Introduction

Electronic controllers provide a method to control process quality or quantity, or both.

At the conclusion of this training unit the trainee should be able to:

Describe the features, operation, and use of electronic controllers.

Following this objective, you should be able to:

Recall typical features, general operation, and typical uses for electronic controllers.

Relate how electronic controllers aid in controlling processes.

Identify the effect improperly calibrated electronic controllers have on plant equipment.

At the conclusion of this training unit the trainee should be able to describe common features, typical operation, and proper use of electronic controllers and relate these principles to their individual job. Trainees may be evaluated by completing a written exam comprised of questions from this training unit and others included in this course. A minimum of 80% accuracy is required to satisfactorily complete this training.

Introduction

A. General Purpose / Typical uses

1. Typically, an electronic controller is used to control plant processes. Except in some cases (as in explosive atmospheres) electronic controllers have replaced pneumatic. Because there is little or no mechanical motion, the electronic controllers tend to be more accurate, require less calibration cycles, and tend to last longer.

B. General Use

1. To use a electronic controller, it must be connected to the other devices. At a minimum, there must be a process input, a process setpoint, and a process output.
2. An improperly calibrated electronic controller will cause incorrect control, or no control of the controlled process.

C. Common Controls/Adjustments

1. Electronic controllers typically have the following controls/adjustments:
   a. Proportional-only Controller (P)
      1) A method to change the proportional value
      2) A method to adjust the setpoint value
      3) A method to set direct or reverse acting
      4) A method to change from automatic to manual control
      5) A method to calibrate the setpoint indicator
      6) A method to calibrate the process indicator
      7) A method to calibrate the output indicator
   b. Proportional and Integral Controller (PI)

1) All the adjustments for a proportional-only controller

2) A method to adjust the Integral value

c. Proportional, Integral, and Derivative Controller (PID)

1) All the adjustments for an Proportional and Integral controller

2) A method to adjust the Derivative value

D. Common Inputs/Outputs

a. Typically, electronic controllers will have the following connections:

1) A connection to the process measurement converter (i.e. temperature input device

2) A connection to the process controlling device (i.e. valve actuator, speed governor, etc.).

3) Some controllers may have and external input for the setpoint.

E. How to connect to other equipment for calibration

Typically, the output/input connections of the electronic controller are connected to a calibration device using test leads.

NOTE: Reset is the same as integral, gain is the same as proportional or proportional band, pre-act is the same as derivative.

F. Controller Theory Review

1. Reason for review

a. In order to calibrate and maintain electronic controllers safely and efficiently, it is necessary to have an understanding of their theory of operation and functions including the inputs, outputs and signal processing.

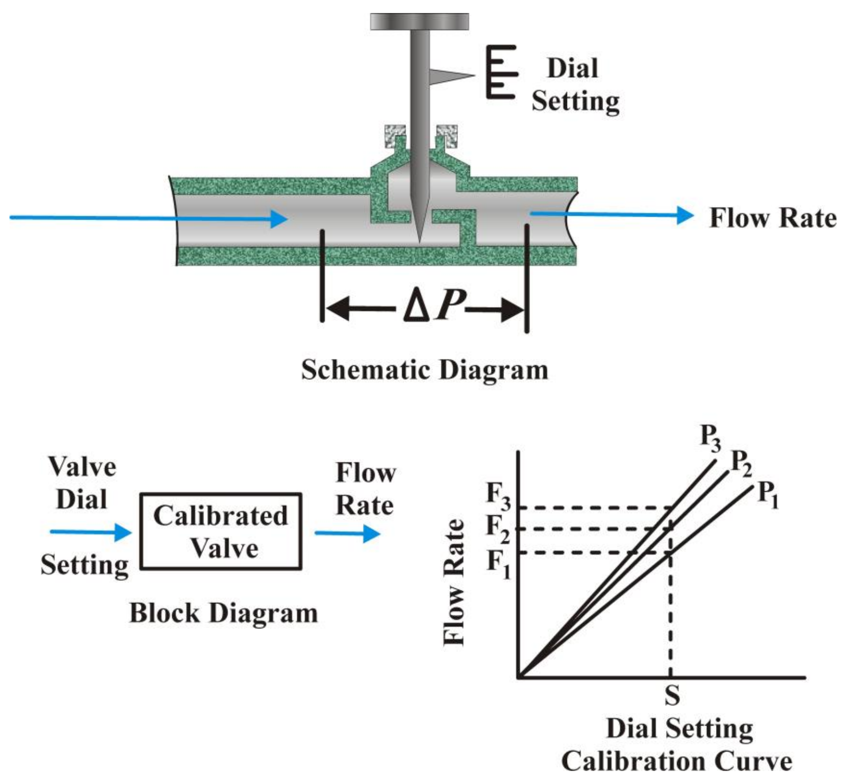
b. This lesson provides a review of basic process control principles and controller terminology and description of various types of electronic controllers

c. Types of Process Control Loops

1) Open Loop Control

a) Open loop control does not compare the actual result with the desired result to determine control action. Instead, a calibrated setting is used to obtain the desired result.

b) No check is made to determine if control action accomplished the desired objective.



Picture 1, Open Loop Control

c) Needle valve analogy

(1) The calibration curve is obtained by measuring flow at different dial settings.

(2) Different calibration curve lines are obtained for different pressure drops (P_1, P_2, P_3).

(3) Assume a flow rate of F2 is desired and a valve dial setting of 5 is used. As long as the pressure drop across the valve remains equal to P2 the flow rate will remain F2.

(4) If the pressure drop decreases to P1 or increases to P3 the flow rate will change to F1 or F3.

(5) The open loop control cannot correct for unexpected changes in the pressure drop.

d) An example is the firing of a rifle bullet.

(1) Desired result is to direct the bullet to the bulls-eye. Desired result is to direct the bullet to the bulls-eye.

(2) Actual result is the direction of the bullet after the rifle is fired.

(3) The open loop control occurs when the rifle is aimed at the bulls-eye and the trigger is pulled.

(4) If there is a disturbance (a sudden gust of wind), the direction will change and no correction will be possible.

e) Disadvantages of open loop control

(1) Errors caused by unexpected disturbances are not corrected.

