LAB 9: PRESSURE PROCESS CONTROL

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LAB 9 Grading Sheet

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Part 1: Setup and Connections	**/5**
Part 2: DP Transmitter Calibration	**/5**
Part 3: Recording Signals using LVProSim	**/5**
Part 4: Proportional Control of the Pressure Process	**/15**
Part 5: PI Control of the Pressure Process	**/15**
General Formatting: **Clarity, Writing style, Grammar, Spelling, Layout of the report**	**/5**
Total Mark	**/50**

LAB 9: PRESSURE PROCESS CONTROL

OBJECTIVES:

- To study the effect of propotional, integral, and derivative control actions of PID controller
- To perform a PID control of a pressure process

DISCUSSIONS OF FUNDAMENTALS:

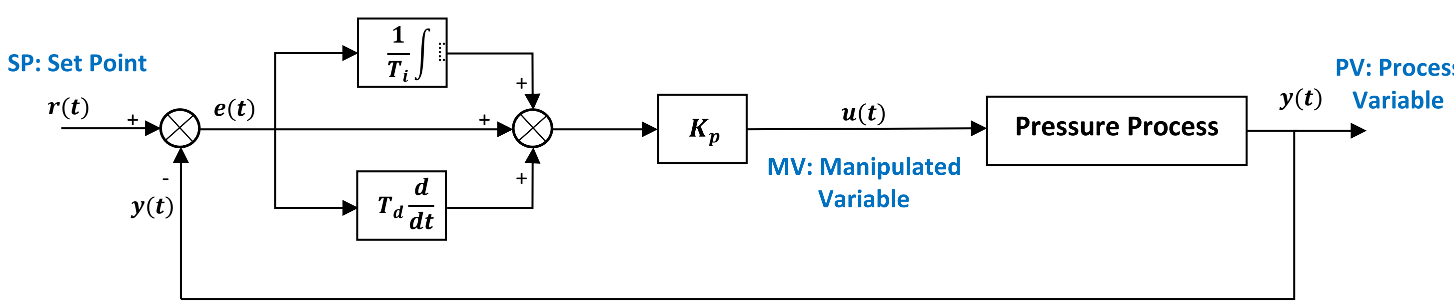
This exercise introduces three control schemes (P, PI and PID) and puts them to use in a pressure process loop. This allows a comparative analysis of the different schemes in terms of efficiency, simplicity, and applicability to various situations.

A controller in **Proportional Mode (P mode)** outputs a control signal (**MV: manipulated variable**) which is proportional to the difference between the target value (**SP: set point**) and the actual value of the variable (**PV: process variable**). This simple scheme works well, but it typically causes an offset. The only parameter to tune is the controller gain K_p.

A controller in **Proportional-Integral Mode (PI mode)** works in a fashion similar to a controller in **P mode**, but it also integrates the error over time to reduce the residual error to zero. The integral action tends to respond slowly to a change in error for large values of the integral time T_i and increases the risks of overshoot and instability for small values of T_i. Thus, the two parameters that require tuning for this control method are K_p and T_i.

A controller in **Proportional-Integral-Derivative Mode (PID mode)** acts like a controller in **PI mode**, but it also incorporates the rate of change of the error to anticipate unwanted changes in the controlled variable. The derivative action is however sensitive to noise and is not recommended for fast-acting processes. Three parameters require tuning with this control scheme: K_p, T_i and T_d.

The following figure shows the standard structure for a non-interacting PID controller with the process:



$$u(t) = K_p\left(e(t) + \frac{1}{T_i}\int e(t)\,dt + T_d\frac{d}{dt}e(t)\right)$$

EQUIPMENT REQUIRED & CONNECTION DIAGRAMS

- Work Surface
- Expanding Work Surface
- 24V DC Power Supply
- Multimeter
- Pumping Unit
- Column
- Rotameter
- DP Transmitter
- Pressure Gauge
- Hose Set and Accessory Kit
- I/O Interface Module
- Connection Leads

