Date:________________ Name: ___________________________________

# LABORATORY EXERCISE 8
# PID CONTROLLER CHARACTERISTICS

**OBJECTIVE**: To demonstrate the characteristics of the proportional, integral (reset) and derivative control modes in open loop operation, including definitions of the tuning parameters.

**PREREQUISITE:** Completion of PC-ControLAB tutorial (under **Help | Tutorial** ) or an equivalent amount of familiarity with the program operation.

## 1. RUNNING THE PROGRAM

Start **WINDOWS**

Run **PC-ControLAB**

## 2. PROPORTIONAL MODE DEMONSTRATION

### 2.1 Set Up

Check the top line of the display. Be sure that you are using the GENERIC process model, the FEEDBACK control strategy. Be sure that the controller is in Manual.

From the Menu Bar, select **Control | Control Options**.

For Control Algorithm, select **Proportional Only**.

While you still have the Control Options box on display, be sure the following options are selected:

| | |
|---|---|
| Control Action | REVERSE |
| Set Pt Tracking | NO |

Press **Clear** to remove the Control Options box.

Select **Control | Measurement Options**.

Select **Yes** for “Use substitute value instead of value from process sensor?”

Press **Clear** to remove the Measurements Option box.

Select **View | Display Range | Percent of Span**

Select **View | Display Proportional Band**. (An auxiliary bar display will appear between the strip chart and the instrument faceplate. Its use will be explained later

## 2.2 Gain and Proportional Band Features

Press **TUNE**. Set or confirm the following values:

| | |
|---|---|
| GAIN | 2.0 |
| MANUAL RESET | 35 |

Click on the **Options** tab and select "Display proportional tuning parameter as" **Prop Band**

Return to the **Tuning** tab.

What value and what name does the Tuning Display now show in place of GAIN?

Value ________ Name ________________________________

Recall that:

$$\text{Prop Band} = \frac{100}{\text{Gain}}$$

$$\text{Gain} = \frac{100}{\text{Prop Band}}$$

Press **Clear** to remove the Tuning dialog box.

Select **View | Data Monitor**.

Record the following present values

Process variable: ________

Set point: ________

Controller output: ________

For a Reverse Acting controller, the controller error is calculated as:

ERROR = SP - PV

and the top and bottom of the proportional band can be calculated from the present values of set point (SP), manual reset (MR) and gain (or PB).

$$PB_{top} = SP + MR \times \left(\frac{PB}{100}\right)$$

$$PB_{bot} = PB_{top} - PB$$

Calculate the $PB_{top}$ and $PB_{bot}$ and confirm the figures from viewing the PB bar (CYAN colored) at the right of the strip chart.

$PB_{top}$ Calculated: ________ Observed: ________

$Pb_{bot}$ Calculated: ________ Observed: ________

Put the controller in AUTO. Change the Set Point to 65. Did the PB bar move as expected? ________

Calculate the theoretical controller output from:

OUTPUT = GAIN * ERROR + MR ________

Does the theoretical output agree with the observed output? ________

From an observation of the Proportional Band bar, what value of PV would cause the controller output to go:

to zero? ________

to 100%? ________

*(Recall that the Proportional Band is the range through which the PV must travel to cause the controller output to change by 100%. For a reverse acting controller, as the PV drops from $PB_{top}$ to $PB_{bot}$ , the controller output goes from 0% to 100%.)*

Select **Control | Measurement Options**. Enter a substitute PV value of 82.5.

Controller Output: ________

*(At this point it is difficult to tell whether the controller output has been calculated at 0.0, or whether it is actually some lower value, but "pegged out" at 0.0. Therefore, back off on the PV slightly by entering a substitute value of 82. That should produce a controller output just slightly above 0.0.)*

Now enter a substitute PV value of 32.5.

Controller Output: ________

*(You can raise the substitute PV value slightly, say to 33, to demonstrate that the output value was truly at 100.0, not just pegged out at the top of the chart.)*

Select **Control | Measurement Options**. Click “Yes” for “Use substitute value ..., then enter a substitute value of 70.0

Observe the PB bar and the present value of the PV. Make a visual estimate of the fraction of PB down from $PB_{top}$ to the PV value.