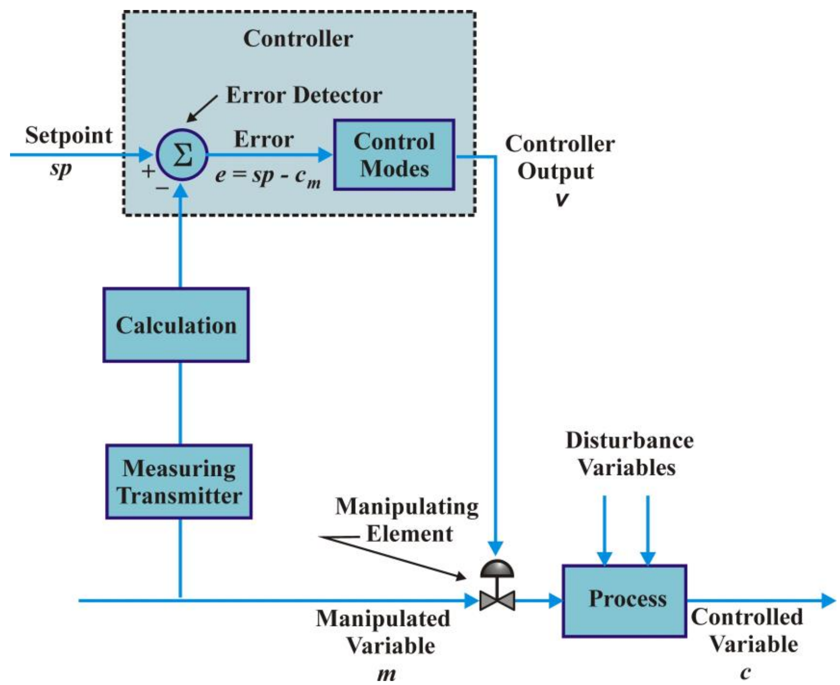
f) Advantages of open loop control

(1) Less expensive than closed loop control, no measurement needed.

(2) Controller is simpler because corrective action based on the error is not required.

2) Closed Loop Control: Feedforward

a) Measurement of input is made (rather than an assumption as in Open Loop Control.



Picture 2, Closed Loop Control - Feedforward

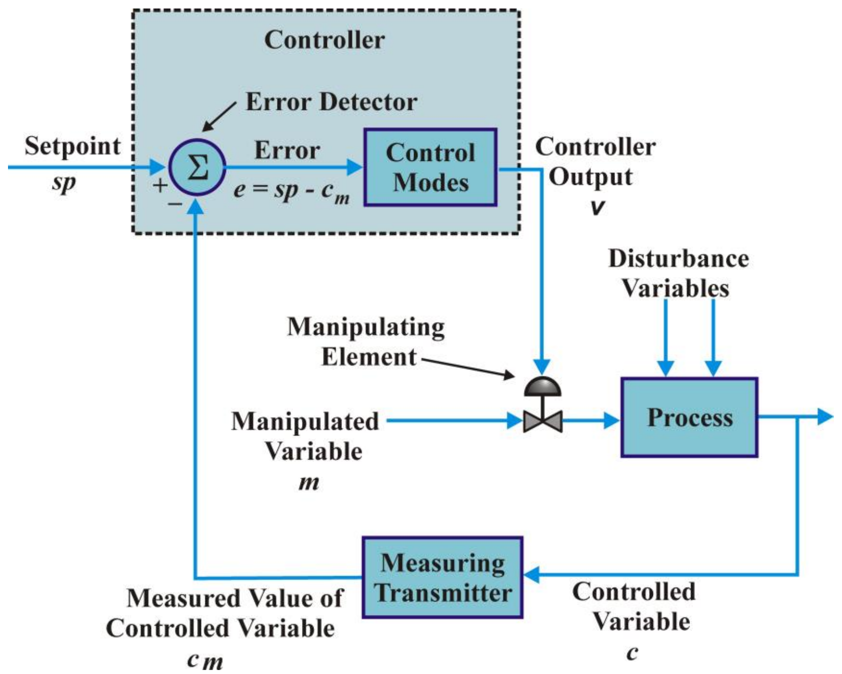
b) Controller calculates amount of additive needed to produce desired product.

c) Feedforward relies on a prediction (like Open Loop Control) but differs from Open Loop Control in that it does not rely on a fixed program to regulate any additives.

d) As changes in the measured variable are sensed by the controller, corrective action is continuously taken.

3) Closed Loop Control: Feedback

a) Feedback is the act of measuring the difference between the desired result and the actual result and using that difference to drive the actual result toward the desired result.



Picture 3, Closed Loop Control - Feedback

b) The measured value signal is fed back from the output of the system to the input.

4) Differences in these control methods

a) In open-loop, no actual process measurement was made

b) In closed-loop feedforward, the measurement was taken in the process feedstream and a predicted amount of correction was made.

c) In closed-loop feedback the actual product was measured and compared with a reference point and corrective action was taken.

d) In either open loop or feedforward closed loop, no measurement of the difference between desired result and actual result is taken.

e) Due to impracticality of precisely predicting amount of correction necessary to achieve satisfactory results with open loop or feedforward control, feedback is most often used.

G. Electronic controllers - theory of operation and functions

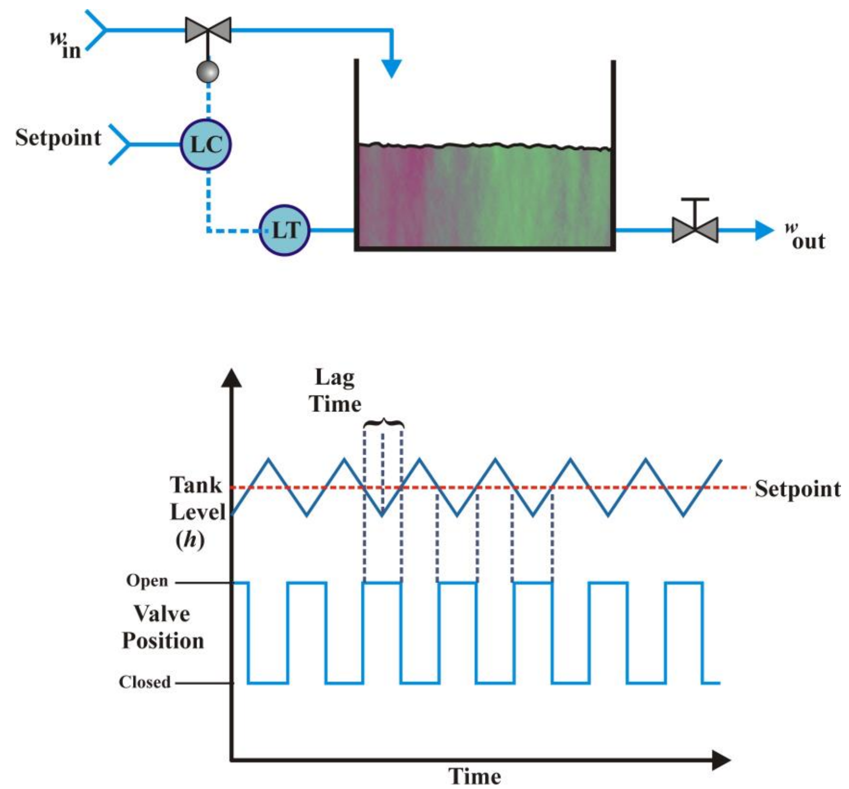
1. Two Position Control

   a. It's the simplest and least expensive mode of control.

   b. Controller output has only two possible valves, depending on the sign of the error.

   c. If the two positions are fully open and fully closed, the controller is called an on-off controller.

   d. Two position control without deadband



Picture 4, Two Position Control Without Deadband

1) Level falls below setpoint, valve is opened.

