

Process Control

Measurement

Air, Pressure, and Flow

Courseware Sample

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Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
	DANGER indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
	WARNING indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
	CAUTION indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
	CAUTION used without the <i>Caution, risk of danger</i> sign  , indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols









Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Preface

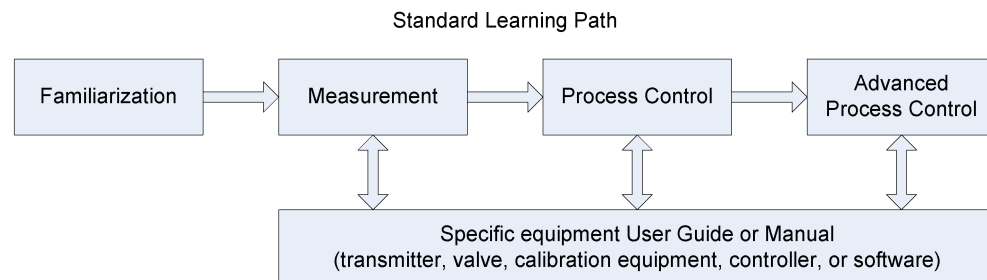
Automated process control offers so many advantages over manual control that the majority of today's industrial processes use it to some extent. Breweries, wastewater treatment plants, mining facilities, and the automotive industry are just a few industries that benefit from automated process control systems.

Maintaining process variables such as pressure, flow, level, temperature, and pH within a desired operating range is of the utmost importance when manufacturing products with a predictable composition and quality.

The Instrumentation and Process Control Training System, series 353X, is a state-of-the-art system that faithfully reproduces an industrial environment. Throughout this course, students develop skills in the installation and operation of equipment used in the process control field. The use of modern, industrial-grade equipment is instrumental in teaching theoretical and hands-on knowledge required to work in the process control industry.

The modularity of the system allows the instructor to select the equipment required to meet the objectives of a specific course. Two mobile workstations, on which all of the equipment is installed, form the basis of the system. Several optional components used in pressure, flow, level, temperature, and pH control loops are available, as well as various valves, calibration equipment, and software. These add-ons can replace basic components having the same functionality, depending on the context. During control exercises, a variety of controllers can be used interchangeably depending on the instructor's preference.

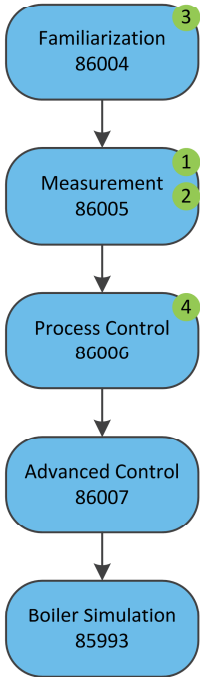
We hope that your learning experience with the Instrumentation and Process Control Training System will be the first step toward a successful career in the process control industry.



