Process Control

Pressure, Flow, and Level Processes

Courseware Sample

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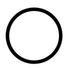
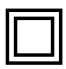
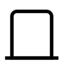
Safety and Common Symbols

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

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* 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
3∿	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

The growing use of process control in all types of industry comes from the need for a fast, low-cost means of production with better quality, less waste, and increased performance. Process control provides many other advantages, such as high reliability and precision at a low cost. Taking advantage of computer technology, controllers are more efficient and sophisticated than ever. To successfully operate and troubleshoot process control systems, effective training on process control systems is essential.

The curriculum using the Process Control Training System, Model 6090, is divided into three courses that respond to the various training needs in the field of instrumentation and process control. All three courses use water as the process medium.

The main objective of the basic course is to teach the operating principles, measurement and control of pressure, flow, and level processes. In addition, students gain valuable experience tuning closed-loop processes using the most frequently encountered industrial methods. Only basic equipment (Model 6090-1) is required for this course, but the industrial pressure, flow, and level add-on (Model 6090-5) can be used to complement the learning experience.

The second course is similarly designed but concentrates on temperature processes. In addition to the basic equipment, the temperature add-on (Model 6090-2) is necessary. An industrial heat exchanger add-on (Model 6090-4) is optional.

The third course is structured like the first two, but focuses on pH processes. This time, the basic equipment and the pH add-on (Model 6090-3) are mandatory.

Processes can be controlled using the Process Control and Simulation Software (LVProSim) or an optional PID controller. The exercises in the manual have been written for 4-20 mA control signals, but they can be easily adapted for 0-5 V signals. The experiments are performed using the I/O interface of the LVProSim controller with 4-20 mA signals. However, they can also be accomplished with other PID controllers and previous versions of the LVProSim I/O interface.

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.

About This Manual

Manual objectives

When you have completed this manual, you should be able to:

- explain the basic principles related to pressure, flow, and level measurement.
- name the different pressure, flow, and level measurement devices.
- understand the physical principles behind the various measurement devices.
- read and understand flow diagrams and wiring diagrams.
- perform pressure, flow, and level measurements.
- characterize pressure, flow, and level processes.
- perform control on pressure, flow, and level processes.
- understand the basic theory of centrifugal pumps.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

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.

The instructor should be familiar with process measurement and control to recognize erroneous results. It is advised that a complete run-through of each exercise be included in the instructor's preparation for class.

The training system can be controlled by using the included Process Control and Simulation Software (LVProSim) or with a trend recorder and any other conventional PID controller compatible with 4-20 mA or 0-5 V signals. For the sake of simplicity, the exercises in the Student Manual Temperature Process Control and their solutions have been written for a controller that works with 4-20 mA signals, which is the case of the LVProSim controller. If a controller that works with 0-5 V signals is used, the instructor should adapt the exercises in consequence prior to their beginning by the students.

Samples Exercises
Extracted from
the Student Manual
and the Instructor Guide

Venturi Tubes

EXERCISE OBJECTIVE

In this exercise, you will study the relationship between the flow rate and the pressure drop produced by a venturi tube. You will describe the behavior of a liquid as it flows through a venturi tube and measure the permanent pressure loss created. You will also calculate and compare the yearly electricity costs of two differential pressure flowmeters of equivalent size.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Venturi tubes
- Measuring principle
- Permanent pressure loss
- Correct installation of venturi tubes
- Industrial applications
- Advantages and limitations of venturi tubes
- Description of the supplied venturi tube
- Power in a flow system

DISCUSSION

Venturi tubes

A **venturi tube** is a differential-pressure flowmeter; it is the oldest and the most accurate type of differential-pressure flowmeter. Clemens Herschel (1842-1930) designed the first venturi tube in 1887. Herschel based his design on principles derived from the Bernoulli equation. Venturi tubes sticking to this first design are sometimes referred to as classic venturi tubes or Herschel venturi tubes. The design of venturi tubes has been fine-tuned over the years to reduce the cost and shorten the laying length. The short form venturi tube was first introduced in the 1950's.

Measuring principle

Like all differential pressure flowmeters, the venturi tube operates by restricting the area through which the liquid flows in order to produce a pressure drop. The pressure drop (ΔP) is measured between a high-pressure tap (H), located upstream of the convergent section, and a low-pressure (L) tap, located at the middle of the throat. Figure 3-18 shows the main steps of flow measurement using a venturi tube.

The built-in taps of the venturi tube allow the measurement of a difference in the static pressure. You cannot measure a dynamic pressure using this kind of tap. To measure the dynamic pressure, you must use a pitot tube.

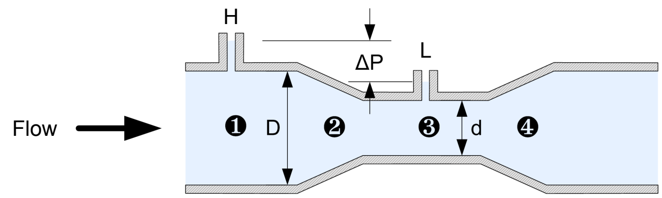


Figure 3-18. Flow measurement using a venturi tube.

1. The fluid enters the straight inlet section and a pressure transmitter measures the static pressure at the high-pressure tap.

2. The fluid continues to the convergent section where the venturi cross-section reduces gradually. This causes the velocity of the fluid to increase and the static pressure to decrease.

3. A second tap allows pressure measurement at the center of the throat, the narrowest section of the venturi. The flow rate of the fluid can be calculated from the static pressure drop between the high and the low pressure taps.

4. The divergent section of the venturi allows the fluid velocity to decrease and the pressure to recover most of its initial level. There is only a small permanent pressure loss over the venturi.

Like other differential-pressure flowmeters, the venturi tube is characterized by its β ratio (beta ratio). The β ratio of a venturi tube is the ratio of the diameter of the throat (d) to the diameter of the inlet section (D). Since β is a ratio of two diameters, it is dimensionless.

The following equation is used to calculate the flow rate Q using the pressure differential between the high-pressure tap and the low-pressure tap:

$$Q = CA_T\sqrt{\frac{2\Delta P}{\rho(1-\beta^4)}} \tag{3-14}$$

where
- Q is the volumetric flow rate
- C is the discharge coefficient, which takes into account the magnitude of the restriction and the frictional losses through this restriction
- A_T is the throat area, $A_T = \pi d^2/4$
- ΔP is the pressure differential between the high and low pressure taps
- ρ is the fluid density
- β is the β ratio, $\beta = d/D$

Permanent pressure loss

Because venturi tubes have no sharp edges or corners, unlike orifice plates, they allow the liquid to flow smoothly, which minimizes friction. However, friction cannot be eliminated altogether, so there is always a permanent pressure loss across the venturi tube. The permanent pressure loss of a venturi tube is typically between 10% and 25% of the pressure drop it produces.

Correct installation of venturi tubes

As for most flowmeters, a minimum length of straight pipe run must be present before and after a venturi tube. This minimizes the effect of turbulences on the measurement. The differential-pressure transmitter used to measure the pressure differential between the ports of the venturi tube must be located as close as possible to the flowmeter.

Venturi tubes also require a fully developed turbulent flow to produce accurate results. If an application requires a laminar or transitional flow to be measured, you will have to rely on a more sophisticated type of instrument such as a magnetic flowmeter or a mass flowmeter to measure the flow rate.

Industrial applications

The venturi tube flowmeter is often used in applications where the pressure drop or the utilization cost would be too high using an orifice plate. They can generally be used in slurry processes, unlike some other flowmeters.

Advantages and limitations of venturi tubes

Venturi tubes are highly accurate; they recover most of the pressure drop they produce, and they are less susceptible to erosion than orifice plates because of their smoother contour. Moreover, venturi tubes can generally be used in slurry processes because their gradually sloping shape allows solids to flow through.

However, venturi tubes are relatively expensive and they require the use of a differential-pressure transmitter, which contributes to the total cost of the flow measurement set up. They tend to be voluminous and they may be difficult to install. Venturi tubes also require a certain length of straight pipe both upstream and downstream to ensure a flow that is undisturbed by fittings, valves, or other equipment. However, the required pipe lengths are shorter than those required for orifice plates.

Description of the supplied venturi tube

Figure 3-19 shows the venturi tube used in the training system. This venturi tube is a short form venturi with a low permanent pressure-loss design. It consists of a cylindrical inlet section, a convergent section, a throat, a divergent section, and a cylindrical outlet section. The water from the inlet port is directed towards the venturi tube through the upstream pipe. As the water flows through the venturi tube, a pressure drop proportional to the square of the flow rate occurs across the high- (H) and low- (L) pressure taps.

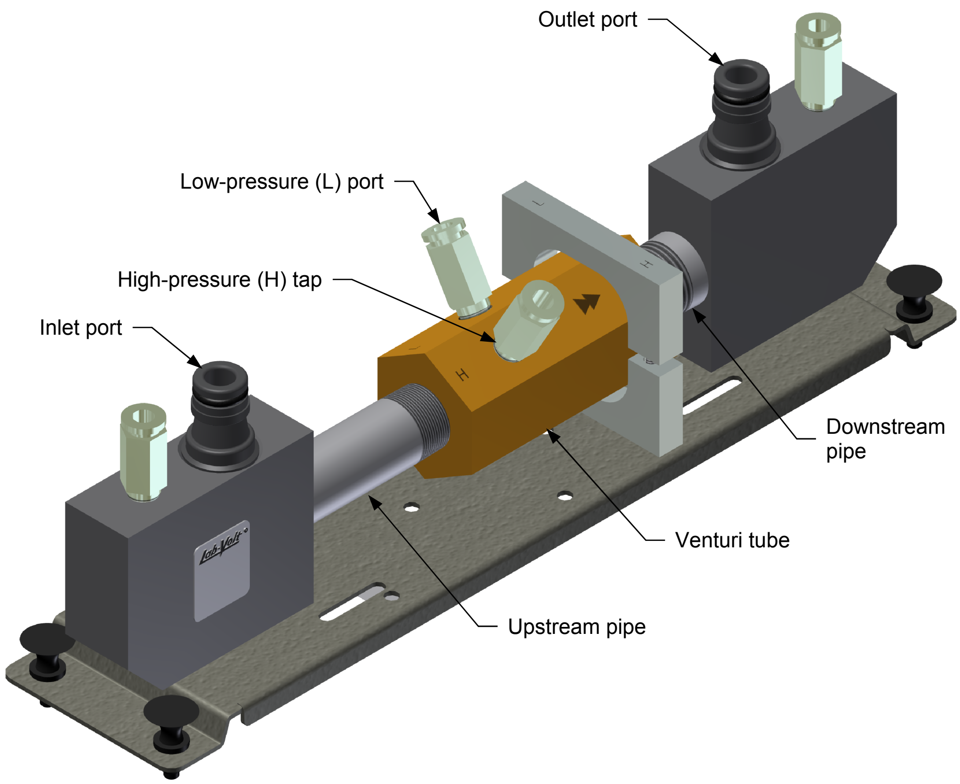


Figure 3-19. Venturi tube, Model 6551.

The venturi tube provided with the system has a throat diameter of 4.7 mm (0.19 in) and an internal pipe diameter of 12.7 mm (0.5 in), making its β ratio equal to 0.37.

Power in a flow system

Power is energy that is used to do useful work, like actuating a hydraulic cylinder, turning a turbine, powering home appliances, or circulating a fluid in a flow system. Power exists in several forms, such as hydraulic, mechanical, and electrical. The most common form of power available in plants is electrical. The machines in the plant use this electrical power to perform their functions. Electrical power is usually obtained from the electrical power distribution system.

Units of power

In the SI system of units, power is measured in watts (W). One watt (1 W) equals 1 $kg \cdot m^2/s^3$. Since the watt is a relatively small unit, the kilowatt (kW) is used more often.

In the US system of units, power is usually measured in horsepower (hp). One horsepower (1 hp) corresponds to the average power developed by a draft horse and is equal to 550 ft·lbf/s, or 746 W.

Power conversion in a flow system

In a flow system, power exists in the form of a pressurized fluid flowing through the system. This fluid power is developed by the pump as it circulates the fluid. The amount of fluid power developed is directly proportional to the flow rate and the pressure of the fluid at the pump outlet.