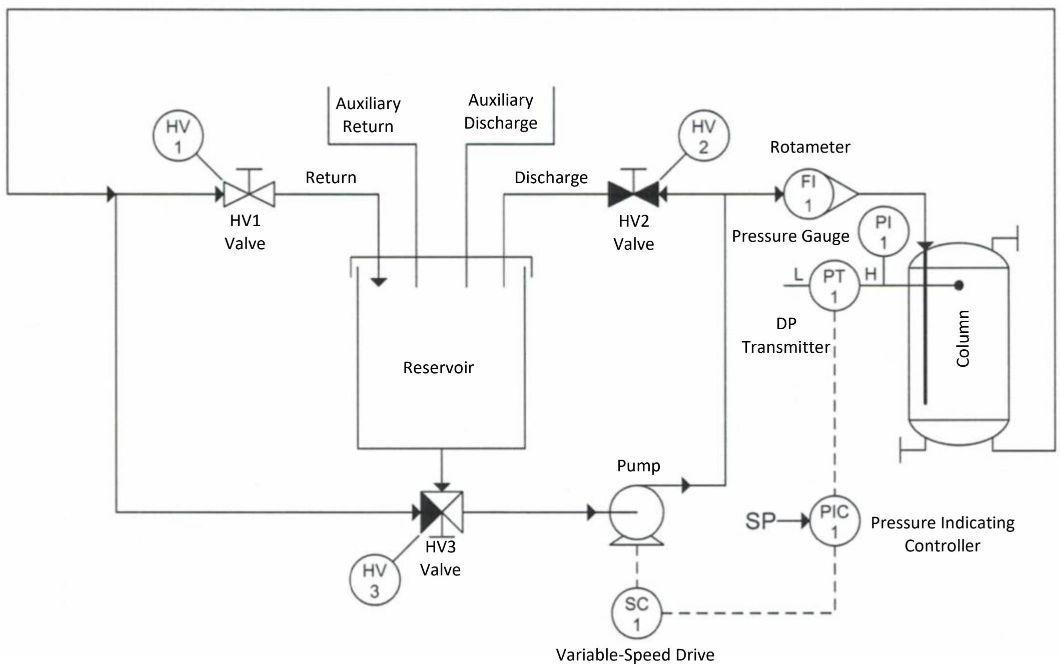


Figure 1: Flow Diagram: Feedback Control of a Pressure Process

Figure 2 shows how to connect a computer running LVProSim to a transmitter and a control element through the I/O interface module.

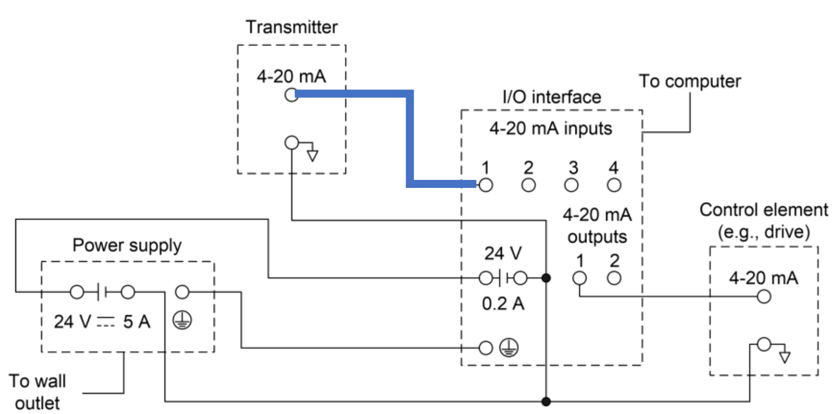


Figure 2: Typical Wiring Diagram

PART 1: Setup and Connections

In this process, the **process variable (PV)** will be the pressure of the air confined within the column. The **manipulated variable (MV)** will be the flow of water into the column. The **actuator** will be the pump drive.

1. Set up the Pressure Process shown in Figure 1.
   - Mount the rotameter, DP transmitter, pressure gauge, and the column on the expanding work surface.