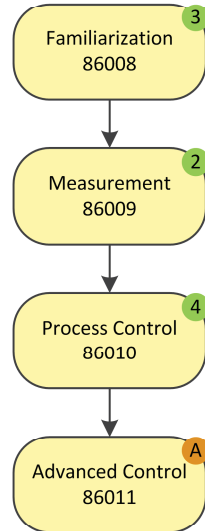
Preface

Manuals of the 353X Series

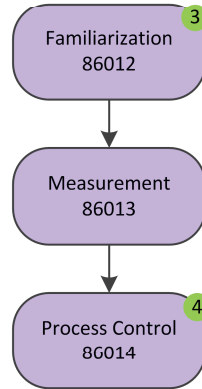
Pressure/Flow/Level



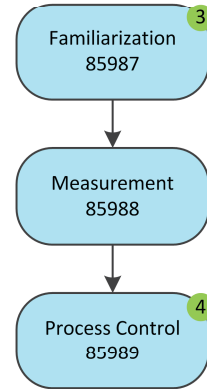
Temperature



pH and Conductivity



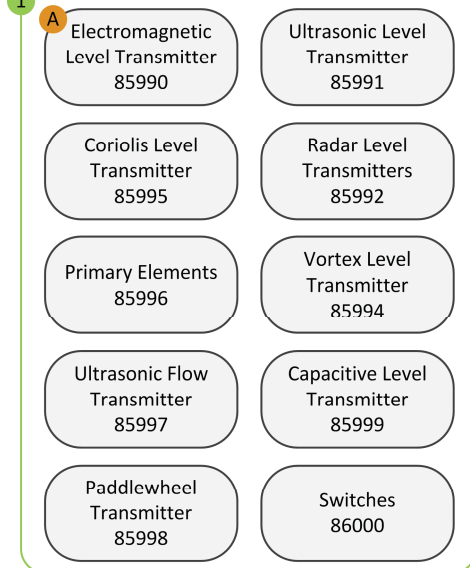
Pressure/Flow (Air)



How to read this chart

- Refer to optional manuals below, if required.
- This optional manual is required at this point.

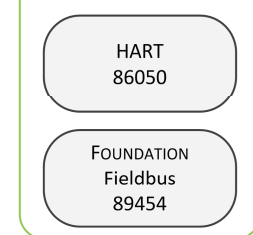
1 Pressure/Flow/Level Add-Ons



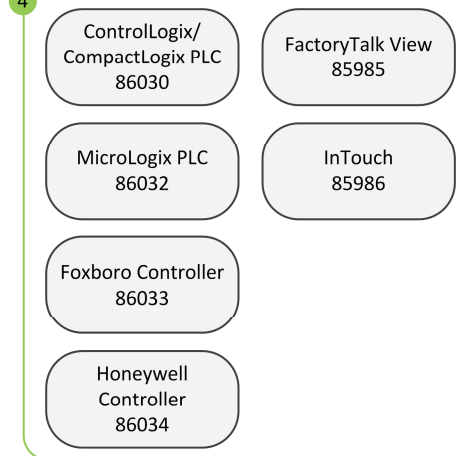
2 Final Elements



3 Communication Protocols



4 Controller/HMI Options



Preface

We invite readers of this manual to send us their tips, feedback and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Equipment installation

In order for students to be able to perform the exercises in the Student Manual, the Process Control Training Equipment – Air Pressure and Flow must have been properly installed, according to the instructions given in the user guide Familiarization with the Instrumentation and Process Control System – Air Pressure and Flow, part number 85987-E.

Sample Exercise
Extracted from
the Student Manual
and the Instructor Guide

Pressure Measurements

EXERCISE OBJECTIVE Familiarize yourself with pressure measurement using different pressure measurement devices.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Strain-gauge pressure sensing devices
- How to install a pressure-sensing device to measure a pressure
- What is bleeding?

DISCUSSION

Strain-gauge pressure sensing devices

The Instrumentation and Process Control Training System comes with pressure sensing elements that use diaphragms to detect changes in pressure. A **diaphragm** for a pressure measurement device is usually made from a thin sheet of metal. The diaphragm may be flat or may have concentric corrugations. Figure 3-12 shows how two corrugated discs can be put together to form a capsule diaphragm.

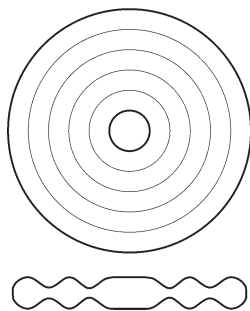


Figure 3-12. Top-view and side-view of a capsule diaphragm.

When a diaphragm is under pressure, it deforms proportionally to the magnitude of the pressure and a **strain gauge** measures the deformation of the diaphragm. Whatever the type of strain gauge(s) in the pressure-sensing device, the deformation of the diaphragm(s) due to the pressure is converted into a change of electrical resistance. An electrical circuit called a Wheatstone bridge measures this change in electrical resistance. Figure 3-13 shows a quarter-bridge strain gauge circuit. In industrial measurement devices, this circuit is usually modified to compensate for the wire's resistance and for the effect of temperature on the strain gauge.