2) Lag time (dead time) between valve opening and tank level rising.

3) Measured variable (tank level) oscillates about the setpoint with amplitude and frequency dependent on capacity and time response of the process.

4) As the process lag time approaches zero, the response curve tends to become a straight line and the open/close frequency of the controller will become higher.

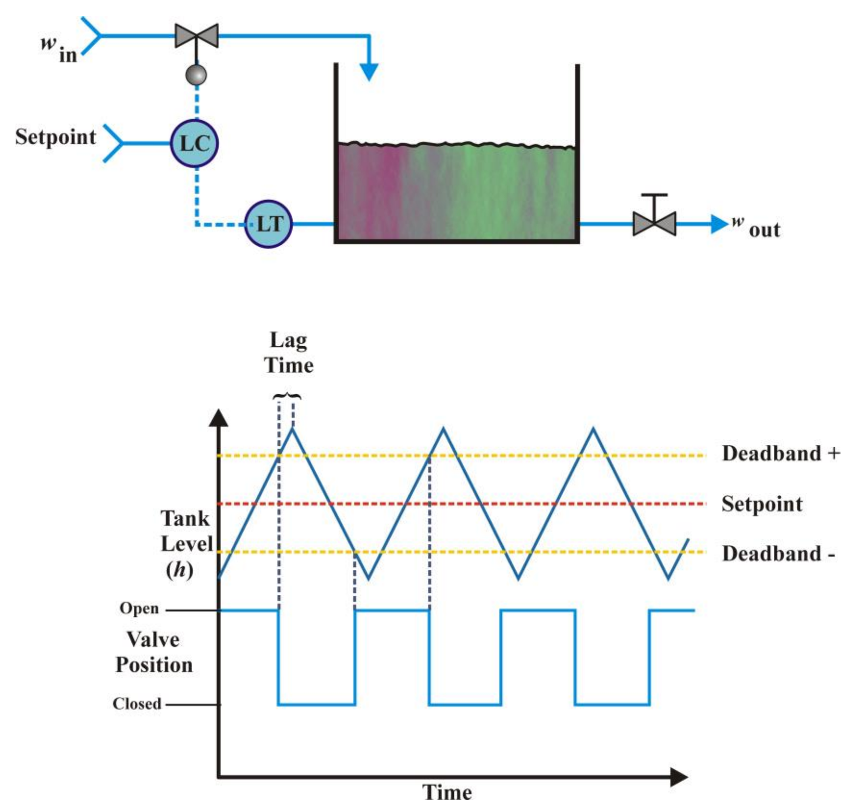
5) The response curve will remain constant (amplitude and frequency) as long as the load on the system (Wout) remains constant.

e. Two position control with deadband

1) Deadband is a range of values around zero in which the control action takes place, the error must pass through the deadband zone before any control action takes place.

2) This saves wear and tear on the final control element by preventing chattering.

3) The process is allowed to swing farther away from the setpoint.



Picture 5, Two Position Control With Deadband

f. For two position control to produce satisfactory results:

1) Precise control must not be needed.

2) Process must have sufficient capacity to allow final control element to keep up with measurement cycle.

g. Examples of two position controllers

1) Household heating system is a good example of two position control.

h. Air in the house has a large thermal capacitance and the dead time lag is small.

i. The rate of heat input from the furnace is just large enough to heat the house on the coldest day and is small compared to the capacitance of the house.

j. The house temperature cycles with an amplitude that is well within the acceptable limits of human comfort.

k. The two positions (on and off) provide heat input equal to the maximum and minimum process loads (enough heat for coldest day to no heat).

l. A poor design would be a furnace ten times larger than required. The large rate of heat would result in a large amplitude of oscillation in house temperature.

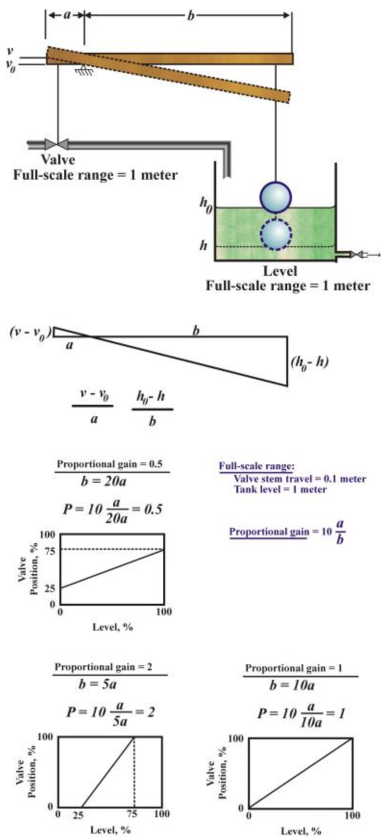
1) Pressure switch on house water tank.

2. Electronic Proportional - only controller

a. Controller responds in Proportion to amount of error between measured variable and set point.

1) Large error produces small change in final operator and vice versa.

b. Examples of proportional control systems



Picture 6, Proportional Control

1) The controlled variable is the liquid level in the tank, the float is the measuring instrument, the valve is the manipulating element, the lever is the proportional controller.

2) There is a different valve position for each level.

3) The desired level is h_o, V_o is the valve position corresponding to h_o.

c. V_o is the position of the valve when the error is zero.

(a) Error = h_o - h

2) The gain of the proportional controller in the illustration above is the change in valve position divided by the corresponding change in level.

a) The gain may be increased by moving the fulcrum to the right.

3) Refer to graphs at bottom of illustration above.

a) An increase in the gain reduces the size of the error required to produce a 100% change in the valve position.

b) High gain also increases the tendency for oscillation in the controlled variable, so a compromise is made to keep the gain as large as possible without producing unacceptable oscillations.

d. Amount of change in output for given change in input is function of controller's gain.

Controller gain = $\frac{\Delta\ Output}{\Delta\ (Setpoint - Measurement)}$

1) Proportional band is the % change in the measured variable that causes final control element to go through 100% of its range.