________

Does this (approximately) agree with the controller output? ________

## 2.3 Closed Loop Proportional Mode Response

Put the controller in MAN. Change the Set Point to 55. Change the controller output to 35.0. Change the substitute PV value to 55. Then select **Control | Measurement Options** and select **NO** for “Use substitute value … ?” (Now we will be using process feedback.) Now put the controller in AUTO.

Change the Set Point to 65. When the control loop comes to equilibrium, note:

PV ________

SP ____65__

Controller output ________

Calculate the error, then calculate the theoretical controller output from the equation given previously. Does this agree with the observed output? ___YES___

ERROR = SP - PV = 65% - 62.5% = 2.5%

OUTPUT = GAIN * ERROR + MR
= 2.0 * 2.5% + 35% = 40.0%

The PV and SP do not agree. Which way, increase or decrease, should the Manual Reset be adjusted to bring the PV into agreement with the SP? ________

Experimentally adjust the Manual Reset until the PV matches the SP.

Final value of Manual Reset: ________

Final value of Controller output: ________

Did the PB bar move as you adjusted the Manual Reset? ________

**What you should have observed:**

1. The relationship between controller Gain and Proportional Band width.
2. The relationship between the Set Point, Manual Reset and Proportional Band position.
3. The relationship between Proportional Band position, PV and controller output, when the controller is in AUTO.
4. That Proportional-Only control will not (usually) cause the PV and SP to agree, unless Manual Reset is adjusted.
5. That adjusting the Manual Reset (in AUTO) is equivalent to shifting the Proportional Band.

# 3. INTEGRAL MODE DEMONSTRATION

## 3.1 Set Up

Select **View** and click on **Display Proportional Band** (to remove it).

Put the controller in MAN.

Select **Control | Control Options** and set or check the following options:

| | |
|---|---|
| Control Algorithm: | PID, Non-Interacting |
| Action, Direct or Reverse: | Reverse |
| Set Point Tracking? | No |
| Deriv on Error or Meas: | Meas |
| Prop on Error or Meas: | Error |

Go to **Control | Measurement Options** and set:

| | |
|---|---|
| Use substitute value: | YES |
| Substitute measurement value: | 50 |

Press **Tune | Options** and set the following:

Display the proportional tuning parameter as GAIN

Return to the **Tuning** tab and set

| | |
|---|---|
| Gain: | 1.0 |
| Reset, Min/Repeat: | 5.0 |
| Deriv, Mins: | 0.0 |

Set the following:

| | |
|---|---|
| Set Point: | 50 |
| Controller Output: | 40 |

Change to AUTO.

*(You should now see the control loop simulation in stable operation with measurement and set point both at 50% and the valve signal at 40%.)*

## 3.2 Integral Mode Response

Go to **Control | Measurement Options** and enter:

Substitute measurement value 60

Observe:

The controller output signal immediately drops from 40% to 30%.

*(Reason: The controller is reverse acting, so a measurement increase causes a controller output decrease. The GAIN is 1.00, so the change in controller output due to proportional action is 1 times the measurement change.)*

The controller output then begins to ramp downward, at the rate of 2% per minute.

*(Reason: The proportional mode change was 10%)*

**What you should have observed**:

A 2%/minute change is equivalent to 5 minutes per 10% change, or 5 minutes per repeat of the proportional response.

Note that the ramping action continues until the output reaches a saturation limit (0%). This condition is called “reset windup.”

### 3.3 Integral Mode Response, A Second Example

Put the controller in MAN.

Enter a substitute measurement value of 50.

Enter a controller output of 40.

Put the controller in AUTO.

Be sure the controller is in a steady state condition, with the measurement at 50% and controller output signal at 40%

Now, enter a substitute measurement value of 55%.

Observe:

The proportional response is now only 5%.