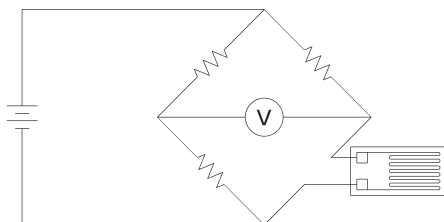


Figure 3-13. Wheatstone bridge coupled with a strain gauge.

Figure 3-15 shows two types of strain gauges: a wire-type strain gauge and a semiconductor strain gauge. The wire-type strain gauge is the older of the two types. It consists of a length of conductor glued onto a flexible membrane using an epoxy resin. When the membrane deforms, the conductor length changes and the resistance of the conductor varies proportionally. Semiconductor strain gauges use the piezoresistive properties of semiconductors to measure a deformation. The electrical resistance of the semiconductor changes when it is subject to a mechanical stress (piezoresistive effect).

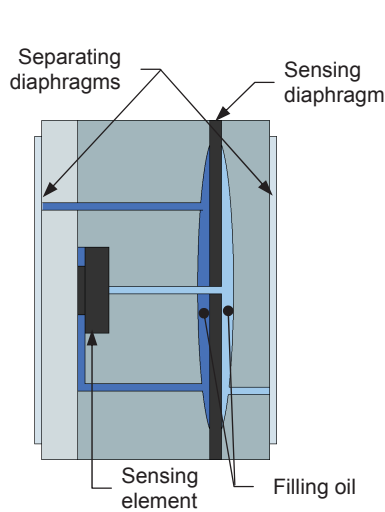


Figure 3-14. Primary element of a pressure transmitter.

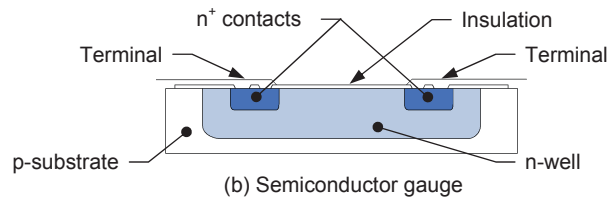
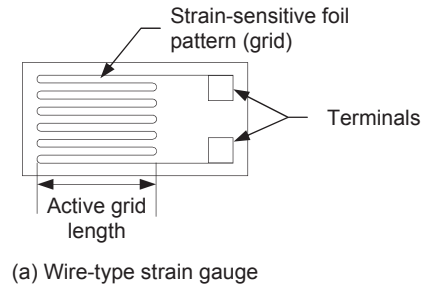


Figure 3-15. Two types of strain gauges.

Figure 3-14 shows a typical arrangement for the primary element of a pressure measurement device such as the pressure transmitter of the Instrumentation and Process Control Training System. In such a transmitter, the sensing element converts the pressure into a change in electrical resistance and the secondary element (the conditioning circuit) converts this change in electrical resistance into a signal suitable for transmission to a controller. This signal can be either a voltage, current, or pressure of normalized range.

How to install a pressure-sensing device to measure a pressure

To ensure accurate pressure measurement, you must take some precautions when you install a pressure-sensing device. The list below enumerates these precautions.

- For pressure measurement in liquids, mount the pressure-sensing device below the measurement point.
- 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.
- Make sure the impulse lines are not bent, restricting the fluid flow.
- Liquid in the impulse line creates a pressure on the sensing element of the pressure-sensing device. You must adjust the zero of the device to compensate for the pressure due to liquid in the impulse line.
- Attach the impulse lines securely to something solid. If the impulse lines vibrate or if you accidentally move an impulse line, the zero of the device may shift.
- Try to keep the temperature of the impulse line as close as possible to the process temperature.

- On a differential-pressure sensing device, make sure both impulse lines have the same length.
- You must bleed the pressure-sensing device to fill both the device and the impulse lines with the process fluid.

What is bleeding?

When you connect a pressure-sensing device to a pressure port, you must fill the impulse line linking the instrument to the pressure port with the process fluid. This is especially important if you are measuring the pressure of a process using a liquid, such as measuring the pressure in a pipe filled with water. Filling the impulse line with the process fluid helps to avoid inaccurate pressure measurements due to the compression of air that may be trapped in the impulse line or in the pressure-sensing device. The procedure for purging air from both the impulse line and the instrument is called **bleeding**.