Gain = $\frac{100}{\%\ Proportional\ Band}$

2) Correction which is proportional to the error is represented mathematically:

Mc P x e

a) Mc $\rightarrow$ Controller Output

b) e $\rightarrow$ error

c) P $\rightarrow$ proportional factor (gain)

Example: 30% controller output for a 10% error has a gain of 3

Problem: 5% controller output for a 10% error has a gain of ________? (one half)

3) This gain setting is for the controller (only). The instrument loop will have a gain for the entire loop.

e. The gain of the controller or loop is often given as a percentage known as proportional band.

1) Proportional band tells what input change (in percent) will give a 100 percent output change.

2) Gain converted to proportional band and vice versa.

$$P = \frac{100}{P.B} \text{ and } P.B = \frac{100}{P}$$

a) P.B $\rightarrow$ Proportional Band in percent

b) P $\rightarrow$ Proportional or gain

c) Find the gain of the following:

Problem: 25 percent P.B. is? (Gain of 4)

Problem: 50 percent P.B. is?

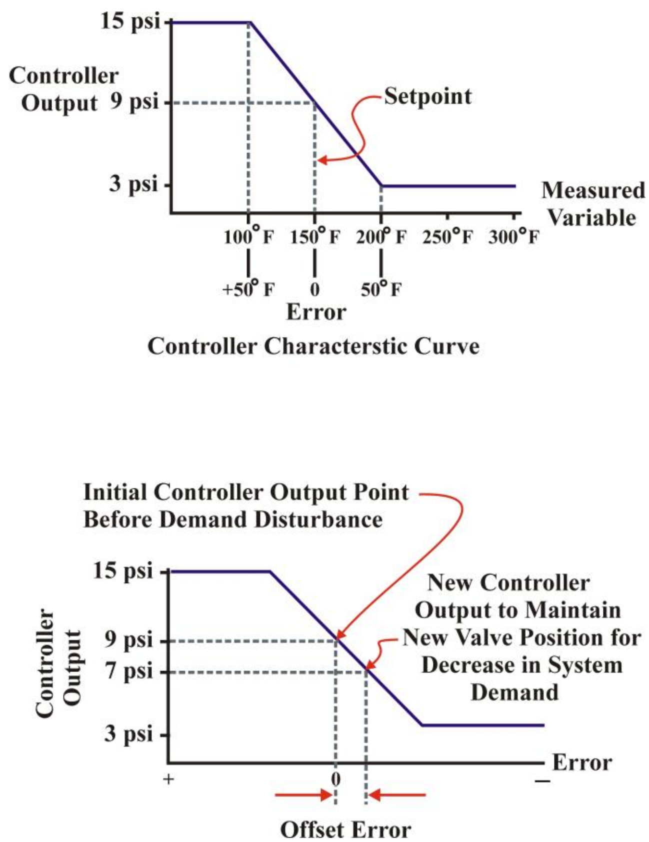
(Gain of 2)

Problem: 200 percent P.B. is?

(Gain of .5)

3) Gain selection of a controller depends on what the system is doing; level, flow, temperature, pressure control.

f. Proportional control attempts to return a measurement to the setpoint after a load upset has occurred - but it cannot, since the error will be at a new position on the curve.



Picture 7, Proportional Control

g. Proportional control reduces effect of load change but cannot eliminate it.

1) The resulting difference between measurement and setpoint after new equilibrium is reached is OFFSET.

2) Amount of OFFSET can be calculated.

$$Ep = \frac{Pp - Po}{Kp}$$

Where:

Ep =Offset error, in percent of full scale from setpoint (%)

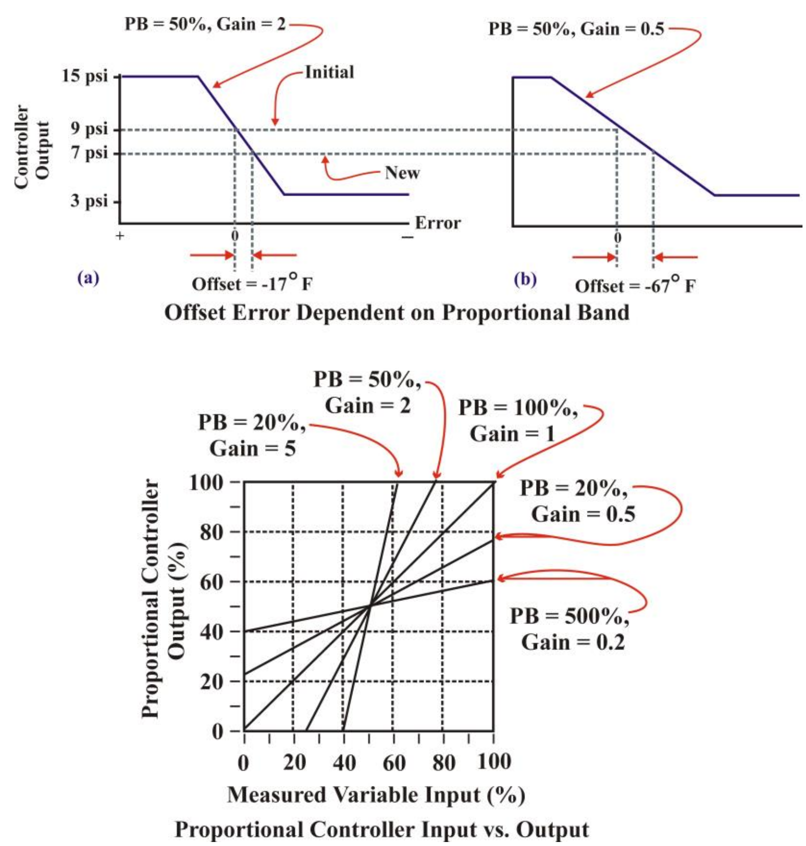
Pp =Controller output, in percent of full scale (%)

Po =Controller output when error = 0, in percent of full scale (%)