> ***NOTE: For pressure measurement in gases, mount the pressure-sensing device above the measurement point. This prevents accumulation of liquid in the impulse line due to condensation.***

   - Connect the pump outlet to the port of the column that is attached to a pipe that extends down into the column.
   - Block the unused hose port of the column using a provided plug.
   - **Firmly tighten the top cap**. If the top cap of the column is not tightened firmly, pressurized air escapes and the water level does **not** stabilize.
   - Use **clear, plastic tube** with a male quick-connect fitting on both ends to connect the **pressure gauge PI1** to the **column**.
   - Get a **clear, plastic tube** with male quick-connect fitting on the end and connect the **bear** end of the tube directly into the **high pressure (H) port** of the DP transmitter and connect the male fitting of the tube into the **pressure gauge PI1.**

> ***NOTE: Since the low-pressure port* (L) *of the DP transmitter is left open to atmosphere, the DP transmitter generates the signal proportional to the gauge pressure at its high-pressure port* (H).**

2. Power up the **DP transmitter**, using the following steps:
   - Connect the + and − terminals of the **24V power supply** to the corresponding power terminals of the DP transmitter.
   - Turn ON the 24V power supply.
3. Make sure the reservoir of the pumping unit is filled with about **12 liters** (3.2 gallons) of water. Make sure the baffle plate is properly installed at the bottom of the reservoir.
4. On the pumping unit, adjust valves HV1, HV2, and HV3 as follows:
   - **Open HV1** completely (turn the handle fully CCW)
   - **Close HV2** completely (turn the handle fully CW)
   - Set **HV3** for directing the full reservoir flow to the pump inlet (turn the handle fully CW)
5. Connect and power up the **I/O interface module**, using the following steps:
   - Connect the **4-20mA output 1** and **ground** terminal of the LabVolt I/O interface module to the same type **4-20mA input** and the **ground** terminal of the pumping unit.
   - Connected the **24V DC power supply** to the LabVolt I/O interface module and turn ON the 24V DC power supply.
   - Connect the I/O interface module to the PC via USB cable.
   - Turn ON the pumping unit by setting its POWER switch to I.
   - If you are using **pumping unit Model 9510-10 or 9510-20**, set the **variable-speed drive** on the pumping unit to **remote mode** using the **keypad** on the pumping unit and make sure it runs at **50Hz**.
   - Run the **LVProSim** in PC from the start menu.
   - Set the “PID 1” in **manual mode** by clicking on **MAN** and put the **controller output** to **0%**. With this configuration, you can modify the pump speed by changing the output signal **manually** in the appropriate PID controller section of **LVProSim**.

PART 2: DP Transmitter Calibration

In steps 6 through 11, you will adjust the **ZERO** and **SPAN** knobs of the DP transmitter so that its output current varies between **4mA** and **20mA** when the pump speed is varied between **0%** and **100%**.

> **NOTE:** ***Do NOT connect the DP transmitter to I/O interface module during the calibration.***
> **It has been shown as blue line in Figure 2.**

6. Set up a multimeter in **ammeter** (**mA**) **mode** and connect the multimeter to the **4-20 mA output** and **ground** of the DP transmitter.
7. Make the following settings on the DP transmitter:
   - **ZERO** adjustment knob: **MAX**
   - **SPAN** adjustment knob: **MAX**
   - **LOW PASS FILTER** switch: **O (OFF)**
8. With the pump speed at **0%**, the air pressure within the column is minimum. Turn the **ZERO** adjustment knob of the DP transmitter **CCW** and stop turning it as soon as the multimeter reads **4.00 mA**.
9. Make the pump run at **100%**. Observe the water level rises in the column, thereby compressing the air confined within the column and causing the air pressure to increase as indicated by the **pressure gauge PI1**. Wait until the water level has stabilized in the column.

   > **NOTE:** ***The air pressure in the column is now maximum. It is equal to the pressure of the water in the column and, therefore, to the pressure required to counteract the resistance to flow caused by the components downstream of the column.***

   Read the **stabilized water level** and the **air pressure** at the top of the column when the pump runs at 100%.

   Water level = 18.5 cm

   Air pressure = kPa or 7 psi.

