LAB 8: DYNAMIC MODEL OF PRESSURE PROCESS

Course Number	MENG 3510
Course Title	Control Systems
Semester/Year	Winter / 2025

Lab/Tutorial Report No.	Lab 8
Report Title	Dynamic Model of Pressure Process
Section No.	0NA
Group No.	2
Submission Date	2025-03-16
Due Date	2025-03-16

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LAB 8 Grading Sheet

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Part 1: Setup and Connections	**/10**
Part 2: DP Transmitter Calibration	**/10**
Part 3: Recording Signals using LVProSim	**/10**
Part 4: Determining the Dynamic Model of the Pressure Process	**/15**
General Formatting: Clarity, Writing style, Grammar, Spelling, Layout of the report	**/5**
Total Mark	**/50**

LAB 8: DYNAMIC MODEL OF PRESSURE PROCESS

OBJECTIVES

- To identify and explain the use of the selected process components and the pumping unit.
- To set up and operate a basic hydraulic circuit.
- To obtain the open-loop step resposne of a pressure process
- To analyze the step response and determine a First-Order-Plus-Dead-Time (FOPDT) model

In this exercise, you will become familiar with the process training system and how to set up and operate a basic flow control circuit. You also learn that a process is mainly characterized by three parameters which are the process gain, the time constant, and the delay-time. These characteristics can be determined from the step response curve of the process to a sudden step change in manipulated variable.

DISCUSSIONS OF FUNDAMENTALS

PROCESS CONTROL TRANING SYSTEM

The **Process Control Traning System** simulates industrial applications for the teaching of process control, including pressure, flow, and level process control. The system essentially consists of,

- **A main work surface**, which is a perfoerated plate hinged to a drip tray on which the process components can be mounted
- **A pumping unit**, which provides water flow through the system. The pumping unit can either be controlled ***locally*** using the drive keypad (**Models 6510-10 & 6510-20**) or ***remotely*** through the speed input control terminals (**Models 6510-00, 6510-10 & 6510-20**).
- **Process componets**, to construct different measurement of the system. The basic process components include:
  - Column
  - Rotameter
  - Differential pressure transmitter
  - Pressure gauge
- **Hoses**, which are flexible, black, garden-type hoses to allow the water flow between the process components.

Refer to **Appendix A** and **B** for more details about the each part.

In addition, a **LabVolt I/O Interface Module** is used to interface with a computer for data acquisition and PID control of a real process. The **I/O Interface** provides interconnection between the process devices and the computer. It performs analog signal and digital signal conversions and sends the information to **LVProSim**, a *process control software* included with the interface.

The **I/O Interface** has four 4-20 mA analog inputs, two 4-20 mA analog outputs, four 24 V digital inputs, and two 24 V digital outputs. It connects to a computer through a USB cable and must be powered using a 24 V DC power supply.

The I/O Interface requires **LVProSim**, a *process control software* specially designed to connect to the interface and collect data at a fast-sampling rate.

Refer to **Appendix C** for more details about the I/O Interface Module.

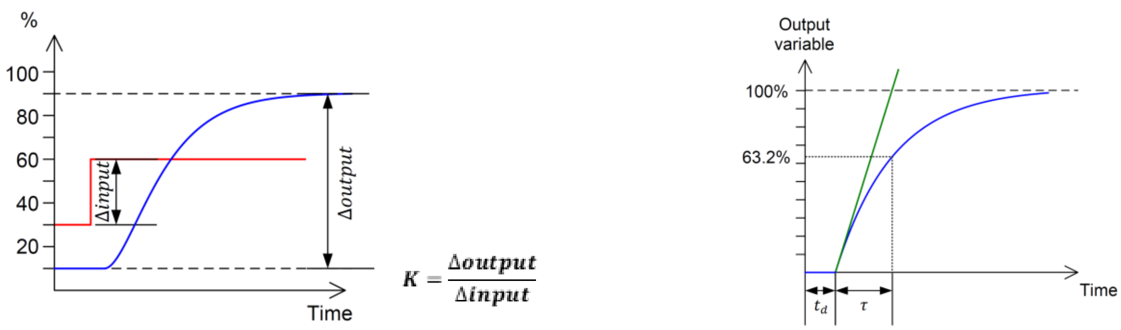
PROCESS MODELING

Ultimately, the purpose of determining the dynamic characteristics of a process is to obtain enough information on the process to be able to tune the controller for efficient process control. The **open-loop approach** of empirical modeling is called **Process Reaction Method**. In this exercise you will use the open-loop approach to obtain a **First-Order-Plus-Delay-Time (FOPDT)** model for the process.