Kp =Controller gain or 100/prop. band

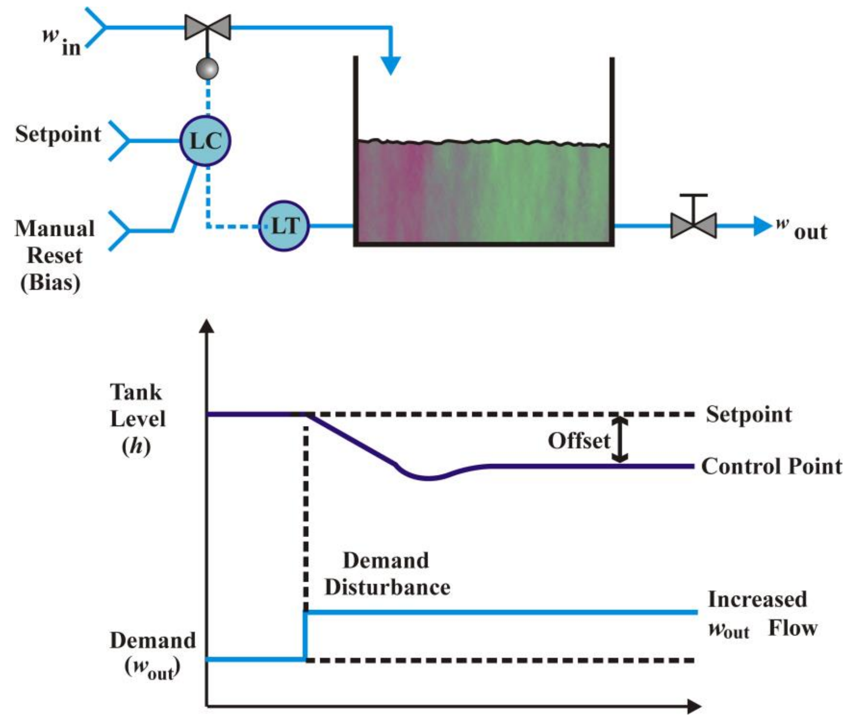
3) As Proportional Band approaches zero, gain approaches infinity and offset will approach zero - this makes sense because a controller with infinite gain is by definition an ON-OFF controller that cannot permit a sustained offset.

4) Conversely, as P.B. increases, gain decreases and offset will increase.



Picture 8, Proportional Control

5) Offset can be eliminated without adjusting the prop. band by manually adjusting the manual reset (bias) until the measured variable = the setpoint.



Picture 9, Proportional Control Closed Loop Characteristics

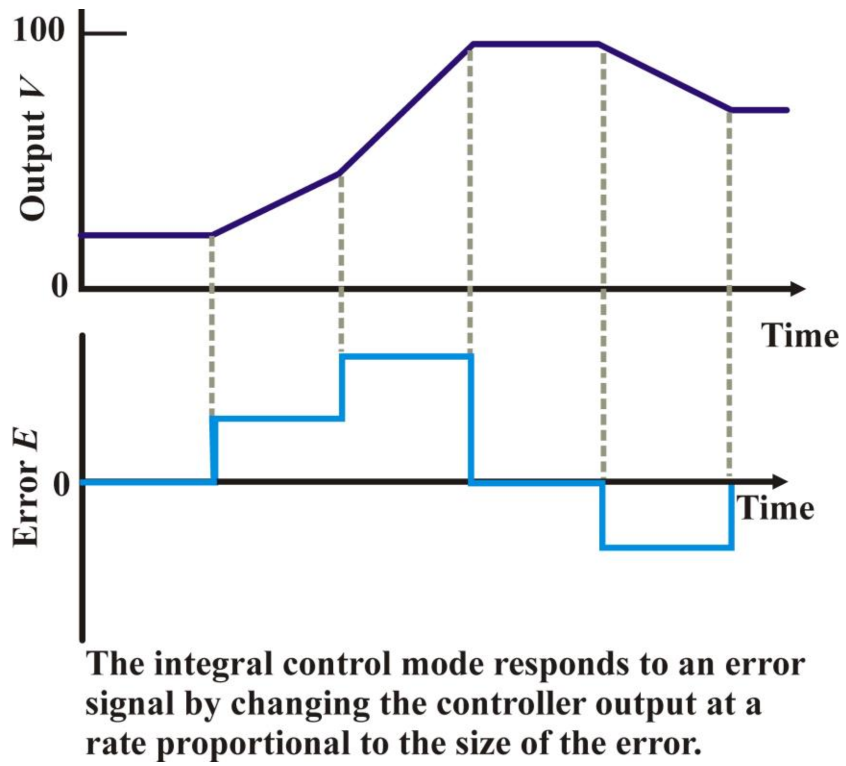
h. Narrow band proportional only controllers use:

1) Non-critical, simple temperature loops

2) Simple level control systems

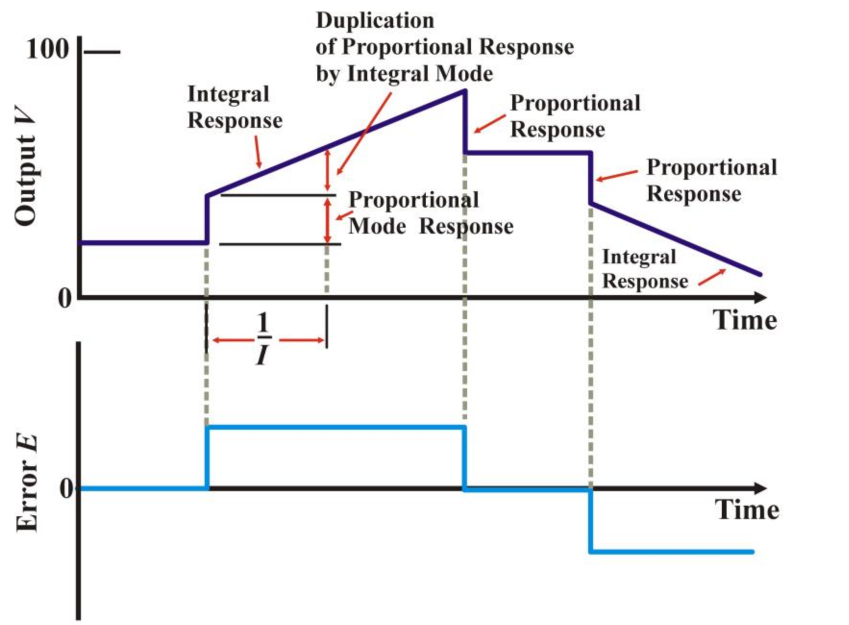
3. Electronic Proportional Plus Reset Controllers (integral) (PI controller)

a. Reset action will integrate any difference between measurement and setpoint and cause controller's output to change until difference between measurement and setpoint (error) is zero.



Picture 10, Integral Control Response

b. Reset time is amount of time required to repeat amount of change caused by the error (Proportional action)



Step response of a proportional plus integral (PI) control mode.

Picture 11, Proportional Plus Integral Control

1) Integral (reset) constant is expressed as "Repeats per Minute" or "Minutes per Repeat".