When the process fluid is a gas, such as when you measure the air pressure at the top of a column, it is a good habit to purge any liquid from the impulse line and the instrument. It is not that the liquid in the impulse line will significantly influence the pressure readings (liquids are relatively incompressible), but it is mainly to protect the process from contamination. In any industry, liquid trapped in the impulse line or in the pressure-sensing device can contaminate the process and ruin a whole batch of product. To avoid such circumstances, always fill the impulse line and device with the fluid you are measuring the pressure of. Figure 3-16 illustrates this principle with a column partially filled with water. Figure 3-16 a) shows that if you measure water pressure, you must fill the impulse line (and the instrument) with water. Figure 3-16 b) shows that if you measure air pressure, you must fill the impulse line with air.

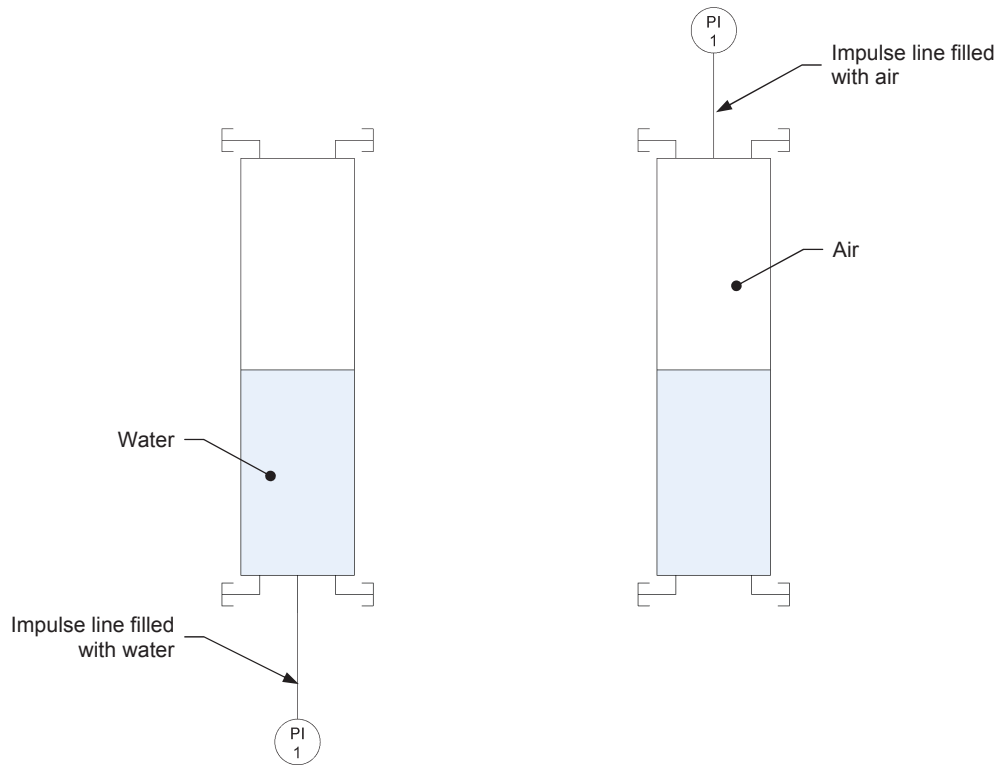


Figure 3-16. Filling the impulse line with water or air.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Preparation questions
- Set up and connections
Purging the pressure gauge and DP transmitter (optional). Adjusting the zero of the pressure gauge and DP transmitter (if necessary). Inspecting the system.
- Comparison of measuring instruments
- Pressurizing a tank

PROCEDURE

Preparation questions

1. Find the span and calculate the absolute errors of the following measuring devices for which the error on the span as provided by the manufacturer is given.

Table 3-1 Characteristics of the pressure measuring devices.