In the open-loop approach, the controller is set to **manual mode** and is only used to create the step change in the input variable that triggers the process response, which is called **open-loop response curve** or **process reaction curve**. This method requires a **stable** process.

This exercise presents determining the dynamic characteristics of a pressure process by analyzing the open-loop step response of the process, which enables the determination of the following process characteristics:

- Process Gain: K
- Time-Constant: τ
- Dead-Time: t_d
- Order of Response (First-order or Higher order)



(a) Calculating the process gain (b) Step response curve

Figure 1: Analysis of the open-loop step response curve

Below are the general steps to obtain the step response curve:

1. Make sure your controller is in manual mode.
2. Start your system and set the calibrator output to a given value (e.g., 50%).
3. Wait for the system to stabilize and start recording the calibrator output and the measured variable on the recorder.
4. Create a step change in the manipulated variable by suddenly changing the calibrator output.
5. Stop your system and prepare your data for analysis.

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

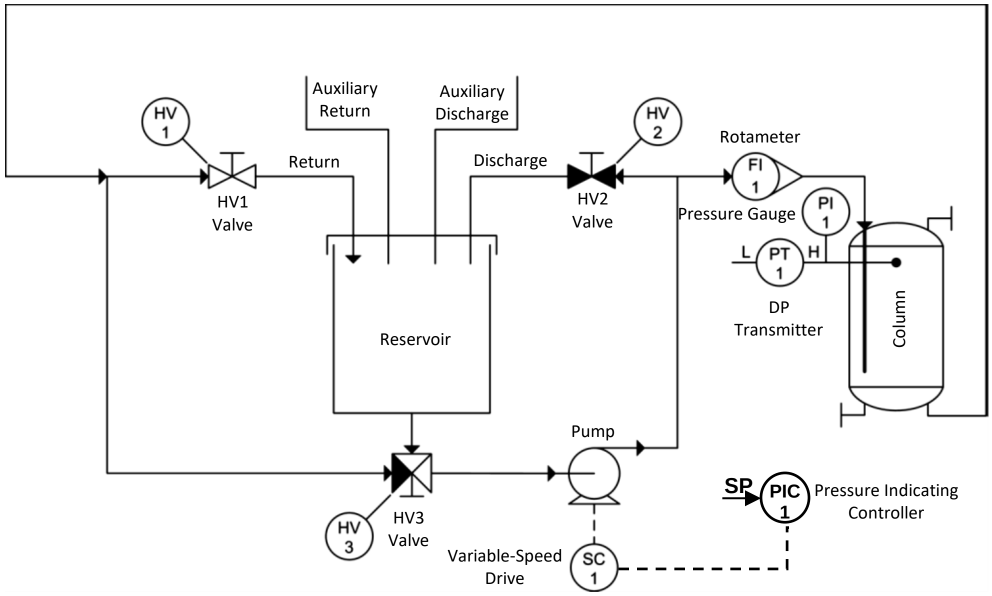


Figure 2: Flow Diagram: Pressure Process Characterization

Figure 2 shows the **flow diagram**, which represents the functional relationship between measuring, recording, and controlling devices of a Pressure Process System.

It shows the direction of water flow in the system if the valve HV1 is fully open, valve HV2 is fully closed, and valve HV3 is set for directing the reservoir flow to the pump inlet.

Refer to **Appendix A** for the symbols that are used to identify the components of the process system.

Figure 3 shows how to connect a computer running **LVProSim** to a transmitter and a control element through the I/O interface module.