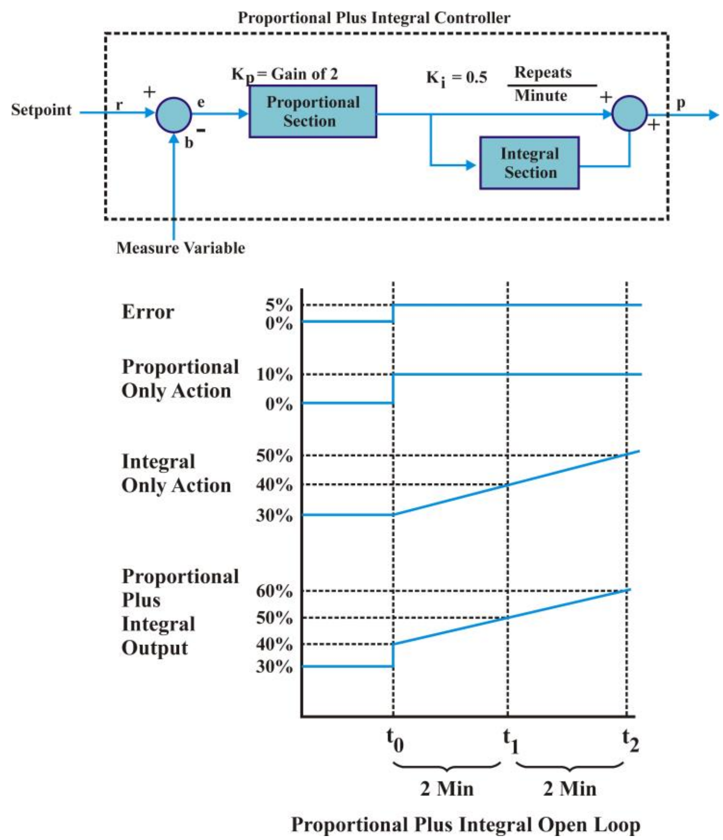
Repeats per minute = $\frac{1}{Minutes\ per\ \mathrm{Re}\ peat}$

c. Reset may be thought of as forcing proportional band to shift - causing new controller output for given relationship between measurement and setpoint.

d. Reset feature added to eliminate OFFSET and bring measured variable back to the set point.

e. Reset accomplishes same function as adjusting the manual reset (bias) in a proportional only controller.

f. Proportional plus integral open loop response.



Picture 12, Proportional Plus Integral Control

1) At To, measured variable decreases and a 5% error is introduced.

2) Error is first applied to the proportional section.

   a) Proportional section output:

      Pp = KpEp

      Pp = (2)(5%)

      Pp = 10%

      Where:

      Pp = Proportional section output (%)

      Kp = Gain (or 100%/P.B.)

      Ep = Percent error (%)

b) The 10% prop. section output is sent to the integral section.

c) At the first instant the 10% prop. output is applied, no time has elapsed. The integral section output is:

$Pi(To) = Ki\ Pp\Delta T + Po$

$Pi(To) = (0.5\ RPM)(10\%)(0\ min.) + (30\%)$

$Pi(To) = 0\% + 30\%$

$Pi(To) = 30\%$

Where:

Pi(To) = Integral section output at specified time (%)

Ki = Integral constant

(repeats/minute)

Pp = Prop. section output (%)

ΔT = Time period of change

Po = Controller output at start

of time period (%)

d) Controller output at To is the sum of the prop and integral section outputs.

$Ppi(To) = Pp + Pi(To)$

$Ppi(To) = (10\%) + (30\%)$

$Ppi(To) = 40\%$

e) Assume that the 5% error is continuously applied, then the 10% prop output continues to be applied to the integral section.

Pi(t1) = Ki Pp☐T + Po

Pi(T1) = (.05 RPM)(10%)(2 min.) + (30%)

Pi(T1) = 40%

f) Controller output at T1 is:

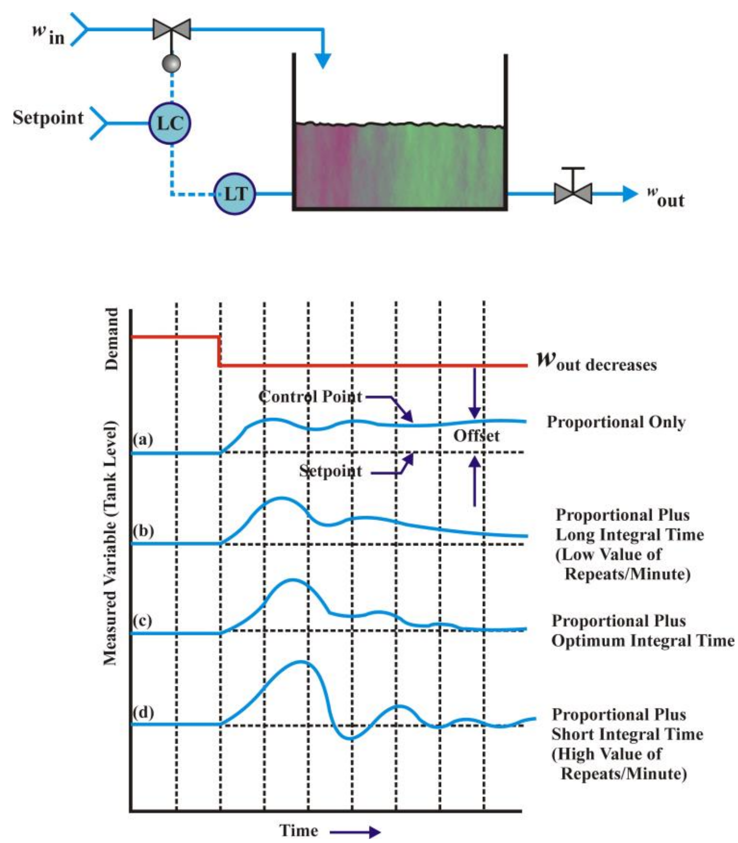
Ppi(T1) = Pp + Pi(T1)

Ppi(T1) = (10%) + (40%)

Ppi(T1) 50%

g) Controller output will continue to ramp up at this rate as long as the error stays at this rate.

