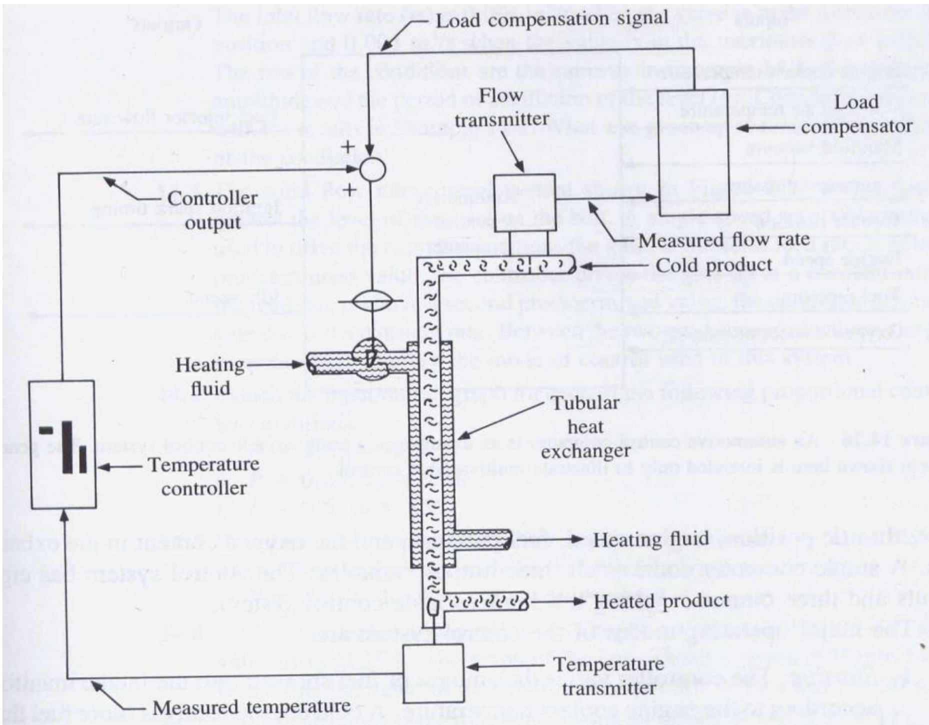


Figure 1.13 Adaptive Control

Feed-forward control is used to compensate for changes in the product flow rate by using a load compensator. See Example below.

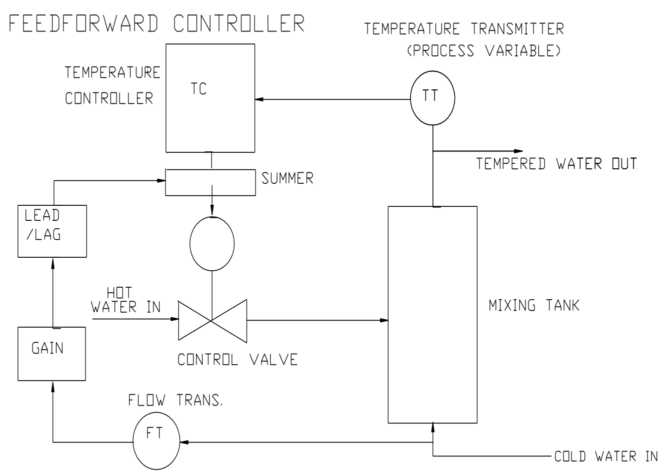


Figure 1.14 Feed-forward control

Feedforward control attempts to prevent an error occurring by using the disturbance to initiate control action.

Advantages:

- Reacts quickly
- The dependence between controlled variable and changes in disturbance can be determined

Disadvantages:

- All the possible disturbances must be known for proper implementation.
- We must be able to determine exactly how much change we will get in the controlled variable for a particular disturbance change
- Much more complicated control scheme
- The feedforward by itself is not measuring the controlled variable.

Cascade Control

Cascade control uses two controllers to regulate its output. The first controller is the primary controller, and the output from the primary controller is the set point for the second controller (secondary controller). See example and practical concept below.

Example Cascade control

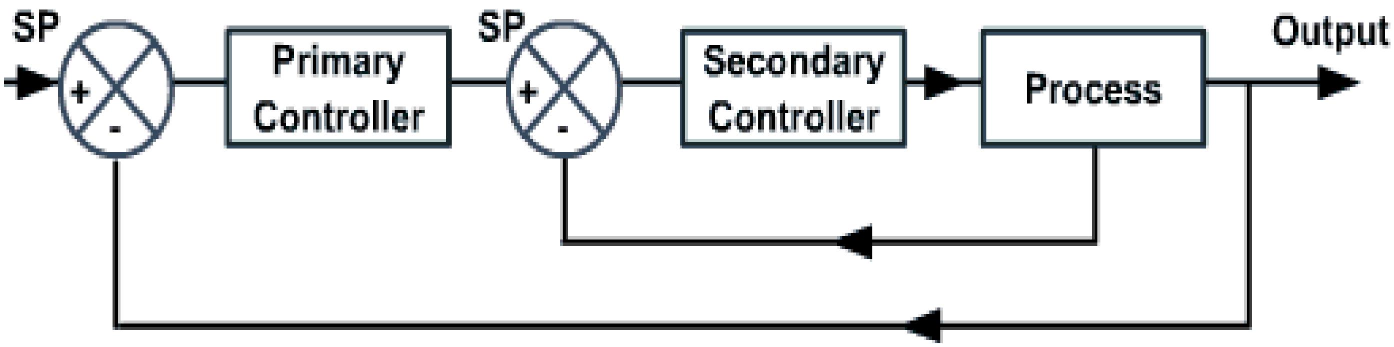


Figure 1.15 Cascade control

A Practical Concept of a Cascade Controller

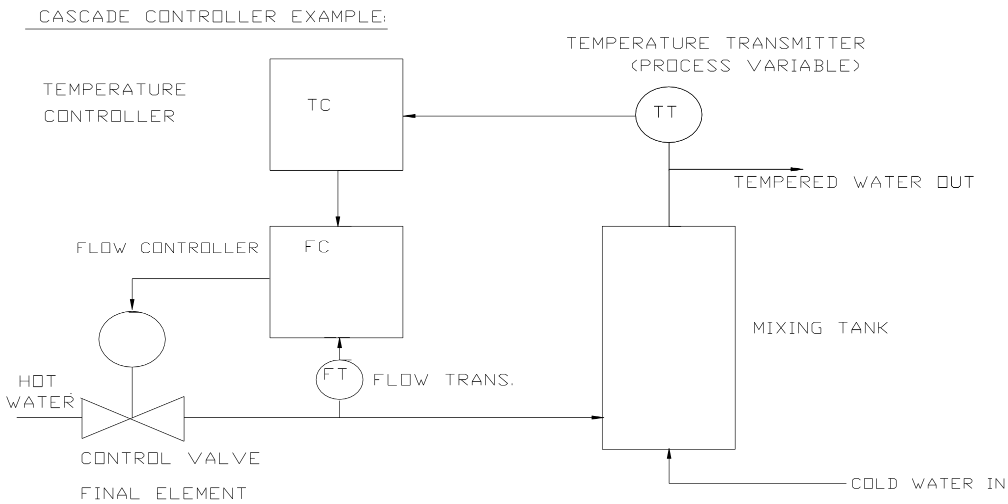


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Figure 1.16 Cascade Controller

Block diagram of Cascade Control showing one feedback loop "nested" inside a second feedback loop. The concept of nesting one feedback loop inside another feedback loop is termed Cascade Control.

For the process being controlled, find some intermediate variable (for example supply disturbances in a level loop) and control it in an in an inner loop. Cascade control is at its best when a slow process is involved. There may be a significant period before corrective action is started and once started you may have to wait a long time for results. Cascade control allows you to correct the intermediate disturbances before they affect the main process.

The primary controller will have the slower overall response time and is termed the Major Lag controller. Conversely the faster loop will contain the Minor Lag controller. A "classic" application of cascade control is for the control of heat exchangers.

The object of the primary controller is to control the temperature of the hot bleed leaving the heat exchanger by manipulating the cold service water flow. The process setpoint is therefore temperature. The intermediate variable is fluctuations in flow of the cold service water.

Section 2.0

Analog Concept & Scaling

2.1 Objectives

Terminal Objective

After completion of this module and all the assigned problems, the Trainee should be able to demonstrate how to scale various analog inputs for the purpose of PLC programming.

Enabling Objectives

During this module you will learn how to:

- Scale analog data into digital equivalent, such as bits
- Scale voltage such as +/- 10 VDC, +/- 5 VDC to represent a analog process
- Scale current such as 4 mA to 20 mA to represent a analog process
- Use scaled values to set the range of a control valve from 0 to 100%
- Use $Y = mX + b$ as mathematical tool to calculate 1% change as function of voltage.
- Use $Y = mX + b$ as mathematical tool to calculate 1% change as function of counts.
- Use $Y = mX + b$ as mathematical tool to calculate 1% change as function of current in mA.
- Use scaled values, slopes and offset to calculate input values
- Use scaled values, slopes and offset to calculate limits such as Low and high

2.2 Analog, Digital & Decimal Components of PLC

Table 2.1 PLC Data Scaling

PLC Register	Output	Output	Parameters
Decimal	0 – 10 VDC mA	KPa	KPa
O	0000 0000 0000 0000	0 VDC 4 mA	0 KPa
2047	0000 0111 1111 1111	5 VDC 12 mA	1000 KPa
4095	0000 1111 1111 1111	10 VDC 20 mA	2000 KPa

Table-2.1 shows some analog, digital and decimal components that is used in PLCs. In addition, the data shown can be scaled to perform any given task. See Scaling diagram and equations below.

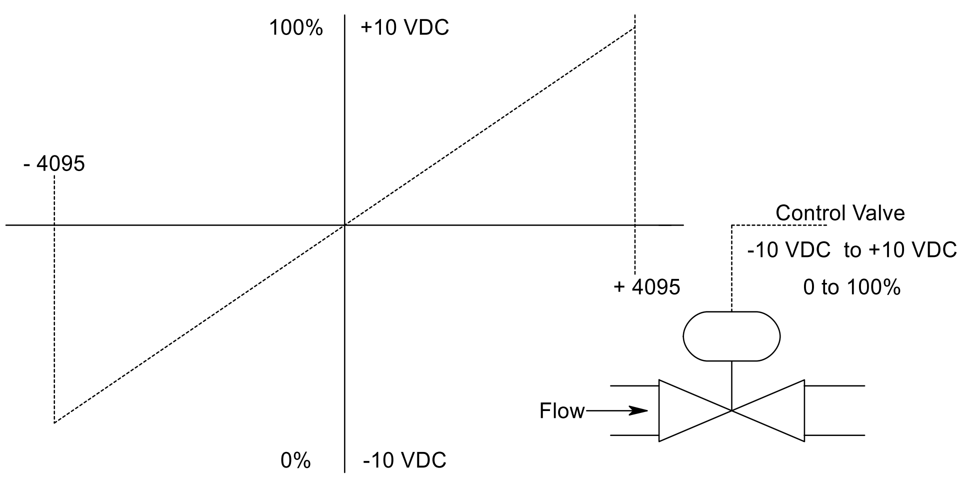


Figure 2.1 Valve Scaling

Figure 2.1 is used to shows the percentage output as it relates to control signal of +/- 10 VDC.

$$Y = (\frac{8190}{100\%}) * X + b$$

2.3 Analog Process

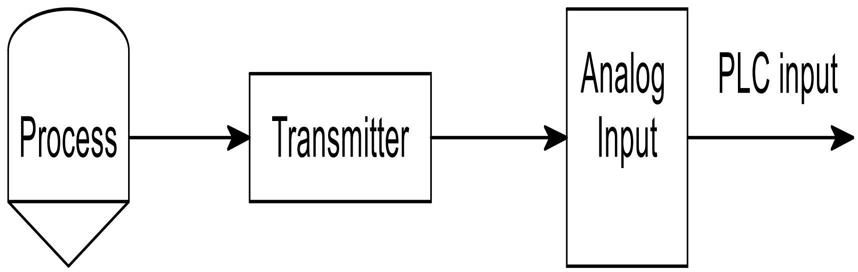
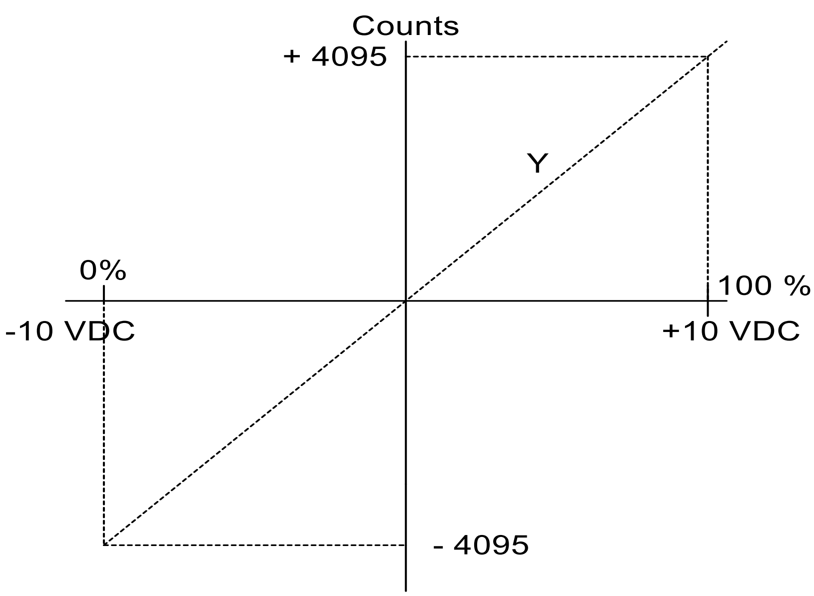


Figure 2.2. Analog Process

The above Figure shows the process of how the major components are link together to achieve a scaled input to the PLC. See Scaling equations below.