   > **NOTE:** ***If the top cap of the column is not tightened firmly, pressurized air escapes and the water level does not stabilize. If this happens, stop the pump, and remove the top cap to empty the column into the reservoir. Once the column is empty, tighten the cap with more force and resume the procedure from Step 8.***

10. Adjust the **SPAN** knob of the DP transmitter until the multimeter reads **20.0 mA**.
11. Due to the interaction between the **ZERO** and **SPAN** adjustments, repeat Steps 8 through 10 until the DP transmitter output actually varies between **4.00mA** and **20.0mA** when the controller output is varied between **0%** and **100%**.

> **NOTE:** ***Do NOT change the ZERO and SPAN adjustments after the calibration.***

PART 3: Recording Signals using LVProSim

12. Using **LVProSim** set the pump speed at **0%**.

13. Connect the **4-20 mA output** of the DP transmitter to the **4-20 mA input 1** of the I/O interface module.

14. **LVProSim** can record the 4-20mA signals from up to four devices via the LVProSim I/O interface module. Refer to **Appendix C** for more details.

15. Have the following signals plotted on a trend recorder:

    - Set Point (**SP**), the **desired pressure**. (Closed-loop Input Signal)
    - Process Variable (**PV**), the **DP transmitter output**. (Closed-loop Output Signal)
    - Manipulated Variable (**MV**), the **PID 1 controller output**. (Control Signal)

    Follow the steps below to plot the **DP transmitter output** signal on the trend recorder of the software,

    - Click on the **Channel (CH)** icon in the **Menu Bar** to display the **Set Channels** window.
    - In the **Set Channels** window, select the channel number corresponding to the input on the I/O interface to which the DP transmitter is connected, which is **Channel 1** in this case.
    - Enter the name you want to give to this channel in the **Label** section, which is **DP Output** in this case.
    - Select **Percentage** as the **type** of measured variable.
    - Select **%** as the measurement unit.
    - If available, select the **minimum value**, which will correspond to a 4 mA signal.
    - If available, select the **maximum value**, which will correspond to a 20 mA signal.
    - Click **OK** to set the channel.

    Once the Channel 1 is configured, you must add it to the curves list to display the data on the trend recorder. To add a channel to the curves list located at the bottom of the trend recorder, select (in the drop-down list) the **Label** that corresponds to the channel you want to record (**DP Output**) and press **ADD.** Refer to **Appendix C** for details on how to use the trend recorder.

    Similarly select and add the set point (**Set Point 1**) and the controller output (**Output PID 1**) to plot on the trend recorder.

16. From the **Settings** menu, change the **sampling interval** to **200ms**.

17. In the **Trend Recorder** menu, set the **Display Time** to **0 min** and **Span** to **5 min** and activate the **X Cursor** and the **Y Cursor**.

PART 4: Proportional Control of the Pressure Process

18. Write down the obtained first-order plus delay-time (FOPDT) model of the pressure system from previous lab.

$$G(s) = \frac{Ke^{-t_d s}}{\tau s + 1} = \frac{1.55e^{-0.42s}}{5.76s+1}$$

19. Ignoring the delay-time part, the **closed-loop transfer function, $T(s)$**, of the pressure process with **proportional controller K_p** only and unit feedback ($H(s) = 1$) is obtained as below.

$$T(s) = \frac{G(s)}{1 + G(s)H(s)} = \frac{K_p K}{\tau s + 1 + K_p K}$$

20. Having the FOPDT model parameters $\boldsymbol{K}$ and $\boldsymbol{\tau}$, calculate the required **proportional controller gain K_p** to achieve the **time-constant of $\tau = 1\ sec$**. Show your calculations.

$$\frac{\boldsymbol{\tau}}{\mathbf{1}+\boldsymbol{K_pK}} = \mathbf{1} \ => \mathbf{1}+\mathbf{K_pK} = \boldsymbol{\tau}$$
$$=> \mathbf{1}+\mathbf{K_p1.55} = \mathbf{5.76} => \mathbf{1.55}\boldsymbol{K_p} = \mathbf{4.76}$$
$$=> \boldsymbol{K_p} = \frac{4.76}{1.55} => \boldsymbol{K_p} = \mathbf{3.07}$$