g. Prop plus integral closed loop response



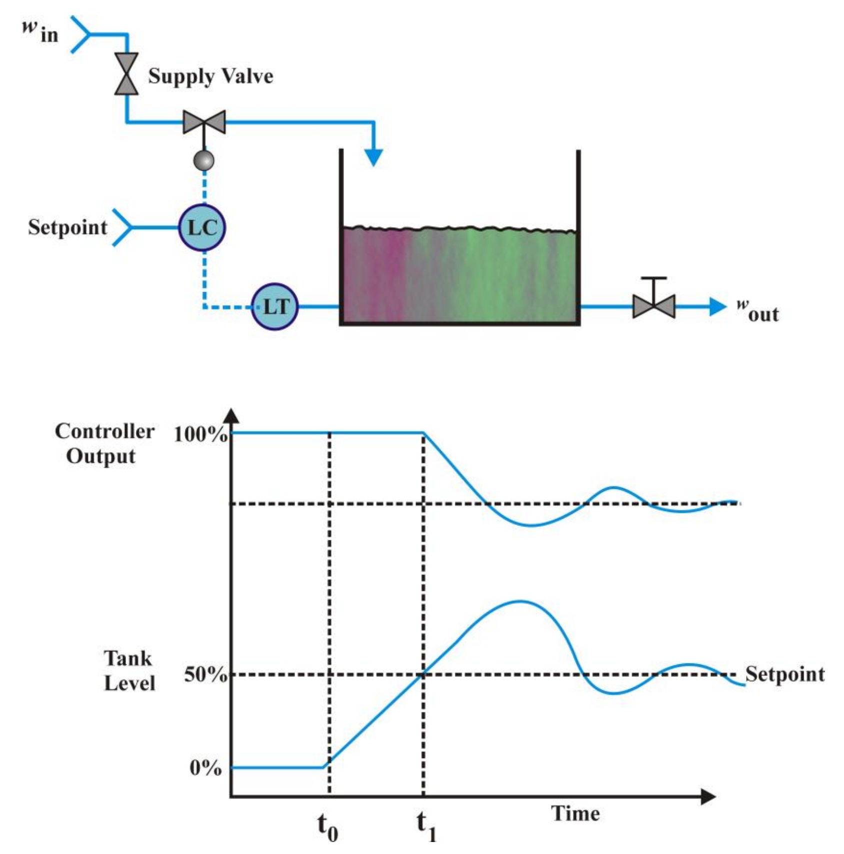
Picture 13, Proportional Plus Ingtegral Control Closed Loop Characteristics

1) Trace (a) shows that prop. only mode responds to the decrease in demand, but leaves a residual error.

2) Trace (b) shows how the integral action acts to eliminate the offset error.

3) Traces (b) and (c) show how making the integral time shorter (more repeats per minute) allows the level to return to setpoint sooner but causes a larger overshoot and greater instability.

h. Reset Windup - a large error can cause the integral section to "windup", saturate, at its high or low limit.



Picture 14, Integral Windup

1) Effect of this can best be seen by viewing a system startup.

a) Assume the supply valve has been shut and the tank has drained (controller in "auto").

b) The integral section has ramped up to saturation trying to eliminate the error between the 50% setpoint and the 0% level.

c) At To the supply valve is opened and the tank begins to fill.

d) Although prop section output will decrease as the tank fills, the integral section keeps the controller output at 100% because it is still trying to ramp up because level is less than setpoint.

e) At T1, the level shoots past the setpoint. The integral section now starts to ramp down because level is greater than setpoint.

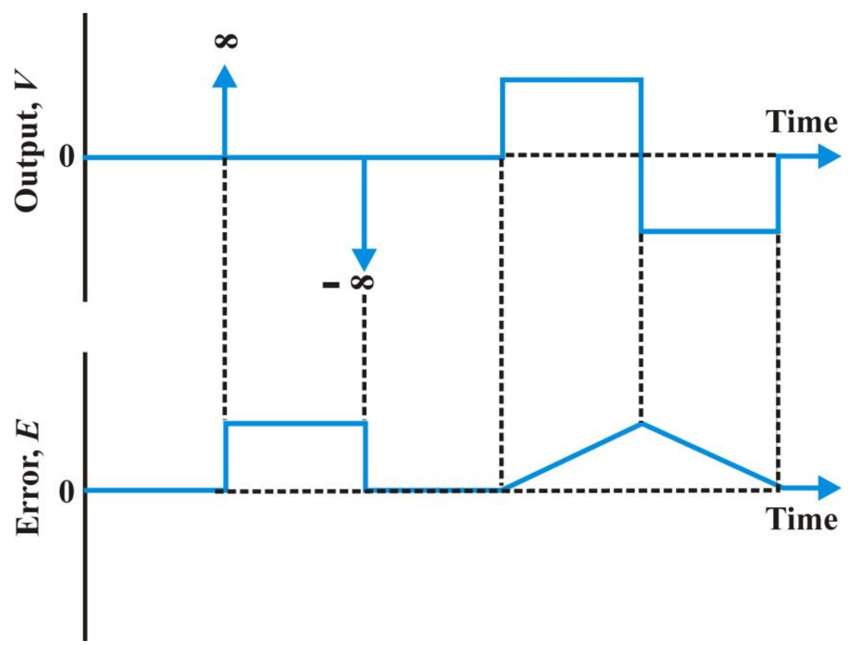
f) Controller output can now decrease to close of the inlet valve. System eventually stabilizes after experiencing a major overshoot in level.

2) Operator may minimize this windup overshoot in one of two ways:

a) Reduce setpoint to 0, allow integral to wind down, then slowly increase setpoint after the supply valve is open.

b) Put the controller in hand (manual) and manually adjust inlet valve till level is close to setpoint. When everything has stabilized, then put controller back into auto.

4. Electronic Prop Plus Reset Plus Rate (PID controller)



Picture 15, Derivative Control Mode

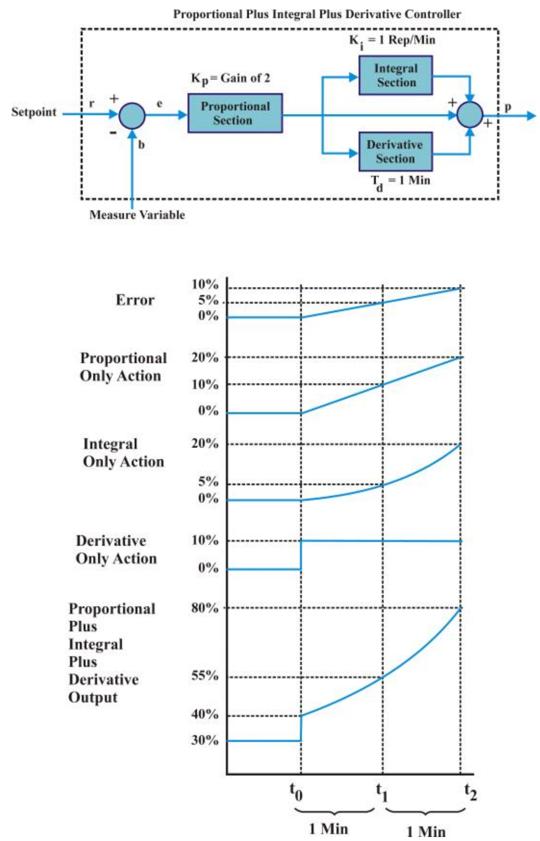
a. Derivative (rate) action helps controller to overcome system inertia and results in faster, more precise control.

b. Derivative section responds to the rate of change of the error signal, NOT the amplitude, and the derivative action responds to the rate of change at the instant it starts.

c. The derivative action causes the controller output to be initially larger in direct relation with the error signal rate of change.