Device	Error on span	Span	Absolute error
Pneumatic unit gauge (low)	± 3%		
Pneumatic unit gauge (high)	± 3%		
Pressure gauge	± 0.5%		
DP transmitter (low range)	± 0.075%		
DP transmitter (high range)	± 0.075%		

Characteristics of the pressure measuring devices.

Device	Error on span	Span	Absolute error
Pneumatic unit gauge (low)	± 3%	200 kPa 30 psi	± 6 kPa ± 0.9 psi
Pneumatic unit gauge (high)	± 3%	700 kPa 100 psi	± 21 kPa ± 3 psi
Pressure gauge	± 0.5%	700 kPa 100 psi	± 3.5 kPa ± 0.5 psi
DP transmitter (low range)	± 0.075%	50 kPa 7.3 psi	± 0.038 kPa ± 0.0055 psi
DP transmitter (high range)	± 0.075%	700 kPa 100 psi	± 0.5 kPa ± 0.075 psi

2. Which differential-pressure transmitter seems the more accurate for use with pressures in the range from 0-200 kPa (0-30 psi)? Why?

The high-range transmitter is more appropriate. The low-range transmitter has a smaller absolute error, but it does not cover the entire working range.

Set up and connections

3. Position and secure all the basic air pressure/flow equipment as shown in Figure 3-17. This fundamental setup, that is also presented at the beginning of the *Familiarization with the Training System* manual (P/N 85987), will be used throughout the manual.

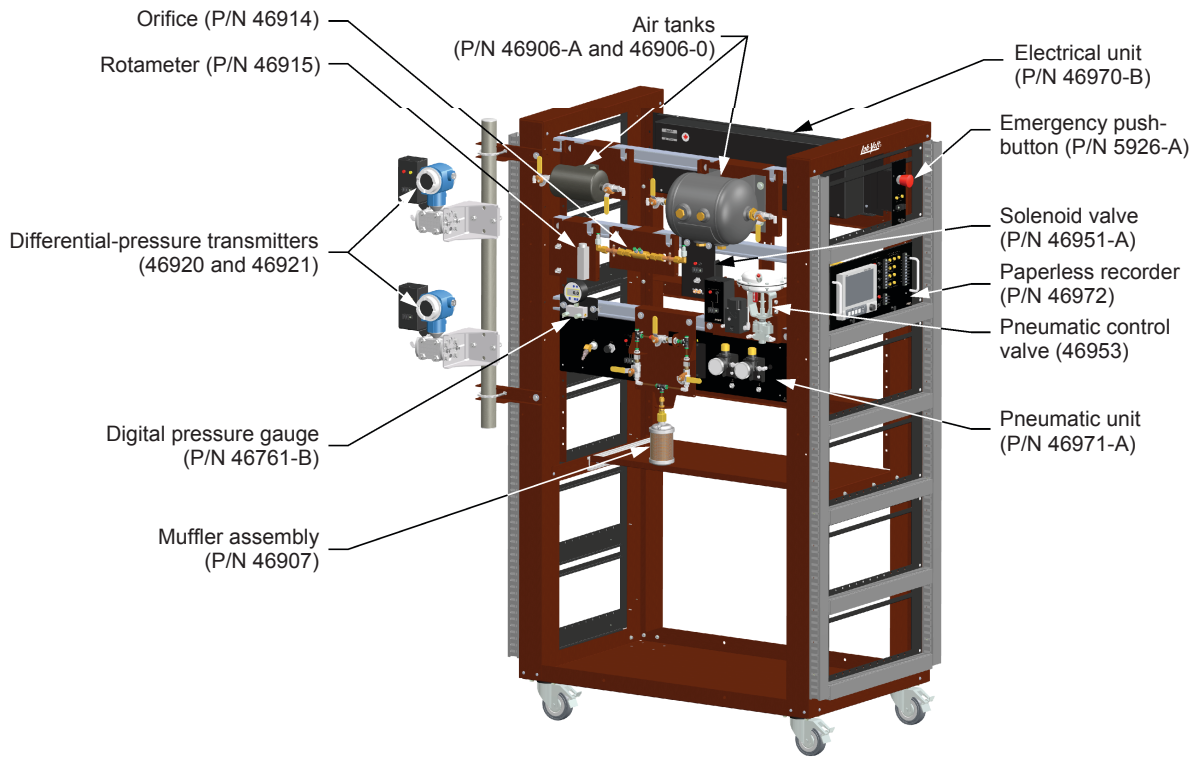


Figure 3-17. The Basic Air Pressure/Flow Training System, Series 3533.