Y = mX + b

Figure 2.3 Scaling Y = mX + b

$$m = \frac{\Delta Y}{\Delta X} = \frac{4095-(-4095)}{10VDC-(-10VDC)} = \frac{8190\,counts}{20VDC} = \frac{8190}{100\%}$$

Equations showing Percentage Change in Voltage and Counts

$$Y = \frac{8190}{20} X + b, \qquad b = Y - (\frac{8190}{100\%})X, when\ X = 0$$

$$Then \quad b = -4095$$

$$1\% \, change\, as\, a\, function\, of\, voltage = \frac{20VDC}{100} = 0.2VDC$$

$$1\% \, change\, as\, a\, function\, counts = \frac{8190}{100} = 81.90\, counts$$

Percentage as function of voltage = (0.2 * percentage) – 10 VDC

Percentage as function of counts = (81.9 * percentage) – 4095 counts

Percentage change in position with respect to voltage and counts

Table 2.2 12-Bit Concept

Percentage Change	Voltage Out	Counts
0%	-10 VDC	- 4095
10	-8	-3276
20	-6	-2457
30	-4	-1638
40	-2	-819
50	0	0
60	2	819
70	4	1638
80	6	2457
90	8	1638
100	10	4095

2.4 Close Loop Process Using PLC control

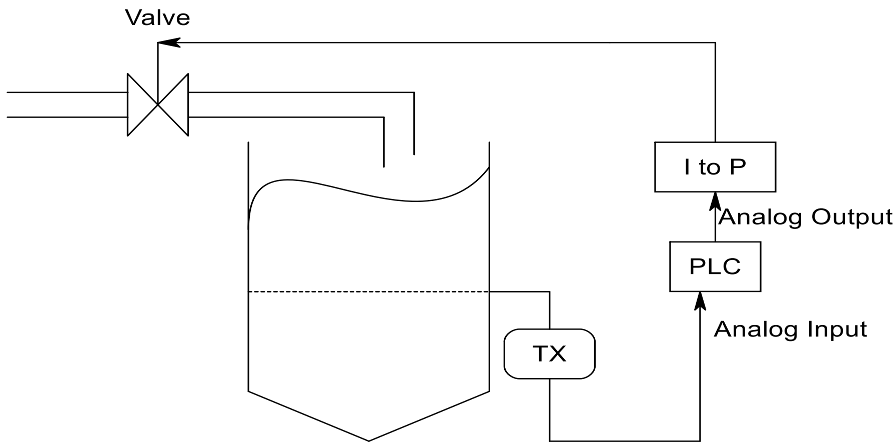


Figure 2.4 Current to Pressure

The above Figure 4 shows the general concept of using the 4 mA to 20 mA output from a transmitter to drive a control valve. The signal leaving PLC is current in mA and the signal to the valve is pressure. Therefore, we must use current to pressure (I/P) convertor to incorporate the valve.

Scaling Temperature Using SLC 500 PLC

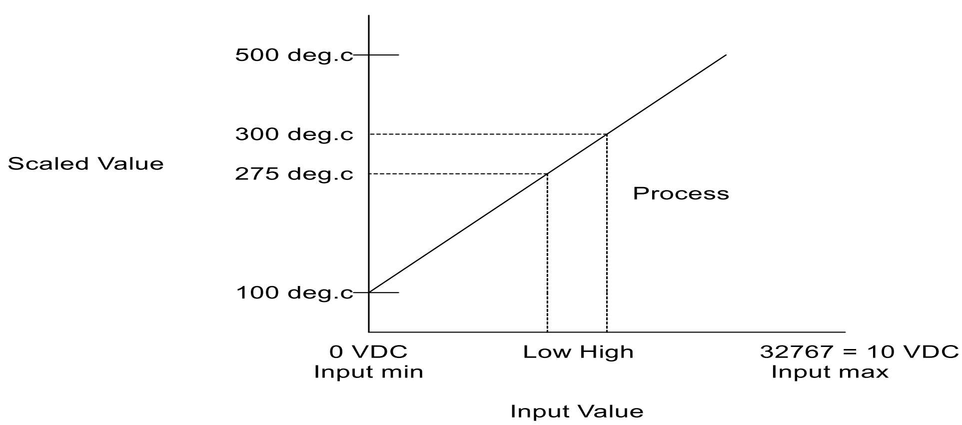


Figure 2.5 Temperature Scaling

2.5 Tabulating the Linear Relationship

The following equations are used to express the linear relationship between the input value and the resulting scaled value.

$$Scaled\ Value = (input\ value * (\frac{400}{32,767})) + 100$$

$$Slope = \frac{(scaled\ \max - scaled\ \min)}{(input\ \max - input\ \min)}$$

$$Slope = \frac{(500 - 100)}{(32,767 - 0)} = \frac{400}{32,767}$$

$$Scaled\ Offset = scaled\ \min - (input\ \min * slope)$$

$$100 - (0 * (\frac{400}{32,767 - 0})) = 100$$

$$Slope = \frac{(500 - 100)}{(32,767 - 0)} = \frac{400}{32,767}$$

$$Offset = scaled\ \min - (input\ \min * slope)$$

$$100 - (0 * (\frac{400}{32,767 - 0})) = 100$$

$$Scaled\ Value = (input\ value * (\frac{400}{32,767})) + 100$$

2.6 Calculating the Out of range Flag

The following equation is used to calculate the low and high limit. The input value is used to determine the out of range flag.

$$Input\ \ Value = \frac{(scaled\ value - offset)}{slope}$$

$$Low\,Limit\ \ = \frac{(275-100)}{(\frac{400}{32,767})} = 14,344$$

$$High\,Limit\ \ = \frac{(300-100)}{(\frac{400}{32,767})} = 16,393$$

Converting Analog Input

Table 2.3

Voltage & Current Range	Decimal Representation	Number of Significant Bits
-10V to 10V	-32768 to 32767	16 bits
0 to 10V	0 to 32767	15 bits
0 to 5V	0 to 16384	14 bits
1 to 5V	3277 to 16384	13.67 bits
0 to 20 mA	0 to 16384	14 bits
4 to 20mA	3777 to 16384	13.67 bits

Example Using SCL Instruction Adapted from Allen Bradley SLC 500

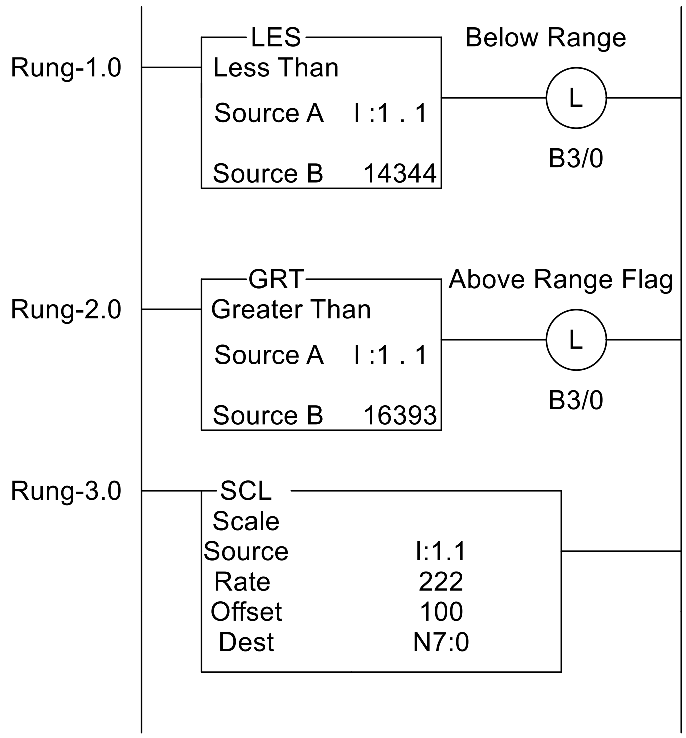


Figure 2.6 Ladder Diagram1

Lab#1 to Lab#3 Procedure:

(1) Show a graph displaying the linear relationship between the input and the resulting scale values.

(2) Show all your mathematical calculation. For example, scale value, slope, offset, low limit and high limit.

(3) Design your circuit with out of range detection for low limit and high limit.

(4) Your circuit should allow the below range flag to turn on a yellow light. In addition, your circuit should turn on a red flashing light if the above range flag is on.

(5) Your circuit should turn on a green light if the process within range

(6) Use 4 – 20 mA source as analog input to the PLC.

2.7 Close Loop Concept Using PLC, Mechanical or Electronic Controller

Lab#1 Controlling in flow and outflow

Objective: To design a PLC program, using the SLC 500, to hold the process output to 40%. Assume control process is reverse acting**.**

Apparatus:

(1) SLC 500 PLC

(2) Computer & interface cable

(3) Level Transmitter (LT)

(4) Analog combination modules: (1746-NIO4I & NIO4V)

(5) Input module: 1746-IA16

(6) Output module: 1746-OA16

$$
\begin{aligned}
MV &= SP - \frac{M - bias}{G} \\
&= 50\% - \frac{60\% - 50\%}{1} \\
&= 40\%
\end{aligned}
$$

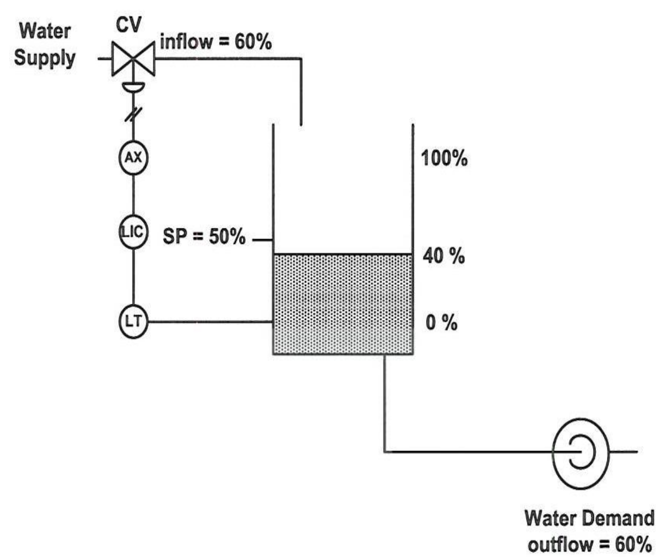


Figure 2.7 Boiler Control

Lab# 2 Introduction to closed loop process

Objective: To design a PLC program, using the SLC 500, to hold the process at 50%.