The controller output ramps downward at 1%/minute. This rate is equivalent to 5 minutes for 5% change, or again, it is 5 minutes per repeat of the proportional response.

## 4. DERIVATE MODE DEMONSTRATION

### 4.1 Set Up

Put the controller in MAN.

In the **Tune | Options** tab, set the following:

| | |
|---|---|
| Reset Action | Off |
| Derivative Gain | 100.0 |

Enter the following tuning values:

| | |
|---|---|
| Gain: | 0.5 |
| Reset, Min/Repeat: | Not applicable (it's OFF) |
| Deriv, Min: | 0.0 |

Enter the following operational values:

| | |
|---|---|
| Set Point: | 50 |
| Controller output: | 40 |

In the **Control | Measurement Options**, select **Yes** for "Use substitute value …?", then enter a substitute measurement value of 50

Change the controller mode to AUTO.

Verify that the controller is in stable operation with set point and process variable at 50, and controller output signal at 40.

## 4.2 Ramp Response with Proportional Mode Only

Under **Control | Measurement Options**, select **Yes** for "Use ramped value instead of value from process sensor?"

Enter a ramp rate of 4%/minute.

Select **Up**.

Observe:

The process variable ramping upward from its initial value of 50% at the rate of 4%/minute.

The controller output ramping downward from its initial value of 40% at 2%/minute, stopping at 15% when the measurement reaches 100%.

*(Reason: It is a reverse acting controller, so as measurement increases, the controller output decreases. The Gain is 0.5, so the controller output drops half as fast as the measurement rises.)*

## 4.3 Ramp Response with Proportional and Derivative Modes

In **Control | Measurement Options** select **No** for "Use ramped value …?"

Change the controller mode to MAN.

Enter a controller output signal of 40

In **Control | Measurements Options** enter a substitute measurement value of 50

Change the controller mode back to AUTO.

Press **Tune** and change the Deriv setting to 5 minutes.

Verify stable operation at a measurement of 50 and controller output signal of 40

In **Control | Measurement Options**, enter the same ramp parameters as before:

Rate: 4%/minute
Direction: UP

then select **Yes** for Use ramped value…?"

Observe:

- The measurement ramping as before.

- The controller output signal makes an almost immediate change from 40% to

30% then ramps downward at the rate of 2% per minute to 5%, when the measurement has reaches 100%. As soon as the measurement ramp stops, the controller output signal makes an almost immediate change from 5% to 15%, then remains constant.

*(Reason: The derivative contribution is*

$$
\begin{aligned}
&= -\,\text{Gain} \times \text{Deriv time} \times \text{Meas ramp rate} \\
&= -\;0.5 \times 5\,\text{minutes} \times 4\,\%/\text{minute} \\
&= 10\,\%
\end{aligned}
$$

*If the controller had no derivative (as in the first trial), you can estimate approximately how long, from the initiation of the ramp, was required for the controller output signal to change from its initial value (40%) to some chosen value (say, 20%). Your estimate should be approximately 10 minutes, with proportional control only.*

*With derivative (as in this trial), estimate the time required for the controller output signal to change from its initial value (40%) to the same point (20%). Your estimate should be approximately five minutes.*

***Conclusion**: With a derivative time of 5 minutes, the controller output signal should lead (or get to the same chosen point) by 5 minutes its behavior with proportional control only.)*

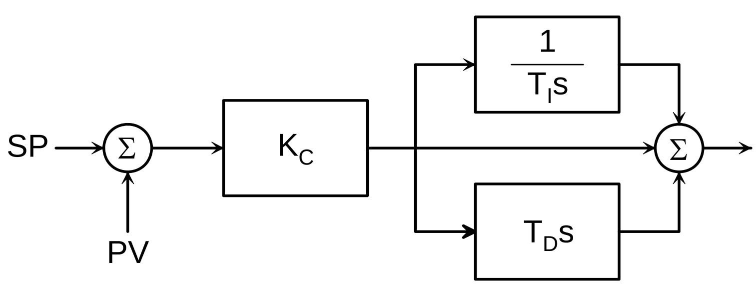
Repeat this part of this laboratory exercise, this time with a measurement ramp rate or a derivative time of your choice. You should observe:

$$
\begin{array}{c} \text{Derivative mode} \\ \text{contribution to} \\ \text{controller output} \end{array} = -\ \text{Gain}\ \text{X}\ \text{Derivative}\ \text{X}\ \begin{array}{c} \text{Rate of change} \\ \text{of} \\ \text{measurement} \end{array}
$$