4. Use plastic tubing to connect the equipment as the piping and instrumentation diagram (P&ID) of Figure 3-18 shows. Table 3-2 lists the equipment that is required for this exercise.



Some of the equipment will only be used in the second part of the exercise.

Couplers are needed to connect tubing to the pneumatic unit and to the digital pressure gauge.

Table 3-2. Devices required for this exercise.

Name	Model	Tag number
Emergency push-button	5926-A	
Digital pressure gauge	46761-B	PI 1
Large tank	46906-0	
Small tank	46906-A	
Muffler assembly	46907	
Rotameter (air)	46915	FI 1
Differential-pressure transmitter (low -pressure range)	46921	PDI 1
Electrical unit	46970-B	
Pneumatic unit	46971-A	
Paperless recorder ¹	46972	
Accessories	46993	
Chronometer ¹	----	

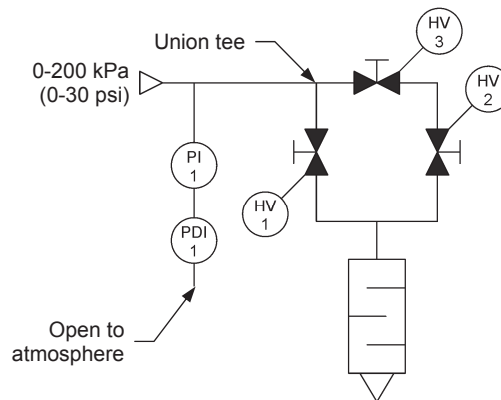


Figure 3-18. First setup (closed valves shown in black).

CAUTION

Verify carefully every tubing connection on your setup before putting the system under pressure. This is very important to ensure that all connections are secure and that no air escapes.

5. Connect the pneumatic unit to a dry-air source with an output pressure of at least 700 kPa (100 psi).
6. Wire the emergency push-button so that you can cut power in case of an emergency. The *Familiarization with the Training System* manual covers the security issues related to the use of electricity with the system as well as the wiring of the emergency push-button.

¹ You can use the paperless recorder in lieu of the chronometer in the second part of the exercise.

Purging the pressure gauge and DP transmitter (optional)

This step is necessary only if the equipment was also used with water.

7. To purge water from the pressure gauge and flexible tubing:
 - Connect one port of the gauge to the pneumatic unit using flexible tubing.
 - Connect a small length of flexible tubing to the other port of the gauge, leaving the other end of this tubing in a container.
 - Slowly increase pressure until all water is expelled from the tubing and the gauge.

The procedure used to purge liquid from a differential-pressure transmitter is a little bit different from the procedure for a pressure gauge because differential-pressure transmitters have vent valves that allow the impulse lines and the instrument to fill easily with the process fluid.

8. To purge water from the DP transmitter and flexible tubing:
 - Fill the impulse lines of the differential-pressure transmitter with the process fluid. In the present case, the tubing must only contain air.
 - Use a wrench to loosen the vent valves on both sides of the transmitter.
 - Slowly increase the pressure in the system, until all water is expelled.
 - Stop the air from the pneumatic unit and use a wrench to tighten the vent valves.

Adjusting the zero of the pressure gauge and DP transmitter (if necessary)

This step is necessary whenever a measuring instrument stops indicating “0” when subject to atmospheric pressure.

9. Connect one port of the digital pressure gauge to a length of tubing from which the other end is open to atmosphere. The other port is not connected. Adjust the zero of the pressure gauge and set the desired units.
10. Disconnect both ports of the DP transmitter. Adjust the zero and set the desired units.