For example, consider the water system shown in Figure 3-20. The electric motor draws electrical power from the electrical power distribution system and converts it into mechanical power to turn the shaft of the pump. The pump then generates a flow of water into the system.

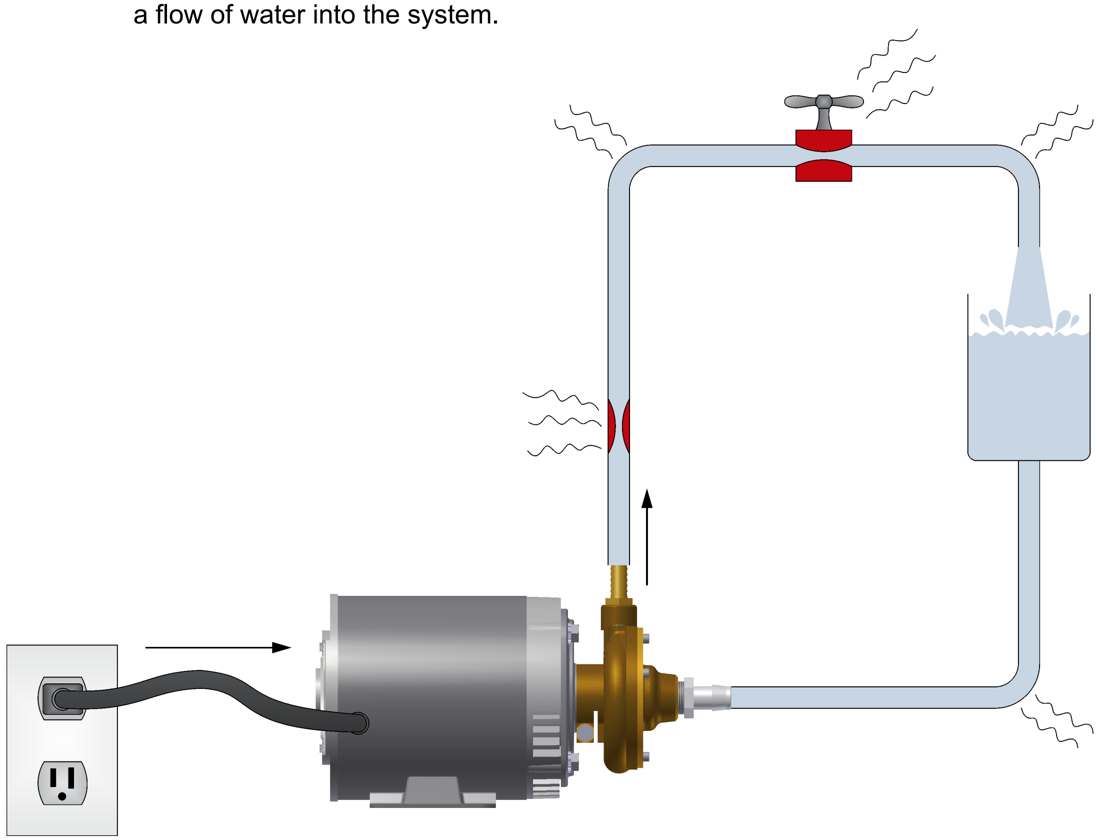


Figure 3-20. Power conversion in a water system.

If there is any resistance to the flow of water, a pressure is created at the pump outlet. The pressure and flow rate of the water at the pump outlet determine the amount of fluid power developed by the pump. This power can be calculated as follows:

$$P_p = p_p \, Q_p \tag{3-15}$$

where P_p is the pump output power

p_p is the pump pressure at the pump outlet

Q_p is the volumetric flow rate at the pump outlet

If you are using psi and gal/min US customary units, you need to divide the second term of Equation (3-15) by the correction factor 1714 to obtain a power value in hp.

The formula shows that doubling either the flow rate or the pressure doubles the fluid power developed by the pump.

Efficiency

If the electric motor and the pump in Figure 3-20 are 100% efficient, the motor develops a mechanical power equal to the electrical power it consumes and the pump develops a fluid power equal to the mechanical power applied to its shaft. Consequently, the fluid power developed by the pump is equal to the electrical power consumed by the motor.

However, some portion of the electrical power consumed by the motor is dissipated as heat by the motor frame. Moreover, some portion of the mechanical power applied to the pump shaft is dissipated as heat within the pump.

As a result, only a certain percentage of the electrical power consumed by the motor is actually used to develop fluid power at the pump output. This percentage is determined by the overall efficiency of the motor and the pump.

Be aware that other power losses (e.g., originating from the use of a motor drive or a coupling) can generate an even lesser overall efficiency.

Motor efficiency is defined as:

$$\eta_m = P_{out}/P_{in} \tag{3-16}$$

where η_m is the motor efficiency
P_{out} is the shaft power output
P_{in} is the electric power input

Pump efficiency tends to decrease over time because of wear.

Pump efficiency varies with flow rate and pressure conditions. It is defined as:

$$\eta_p = P_p/P_{out} \tag{3-17}$$

where η_p is the pump efficiency
P_p is the pump output power
P_{out} is the shaft power output

The overall efficiency, η_o, can be calculated by multiplying the motor efficiency by the pump efficiency:

$$\eta_o = \eta_m \, \eta_p \tag{3-18}$$

If, for example, the motor efficiency is 90% and the pump efficiency is 70% under given circumstances, then the overall efficiency is 63%. This implies that only 63% of the electrical power consumed by the motor is used to develop fluid power at the pump output. The remainder of the power is lost in the conversion process.

Dissipated power in a flow system

The fluid power developed by the pump is converted into heat by each of the system components (restrictions, valves, flowmeters, etc.), due to their frictional resistance. The amount of power dissipated as heat by any component is determined by the pressure loss across the component and the flow rate through the component:

$$P_c = p_c\, Q_c \tag{3-19}$$

where P_c is the power dissipated by the component
p_c is the pressure loss across the component
Q_c is the volumetric flow rate through the component

If you are using psi and gal/min US customary units, you need to divide the second term of Equation (3-19) by the correction factor 1714 to obtain a power value in hp.

Yearly electricity cost of a differential-pressure flowmeter

The power dissipated as heat by a differential pressure flowmeter is a source of wasted energy and the additional electricity the pump motor consumes to compensate for the permanent pressure loss comes at a price. The yearly electricity cost of any differential pressure flowmeter can be estimated by using the following equation:

$$C_y = \frac{P_c\, T_u\, R_e}{\eta_o} \tag{3-20}$$

where C_y is the yearly electricity cost
P_c is the power dissipated by the component
T_u is the annual utilization time
R_e is the electricity rate
η_o is the overall efficiency

0.746 kW is equivalent to 1 hp.

Selection of a differential-pressure flowmeter

In several applications, the yearly electricity cost of a flowmeter can exceed its initial purchase cost, especially if the flow rate is high and the meter produces a high permanent pressure loss. Consequently, the selection of a particular type of flowmeter should also be based upon its yearly electricity cost and not only on its purchase cost.

If, for example, the choice is between a venturi tube and an orifice plate of equivalent size, the purchase cost of the venturi tube can be much higher than that of the orifice plate. However, the total cost of ownership of the venturi tube can still be favorable because of the savings made in yearly electricity costs. This occurs because the venturi tube far outperforms the orifice plate in regard to permanent pressure loss:

- The permanent pressure loss of an orifice plate is typically 60 to 80% of the pressure drop it produces. The permanent pressure loss can be estimated, for turbulent flow, by $1 - \beta^2$. For example, the orifice plate of the training system, with its β ratio of 0.45, produces a permanent pressure loss greater than 80% of the pressure drop it creates.
- The permanent pressure loss of a venturi tube is as low as 10 to 25% of the pressure drop it produces. For example, the venturi tube of the training system produces a permanent pressure loss of about 30% of the pressure drop it creates.

EXAMPLE 1

The permanent pressure loss caused by a differential pressure flowmeter is 30 kPa (4.35 psi), the flow rate through the flowmeter is 5000 L/min (1320 gal/min), the cost of electricity is \$0.1/kW·h, the overall efficiency of the motor and the pump is 70%, and the meter is operating continuously. What is the yearly electricity cost of the flowmeter?

Solution (SI units)

$$C_y = P_c\, T_u\, R_e\, \eta_o = \frac{(p_c\, Q_c)\, T_u\, R_e}{\eta_o}$$

$$C_y = \left(30\ kPa \times 5000\,\frac{\mathrm{L}}{\mathrm{min}}\right) \times (365\ \mathrm{d} \times 24\ \mathrm{h/d}) \times \frac{\$0.10}{\mathrm{kW \cdot h}} \div 70\%$$

$$C_y = \frac{30\ 000\ \mathrm{kg}}{\mathrm{m \cdot s^2}} \times 0.0833\,\frac{\mathrm{m^3}}{\mathrm{s}} \times 8760\ \mathrm{h} \times \frac{\$0.10}{0.7 \times 1000\,\frac{kg \cdot \mathrm{m^2}}{\mathrm{s^3}} \cdot \mathrm{h}}$$

$$C_y = \$3127$$

EXAMPLE 2

What is the yearly electricity cost saving that results from using a venturi tube instead of an orifice plate of equivalent size if the permanent pressure loss caused by these meters are, respectively, 13.8 kPa (2 psi) and 138 kPa (20 psi), the flow rate is 2000 L/min (528 gal/min), the cost of electricity is \$0.1/kW·h, the overall efficiency is 60%, and the meters are operating continuously?

Solution (US customary units)

The yearly cost saving that results from using the venturi tube instead of the orifice plate is around \$6038, as demonstrated below.

Venturi tube:

$$C_y = \left(\frac{2\ \text{psi} \times 528\,\frac{\text{gal}}{\text{min}}}{1714\ \frac{\text{psi}\cdot\text{gal}}{\text{min}\cdot\text{hp}}} \right) \times (365\ \text{d} \times 24\ \text{h/d}) \times \frac{\$0.10}{\text{kW}\cdot\text{h}} \times \frac{0.746\ \text{kW}}{\text{hp}} \div 60\%$$

$$C_y = 0.616\ \text{hp} \times 8760\ \text{h} \times \frac{\$0.10 \times 0.746}{0.6\ \text{hp}\cdot\text{h}}$$

$$C_y = \$671$$

Orifice plate:

$$C_y = \left(\frac{20\ \text{psi} \times 528\,\frac{\text{gal}}{\text{min}}}{1714\,\frac{\text{psi}\cdot\text{gal}}{\text{min}\cdot\text{hp}}} \right) \times (365\ \text{d} \times 24\ \text{h/d}) \times \frac{\$0.10}{\text{kW}\cdot\text{h}} \times \frac{0.746\ \text{kW}}{\text{hp}} \div 60\%$$

$$C_y = 6.16\ \text{hp} \times 8760\ \text{h} \times \frac{\$0.10 \times 0.746}{0.6\ \text{hp}\cdot\text{h}}$$

$$C_y = \$6709$$

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and connections
- Measuring the pressure drop-versus-flow curve of the venturi tube
- Linearizing the venturi tube curve
- Permanent pressure loss of the venturi tube
- Electricity cost of flowmeters
- End of the exercise

PROCEDURE

Set up and connections

1. Set up the system shown in Figure 3-21.

Connect the pressure measuring devices to the high- and low-pressure ports.

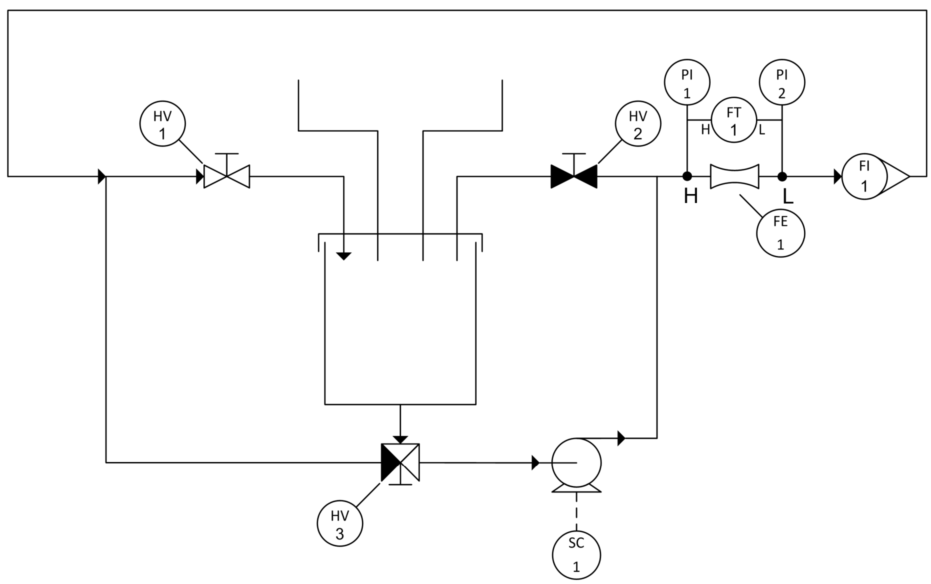


Figure 3-21. Measuring flow rate with a venturi tube.