Apparatus:

(1) SLC 500 PLC

(2) Computer & interface cable

(3) Level Transmitter (LT)

(4) Analog combination modules: (1746-NIO4I & NIO4V)

(5) Input module: 1746-IA16

(6) Output module: 1746-OA16

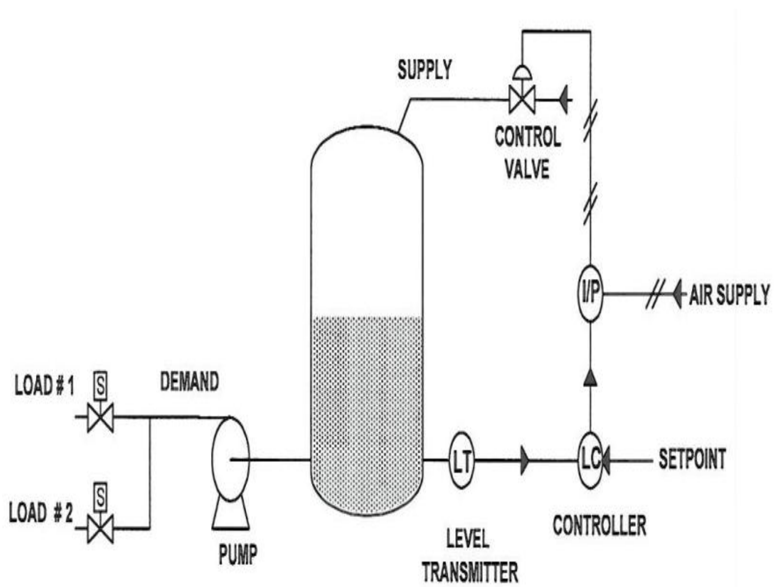


Figure 2.8 Inflow and Outflow Control

Lab #3

Objective: To design a PLC program, using the SLC 500, to hold the process output to 50%. Assume control process is direct acting.

Apparatus:

(1) SLC 500 PLC

(2) Computer & interface cable

(3) Level Transmitter (LT)

(4) Analog combination modules: (1746-NIO4I & NIO4V)

(5) Input module: 1746-IA16

(6) Output module: 1746-OA16

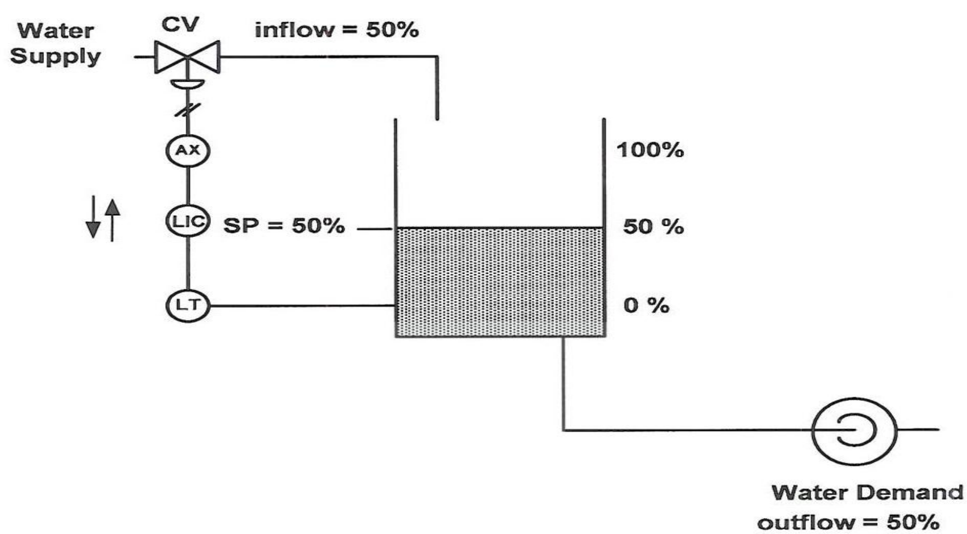


Figure 2.9 Inflow and Outflow Control

2.8 Scaling Analog Inputs 4 - 20MA for SLC 500

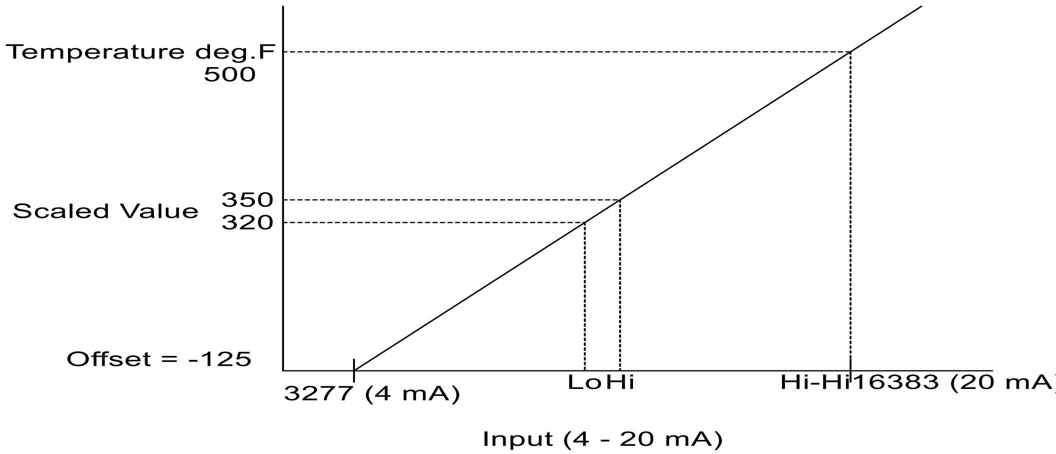


Figure 2.10 Scaling Analog Input

$$\text{Slope} = \frac{Y2 - Y1}{X1 - X2} = \frac{\text{scaled max - scaled min}}{\text{input max. - input min.}}$$

$$\text{Slope} = \frac{(500 - 0)}{(16383 - 3277)} = \frac{500}{13107} = 0.038$$

Offset = Scaled Min - (Input Min * Slope)
= 0 - (3277 * 0.038) = -125

$$\text{Input value} = \frac{(\text{scaled value - offset})}{\text{Slope}}$$

$$\text{Lo Limit} = \frac{320 - (-125)}{0.038} = 11710$$

$$\text{Hi limit} = \frac{350 - (-125)}{0.038} = 12500$$

Scaled Value = (input value * slope) + offset)
Lo = (11710 * 0.038) + (-125) = 320
Hi = (12500 * 0.038) + (-125) = 350
Hi Hi = (12578 * 0.038) + (-125) = 353

Scaling Analog Output (4 mA to 20 mA) for SLC 500 PLC

Example

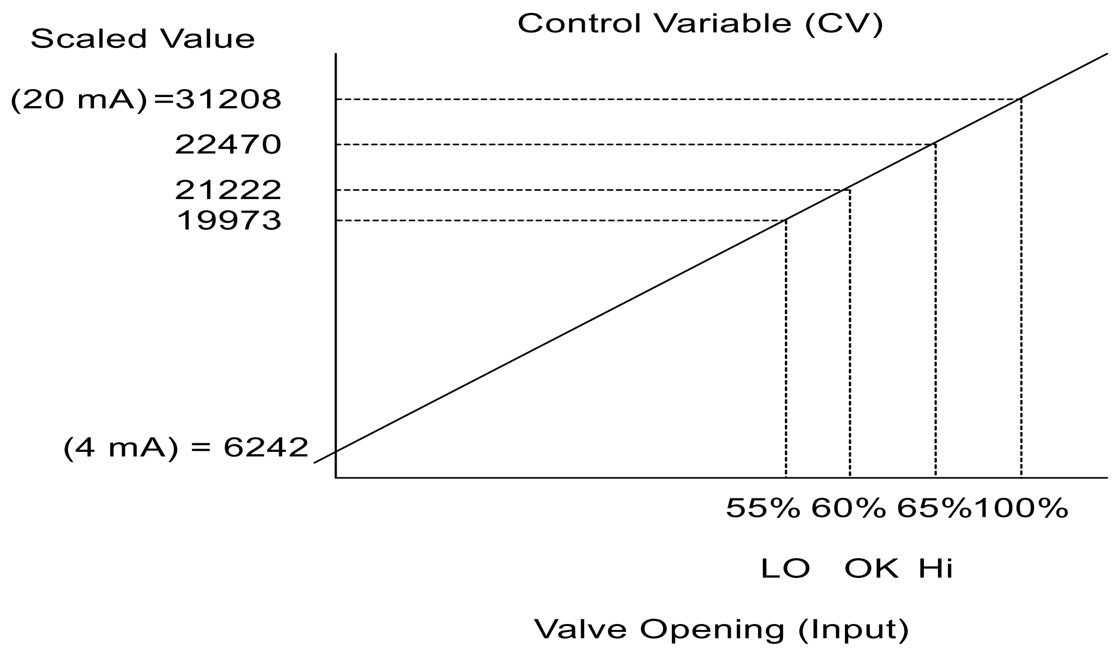


Figure-2.11 Control Valve Percentage Scaling

See Figure-4 for an overview of a close loop process using a valve.

$$Slope = \frac{Y_{\max} - Y_{\min}}{Input_{\max} - Input_{\min}} = \frac{31208 - 6242}{100 - 0} = 249.66$$

$$Offset = 6242$$
$$Scale\ Valve = (input * Slope + offset)$$
$$@65\% \quad = (65 * 249.66) + 6242) = 22470$$
$$@60\% \quad = (60 * 249.66) + 6242) = 21222$$
$$@55\% \quad = (55 * 249.66) + 6242) = 19973$$

Lab #4: Heat Exchanger

Objective: To design a PLC program, using the SLC 500, to hold the hot water output temperature between 275° and 300º C.

Apparatus:

(1) SLC 500 PLC

(2) Computer & interface cable

(3) Resistance temperature detector (RTD)

(4) Analog combination modules: (1746-NIO4I & NIO4V)

(5) Input module: 1746-IA16

(6) Output module: 1746-OA16

Heat Exchanger:

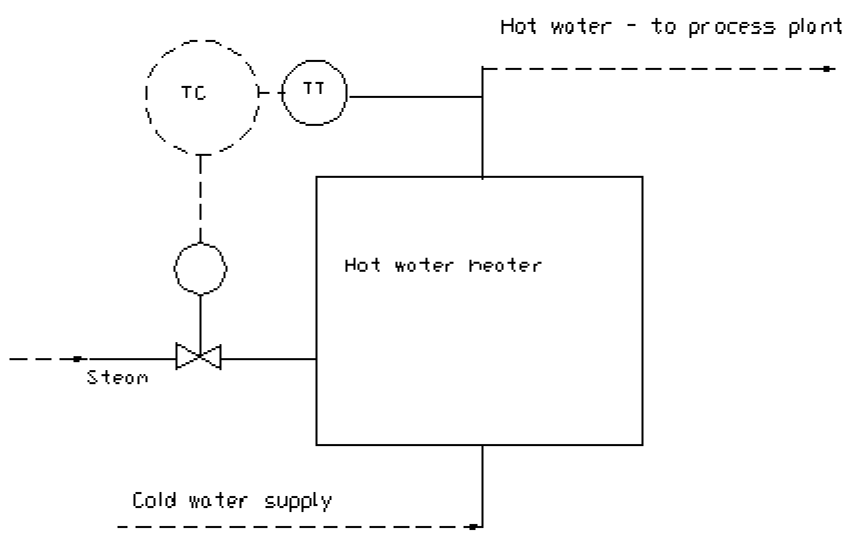


Figure-2.12 Heat Exchanger

Procedure:

(1) Show a graph displaying the linear relationship between the input and the resulting scale values.

(2) Show all your mathematical calculation. For example, scale value, slope, offset, low limit and high limit.

(3) Design your circuit with out of range detection for low limit and high limit.

(4) Your circuit should allow the below range flag to turn on a yellow light. In addition, your circuit should turn on a red flashing light if your above range flag is on.

(5) Your circuit should turn on a green light if the process temperature is between 275 and 300º C.

(6) Use 4 – 20Ma source as analog input to the PLC.