Proportional Controller Gain: K_p = 3.07

21. Adjust the controller tunning parameters for **Proportional Control** by **turning off** the integral and derivative actions in **LVProSim**. Set the following values:

- Proportional control gain: K_p
- Integral time: OFF
- Derivative time: OFF

22. Place the controller in the automatic (closed-loop) mode by clicking **AUTO** in **LVProSim**.
23. Adjust the controller **Set Point** to **50%**. Record the output of the DP transmitter once it has stabilized on the trend recorder.

Steady-state value of DP transmitter output = 30 %

Wait until the water level being stabilized. Read the **stabilized water level** and the **air pressure** at the top of the column when the pump runs at **50**%.

Water level = 8.4 cm

Air pressure = 18 kPa or ……………………… psi.

24. Create a sudden change in set point from **50%** to **60%. Make sure the manipulated variable or the control signal (Output PID 1) is not saturated.**

Record the output of the DP transmitter once it has stabilized on the trend recorder. **Pause** the trend recorder.

Steady-state value of DP transmitter output = 38.22 %

Wait until the water level being stabilized. Read the **stabilized water level** and the **air pressure** at the top of the column when the pump runs at **60**%.

Water level = 10 cm

Air pressure = 22 kPa or ………………………… psi.

25. **Pause** the trend recorder. Take a screen shot of the graph and provide the graph below.

26. Determine the **time-constant τ** of the closed-loop system response by analyzing the recorded trend graph. The **time-constant τ** of the process is determined by measuring, on the trend recorder, the time it took for the process variable to reach approximately 63.2% of the total change that followed the step change in manipulated variable.

0.632*(3.502-3.455) =0.632*0.0437 = 0.029*60= 1.78 sec

Closed-loop Time-Constant: $\tau \cong$ 1.78 sec.

Does the closed-loop system respond faster compared to the open-loop system?

YES X **NO**

Does the time-constant almost same as to the designed value (1 sec)?

YES X **NO**

27. Return the set point to **50**% and allow the process variable (PV) to stabilize.

PART 5: PI Control of the Pressure Process

28. Keep the proportional gain at the designed value in **Part 4**. Add some integral action by setting the integral time to $\boldsymbol{T_i = 3\ sec}$. Set the following values in LVProSim:

- Proportional control gain: K_p
- Integral time: $T_i = 3\ sec$
- Derivative time: OFF

29. Once the controlled variable has stabilized, make a **50%** to **60%** step change in set point. **Make sure the manipulated variable or the control signal (Output PID 1) is not saturated.**

Record the output of the DP transmitter once it has stabilized on the trend recorder. **Pause** the trend recorder.

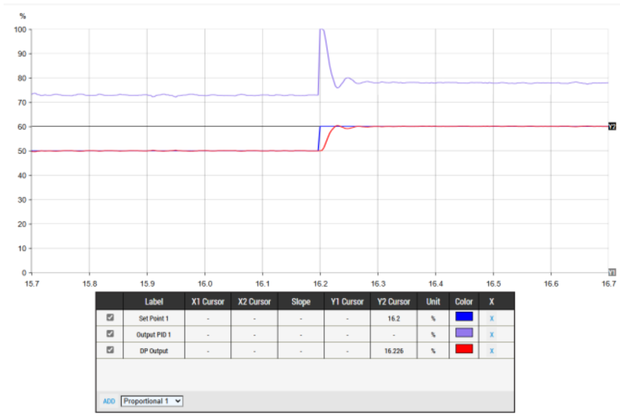
Steady-state value of DP transmitter output = 50 %

Read the **stabilized water level** and the **air pressure** at the top of the column when the pump runs at **60**%.

Water level = 13.5 cm

Air pressure = 32 kPa or ……………………… psi.

30. **Pause** the trend recorder. Take a screen shot of the graph and provide the graph below.