2. Power up the DP transmitter.

3. Make sure the reservoir of the pumping unit is filled with about 12 L (3.2 gal) of water. Make sure the baffle plate is properly installed at the bottom of the reservoir.

4. On the pumping unit, adjust pump valves HV1 to HV3 as follows:
   - Open HV1 completely.
   - Close HV2 completely.
   - Set HV3 for directing the full reservoir flow to the pump inlet.

5. Turn on the pumping unit.

Transmitter calibration

This exercise can also be accomplished using the optional industrial differential-pressure transmitter (Model 46929). Should you choose this piece of equipment, refer to Appendix I for instructions on how to install and use the transmitter for pressure measurements.

In steps 6 through 11, you will adjust the ZERO and SPAN knobs of the DP transmitter so that its output current varies between 4 mA and 20 mA when the flow rate through the venturi tube is varied between 0 L/min and 11 L/min (0 gal/min and 2.75 gal/min).

6. Connect a multimeter to the 4-20 mA output 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: *I (ON)*

8. With the pump speed at 0%, turn the *ZERO* adjustment knob of the DP transmitter counterclockwise and stop turning it as soon as the multimeter reads 4.00 mA.

9. Adjust the pump speed until you read a flow rate of 11 L/min (2.75 gal/min) on the rotameter. This is the maximum flow rate through the venturi tube.

10. Adjust the *SPAN* knob of the DP transmitter until the multimeter reads 20.0 mA.

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

Measuring the pressure drop-versus-flow curve of the venturi tube

12. Adjust the pump speed to obtain a flow rate of 11 L/min (2.75 gal/min).

13. Measure and record the difference between the readings of pressure gauges PI1 and PI2. This is the pressure drop produced by the venturi tube at maximum flow rate.

The DP transmitter should generate 100% output, i.e., 20 mA.

PI1: 43 kPa (5.6 psi)

PI2: 16 kPa (2.0 psi)

ΔP_{20mA}: 27 kPa (3.6 psi)

This also means that a drop of 1 mA corresponds to approximately 1.7 kPa or 0.23 psi.

14. Adjust the pump speed until you read a flow rate of 2 L/min (0.5 gal/min) on the rotameter. In Table 3-4, record the analog output value generated by the DP transmitter for that flow rate.

15. By varying the pump speed, increase the flow rate by steps of 1 L/min (or 0.25 gal/min) until you reach 11 L/min (2.75 gal/min) on the rotameter. After each new flow setting, measure the analog output value generated by the DP transmitter and record it in Table 3-4.

Table 3-4. Venturi tube data.

Rotameter flow L/min (gal/min)	DP transmitter output mA	Pressure drop ΔP_{HL} kPa (psi)	$\Delta P_{HL}^{1/2}$ $kPa^{1/2}$ ($psi^{1/2}$)
2 (0.50)			
3 (0.75)			
4 (1.00)			
5 (1.25)			
6 (1.50)			
7 (1.75)			
8 (2.00)			
9 (2.25)			
10 (2.50)			
11 (2.75)			

The following analog output values were obtained using the DP transmitter, Model 6540. Values are in mA.

Venturi tube data (SI units).

Rotameter flow L/min	DP transmitter output mA	Pressure drop ΔP_{HL} kPa (psi)	$\Delta P_{HL}^{1/2}$ $kPa^{1/2}$
2	4.16	0.27	0.52
3	4.58	0.97	0.99
4	5.44	2.43	1.56
5	6.59	4.37	2.09
6	8.06	6.86	2.62
7	9.98	10.10	3.18
8	12.35	14.09	3.75
9	14.82	18.25	4.27
10	17.50	22.79	4.77
11	20.00	27.00	5.20

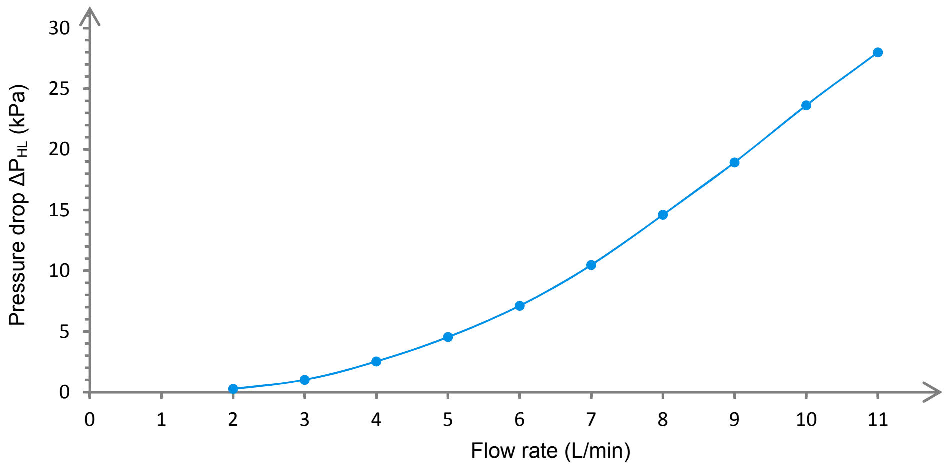
Venturi tube data (US customary units).

Rotameter flow gal/min	DP transmitter output mA	Pressure drop ΔP_{HL} kPa (psi)	$\Delta P_{HL}^{1/2}$ $psi^{1/2}$
0.50	4.16	0.04	0.19
0.75	4.61	0.14	0.37
1.00	5.47	0.33	0.58
1.25	6.59	0.58	0.76
1.50	8.03	0.91	0.95
1.75	9.98	1.35	1.16
2.00	12.42	1.89	1.38
2.25	14.66	2.40	1.55
2.50	17.34	3.00	1.73
2.75	20.00	3.60	1.90

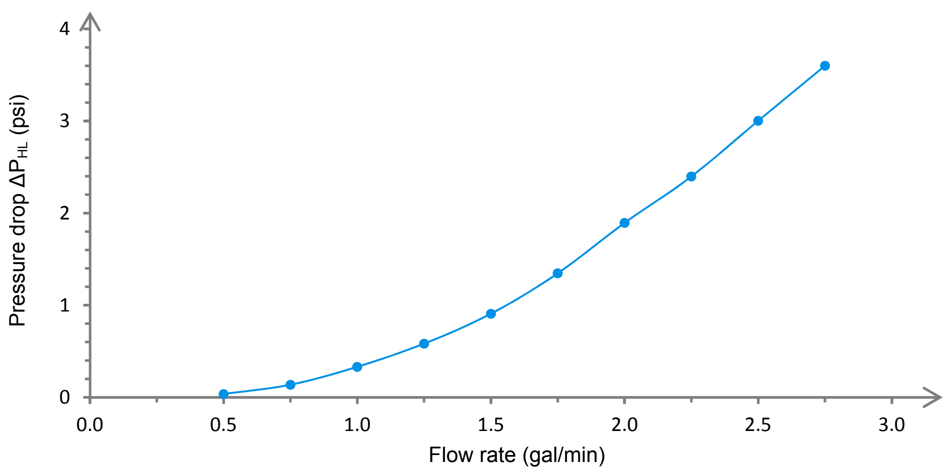
16. Stop the pump.

17. Based on the pressure drop you obtained in step 13 for an output of 20 mA, calculate the pressure drop ΔP_{HL} produced by the venturi tube for each flow rate listed in Table 3-4. Record your results in this table.

18. Using Table 3-4, plot the relationship between the flow rate and the pressure drop ΔP_{HL}.



Flow rate and differential pressure produced by a venturi tube (SI units).



Flow rate and differential pressure produced by a venturi tube (US customary units).

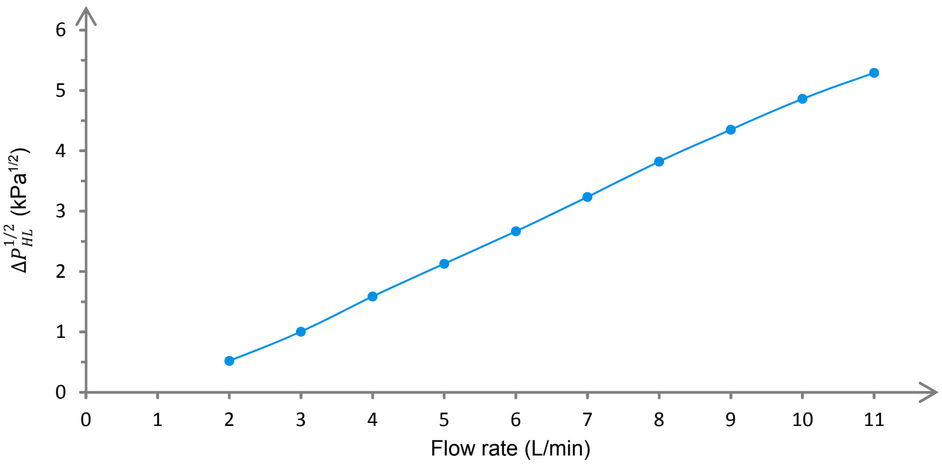
19. From the curve obtained, is the relationship between the flow rate and the pressure drop produced by the venturi tube linear? Explain.

No. The relationship between the flow rate and the pressure drop produced by the venturi tube is not linear, as indicated by the parabolic shape of the curve. This occurs because the pressure drop is proportional to the square of the flow rate.

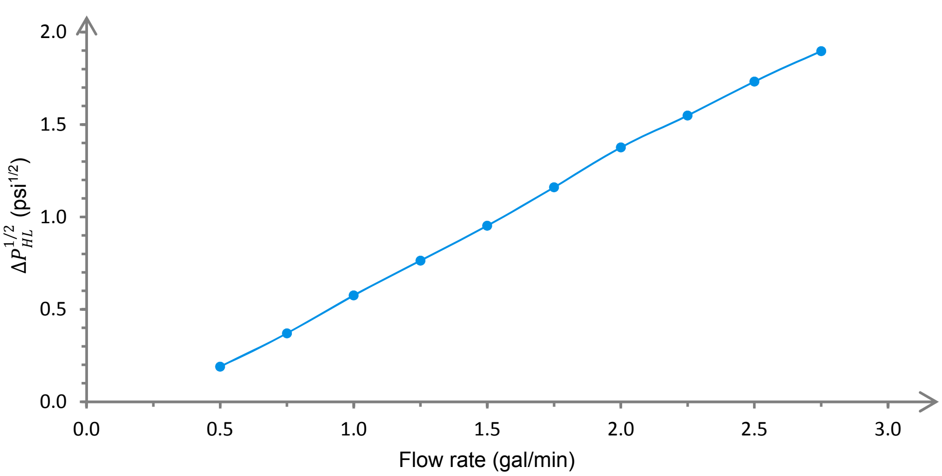
Linearizing the venturi tube curve

20. Calculate the square root of the pressure drop for each flow rate listed in Table 3-4. Record your results in this table.

21. Using Table 3-4, plot the relationship between the flow rate and the square root of the pressure drop, $\Delta P^{1/2}$.



Flow rate and square root of the differential pressure produced by a venturi tube (SI units).



Flow rate and square root of the differential pressure produced by a venturi tube (US units).

22. From the curve obtained, does a linear relationship exist between the flow rate and the square root of the pressure drop produced by the venturi tube? Explain.

Yes. The relationship between the flow rate and the square root of the pressure drop produced by the venturi tube is quite linear. The obtained curve is a straight line of nearly constant slope. This occurs because the square root of the pressure drop is proportional to the flow rate.

Permanent pressure loss of the venturi tube

23. Set up the system shown in Figure 3-22. It is the same set up as Figure 3-21 except that the pressure measuring devices are connected to the inlet and outlet pressure ports of the venturi tube instead of the *H* and *P* pressure taps.