Process Module 3

Process Measurement

&

Control

3.1 Objectives

Upon completion of this module, trainees should have a working knowledge of the following:

(1) Tank suppression process

(2) Wet leg application

(3) Gas pressurized vessel

(4) Non interactive 2^{nd} order process

(5) Design and implement an Estimated model built

(6) An interactive 2^{nd} order process

(7) Using liquid dynamic to establish an integral time constant

(8) Zero suppression system with seal diaphragm

(9) Elevated zero

(10) Closed tank with seal diaphragm

(11) Flow measurement using square root extractor

(12) PID process design and implementation

3.2 Process Control Systems

Zero Suppression Concept & Calculation

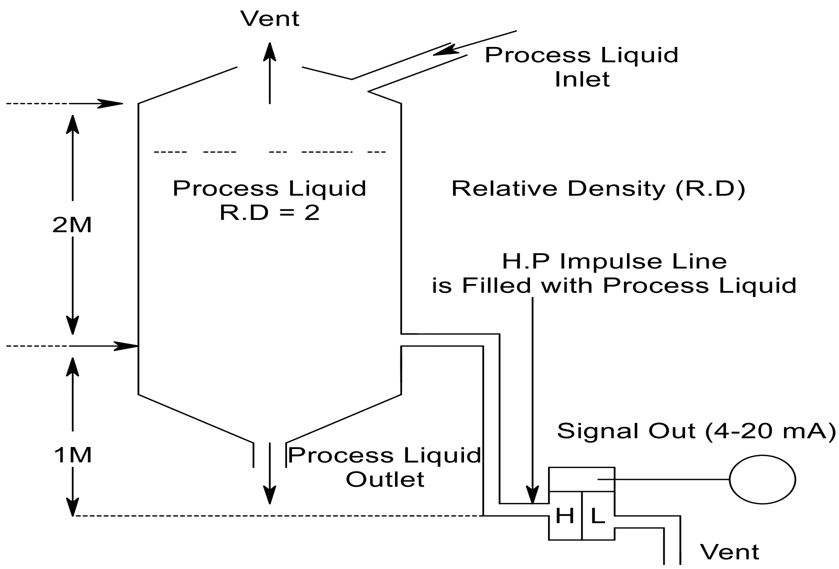


Figure 3.1 Process Tank

The process liquid on the high pressure (HP) impulse

Line = h * RD * 9.81kn/m^3

@ 0% = 1M * 2 * 9.81kn/m^3 = 19.6 KPa (Constant head)

@ 100% = (h * RD * 9.81kn/m^3) + (h * RD * 9.81kn/m^3)

= 1M * 2 * 9.81kn/m^3 + (2M *2 * 9.81kn/m^3)

= 19.6 KPa (Constant head) + 39.2 KPa (Variable)

= 58.8 KPa (0 to 58.8KPa range)

Zero suppression = 19.6 KPa

The range is the process level from 0% to 100%, while the suppression is the head of the zero level.

The transmitter is calibrated to suppress the output signal introduced by the liquid in the tank at 0% level. Therefore, if we need to know the differential pressure across the transmitter at 0% and 100% tank level, then the calculation becomes:

Solution:

0% level $\Delta P = 1M * 2 * 9.81Kn/m^3 = 19.6$ KPa

100% level $\Delta P = 19.6$ KPa + $(3M * 2 * 9.81Kn/m^3) = 78.4$ KPa

The suppressed zero range is = 19.6 KPa to 78.4 KPa

Range	=	0 to 58.8 KPa
Zero Suppression	=	19.6 KPa

Wet Leg Application

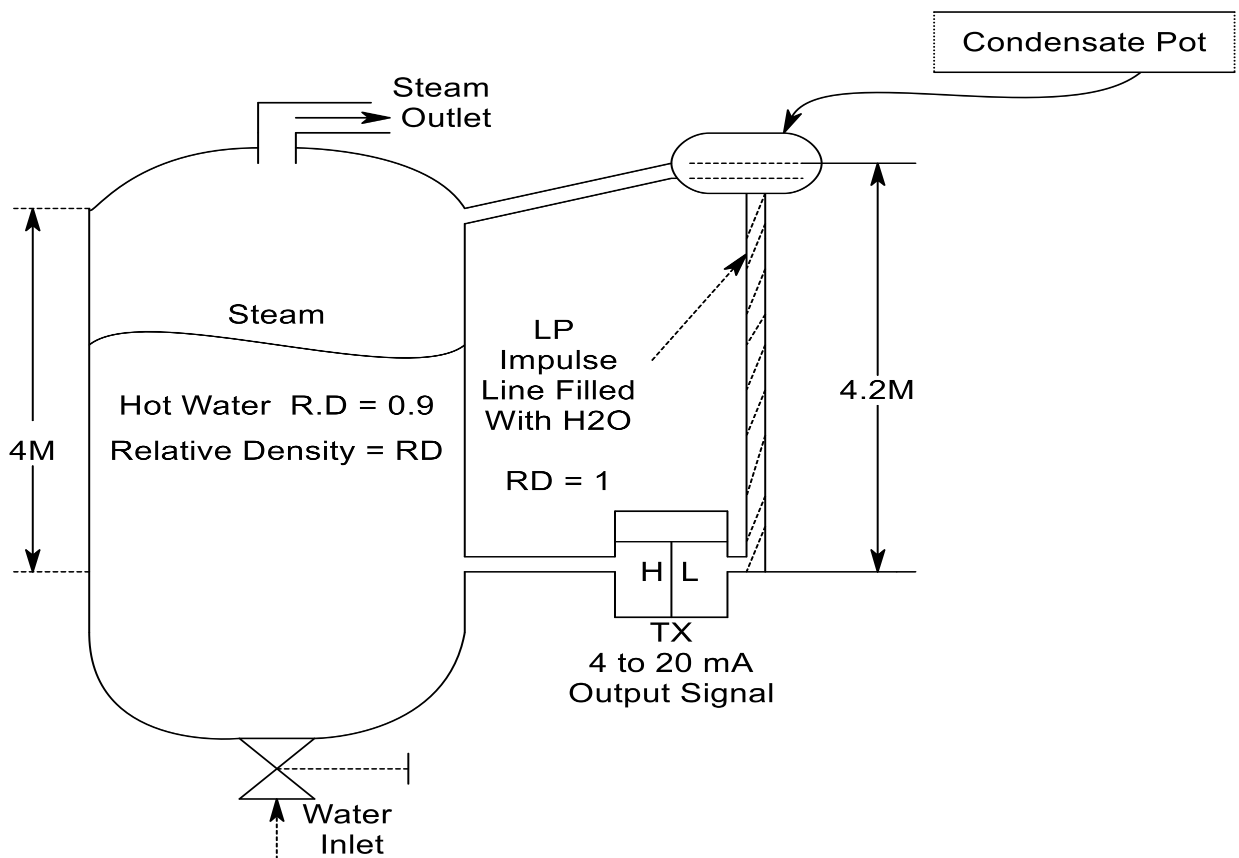


Figure 3.2 Wet leg

The steam pressure can be ignored in the case of dry leg application. The pressure applied on the transmitter at 0% level and 100% levels are as follows:

0% Level LP side = LP impulse line liquid head pressure

= h * RD * 9.81 Kn/m^3

= 4.2M * 0.9 * 9.81 Kn/m^3 = 37.081KPa

HP side = Liquid head pressure in the tank

= 0 KPa

ΔP acting on the transmitter = HP – LP = - 37.081 KPa

The highest pressure is acting on the LP side

100% level LP = LP impulse line liquid head pressure

= 37.081KPa

HP = Liquid head pressure in the tank

= 4 M * 0.9 * 9.8 Kn/m^3

= 35.316 KPa

ΔP acting on the transmitter = HP - LP = 35.316 – 37.081 = - 1.765 KPa

Note, since the highest pressure acts on the low (LP) side, then resulted in a negative ΔP value.

We can therefore calibrate the transmitter for 4 mA to 20 mA output range by applying the following pressures:

0% Level LP side has 37.081KPa

0% PH side is vented

Transmitter output = 4 mA

100% Level LP has 1.765 KPa applied

HP side is vented

Transmitter output = 20 mA

Now we can establish a calibration range from -37.081 to – 1.765 KPa

Which yields an Elevated Zero Range of -37.081 KPa to –1.765 KPa?

Gas Pressure Vessel

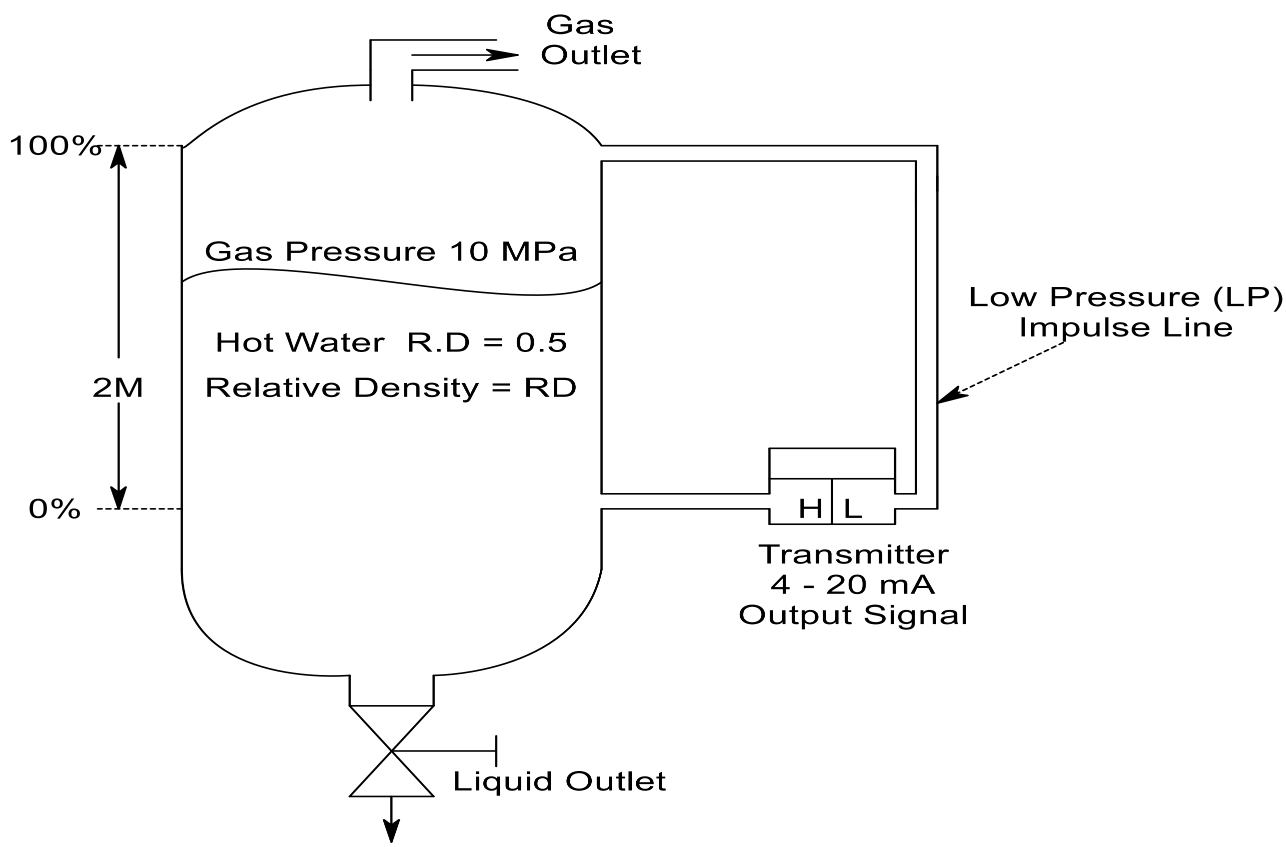


Figure 3.3 Level Measurements on a Pressure Tank

10% Level LP Pressure = 10 MPa

HP Pressure = 10 MPa

Therefore, ΔP = 0 MPa = 0 KPa

100% Level LP Pressure = 10 MPa

HP Pressure = 10 MPa + (2 M * 0.5 * 9.81 Kn/m^3)