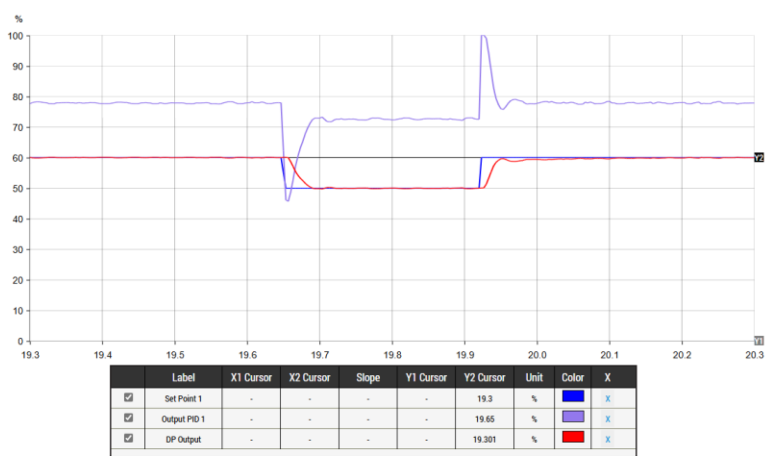


Does the integral action help to eliminate the steady-state error?

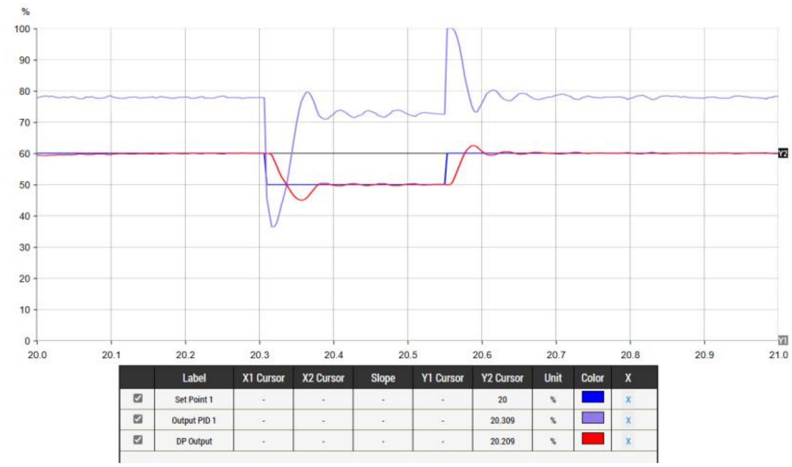
<u>YES</u> X **<u>NO</u>**

31. Return the set point to **50**% and allow the process variable (PV) to stabilize.
32. Change the integral time to $\boldsymbol{T_i = 6\ sec}$ and $\boldsymbol{T_i = 1\ sec}$. Make a **50**% to **60**% set point change after each setting until the controlled variable has stabilized. **Pause** the trend recorder each time and provide the graphs below. **Make sure the manipulated variable or the control signal (Output PID 1) is not saturated.**

Time Response for $T_i = 6\ sec$



Time Response for $T_i = 1\ sec$



Explain the effect of decreasing and increasing the **integral time** T_i on the response of the closed-loop system.

The effect of increasing the integral time on the response of the close-loop system is that the elimination of the error takes longer, overshoot decreases and the system remains stable overall. However, when decreasing the integral time, error gets eliminated faster, overshoot increases and there are more oscillations which can mean a potential instability.

LOAD DISTURBANCE EFFECT

33. Return the **integral time** to $T_i = 3\ sec$ and set the **set point** to **60%**. Let the process variable **stabilize**.
34. We can create a **load disturbance** by closing the **valve HV1**. **Rapidly close valve HV1** of the pumping unit to create a sudden change in process load. Observe the recorded graphs. Is the controller able to rapidly correct for the load change without oscillation of the process variable?

YES X **NO**

35. **Open** the valve HV1 and **Stop** the pump unit by setting the controller output to **0%** (4 mA).
36. **Turn OFF** the pumping unit by setting its **POWER** switch to **O**.
36. **Disconnect** the circuit. **Return** the components and hoses to their storage location.
37. **Wipe off** any access water from the floor and the Process Control Training System.