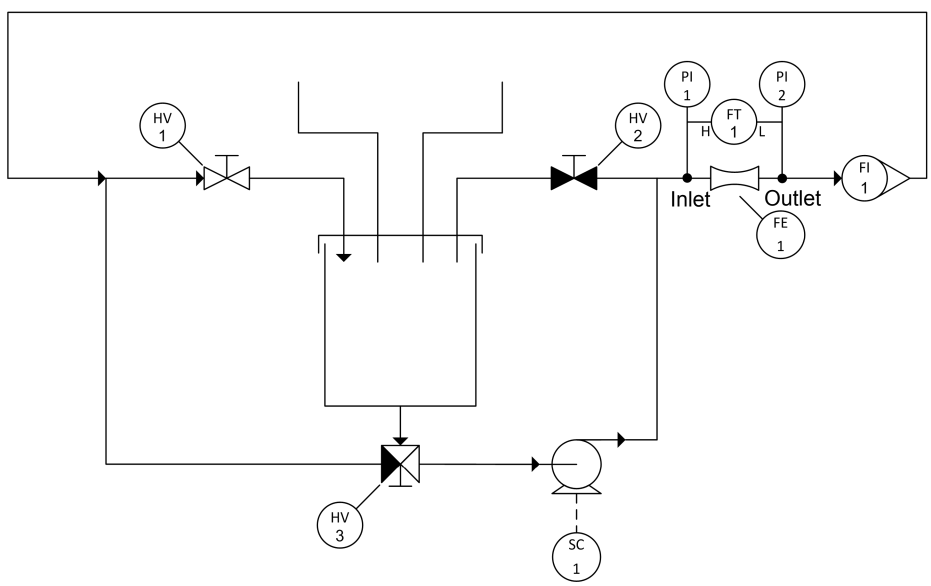


Figure 3-22. Measuring flow rate with a venturi tube.

24. Adjust the pump speed to obtain a flow rate of 11 L/min (2.75 gal/min).

25. Calibrate the DP transmitter so that the analog output generates 4 mA at 0 L/min (0 gal/min) and 20 mA at 11 L/min (2.75 gal/min). Adjust the pump speed and use the rotameter to obtain your two reference flow rate values.

26. Measure and record the difference between the readings of pressure gauges PI1 and PI2. This is the permanent pressure drop loss produced by the venturi tube at maximum flow rate.

The DP transmitter should generate 100% output, i.e., 20 mA.

PI1: 44 kPa (5.7 psi)

PI2: 36 kPa (4.6 psi)

ΔP_{20mA}: 8 kPa (1.1 psi)

This also means that a drop of 1 mA corresponds to approximately 0.5 kPa or 0.07 psi.

27. Adjust the pump speed until you read a flow rate of 2 L/min (0.5 gal/min) on the rotameter. In Table 3-5, record the analog output value generated by the DP transmitter for that flow rate.

28. By varying the pump speed, increase the flow rate by steps of 1 L/min (or 0.25 gal/min) until you reach 11 L/min (2.75 gal/min) on the rotameter. After each new flow setting, measure the analog output value generated by the DP transmitter and record it in Table 3-5.

Table 3-5. Venturi tube permanent pressure loss.

Rotameter flow L/min (gal/min)	DP transmitter output mA	Pressure loss ΔP_{IO} kPa (psi)	Loss %
2 (0.50)			
3 (0.75)			
4 (1.00)			
5 (1.25)			
6 (1.50)			
7 (1.75)			
8 (2.00)			
9 (2.25)			
10 (2.50)			
11 (2.75)			

The following analog output values were obtained using the DP transmitter, Model 6540. Values are in mA.

Venturi tube plate permanent pressure loss (SI units).

Rotameter flow L/min	DP transmitter output mA	Pressure loss ΔP_{IO} kPa	Loss %
2	4.45	0.22	83
3	5.09	0.54	54
4	5.95	0.98	39
5	6.91	1.46	32
6	8.42	2.21	31
7	10.46	3.23	31
8	12.67	4.34	30
9	14.85	5.42	29
10	17.66	6.83	29
11	20.00	8.00	29

Venturi tube plate permanent pressure loss (US customary units).

Rotameter flow gal/min	DP transmitter output mA	Pressure loss ΔP_{IO} psi	Loss %
0.50	4.48	0.03	92
0.75	5.12	0.08	56
1.00	5.86	0.13	39
1.25	6.88	0.20	34
1.50	8.13	0.28	31
1.75	10.14	0.42	31
2.00	12.58	0.59	31
2.25	14.98	0.75	31
2.50	17.60	0.94	31
2.75	20.00	1.10	31

29. Stop the pump and turn off the pumping unit.

30. Based on the permanent pressure loss you obtained in step 26 for an output of 20 mA, calculate the permanent pressure loss ΔP_{IO} produced by the venturi tube for each flow rate listed in Table 3-5. Record your results in this table.

31. Calculate the percentage of permanent pressure loss for the venturi tube at different flow rates. Use Equation (3-13) and record your results in Table 3-5.

32. Is the percentage of permanent pressure loss relatively constant over the range of interest? Explain.

Yes, the permanent pressure loss is constant at around 30%, except for low flow rates where the measuring error is more important.

33. Compare the permanent pressure loss of the venturi tube with that of the orifice plate obtained in Ex. 3-2. Which flowmeter generates the lesser permanent pressure loss? Explain.

The venturi tube is the flowmeter generating the lesser permanent pressure loss with about 30%. The orifice plate generates over 80% permanent pressure loss.

Electricity cost of flowmeters

34. What is the yearly electricity cost of using your venturi tube continuously at a flow rate of 8 L/min (or 2 gal/min) if the motor efficiency is 66%, the pump efficiency is 70%, and the cost of electricity is 0.15$/kW·h?

$$\eta_o = \eta_m \, \eta_p = 66\% \times 70\% = 46.2\%$$

$$C_y = \left(4.34\ \mathrm{kPa} \times 8\,\frac{\mathrm{L}}{\mathrm{min}}\right) \times (365\ \mathrm{d} \times 24\ \mathrm{h/d}) \times \frac{\$0.15}{\mathrm{kW \cdot h}} \div 46.2\%$$

$$C_y = \frac{4340\ \mathrm{kg}}{\mathrm{m \cdot s^2}} \times 0.000133\,\frac{\mathrm{m^3}}{\mathrm{s}} \times 8760\ \mathrm{h} \times \frac{\$0.15}{0.462 \times 1000\,\frac{kg \cdot \mathrm{m^2}}{\mathrm{s^3}} \cdot \mathrm{h}}$$

$$C_y = \$1.64$$

35. What is the yearly electricity cost of using your orifice plate under the same circumstances? Refer to Ex. 3-2 for permanent pressure loss data.

$$C_y = \left(11.90\ \text{kPa} \times 8\frac{\text{L}}{\text{min}}\right) \times (365\ \text{d} \times 24\ \text{h/d}) \times \frac{\$0.15}{\text{kW} \cdot \text{h}} \div 46.2\%$$

$$C_y = \frac{11900\ \text{kg}}{\text{m} \cdot \text{s}^2} \times 0.000133\frac{\text{m}^3}{\text{s}} \times 8760\ \text{h} \times \frac{\$0.15}{0.462 \times 1000\frac{kg \cdot \text{m}^2}{\text{s}^3} \cdot \text{h}}$$

$$C_y = \$4.50$$

36. How much do you save each year if you use the venturi tube instead of the orifice plate?

$2.86

End of the exercise

37. Disconnect the circuit. Return the components and hoses to their storage location.

38. Wipe off any water from the floor and the training system.

CONCLUSION

In this exercise, you learned that a venturi tube produces a pressure drop proportional to the square of the flow rate. Therefore, by measuring the pressure drop with a pressure transmitter, a signal proportional to the square of the flow rate can be obtained.

You compared the permanent pressure losses caused by a venturi tube to that of an orifice plate of equivalent size. You saw that the venturi tube produced less permanent pressure loss than the orifice plate for any given flow rate. Then, you calculated that even a small difference between the permanent pressure losses of two differential pressure flowmeters can imply a great difference between their yearly electricity costs. Thus, you can either spend money paying the extra electricity consumed by a cheaper flowmeter or you can spend money on a better low-loss flowmeter and later make savings in electricity costs.

REVIEW QUESTIONS

1. What is meant by the "throat" of a venturi tube?

The throat is the center part of the venturi tube where the cross section is constant and the decreased pressure is measured.

2. How is the beta (β) ratio of a venturi tube calculated?

The beta (β) ratio of a venturi tube is calculated by dividing the diameter of the throat section by the internal diameter of the upstream pipe.

3. What factors determine the permanent pressure loss of a venturi tube?

The permanent pressure loss of a venturi tube depends both on its β ratio and on the angle of divergence of its outlet section.

4. What are the advantages and limitations of venturi tubes?

Venturi tubes have the following advantages: they are highly accurate, they recover most of the pressure drop they produce, and they are less susceptible to erosion than orifice plates.

However, venturi tubes are relatively expensive, they tend to be voluminous, they may be difficult to install, and they require that a certain length of straight pipe be provided both upstream and downstream to ensure a flow that is undisturbed by fittings, valves, or other equipment.

5. How does the venturi tube compare to the orifice plate in regard to permanent pressure loss?

The venturi tube far outperforms the orifice plate in regard to permanent pressure loss. Thus, the permanent pressure loss caused by a venturi tube is as low as 10% to 25% of the pressure drop it produces while that caused by an orifice plate is typically 60 to 80% of the pressure drop it produces.

Exercise 4-6

Ultrasonic Level Transmitters (Optional Exercise)

EXERCISE OBJECTIVE

In this exercise, you will study how ultrasonic level transmitters operate. You will measure level in a column using an ultrasonic level transmitter and perform on-off control using a relay.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Introduction
- How does an ultrasonic level sensor work?
- Relay control
- Characteristics of ultrasonic level sensors
- Advantages and limitations
- Description of the supplied ultrasonic level transmitter

DISCUSSION

Introduction

Ultrasonic level sensors use sound waves to detect the level of liquid or solid in different types of containers and environments such as tanks, silos, or even a lake. Ultrasonic sensors are also suitable for flow measurement and level limit detection. They have the advantage of being non-contact sensors, which means they can be used in corrosive environments, and they are not affected by changes in the density, conductivity, and composition of the process fluid or solid. Since they have no moving parts, they also require very low maintenance. Figure 4-23 shows two level measurement applications (solid and liquid), one conveyor belt application, and one flow measurement application for a weir.

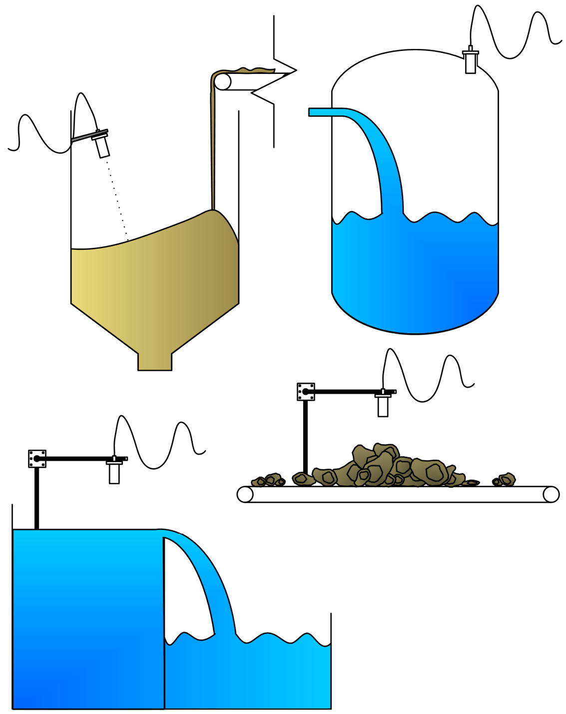


Figure 4-23. Typical applications of ultrasonic sensors.