Therefore, ΔP = 2 M * 0.5 * 9.81 Kn/m^3 = 9.81 Kn/m^3

Our calibration range of this transmitter would be: 0 KPa to 9.81 KPa

Where 4 mA = 0 KPa & 20 mA = 9.81 KPa

Pressurized Vessel

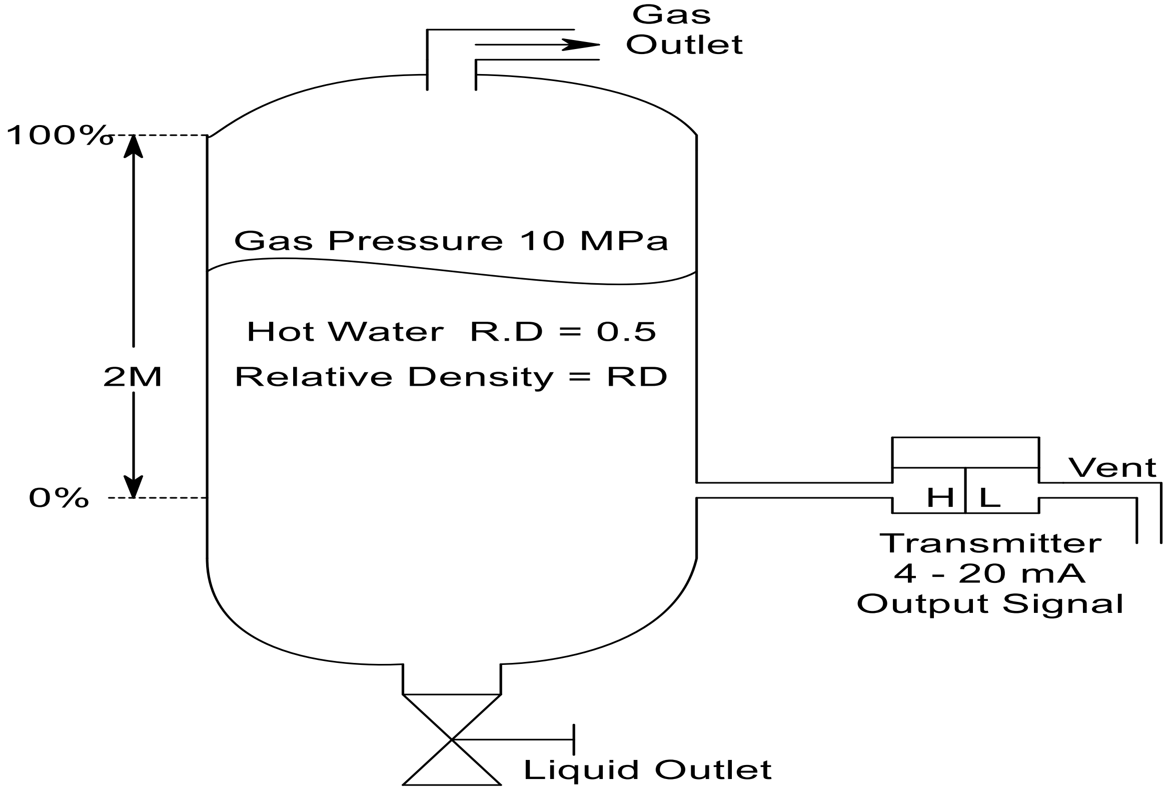


Figure 3.4 Applied Gas Pressure

HP side of transmitter = Gas pressure + liquid head pressure

= 10 MPa + (H * RD * 9.81)

= 10 MPa + (2 * 0.5 * 9.81 Kn/m^3

= 10 .00981 MPa (g)

Therefore, the delta pressure across the transmitter is 10 .00981 MPa (g)

Non-interacting second order process

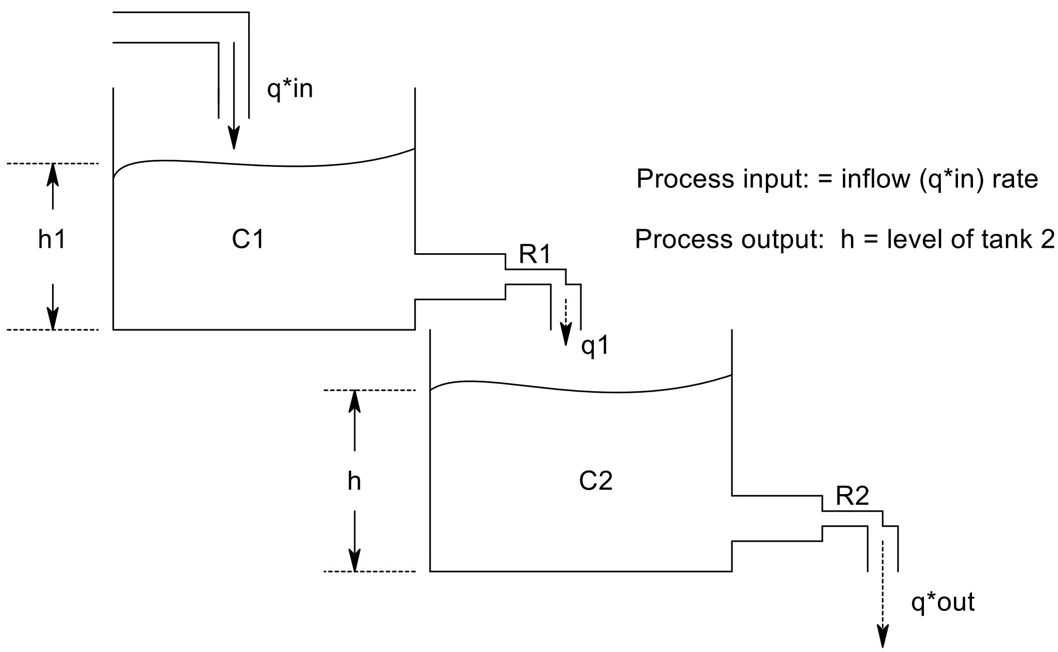


Figure 3.5

(a) Non-interacting liquid process

The time domain equation for the non-interactive with input (x) and output (y) is shown below.

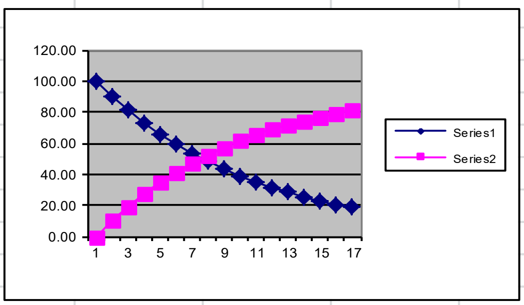
$$\tau_1 \tau_2 \frac{d^2 y}{dt^2} + (\tau_1 + \tau_2)\frac{dy}{dt} + y = Gx$$

By using hand integration we can establish an Estimate Model Built (ESB) to give us a guideline of what our real world output will look like. This will also help us to verify and validate the process before commissioning.

Table 3.1

Estimate Model Built (ESB) Data-a

Time	At = Tank A	Bt = Tank B	parm	F(t) = parm*A
0	100.00	0	0.1	10
1	90.00	10	0.1	9
2	81.00	19	0.1	8.10
3	72.90	27	0.1	7.29
4	65.61	34	0.1	6.56
5	59.05	41	0.1	5.90
6	53.14	47	0.1	5.31
7	47.83	52	0.1	4.78
8	43.05	57	0.1	4.30
9	38.74	61	0.1	3.87
10	34.87	65	0.1	3.49
11	31.38	69	0.1	3.14
12	28.24	72	0.1	2.82
13	25.42	75	0.1	2.54
14	22.88	77	0.1	2.29
15	20.59	79	0.1	2.06
16	18.53	81	0.1	1.85



(b) Non-interacting second order process

The Euler's Method of numerical solution for differential Equations is used to create the estimated model. The Euler's Method approximates the graph of f(t) by straight line: $y = yo + g(to, yo).(t - to)$. The steps are as follows:

$$yo \ (given)$$
$$y1 = yo + g(to, yo) * h$$
$$y2 = y1 + g(t1, y1) * h$$
$$y3 = y2 + g(t2, y2) * h$$

The steps continues until the change becomes minimal

Example of a zero Suppression Process

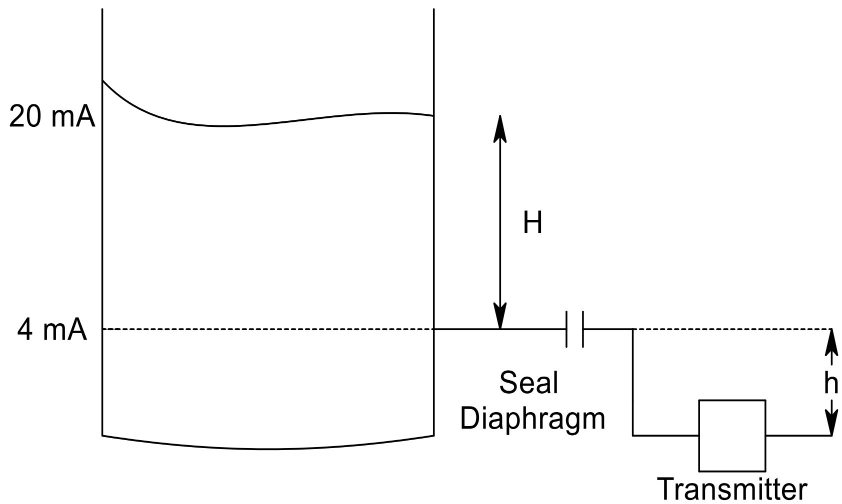


Figure 3.6 Zero Suppression System

Given:

Tank fill	Fluid fill
Sf = 0.93 in H20/inch	p = 930 Kg/m3
h = 40 inches	h = 1 meter
Sp = 1.2 inches	p = 1200 kg/m^2
H = 120 Inches	H = 3 meters
	G = 9.81 m/s

We can calculate the amount of zero suppression by multiplying the distance between the process connection and the transmitter (h) by the fill fluid specific gravity (Sf).

Imperial Units Step 1 Zero Suppression = (hs) * (Sf)

= (40 inches) * (0.93 inH2O/inch) = 37.2 inH2O

We can calculate the span by multiplying the maximum process fluid height (H) by the specific gravity of the process liquid (Sp).

Step 2 Span = (H) *(Sp)

= (120 inches) * (1.3 incH2O = 156 inH2O

Now we can calibrate the transmitter using the following equation:

Step 3 Calibration = Zero Suppression to (Zero Suppression + Span)

= 37.2 to (37.2 + 156 inH2O)

= 37.2 to 193.2 inH2O

To calibrate our transmitter we would set 37.2 inH2O = 4 mA

and 181.2 inH2O = 20mA

Using SI Units

Step 1 Zero Suppression = $\rho f * g * h$ = 930 * 9.81 * 1/100 mbar = 91.2 mbar

Step 2 Span = H * ρ_p * g = 3/100 * 1300 * 9.81 mbar = 382.59 mbar

Step 3 Calibration Data

4 mA = Zéro Suppression = 91.2 mbar

20 mA = Suppression + Span

= 91.2 mbar + 353 mbar

= 473.7 mbar

Example of an Elevated Zero Process

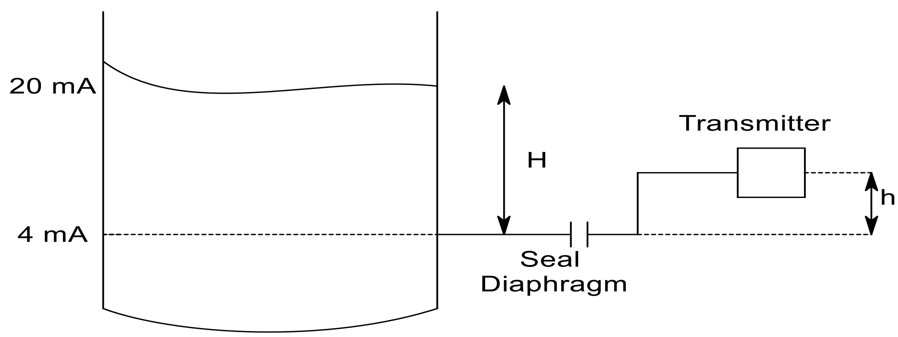


Figure- 3.7 Elevated Zero

Given:

Tank fill	Fluid fill
Sf = 1.85 in H20/inch	pf = 1850 Kg/m3
h = - 30 inches	-h = 0.75 meter
Sp = 1.2 inH2O	ρf = 1200 Kg/m3
H = 120 inches	H = 3 meters
	g = 9.81 m/s

We can calculate the by multiplying the distance between the process connection and the transmitter (h) by the fill fluid specific gravity (Sf).

Imperial Units Step 1 Zero Elevation = (-h) * (Sf)

= (-30 inches) * (1.85 inH2O/inch) = - 55.5 inH2O

We can calculate the span by multiplying the maximum process fluid height (H) by the specific gravity of the process liquid (Sp).