The Familiarization with the Training System manual (P/N 87987) contains a step by step procedure.

Inspecting the system

11. Reconnect the pressure gauge and DP transmitter according to Figure 3-18, if necessary.

- 12.** Before proceeding further, complete the following checklist to make sure you have set up the system properly. The points on this checklist are crucial elements for the proper completion of this exercise. This checklist is not exhaustive. Be sure to follow the instructions in the *Familiarization with the Training System* manual as well.



- All equipment is correctly fastened to the workstation.
- The air supply activation valve of the pneumatic unit is closed.
- The two pressure adjustment knobs of the pneumatic unit are set to minimum pressure.
- The pneumatic connections are made correctly.
- All tubing is exempt of water.

- 13.** Ask your instructor to check and approve your setup.

- 14.** Power up the electrical unit. This starts all electrical devices as well as the pneumatic devices.

- 15.** Test your system for leaks:

- Open the air supply activation valve of the pneumatic unit.
- Lift and gradually turn the pressure adjustment knob to increase pressure.

- 16.** Close the air supply and depressurize the system by opening HV-1 before arranging any faulty connections.

Comparison of measuring instruments

- 17.** Fill out Table 3-3, using the differential-pressure transmitter as a reference. Start at 0 kPa (0 psi). Lift and gradually turn the pressure adjustment knob to increase pressure by approximately 25 kPa or 5 psi increments.



Open and close HV-1 to help you reduce pressure, if necessary.

Table 3-3. Comparative pressure table.

DP transmitter	Pressure gauge	Pneumatic unit gauge
<i>Accuracy:</i>	<i>Accuracy:</i>	<i>Accuracy:</i>



The pressure observed on the pneumatic unit gauge can be significantly larger than what is actually measured due to the check valve inside the unit that protects the regulator against possible incoming water.

Comparative pressure table (SI units).

DP transmitter	Pressure gauge	Pneumatic unit gauge
<i>Accuracy: ± 0.53 kPa</i>	<i>Accuracy: ± 3.5 kPa</i>	<i>Accuracy: ± 6 kPa</i>
21.9	21.7	25
48.7	48.5	50
73.0	72.7	75
100.0	99.8	105
126.4	126.0	125
150.1	149.7	155
173.4	172.8	175
193.9	193.3	195

Comparative pressure table (US customary units).

DP transmitter	Pressure gauge	Pneumatic unit gauge
<i>Accuracy: ± 0.075 psi</i>	<i>Accuracy: ± 0.5 psi</i>	<i>Accuracy: ± 0.9 psi</i>
5.0041	4.98	5.5
9.9977	10.01	11.0
14.7414	14.71	15.5
19.6130	19.55	20.5
25.5666	25.50	26.0
29.0541	28.99	30.0

18. In Table 3-3, highlight the measurements made with the pressure gauge and pneumatic unit pressure gauge that do not fall into the total error margin with the corresponding DP transmitter measurement. Which measurement device (pressure gauge or pneumatic unit gauge) seems to be more reliable?

Normally, only some measurements made with the pneumatic unit gauge should be highlighted. The pressure gauge is a more reliable device.

19. Close the air source and depressurize the system.

Pressurizing a tank

A differential-pressure transmitter has two pressure ports: a high-pressure port and a low-pressure port. The output of the transmitter is the pressure differential between these two ports. A differential-pressure transmitter can measure the pressure difference between the local atmospheric pressure and a particular measured pressure, like a simple pressure gauge does. However, it can also measure the pressure difference between any two pressure measurement points.

- 20.** Use plastic tubing to connect the equipment as the piping and instrumentation diagram (P&ID) of Figure 3-19 shows.