   1) The higher the error rate of change, the sooner the final control element is positioned to the desired valve.

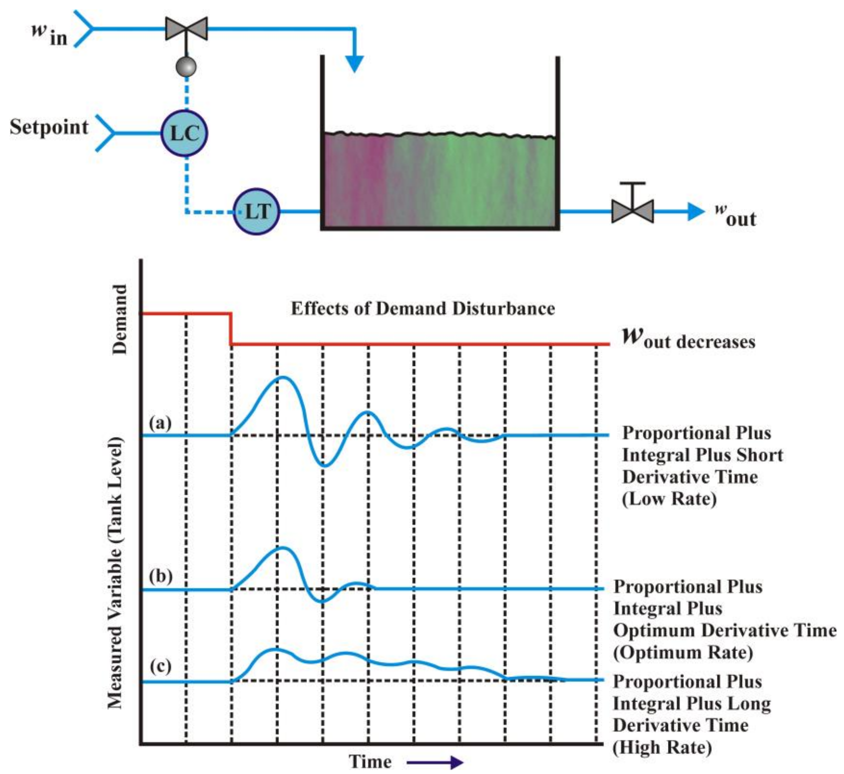
   2) The derivative section of the PID controller acts to reduce the initial overshoot of the measured variance, and therefore aids in stabilizing the process sooner.



Picture 16, Proportional Plus Integral Plus Derivative Controller

d. The derivative control mode is never used alone. It is always used in combination with the prop or prop plus integral modes.

e. Closed Loop Characteristics

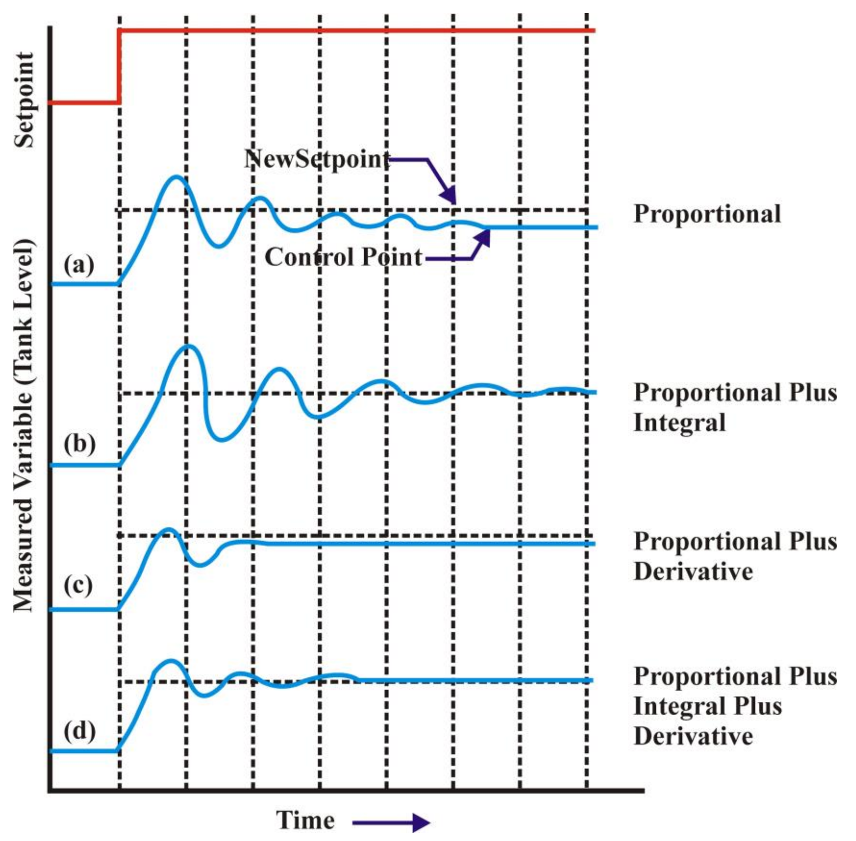


Picture 17, PID Controller Closed Loop Characteristics

1) Trace (a) shows the prop action stabilizes the process and the integral causes the control point to return to setpoint.
   a) Derivative reduces the initial overshoot of the level but the settling time of the process is longer since the derivative setting is low.
2) Increasing the derivative setting in trace (b) shows the overshoot amplitude decreased and the settling time shortened.
   a) For most processes that us PID control, this trace represents the optimum characteristics.
3) Trace (c) shows an excessively high setting of derivative. The overshot amplitude is lower but since the derivative tends to cancel out the integral, the time to return to setpoint is longer.

f. Derivative is usually not used on noisy processes because the derivative action responds to any rate of change in the error signal, including the noise.

5. Response of Various Control Modes



Picture 18, Response of Various Control Modes

a. Trace (a) shows prop only control, characterized by several cycles to stabilize and residual offset error.

b. Trace (b) shows prop plus integral, characterized by larger overshoot, longer stabilization time and elimination of offset error.

c. Trace (c) shows prop plus derivative, characterized by good stability but still some offset error.

d. Trace (d) shows prop plus integral plus derivative, characterized by good overall response, good process stability and zero offset error.

PRACTICE:

1 To what gain value does a proportional value of 50% equate?

2. What are the three basic control modes used in electronic controllers?