Ultrasonic level sensors are sensitive to temperature changes. For processes where the temperature may vary, a temperature compensation mechanism is required. The quality of the detection is strongly dependent on the quality of the sound wave reflected by the process liquid or solid. This reflected sound wave is called the echo and its intensity is proportional to the square of the distance between the sensor membrane and the surface of the process substance. Thus, the further the sensor is from the surface of the substance, the weaker the echo. The intensity of the echo is also reduced by the natural absorption of the sound wave by air, and by vapor, mist, foam, or dust in the measuring path. The sound waves can be reflected by other apparatuses (such as inlets or other sensors) in the detection path of the sensor. An echo suppression system usually reduces these extra reflections.

How does an ultrasonic level sensor work?

Normal human hearing ranges from about 20 Hz to 20 kHz. In comparison, most ultrasonic level sensors have an operating frequency of over 20 kHz, beyond the upper limit of human hearing. Ultrasonic level sensors use a vibrating diaphragm to produce ultrasonic pulses travelling in the air at the speed of sound. These ultrasound pulses are directed toward the product (liquid or solid) with the level we want to measure. The pulses are reflected at the interface between the air and the medium and travel back to a receiver, which is usually built into the sensor housing. Figure 4-24 shows a standard installation of an ultrasonic level sensor in a vessel.

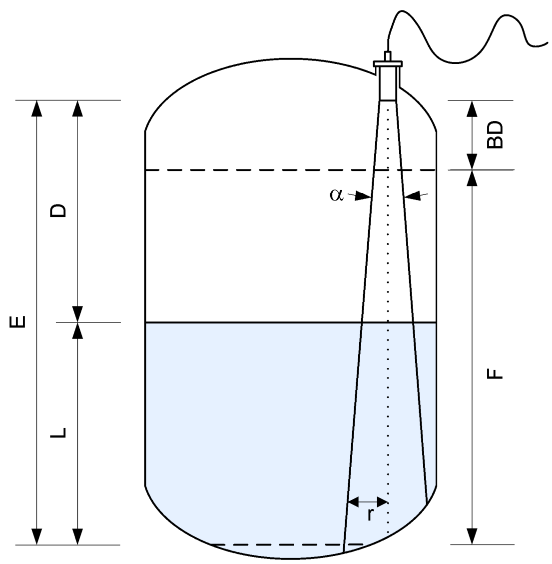


Figure 4-24. Relevant dimensions for a typical ultrasound set up.

In this figure, **BD** is the blocking distance. A level cannot be properly evaluated within the blocking distance, because the sensor must first stop emitting a pulse before it can detect its echo, i.e., the reflected signal. If the distance is too short, there is not enough time to emit the whole pulse before the return of the echo which is then not properly detected by the sensor. This is why the level of the product must not be allowed to rise within the blocking distance. **F** is the span or full distance in which measurements take place, **E** is the total distance between the sensor membrane and the lowest measureable level of the span, **L** is the portion of **E** currently filled with the product, and **D** is the portion of **E** which is empty. The emitting angle **α** can be used to calculate the detection radius **r** for a given height.

The distance between the sensor and the surface of the product is calculated using the velocity of sound in air and by measuring the time between the emission of the pulse and its subsequent reception by the receiver. This method of measuring distances is the time-of-flight measurement method.

$$D = \frac{c_{air}\, t}{2} \tag{4-13}$$

where D is the distance between the ultrasonic sensor and the surface of the product

c_{air} is the speed of sound in the air

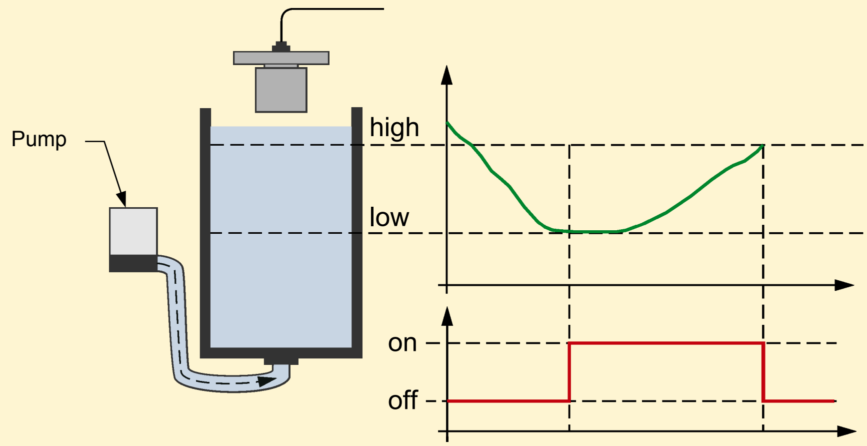
t is the time taken by the ultrasonic pulse to travel to and from the surface of the product

Relay control

Ultrasonic transmitters are often bundled with relays that open and close at discrete levels. These relays can be configured for a given application (e.g., pump control, overflow) as shown in the examples below.

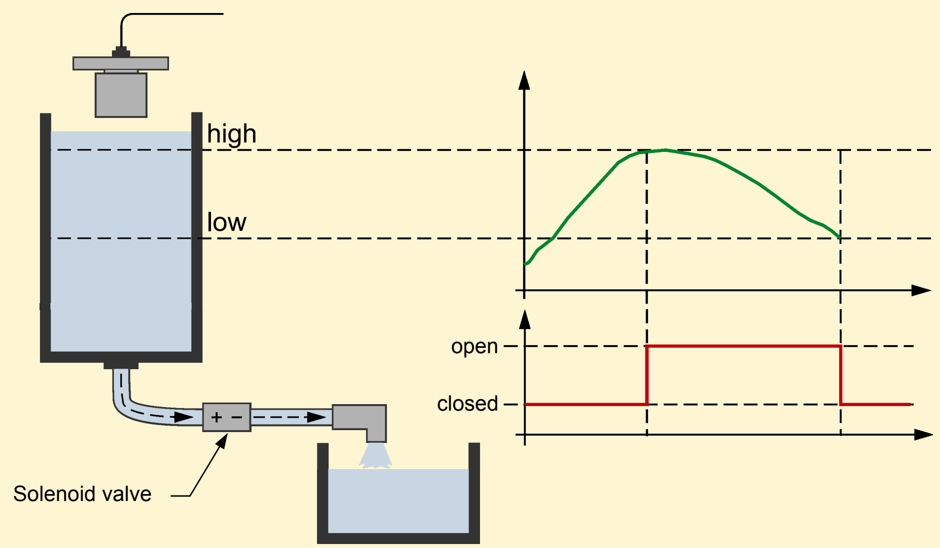
Example 1 – Water supply

In the arrangement shown below, a pump is located outside the column and feeds water to the column. The pump turns on when the level is low and switches off when the level is high, so that the level is kept within a specific range. Note that the same type of control can be accomplished by restricting the incoming flow of water (e.g., using a solenoid valve).



Example 2 – Overflow control

In the configuration shown below, a solenoid valve is controlling the output flow of a column to prevent the water from overflowing. The valve opens when the level is high and closes when the level is low.



Characteristics of ultrasonic level sensors

Most characteristics of ultrasonic level sensors are related to the physics of sound wave propagation and to the properties of the media in which the waves travel. The reflection, propagation, and absorption of sound waves have an influence on the resultant echoes as does the temperature of the air in the tank.

What is the influence of the temperature?

As specified above, the speed of sound is used to calculate the distance between the sensor and the surface of the product. Therefore, to measure the level correctly, the sensor must use the correct value for the speed of sound.

If air is treated as an ideal gas, the speed of sound is influenced only by the air temperature. When measuring a level using an ultrasonic level sensor, a correction must be made to the time-of-flight to compensate for the change in the speed of sound due to temperature variations. Equation (4-14) gives the relation between the speed of sound in the air and the temperature.

$$c_{air} = c_{air(0°C)} \sqrt{1 + \frac{T_{°C}}{273.15}} \tag{4-14}$$

where c_{air} is the speed of sound (m/s)
$c_{air(0°C)}$ is 331.3 m/s, the speed of sound at 0°C
$T_{°C}$ is the temperature (°C)

Equation (4-15) is an approximate formula to calculate the speed of sound derived from Equation (4-14) using Taylor series expansion. This equation is valid for $T_{°C}$ much smaller than 273.15°C.

$$c_{air} \approx c_{air(0°C)} + 0.606\, T_{°C} \tag{4-15}$$

The previous equations can be restated in US customary units as shown below:

$$c_{air} = c_{air(32°F)} \sqrt{1 + \frac{5}{9}\left(\frac{T_{°F} - 32}{273.15}\right)} \tag{4-16}$$

where c_{air} is the speed of sound (ft/s)
$c_{air(32°F)}$ is 1086.9 ft/s, the speed of sound at 32°F
$T_{°F}$ is the temperature (°F)

This yields the following approximation for $T_{°F} \ll\ 523.7\ °F$

$$c_{air} \approx 1051.5 + 1.11\, T_{°F} \tag{4-17}$$

Equation (4-15) or Equation (4-17) shows that (for dry air at normal pressure) the speed of sound is approximately proportional to the temperature. As the temperature increases, so will the velocity of the ultrasound pulses. If no temperature compensation is used, the changes in the value of the speed of sound add an error of 1.8% to the measured level for each 10°C augmentation (1% error per 10 °F). This clearly demonstrates the need for a temperature compensation system on ultrasonic level sensors in order to retain adequate precision.

What are the factors influencing the intensity of the echo?

To measure a level, the sensor must detect the echo of the emitted ultrasonic pulse. In order to do so, the echo must have a sufficient intensity to be detected. Many factors influence the intensity of the echo; the most important ones are related to the propagation, absorption, and reflection of sound waves.

Sound waves naturally disperse as they propagate so that their intensity is inversely proportional to the square of the distance traveled. The more distance there is between the ultrasonic sensor and the surface of the product, the weaker the intensity of the echo is.

When the ultrasonic pulse hits the surface of the product, a portion of its energy is absorbed by the product instead of being reflected, thus diminishing the intensity of the returning sound wave. A sharp transition between the air and the medium whose level is to be measured is advisable to obtain reliable measurements. Foam, for example, can cause discrepancies when measuring the level of liquid in a tank with an ultrasonic level sensor.

To measure the level of product, the ultrasonic pulse must return to the sensor. This does not happen if the sensor membrane is not parallel to the surface of the measured product. When ultrasonic pulses are produced by the sensor, they travel in a straight line. If the angle of incidence of the ultrasonic pulse with respect to the surface normal is not 0° (i.e., perpendicular to the surface) the pulse is reflected with an angle and the echo is likely to miss the sensor and escape detection.

Advantages and limitations

Ultrasonic technologies can be used for a large spectrum of applications and are typically very reliable. This explains why devices using ultrasound signals are so widespread in the industry. Some of their main advantages are:

- They are non-contact sensors and are suitable for most liquids and bulk products.
- They are reliable and accurate.

However, some limitations should also be considered:

- The surface of the product must be still and smooth to ensure the quality of the reading.
- The temperature must remain within operational bounds and has to be uniform throughout the path of the sound wave to avoid unreliable results.

Description of the supplied ultrasonic level transmitter

The ultrasonic level transmitter (Model 6545) designed for the Process Control Training System is shown in Figure 4-25. It is composed of an ultrasonic sensor/emitter that can be inserted on top of column and a transmitter that can be connected to a computer for use of the accompanying software, *SenixVIEW™*.

A temperature sensor is located inside the sensor and temperature compensation is turned on by default in SenixVIEW*.*

5. **Sensor / Emitter and cable.** The ultrasonic sensor emits ultrasound waves and detects the reflected echoes.

6. **Column adapter.** A plastic threaded adapter permitting to fit the sensor on top of the column.

7. **Transmitter.** The transmitter is the interface between the sensor and the other components of the system.

8. **24 V dc input.** Used to energize the ultrasonic level transmitter.

9. **Relay outputs.** Two normally open contacts (SW1 and SW2) are accessible from these pairs of jacks.

10. **Sensor connector.** Used to connect the sensor cable to the transmitter.

11. **Communication port.** Serial cable between the computer and the transmitter connects here.

12. **Analog output.** An analog (4-20 mA) output signal proportional to the level of liquid in the column is sent from these jacks.

13. ***SenixVIEW* software.** Ultrasonic level transmitter configuration software.