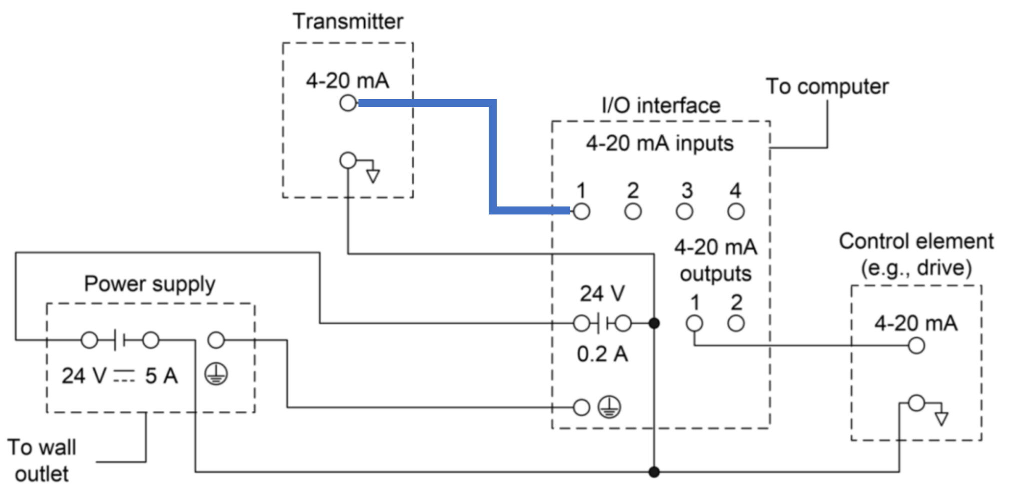


Figure 3: Typical Wiring Diagram

PART 1: Setup and Connections

1. Set up the Pressure Process shown in Figure 2
   - Mount the ***rotameter***, ***DP transmitter***, ***pressure gauge***, and the ***column*** on the expanding work surface.

> ***NOTE: The <u>rotameter</u> must be connected <u>vertically upright</u> to function properly, and it must be connected for the <u>direction of flow</u> to be measured. The inlet port is at the <u>bottom</u> of the graduated scale.***
>
> ***NOTE: For pressure measurement in gases, mount the pressure-sensing device <u>above</u> 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.

> ***NOTE*: *Always make sure the reservoir of the pumping unit is filled with the proper amount of water* (*12 L* [*3.2 gal*]) *before turning on the pumping unit. Failure to do so might cause the pump to run dry, causing the pump seal to overheat and wear out prematurely.***

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:
   - Using the electrical leads, connect the **4-20mA current 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**.
   - Connect 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.

6. **Turn ON** the pumping unit by setting its **POWER** switch to **I**.

7. If you are using **pumping unit Model 9510-10 or 9510-20,** set the variable-speed drive in the **remote mode** using the **keypad** on the pumping unit and make sure it runs at **50Hz**.

Refer to **Appendix B** for details on how to use the variable-speed drive of the pumping unit.

8. Run the **LVProSim** in PC from **Start Menu**. A new browser tab opens and **LVProSim** prompts you to select the mode in which you want to run the application. Select the **USB-IO** data acquisition mode from the drop-down menu and click **Confirm**. The software **interface window** will open.
9. Set the "**PID 1**" in **manual** mode by clicking on **MAN** ($K_c = 1$) 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**.
10. **Slightly drag** the **bar** at the bottom of the PID sub-window to increase the controller output gradually from **0%** to **100%** to make the variable-speed drive of pumping unit rotate at maximum speed.
11. You should now observe that the pump is pumping a stream of water that passes through the rotameter and fills into the column and returns to the reservoir through the open end of the hose from valve HV1 of the pumping unit. ***The water level must be raised and stabilized at a certain level.***

    Is this your observation?

    Yes ☒ **No**

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 10.***

12. **STOP** the pump unit by setting the controller output to **0%.**

PART 2: DP Transmitter Calibration

In Steps 13 through 19, 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%**.

13. **Disconnect** the **DP transmitter** from the **I/O Interface** module.
14. Set up a multimeter in **ammeter** (**mA**) **mode** and connect the multimeter to the **4-20 mA output** and **ground** of the DP transmitter.
15. Make the following settings on the DP transmitter:
    - **ZERO** adjustment knob: **MAX**
    - **SPAN** adjustment knob: **MAX**
    - **LOW PASS FILTER** switch: **O (OFF)**
16. 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**.
17. 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 = 13.1 cm

Air pressure = 32 kPa or 5 psi.

18. Adjust the **SPAN** knob of the DP transmitter until the multimeter reads **20.0 mA**.
19. Due to the interaction between the **ZERO** and **SPAN** adjustments, repeat Steps 13 through 18 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

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.

20. Using **LVProSim** set the pump speed at **0%**.
21. Connect the **4-20 mA output** of the DP transmitter to the **4-20 mA input 1** of the I/O interface module.
22. **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.
23. Have the following signals plotted on a trend recorder:

    - Process Variable (PV), the **DP transmitter output**. (Open-loop System Output Signal)
    - Manipulated Variable (MV), the **PID 1 controller output**. (Open-loop System Input 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 and select **%** as the measurement unit.
    - If available, select the **min and max values**, which will correspond to a 4mA and 20mA signals.
    - 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 **Output PID 1** from the drop-down list to plot the MV.