Step 2 Span = (H) *(Sp)

= (120 inches) * (1.2 incH2O = 144 inH2O)

Now we can calibrate the transmitter using the following equation:

Step 3 Calibration = Zero Elevation to (Zero Evaluation + Span)

= - 57 inH2O to (-57 + 144 inH2O)

= - 57 to 87 inH2O

To calibrate our transmitter we would set - 57 inH2O = 4 mA and 75 inH2O = 20mA

Using SI Units

Step 1 Zero Evaluation = $-\rho f * g * h$ = -1850 * 9.81 * 0.87/100 mbar = - 136 mbar

Step 2 Span = $H * \rho_p * g$ = 3/100 * 1300 * 9.81 mbar = 382.59 mbar

Step 3 Calibration Data

4 mA = Zero Elevation = - 136 mbar

20 mA = Zero Elevation + Span

= -136 mbar + 382.59 mbar

= 110.57 mbar

Seal Diaphragm System

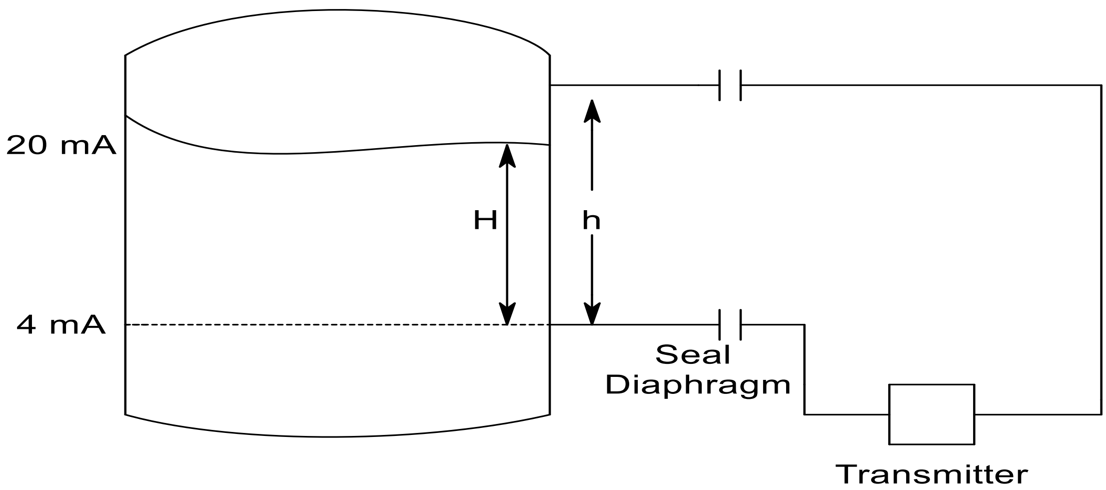


Figure 3.8 Closed Tank with Seal Diaphragm

Given:

Tank fill	Fluid fill
Sf = 1.07 in H20/inch	pf = 1070 Kg/m3
-h = - 400 inches	-h = -10 meters
Sp = 0.95 inH2O	ρf = 950 Kg/m3
H = 350 inches	H = 8.5 meters
	g = 9.81 m/s

We can calculate the amount of zero suppression by multiplying the distance between the process connection and the transmitter (h) by the fill fluid specific gravity (Sf).

Imperial Units Step 1 Zero Elevation = (-h) * (Sf)

= (-400 inches) * (1.07 inH2O/inch) = - 428 inH2O

We can calculate the span by multiplying the maximum process fluid height (H) by the specific gravity of the process liquid (Sp).

Step 2 Span = (H) *(Sp)

= (350 inches) * (0.95 incH2O = 332.5 inH2O)

Now we can calibrate the transmitter using the following equation:

Step 3 Calibration = Zero Elevation to (Zero Evaluation + Span)

= - 428 inH2O to (- 428 + 332.5 inH2O)

Step 4 = - 428 inH2O to - 95.5 inH2O

To calibrate our transmitter we would set – 428 inH2O = 4 mA

and -113 inH2O = 20mA

Using SI Units

Step 1 Zero Evaluation = $-\rho f * g * h$ = -1070 * 9.81 * 0.10/100 mbar = - 1050 mbar

Step 2 Span = $h * \rho_p * g$ = 0.10/100 * 950 * 8.5/100 mbar = 792.157 mbar

Step 3 Calibration Data

4 mA = Zero Elevation = - 1050 mbar

20 mA = Zero Elevation + Span

= - 1050 mbar + 792.157 mbar

= -257.843 mbar

3.3 Measuring Flow

Technical Square Root Extractor Application in a Flow Loop

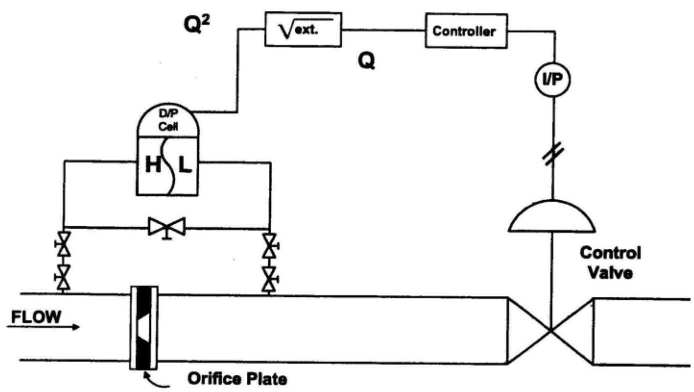


Figure-3.9 Square Root Extractor

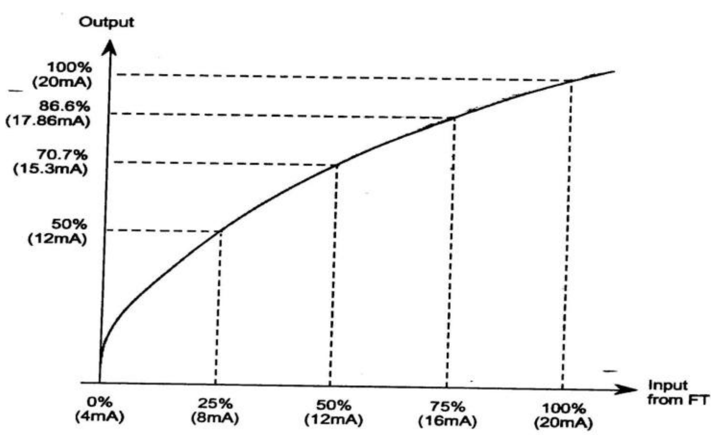


Figure-3.10 Graph of SORT extractor

The Graph of SORT extractor input % DP from FT versus % output the Figure above shows the measurement concept that utilizes a differential pressure transmitter to give an output that is proportional to the square of flow (flow)^2. The flow equation states that flow "Q" is proportional to the square root of the different pressure delta-P α Flow^2 or the Flow α (delta-P)^(1/2). In looking at the graph of differential pressure created by the flow in the pipe, we easily see that the increase is very small at low flow rates.

For example, a differential pressure of 1% will give a 10% process flow. However, for control purposes we need a linear signal to represent flow. Square Root Extractor Input & Output Calculations Requirement

There are four common signal ranges that are industry approved. They are two electronic ranges: 4-20 mA and 10-50 mA, and two pneumatic ranges: 3-15 psi. and 6-30 psi. These ranges all have a positive “Live” zero value to represent a 0% signal.

To calibrate a square root extractor we must first know what output values to expect for a set of input values representing 0 to 100% transmitter output signal. Tables B1 and B 2 show the input and output values for electronic square root extractors.

10-50 mA Loops

Table-3.2 Office Plate Measurement

10 - 50 mA Loops			
△P INPUT		**FLOW OUTPUT**	
%	**mA**	**%**	**mA**
0	100.00	0	10.00
1	10.40	10	14.00
25	20.00	50	30.00
50	30.00	70.71	38.28
75	40.00	86.60	44.60
100	50.00	100	50.00

Using Orifice Plate Measure Flow

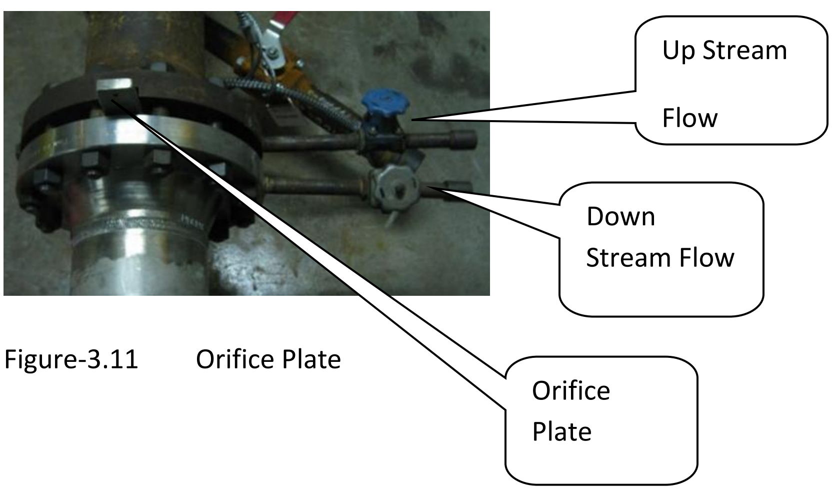


Figure-3.11 Orifice Plate

Table-3.3 4-20 mA Loops

4 - 20 mA Loops			
∆P INPUT		**FLOW OUTPUT**	
%	**mA**	**%**	**mA**
0	4.00	0	4.00
1	4.16	10	5.60
25	8.00	50	12.00
50	12.00	70.71	15.31
75	16.00	86.60	17.86
100	20.00	100	20.00

To make up the calibration values in Tables B1 & B2 the input values versus output values are calculated by:

a) Input % = $(\text{output }\%)^2$

b) Output % = $\sqrt{\text{input}\%}$

c) % signal = $\dfrac{\text{signal value - live zero}}{\text{signal range}}$

d) Signal value = (% signal value x signal range) + live zero

Monitoring Flow

Lab # 1

Assume you are a new graduate, and your first job is with the City Water Authority. Your first project as an Engineer is to remotely monitor the flow various water supply tank. This process is known as Supervisory Control and Data Acquisition (SCADA). If the percentage output of the square root extractor is 70.7% and the output signal range is 10 – 50 mA. Calculate the square root extractor output signal to be remotely transmitted through Radio, or internet to a central monitoring station. See Figure 3.12 below.

Design a PLC program to monitor the process, and to enable a flashing red light at the monitoring station, if the percentage output of the square root falls below 70.7%. The flashing light must maintain at one second on, and a one second off for period a of 15 minutes before it can be reset.

Lab #1 to Lab #3 Procedures:

(1) Show a graph displaying the linear relationship between the input and the resulting scale values.

(2) Show all your mathematical calculation. For example, scale value, slope, offset, low limit and high limit.

(3) Design your circuit with out of range detection for low limit and high limit.

(4) Your circuit should allow the below range flag to turn on a yellow light. In addition, your circuit should turn on a red flashing light if the above range flag is on.

(5) Your circuit should turn on a green light if the process is within range

(6) Use 4 – 20Ma source as analog input to the PLC.

Controlling the Flow

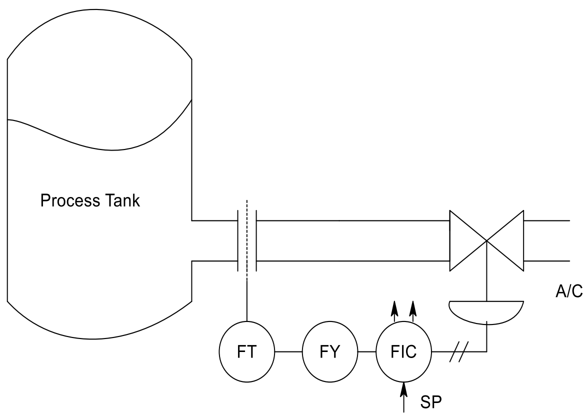


Figure 3.12   Square Extractor Process

Lab #2

If the output of the square root extractor in Figure 12 is 86.6%. Calculate the percentage input signal to the square root extractor. Design a PLC program to enable a flashing yellow light, if the output flow is less than 17.86 mA, and red light if the output flow is less than 12 mA. Assume the process signal range is 4 mA to 20 mA. Show all scaling values.