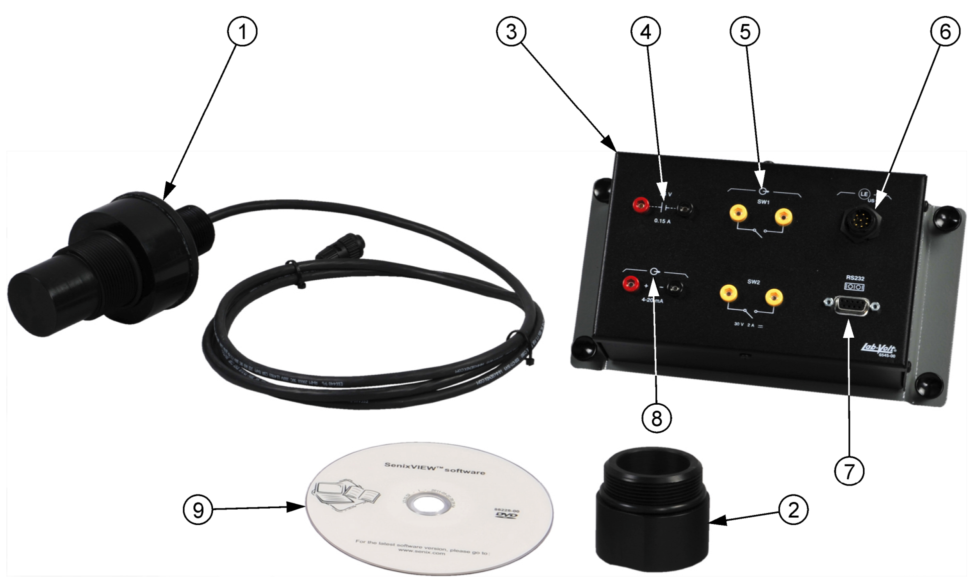


Figure 4-25. Ultrasonic level transmitter (Model 6545).

Summary of technical specifications

Technical specifications for the ultrasonic level transmitter are summarized in the table below. For more details, please refer to the documentation provided with the device.

Operating frequency of the sensor	125 kHz
Operating temperature of the sensor	-40 to 70°C (-40 to 158°F)
Blocking distance of the sensor (RangeMIN in *SenixVIEW*)	6.4 cm (2.5 in)
Optimum range	203 cm (80 in)
Repeatability	0.1%of target distance
Accuracy	0.5% of target distance
Analog resolution	41 000 steps over chosen range
Serial data resolution	0.086 mm (0.003384 in)

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and connections
- Varying the column level
- Measuring the water level
- Using the relays
- End of the exercise

PROCEDURE

Set up and connections

General arrangement

1. Get the ultrasonic level transmitter and the column from your storage location. Install the sensor on top of the column as shown in Figure 4-26 and connect the ultrasonic sensor cable to the transmitter.

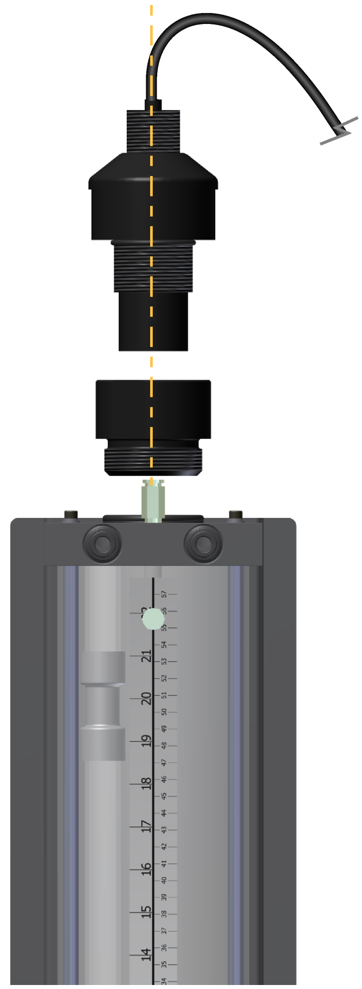


Figure 4-26. Installing the sensor on the column.

2. Set up the system according to Figure 4-27.

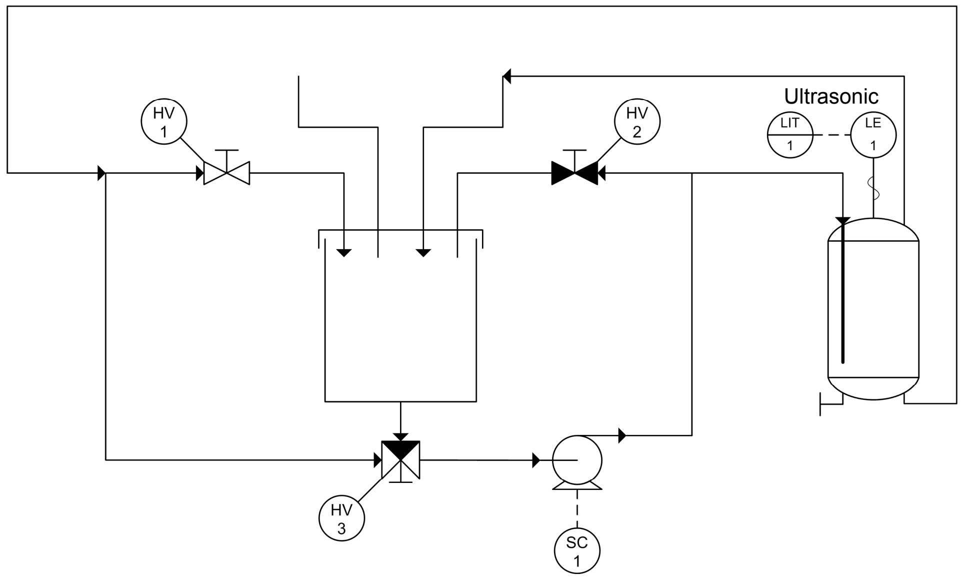


Figure 4-27. Measuring the water level using an ultrasonic level transmitter.

3. Make sure the reservoir of the pumping unit is filled with about 12 L (3.2 gal) of water. Make sure the baffle plate is properly installed at the bottom of the reservoir.

4. On the pumping unit, adjust valves HV1 to HV3 as follows:

- Open HV1 completely.
- Close HV2 completely.
- Set HV3 for directing the full reservoir flow to the pump inlet.

Commissioning the ultrasonic level transmitter

5. Connect the communication cable between the transmitter and your computer. Use the provided serial-to-USB adapter, if necessary.

6. Power up the transmitter.

7. If the software is not already installed on your computer, insert the *SenixVIEW*™ software disk and run *setup.exe*. Follow the on-screen instructions to install the software.

8. Open *SenixVIEW* and load default (LVL-100) sensor settings (*Workspace* ► *Default LVL-100 Settings*) on the workspace, as shown in Figure 4-28.

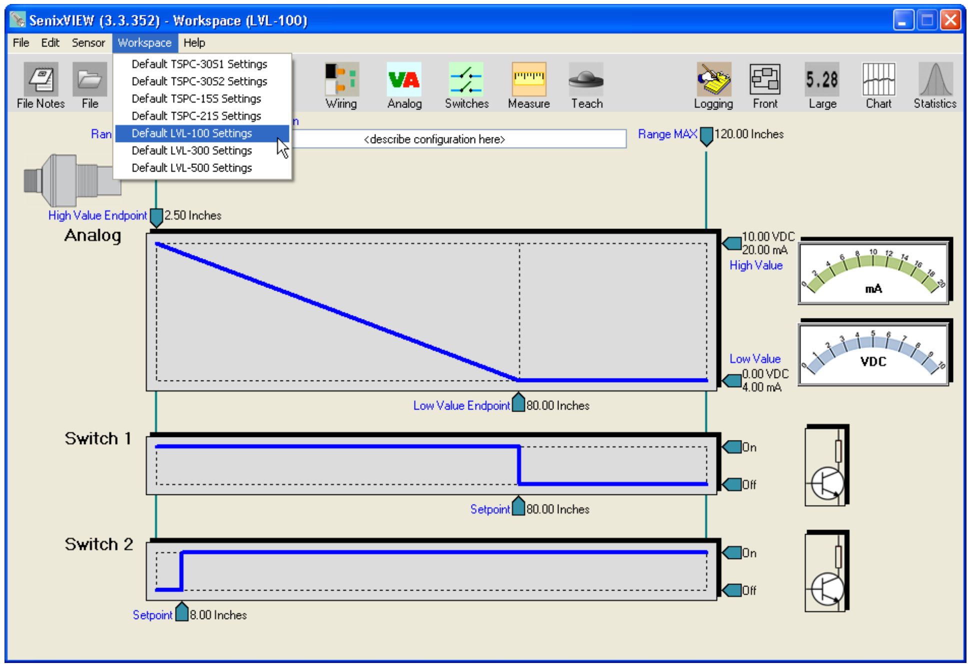


Figure 4-28. Loading default LVL-100 settings.

9. Open the Connect Sensor window (*Sensor* ► *Connect…*) of Figure 4-29. Select the appropriate *COM Port*, *Baudrate*, and *Network Address* and click *Connect*.

Default Baudrate is 9600 and default Network Address is 1. The COM port can be checked using Windows Device Manager utility.

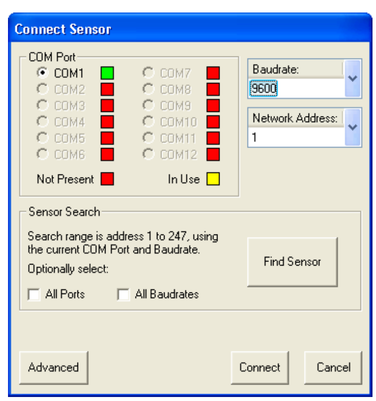


Figure 4-29. Connect Sensor window.

10. Click *No* when prompted to copy sensor set up to workspace to keep the default configuration.

11. Select a distance unit (*Edit* ▶ *User Preferences* ▶ *Distance Units*) and click *OK*.

12. Click on the *Workspace* icon to return to the editable version of the sensor parameters (Figure 4-30).

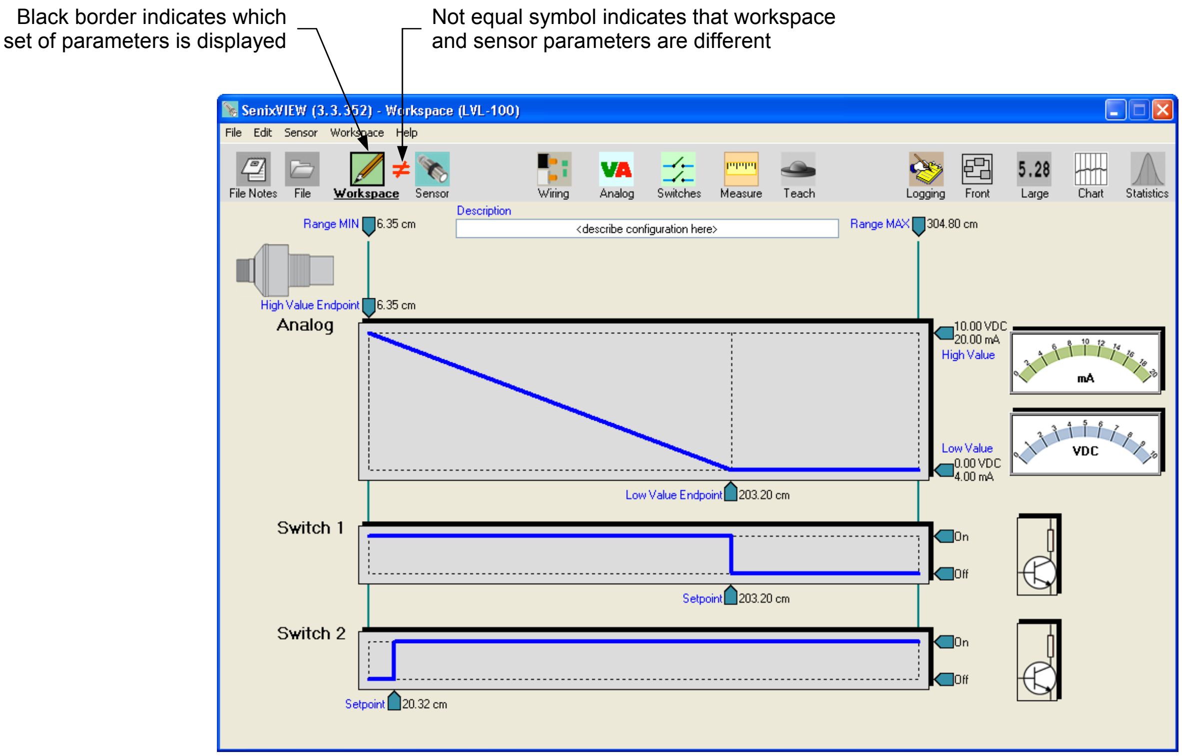


Figure 4-30. Default workspace.