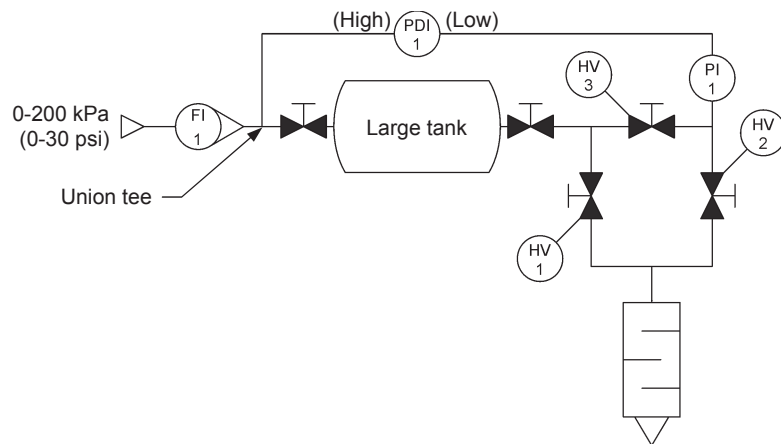


Figure 3-19. Second setup (closed valves shown in black).

- 21.** Adjust the zero of your measuring devices, if necessary.
- 22.** Ask your instructor to check and approve your setup.
- 23.** Open HV-2 to vent the pressure gauge and the low-pressure port of the DP transmitter to atmosphere.
- 24.** Apply a pressure of 200 kPa (30 psi) at the inlet of the tank. What value does the DP transmitter indicate?

200 kPa (30 psi)

- 25.** Close HV-2 and open the tank outlet valve and HV-3.

- 26.** Do you think the pressure gauge value will stabilize instantly if you open the tank inlet valve? Why?

No. The tank will fill up gradually and the pressure will take some time to build up inside the tank.

What will happen to the differential pressure between the inlet and outlet of the tank?

The differential-pressure value will tend toward zero.

The rotameter indicates the flow of air through the system.

- 27.** Start the chronometer² when opening the tank inlet valve. How long does it take before the value on the DP transmitter and pressure gauge stabilize?

Between 20 and 30 seconds

- 28.** What is indicated on the pressure gauge once the pressure is stabilized?

Approximately 160 kPa (23.3 psi)

- 29.** What is indicated on the DP transmitter once the pressure is stabilized?

0 kPa (0 psi)

- 30.** Close the air source and depressurize the system.

- 31.** Close all valves.

- 32.** Replace the large tank by the small tank in your setup of Figure 3-19.

- 33.** Set the tank inlet pressure to 200 kPa (30 psi). Open the tank outlet valve and HV-3. Start the chronometer (or observe on the paperless recorder) when opening the tank inlet valve. How long does it take before the values on the DP transmitter and pressure gauge stabilize?

Between 10 and 20 seconds

² You can use the Trend recorder instead of a chronometer to observe the time required for pressure stabilization on the DP transmitter. Refer to the *Familiarization with the training system* manual for connection details.

34. Explain the difference compared to when the large tank is filled.

The small tank is 8 times smaller than the large tank, hence the lesser time required to fill the tank. The time required is however not 8 times smaller because of the restrictions in the system.

35. Close the air supply and depressurize the system.

36. Use the main switch to cut the power to the Instrumentation and Process Control Training System.

CONCLUSION

In this exercise, you learned to measure pressure using both a digital pressure gauge and differential-pressure transmitter.

REVIEW QUESTIONS

1. Why are quarter-bridge strain gauge circuits not used in DP transmitters?

Quarter-bridge strain gauge circuits do not offer any mechanism to compensate for the electrical resistance of the circuit wires or to compensate for the change in the resistance of the strain gauge due to temperature.

2. Why does moving the impulse line of a pressure-sensing device influence the pressure reading?

The fluid in the impulse line exerts a pressure on the diaphragm of the device. If the impulse line is elevated or lowered, the pressure due to the weight of the fluid changes and this causes a shift of the zero of the device.

3. Why do you need to bleed pressure-sensing devices?

If air is trapped in a liquid tubing or in the pressure-sensing device, it will compress under pressure and small variations of pressure may become undetectable. This may also cause signal dampening. If liquid is trapped in a gas tubing, this may contaminate the process.

4. What must be taken into account along with the measured value?

The accuracy of the measurement

5. Where should the pressure-sensing device be mounted for gas pressure measurements?

Above the measurement point

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