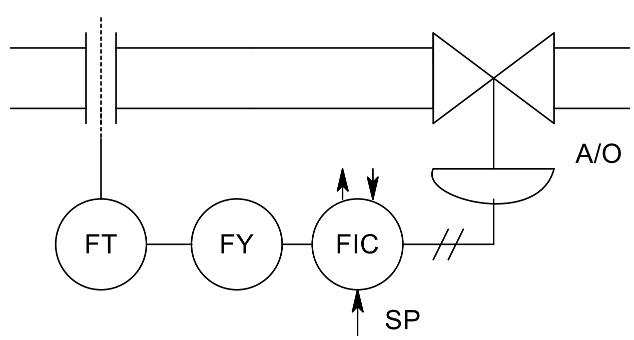


Figure 3.13 Flow Control Process

3.4 PID Process

LAB # 3

A PID controller has the following parameters: P = 4.5, I = 1/6 1/s, D = 0.5 s, vo = 10%.

$$v = Pe + PI\int_0^t edt + PD\frac{de}{dt} + vo$$

The integral term $\int_0^t \frac{de}{dt}$ is the net area under the error from 0 to t seconds, while the term $\frac{de}{dt}$ is the slope of the curve at any given instant in time. Let us assume a net area of 2.5%/s and a slope providing and error of 5% at t = 5 Sec. V = 4.5e + 0.75 $\int_0^t edt$ + 2.25 $(\frac{de}{dt})$ +10. Note, net area = e * t = (5 * 5)%

V = (4.5 * 5) + (0.75 * 2.5) + (2.25 * 0.5) +10 = 35.5%

Design a PLC program to emulate the above process. Assume the process is direct acting and the derivative action is 0. The mathematical approach to the PID controller can be expressed as:

Output = $G(e + K_i \int edt + K_d \frac{de}{dt}) + bias$

Where G = Gain, K_i = Reset in repeats per minutes, K_d = The derivative setting in minutes, e = error in %, for direct acting e= (MV – SP), while reverse acting e = (SP – MV). In addition, $\frac{de}{dt}$ = the rate of change of the error in %/min. See Figure below.

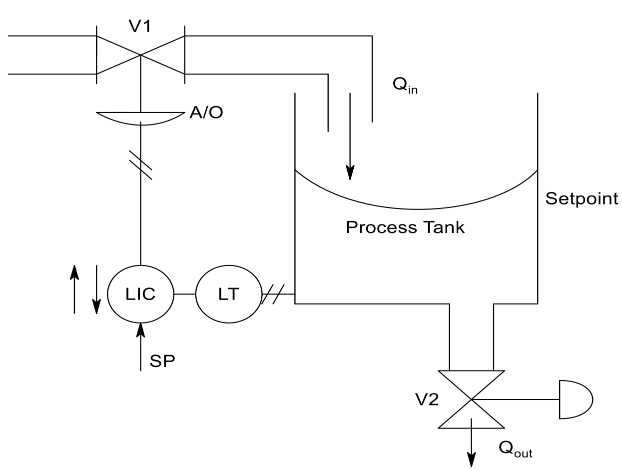


Figure 3.14 Level Control

Lab #4

As a System Engineer your job is to replace a aging mechanical controller with a PLC. By using a PLC system we can incorporate process pumps and other equipment that is apart of the same process.

The controller proportional band is set at 40%, the reset rate is set at 2 Minute per reset, and the set point set at 50%. The Chief System Engineer would like you calculate the controller output if a disturbance occurs, and causes the measure variable to rise to 56% over a period of 4 minutes. Assume the controller is direct acting.

Solution:

$$Output = G * e + K_i \int edt + bias$$

$$= \frac{1}{40\%}(MV - SP) + \frac{1}{40\%} * (\frac{0.5\,resets}{\min} \int [(MV - SP] + 50$$

$$= 2.5(56\% - 50) + 2.5 * (\frac{0.5\,resets}{\min} \int [(56\% - 50\%] + 50$$

$$= 2.5(6\%) + 2.5 * 0.5 * 6\% * 4 + 50\%$$

= 0 95%

Write a PLC program to control the process described above.

Lab #5 to Lab #9: use the data given to develop a calibration sheet for the transmitter. See Appendix-A for a reference sheets. Write a PLC program to show how each process can be controlled using the 4 mA to 20 mA. The transmitter provides the input signal to the PLC. In addition, set a high range flag for each process at 55% and a low range flag for each process at 45%. Show all your scaling and calculation.

3.5 Open Tank Concept

Lab #5 Open Tank Concept

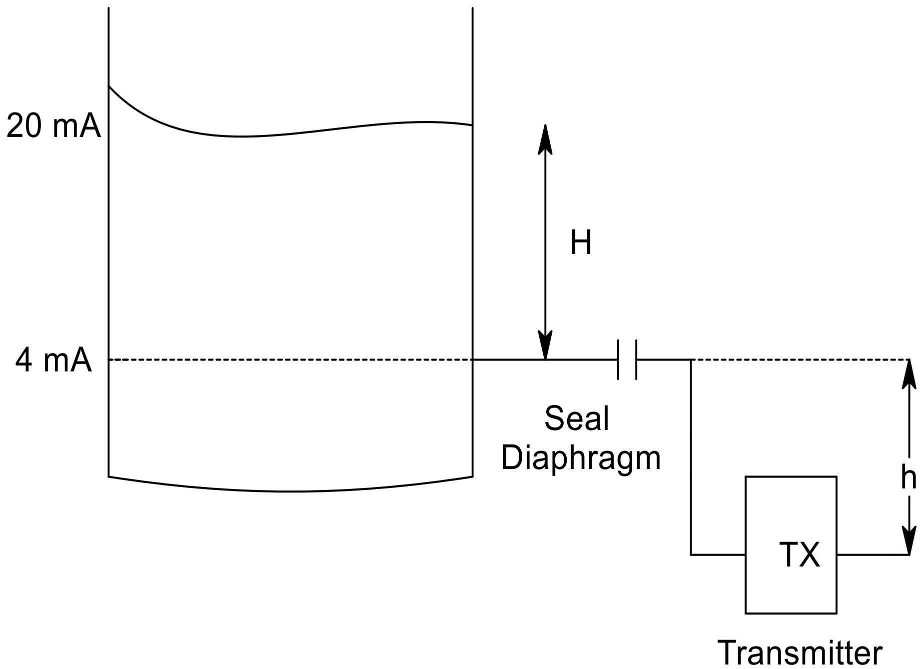


Figure 3.15 Seal Diaphragm

Given:

Tank fill	Fluid fill
Sf = 0.93 in H20/inch	p = 930 Kg/m3
h = 40 inches	h = 1 meter
Sp = 1.2 inches	p = 1200 kg/m^2
H = 120 Inches	H = 3 meters
	G = 9.81 m/s

Lab #6

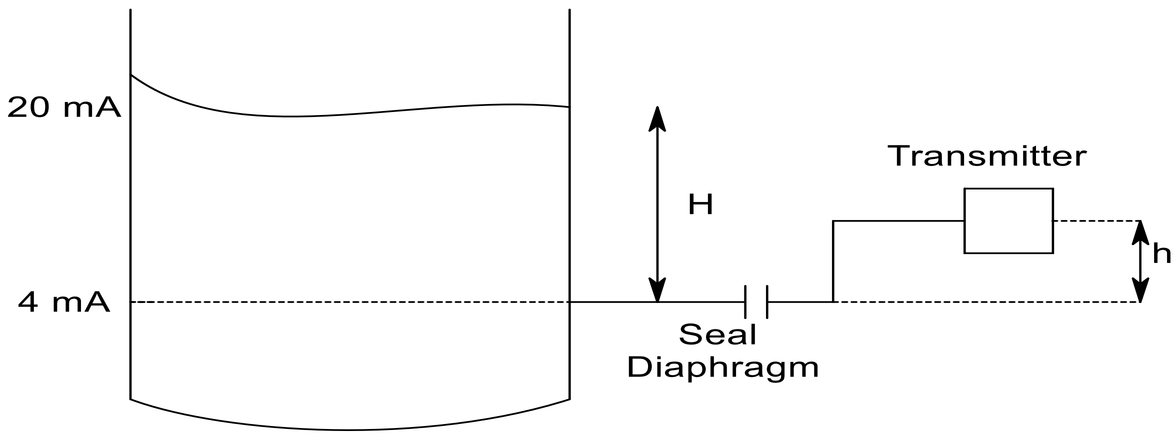
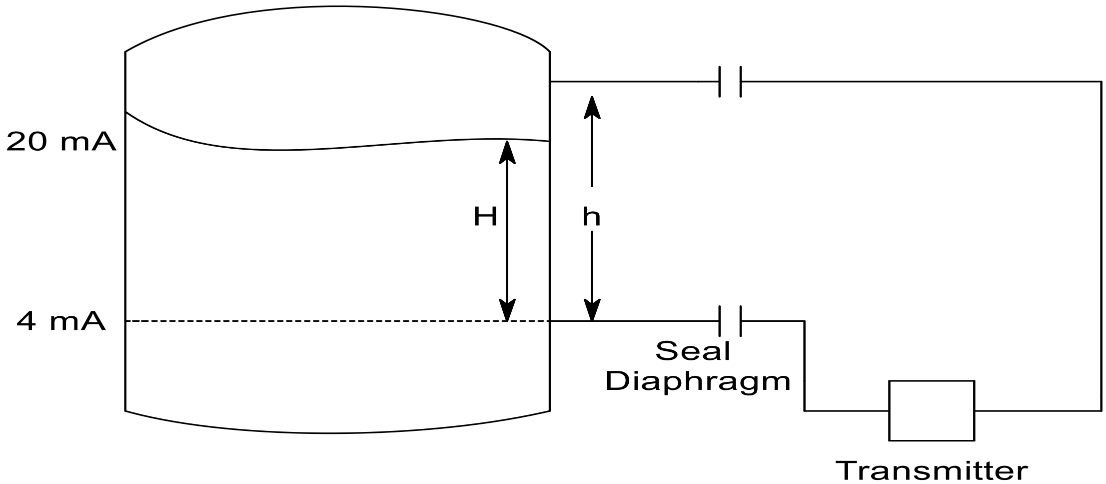


Figure 3.16 Open Tank Seal Diaphragm

Given:

Tank fill	Fluid fill
Sf = 01.9 in H20/inch	p = 1900Kg/m3
h = - 40 inches	h = 0.75 meter
Sp = 1.1 inches	p = 1100 kg/m^2
H = 120 Inches	H = 3 meters
	G = 9.81 m/s^2

Lab #7



3.6 Close Tank Concept

Figure 3.17

Given:

Tank fill	Fluid fill
Sf = 1.07 in H20/inch	p = 1070 Kg/m3
h = 400 inches	h = -10 meter
Sp = 0.9 in H2O	p = 900 kg/m^2
H = 350 Inches	H = 8.5 meters
	G = 9.81 m/s

3.7 Suppressed Zero

Lab #8

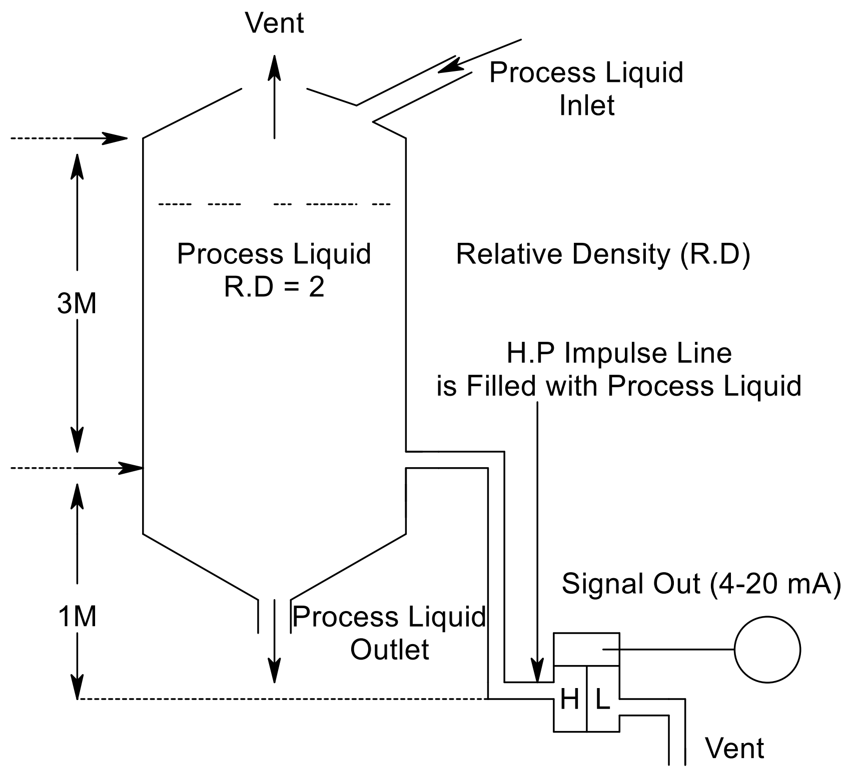


Figure-3.18 Suppressed zero

Using the parameters given, calculate the ΔP across the transmitter in Figure-17 at 0% and 100% tank level. Bear in mind that in order to calculate the correct output signal from 0% to 100% liquid level, it is necessary to suppress (adjust zero down) the HP impulse line head. This must be down during the calibration process of the transmitter.