13. Editable parameters are displayed in blue. *High Value* and *Low Value* are the transmitter output signal. By default, they are set to 20 mA (or 10 V dc) and 4 mA (or 0 V dc) by default.

LVProSim

You can use LVProSim to monitor the 4-20 mA output of the transmitter. To do so, connect the computer running LVProSim to the transmitter via the I/O interface. Refer to Appendix B for details on how to make the connections and how to use LVProSim.

It is not recommended to set Range MIN *smaller than the default value and* Range MAX *larger than the default value as the sensor may yield incorrect distance values outside these boundaries.*

Varying the column level

14. Turn on the pumping unit.

15. Set the pump speed to a low value. Stop the pump when the level of water slightly exceeds the bottom of the column ruler. Close HV1 when water is exactly in front of the 0 cm (0 in) mark.

16. In *SenixVIEW*, go to the Sensor view. What position is measured by the sensor?

Note to the Instructor:

The answers in this exercise vary on the type of adaptor that you have. The low adaptor measures 57 mm in height and the high adaptor measures 72.7 mm.

Low and high adaptors

Low adaptor: 59.50 cm (23.20 in)

High adaptor: 60.70 cm (23.90 in)

17. Restart the pump and add water until you exceed the 55 cm (or 22 in) ruler mark for a low adaptor or the 50.8 cm (or 20 in) for a high adaptor. Stop the pump and change HV3 position to prevent water to return to the reservoir through the pump. How is the measurement value obtained in *SenixVIEW?* Explain what happens.

The measurement is unstable because the water is within the sensor blocking distance.

18. Open and close HVI until water level is exactly equal to 50 cm (or 20 in) on the ruler. What position is measured by the sensor?

Low adaptor: 8.60 cm (3.40 in)

High adaptor: 10.20 cm (4.00 in)

19. Return to the Workspace view. Enter the value of step 16 as the *Low Value Endpoint* and the value of step 18 as the *High Value Endpoint*.

20. Copy the workspace to the sensor (*Sensor* ► *Move Workplace to Sensor*).

Measuring the water level

21. Vary the water level in the column by 5 cm (2 in) steps using HV 1 and record your results in Table 4-6. The table *Analog Output* column requires that you either:

- read the actual output on the transmitter.
- use the simulated current or voltage reading given by *SenixVIEW* (*Large* icon, *Mode* ► *Current* or *Voltage).*

Table 4-6. Comparison between readings.

Ruler reading cm (in)	*SenixVIEW* reading cm (in)	Analog output mA (or V)
0 (0)		
5 (2)		
10 (4)		
15 (6)		
20 (8)		
25 (10)		
30 (12)		
35 (14)		
40 (16)		
45 (18)		
50 (20)		
55 (22)		

Low adaptor:

Comparison between readings.

Ruler reading cm (in)	*SenixVIEW* reading cm (in)	Analog output mA (V)
0 (0)	59.4 (23.2)	4.0 (0.0)
5 (2)	54.5 (21.4)	5.6 (1.0)
10 (4)	49.5 (19.4)	7.2 (2.0)
15 (6)	44.5 (17.4)	8.8 (3.0)
20 (8)	39.5 (15.4)	10.4 (4.0)
25 (10)	34.5 (13.4)	12.0 (5.0)
30 (12)	29.5 (11.4)	13.6 (6.0)
35 (14)	24.5 (9.4)	15.2 (7.0)
40 (16)	19.5 (7.4)	16.8 (8.0)
45 (18)	14.5 (5.4)	18.4 (9.0)
50 (20)	9.5 (3.4)	20.0 (10.0)

High adaptor:

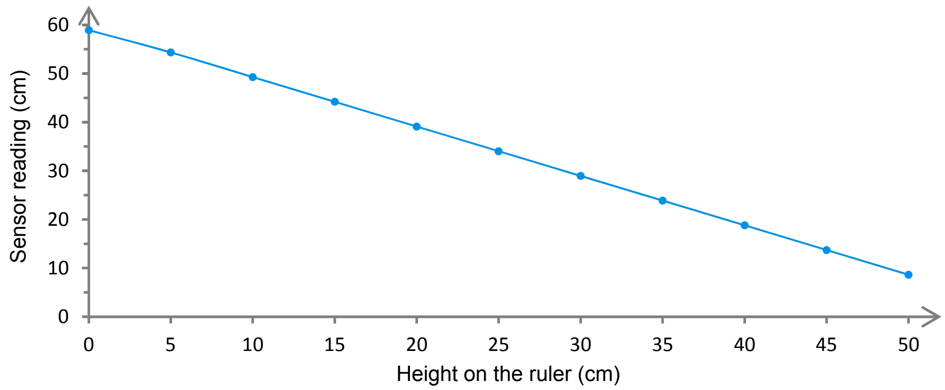
Comparison between readings.

Ruler reading cm (in)	*SenixVIEW* reading cm (in)	Analog output mA (V)
0 (0)	60.7 (23.9)	4.0 (0.0)
5 (2)	55.6 (21.9)	5.6 (1.0)
10 (4)	50.5 (19.9)	7.2 (2.0)
15 (6)	45.5 (17.9)	8.8 (3.0)
20 (8)	40.4 (15.9)	10.4 (4.0)
25 (10)	35.3 (13.9)	12.0 (5.0)
30 (12)	30.2 (11.9)	13.6 (6.0)
35 (14)	25.1 (9.9)	15.2 (7.0)
40 (16)	20.1 (7.9)	16.8 (8.0)
45 (18)	15.0 (5.9)	18.4 (9.0)
50 (20)	10.2 (4.0)	20.0 (10.0)

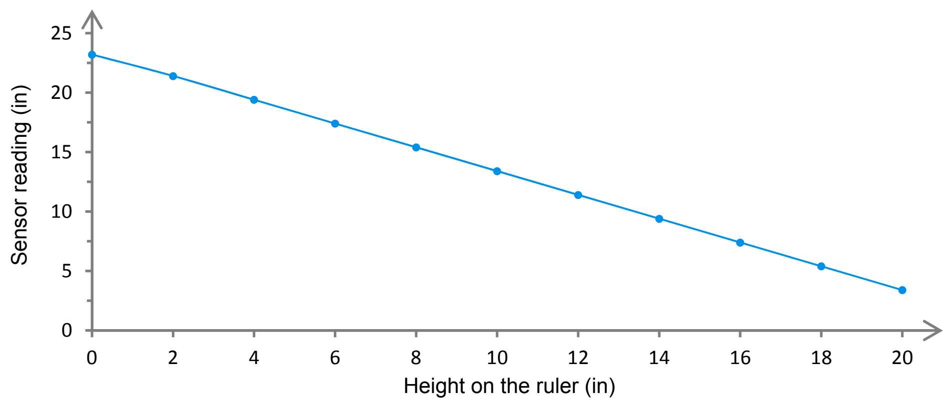
22. Stop the pump.

23. From the data recorded in Table 4-6, plot the relationship between the ruler and *SenixVIEW* readings.

Low Adaptor:

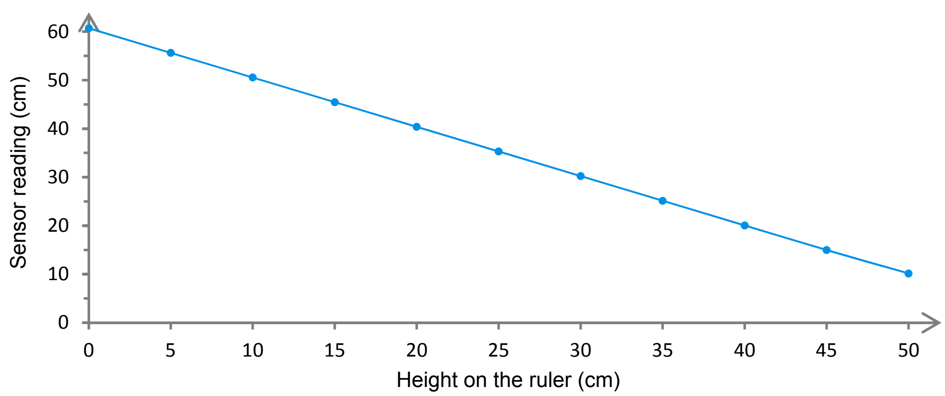


Ruler and transmitter readings (SI units).

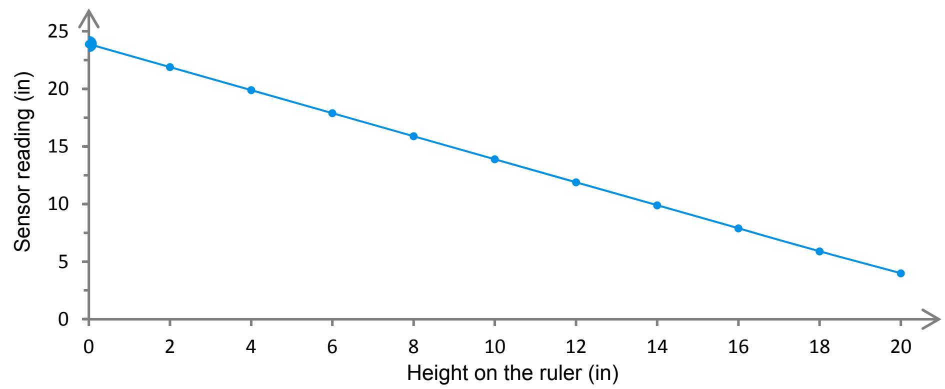


Ruler and transmitter readings (US customary units).

High Adaptor:



Ruler and transmitter readings (SI units).



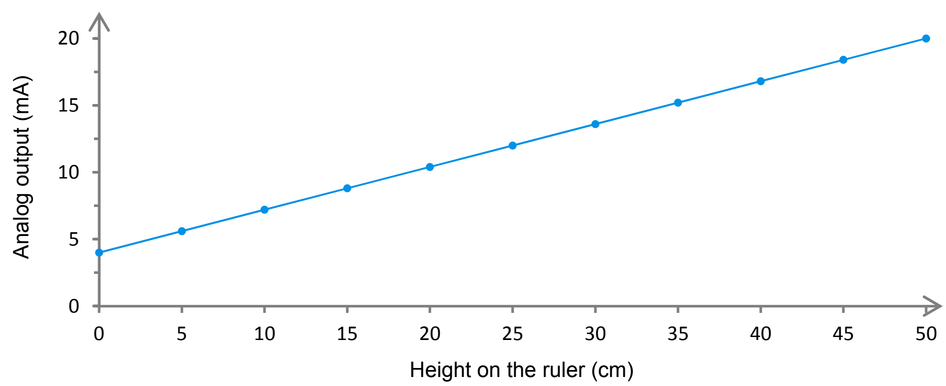
Ruler and transmitter readings (US customary units).