24. From the **Settings** menu, change the **sampling interval** to **200ms**.
25. 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: Determining the Dynamic Model of the Pressure Process

26. Increase the pump speed from **0%** to **50%**. Record the output of the DP transmitter once it has stabilized on the trend recorder.

    Steady-state value of DP transmitter output = 19.031 %

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

    Water level = 3 cm

    Air pressure = 6 kPa or 1 psi.

27. Suddenly increase the pump speed from **50%** to **70%**. Record the output of the DP transmitter once it has stabilized on the trend recorder. **Pause** the trend recorder.

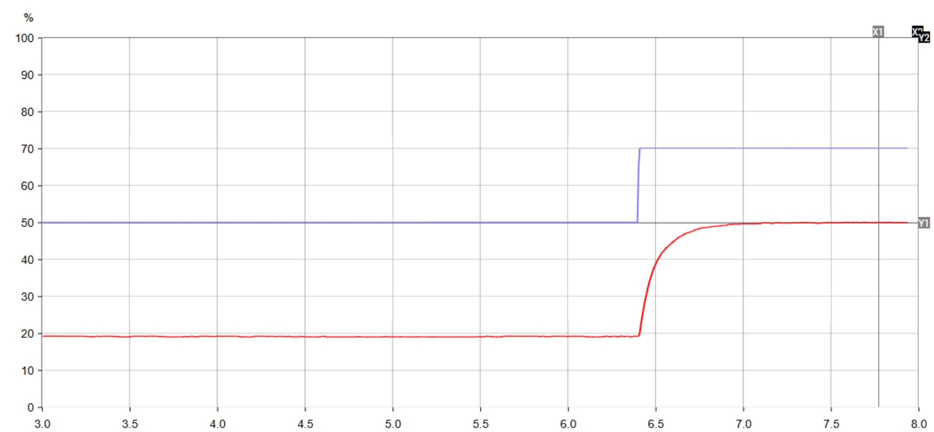
    Steady-state value of DP transmitter output = 50.039 %

    Read the **stabilized water level** and the **air pressure** at the top of the column when the pump runs at **70**%.

    Water level = 7.6 cm

    Air pressure = 17 kPa or 2.5 psi.

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



29. **Stop** the pump and **turn OFF** the pumping unit by setting its **POWER** switch to **O**.

Data recorded with LVProSim can be exported to a csv file using the export button in the menu bar. The export function saves the data file to your browser downloads folder. This file can be imported later into a spreadsheet program for accurate plot and measurement of the process characteristics.

30. Determine the **process gain K**, the **time-constant τ**, and the **dead-time t_d** by analyzing the recorded trend graph. Record these values in Table 1 and provide the **First-Order-Plus-Delay-Time (FOPDT)** model of the Pressure Process.

    You can determine the **process steady-state gain K** by dividing the percentage of change in the process variable (PV) after the step change ($\Delta output$ total changes in DP transmitter output) by the height of the step change in percent ($\Delta input$). Record the calculated gain in **Table 1**.

$$\boldsymbol{K} = \frac{\boldsymbol{\Delta output}}{\boldsymbol{\Delta input}} = \frac{31.008\%}{20\%} = 1.55$$

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. Record the time constant in **Table 1**.

Change in Y = 49.976-19.236 = 30.74 30.74*0.632 = 19.42 At 19.42, x= 6.404 6.5-5.54= 0.96 minutes 0.0096*60= 5.76 secs

Open-loop Time Constant: $\tau =$ 5.76 sec

If possible, determine the **delay-time** t_d of the process by measuring, on the trend recorder, the time difference between the manipulated variable was changed suddenly and when the process variable first started to change. Record the delay-time in **Table 1**.

Delay-Time: $t_d =$ 0.42 sec

Table 1

Characteristic	Value	First-Order-Plus-Delay-Time Model
Process Gain, K	1.55	$$\frac{Ke^{-t_d s}}{\tau s+1} = \frac{1.55e^{-0.42s}}{5.76s+1}$$
Time-Constant, τ	5.76	
Delay-Time, t_d	0.42 sec	

31. **Disconnect** the circuit. **Return** the components and hoses to their storage location.
32. **Wipe off** any access water from the floor and the Process Control Training System.