Write a PLC program to control the tank level at 70%, if the tank level increases to 80%, then show a flag to indicate a high level. In addition, if the level drops below 65% then show a flag indicating a low condition.

Note, Suppressed Zero Range is a range in which the zero valve of the measured variable is less than the low value

3.8 Boiler Feed Water Flow Control Process

Lab #9

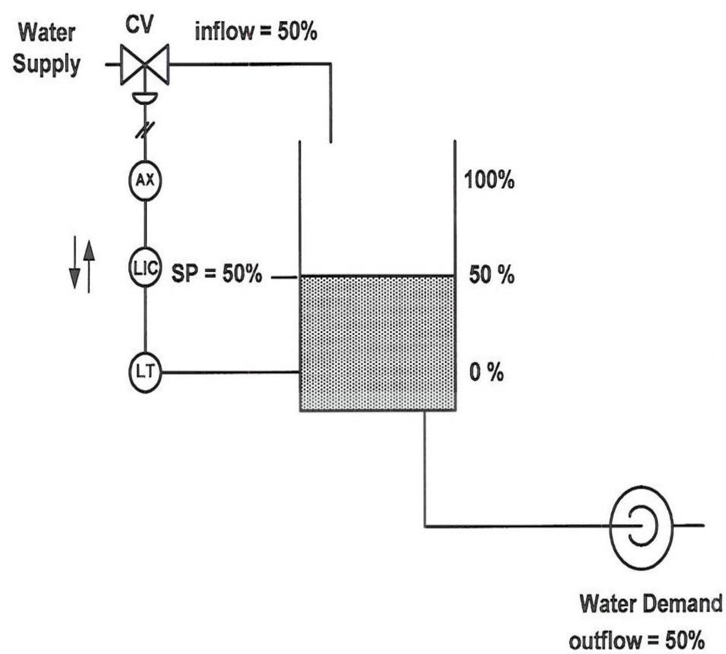


Figure 3.19 Boiler Feed water Control

See calibration & setup procedure for Duplex level controllers below.

Use Arduino to measure the process outcome

The objective is to write program for the Arduino board to bring on a yellow LED light when the liquid in Tank-1 drop to 25 %, turn on a green LED light at 50 % and turn a red LED light at 75 % of the total water column. This can be down by lowering or raising the liquid level in the tank.

Field Calibration/Alignment of Proportional & Proportional Plus Reset.

Duplex level controllers contain two separate controller mechanism in the same instrument. Each controller mechanism must be adjusted & calibrated separately.

Step-1	**SET** Proportional Band (PB) to 100%
Step-2	Set: Reset Rate index to 6 (open position), then **ADJUST** Control Index (Set-point) for maximum output pressure. Now check for air leak and repair as required.
Step-3	Fill up displacer chamber with de-mineralized water until level side glass reads or poly-flo tubing at 50% or mid-range.
Step-4	**ADJUST** Control setting index (Set-point) for 60 KPa (9 PSI) output.
Step-5	**KEEP** output 60 KPa (9PSI) for 30 seconds, **THEN** set **RESET RATE** index at white dot (closed position) to lock the 60 KPa (9PSI) bellows.
Step-6	**MONITOR** output pressure for 1 minute, if output falls, **THEN** check for air leak in reset circuit.
Step-7	IF output pressure increase, then the resistance unit is passing air to the reset bellows.
Step-8	Ensure Control Index (Set-Point) is at 5 (mid scale on the older controller)
Step-9	**ADJUST** micrometer to obtain 60 KPa (9 PSI) output if required
Step-10	**ENSURE 50%** water level is in the displacer chamber/poly-flo side glass
Step-11	The output should be linear from 20 KPa (3 PSI) to 100 KPa (15 PSI)
Step-12	**PERFORM** calibration check of the controller by **RASING & LOWERING** the water level by 25%
Step-13	Check proportional band responses by **SETTING** the PB to 50%
Step-14	**RAISE & LOWER** the water level in the displacer by 25%
Step-15	Log your readings

Step-16 Return the controller settings to the As Found state if readings are Acceptable

Table 3.4 **Direct Acting**

% Actual Level	Transmitter Output Expected KPa	Transmitter Output Actual KPa
0	20	
25	40	
50	60	
75	80	
100	100	

Transmitter Output Expected KPa Up ↑

% Actual Level Up ↑

Table-3.5 **Reverse Acting**

% Actual Level	Transmitter Output Expected KPa	Transmitter Output Actual KPa
0	100	
25	80	
50	60	
75	40	
100	20	

Transmitter Output Up ↑ Valve Opening ↓

Decrease

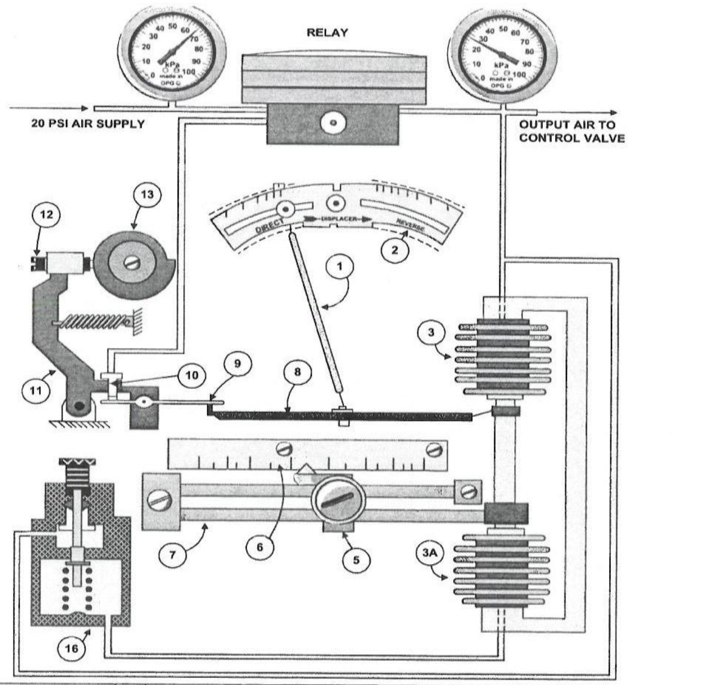
Controller Loop prior to offset condition is:

M = G * (SP - MV) + bias

1 * (50% - 50%) + 50

= 50%

Mechanical Controller

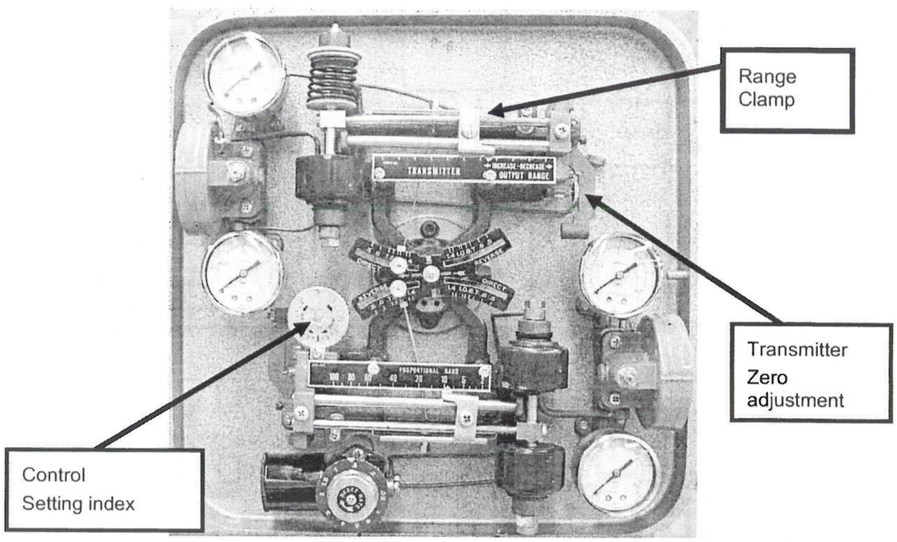


1	control link	5	PB clamp	9	Flapper	13	Control setting cam
2	reversing arc	6	PB scale	10	nozzle	16	resistance unit
3	proportional bellows	7	proportional spring	11	nozzle bracket		
3A	reset bellows	8	control arm	12	alignment micrometer		

Masoneilan 12812 Functional Schematic (Single Unit)

Figure 3.20 Masoneilan Controller

Dual Controller (Direct & Reverse)



Transmitter Zero and Span, Controller Control Setting Index

Figure 3.21 Dual Process Controller

3.9 Simulating the Process

Lab #10

Assemble circuit shown below

Parts: 1 X Transmitter (TX), Clear hose to a match available tubing, 2 x Valve (1/2”),

1 X drain valve, fluke and fittings as required,

Given: Transmitter range 0 -180 inches H2O

- Calibrate the TX to operate within a range of 0 – 100 inches H2O to correspond to 4-20mA
- Fill the tall hose with 100 inches H2O, and the short hose 50 inches of water.
- Valve in the tall hose and then read your output in mA.
- Valve in the short hose and then read your output in mA. Now measure TX output (mA) when water level in the tall hose is at 0, 25”, 50”, 75” & 100”. Reading should match your calibration sheath. Notes: calibration error should be within 0.003 of the desired value.

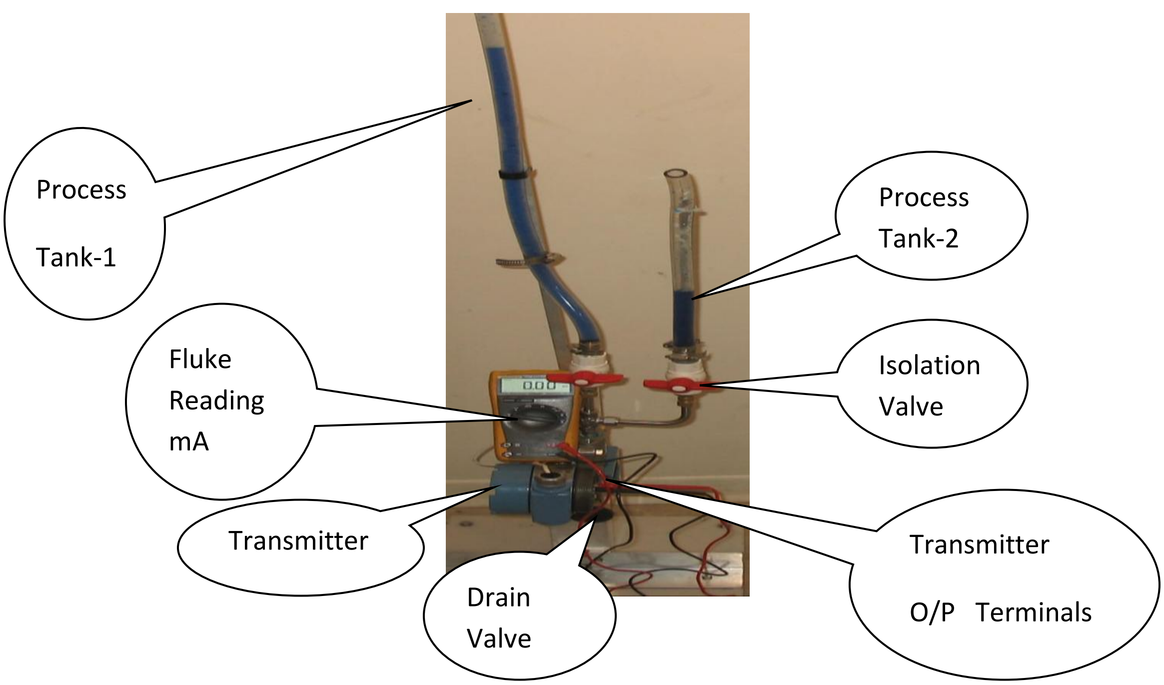


Figure 3.22 Measuring the process

Use Arduino to measure the process outcome

The objective is to write program for the Arduino board to bring on a yellow LED light when the liquid in Tank-1 drop to 25 %, turn on a green LED light at 50 % and turn a red LED light at 75 % of the total water column. This can be down by lowering or raising the liquid level in the tank.