24. How would you characterize this relationship?

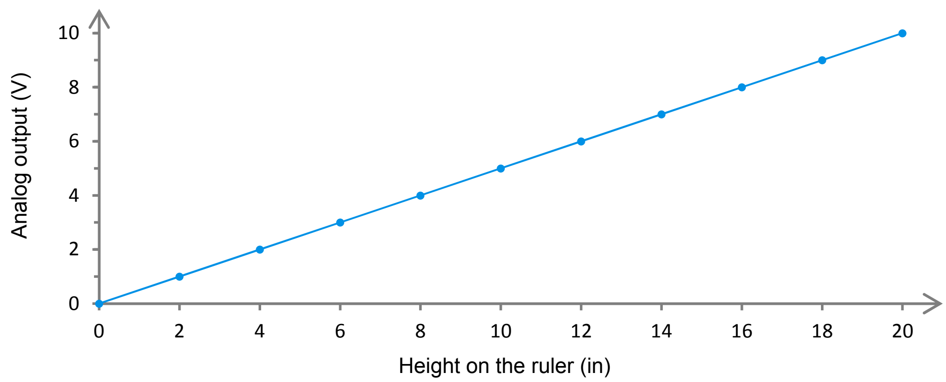
Inversely proportional

25. From the data recorded in Table 4-6, plot the relationship between the ruler and analog output readings.

Low Adaptor:

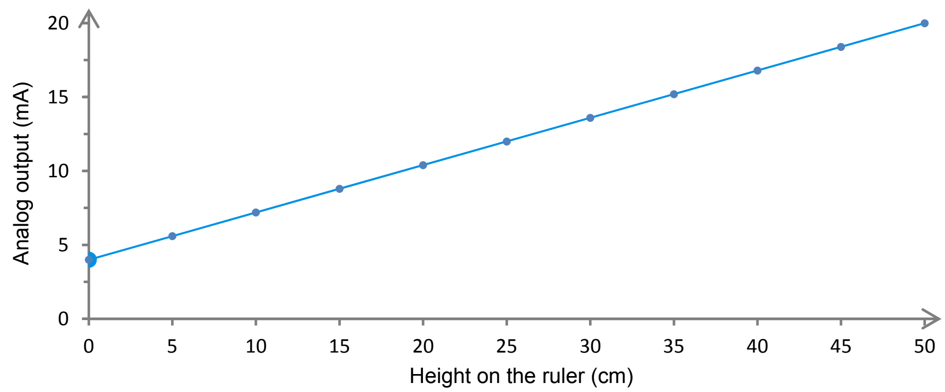


Height and analog output (cm and mA).

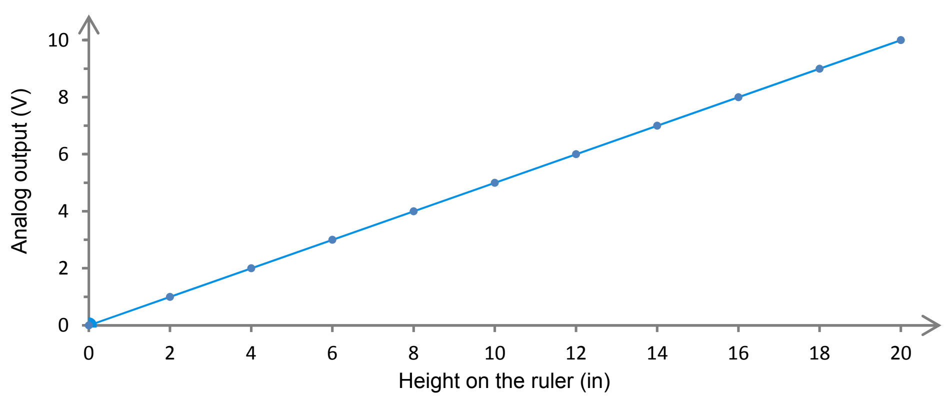


Height and analog output (in and V).

High Adaptor:



Height and analog output (cm and mA).



Height and analog output (in and V).

26. How would you characterize this relationship?

Directly proportional

Using the relays

27. On the Workspace view, click the *Wiring* icon. Set the transmitter relays (*Switch #1* and *Switch #2*) to *Switch (Sourcing-PNP)* as shown in Figure 4-31 The relays are now configured to be open in the *Off* state and closed in the *On* state. Click *OK* to return to the Workspace view.

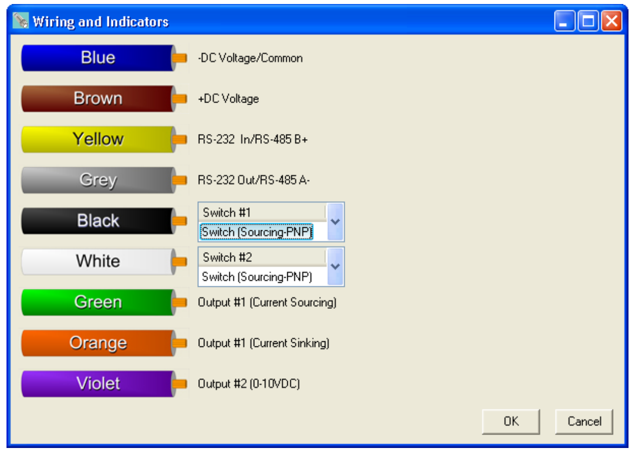


Figure 4-31. Configuring switch #1 and switch #2.

28. Get the Solenoid Valve from your storage location. Make the connections shown in Figure 4-32 to prepare for a simple on-off control of the water level using *Switch 1*. Connect one switch terminal to the solenoid valve and the other terminal to a 24 V dc supply.

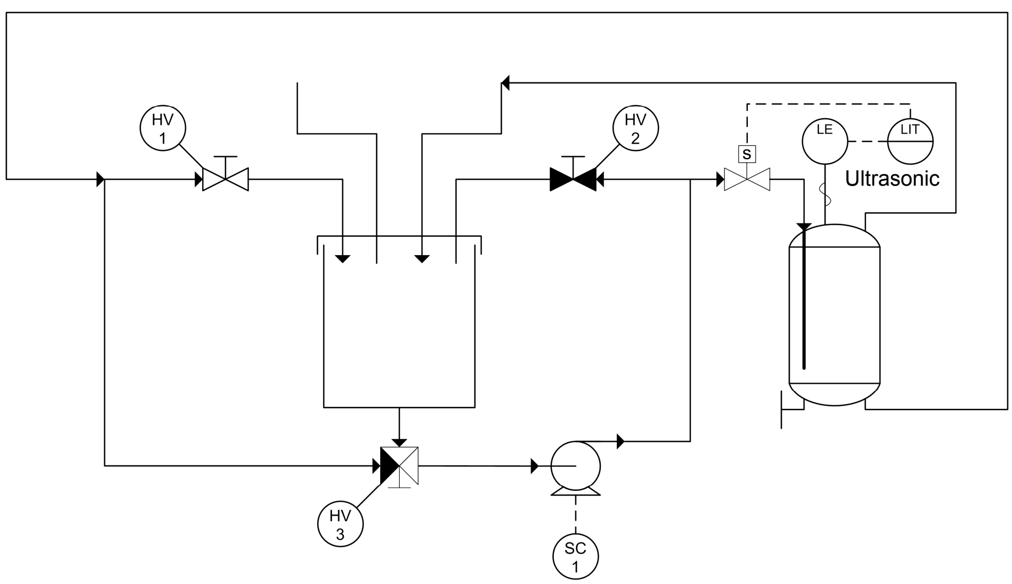


Figure 4-32. Simple On-Off control scheme using the transmitter.

29. On the Workspace view, click the *Switches* icon. Set *Switch #1 Polarity* to *ON-Farther* as shown in Figure 4-33. That way, the switch is activated (open state) when the level is low and deactivated (closed state) when the level is high. Click *OK*.

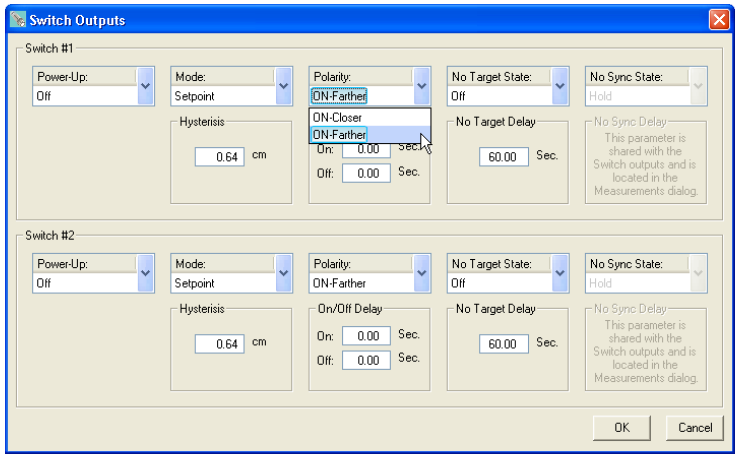


Figure 4-33. Switch #1 polarity.

30. Back on the Workspace view, set *Switch 1 Setpoint* to an intermediate value (e.g., 34.5 cm or 13.40 in).

31. Copy the workspace to the sensor (*Sensor* ► *Move Workplace to Sensor*). Switch 1 is now configured to open the solenoid valve when the level is below the set point and permits the water to flow into the column.

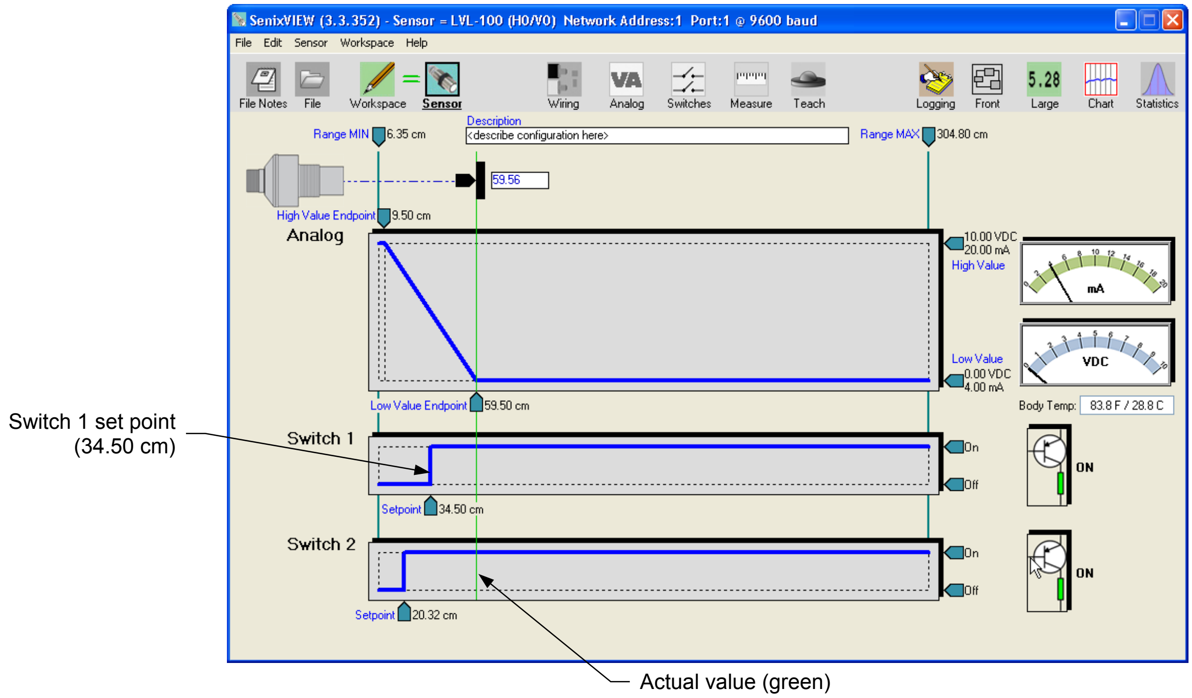


Figure 4-34. Switch 1 set point.

32. Turn on the pump and set the speed to a moderate value (about 50%).

33. Does your set up permit keeping the water level around the set point?

❑ Yes ❑ No

Yes

End of the exercise

34. Stop the pump and turn off the pumping unit.

35. Disconnect the circuit. Return the components and hoses to their storage location.

36. Wipe off any water from the floor and the training system.

CONCLUSION

In this exercise, you became acquainted with the use and commissioning of an ultrasonic level transmitter.

REVIEW QUESTIONS

1. Describe briefly the principle of operation of an ultrasonic level sensor.

An ultrasonic level sensor emits ultrasound wave packets and detects them as they return to the sensor. It measures the distance using a time-of-flight method.

2. Why can't an ultrasonic sensor measure adequately a distance within the blocking distance?

The distance is too short and the front of the quickly traveling ultrasound wave packet has enough time to return to the sensor before the whole pulse is sent. The sensor which cannot emit and detect ultrasounds at the same time misses the signal.

3. Cite one advantage and one disadvantage of ultrasonic level transmitters.

Many answers are possible. Here are a few suggestions.

Advantages

- They are non-contact sensors, making the sensor less subject to wear and tear.
- They have a wide range of applications.
- They are typically very precise and reliable.

Limitations

- The surface of the product must be still and smooth to obtain good readings.
- The temperature must remain within operational bounds and must be uniform throughout the path of the sound wave.

4. What is the operating frequency of ultrasonic level transmitters?

Above 20 kHz

5. Why is temperature compensation important when using ultrasonic level transmitters?

The air temperature has an effect on the speed of sound.

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