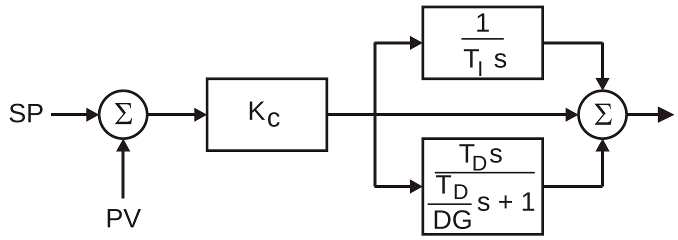
> *The " – " sign is due to the fact that the derivative contribution is always in a direction which **opposes** the direction of measurement change*.

## 4.4 Derivative Gain and Set Point Changes Using Derivative (Optional)

A block diagram for the classical form of PID controller is shown below.




Many commercial manufacturers of controllers, however, place a filter, in the form of a first order lag, in the derivative portion of the controller. This results in the modified block diagram shown below:




The usual practice is for the time constant of the first order lag to be some fraction of the derivative time setting. This is accomplished by dividing the time constant by a factor known as "derivative gain" (DG). In commercial controllers, the value of DG is usually in the range of 8 to 15.

The filter in the derivative portion has two purposes:

1. If there is measurement noise, the filtering action minimizes the amount of noise amplification placed on the controller output by the derivative unit.

2. With the classical form of PID, a step change in set point will result in a spike in the controller output caused by the derivative unit. Theoretically this spike will be of infinite height and infinitesimal width. As a practical matter, the spike height is limited by the maximum or minimum controller output. With the filter added, the spike height following a step set point change will be the value of DG times the proportional response. The output will then decay to normal with the time constant of the first order lag.

Select **Process | Initialize** (This returns all options to their original settings.)

Select **Control | Control Options** and set Derivative on Error. (The default setting is Derivative on Measurement.)

Enter the following tuning parameters:

| | |
|---|---|
| Gain | 2.0 |
| Reset, Minutes/Repeat(reset) | 8.0 |
| Derivative, Min | 2.0 |

Through the **Tune | Options** tab make the following setting:

| | |
|---|---|
| Derivative Gain | 100.0 |

*(This large of value for derivative gain essentially eliminates the filtering action on the derivative.)*

Change the controller mode to AUTO.

The controller should be in stable operation with the following values:

| | |
|---|---|
| Set Point | 55 |
| Process Variable | 55 |
| Controller Output | 35.0 |

Change the set point to 57

Observe:

Even with this moderate set point change, the controller output “spikes” all the way to 100%, then very quickly drops back to a normal control range. In a real world situation, you probably would not want to send a severe shock like that to your process.

Now change the set point back to 55

Through the **Tune | Options** tab, set:

Derivative Gain 10.0

Change the set point to 57.

Observe:

This time the controller output spike is limited. The immediate change in controller output should be:

SP Change X Controller Gain X Deriv Gain

2 X 2.0 X 10 = 40%

*(Quantization error in the digital algorithm may cause some deviation between the actual value and the theoretical value):*

Also note that the return to the normal operating range is not as abrupt.

Change the set point back to 55

Change the controller to MAN

Select **Control | Control Options** and set Derivative on Measurement

Change the controller to AUTO

Change the set point to 57

Observe:

With derivative on measurement, the immediate response of the controller output is the proportion response only – there is no derivative spike. Now one of the purposes of the filter on the derivative component has been removed, but the filter is still useful in minimizing the effect of measurement noise being amplified by the derivative unit.