

Process Control

Pressure, Flow, and Level Processes

Courseware Sample

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e-mail: did@de.festo.com

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Safety and Common Symbols

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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

Table of Contents

Preface	XIX
About This Manual	XXI
To the Instructor	XXIII

Unit 1	Introduction to Process Control	1
---------------	--	----------

DISCUSSION OF FUNDAMENTALS.....	1
Process control system.....	1
Open loop and closed loop	2
Variables in a process control system	2
Operations in a process control system.....	2
The study of dynamical systems	3
Block diagrams	3
The controller point of view	4
Process instrumentation	5
Measuring devices.....	5
Recording devices	5
Controlling devices	6
ISA instrumentation symbols	6

Ex. 1-1	Familiarization with the Training System.....	7
----------------	--	----------

DISCUSSION	7
The Process Control Training System	7
Main Work Surface	7
Process components	7
Pumping Unit (Model 6510-1).....	10
Local and remote pump control	10
Connecting circuits.....	12
Hoses connection	13
Impulse lines connection	14
Preparing impulse lines	15
PROCEDURE	16
Identification of the components	16
A basic flow circuit.....	23

Table of Contents

Unit 2	Pressure Processes	33
	DISCUSSION OF FUNDAMENTALS.....	33
	Introduction	33
	What is a fluid?.....	33
	The continuum hypothesis	34
	What are the main characteristics of fluids?	35
	Density	35
	Dynamic viscosity	35
	Compressibility.....	35
	Vapor pressure	36
	Surface tension	36
	Hydrostatic pressure	36
	Pascal's law	37
	Dynamic pressure	38
	Pressure measurement.....	38
	Units of pressure measurement.....	38
	Head	39
	Types of pressure measurements	39
	Absolute pressure	39
	Gauge pressure	40
	Differential pressure	40
	Pressure in a water system.....	40
Ex. 2-1	Pressure Measurement	43
	DISCUSSION	43
	Classic pressure measurement devices	43
	U-tube manometers	43
	Bourdon tube pressure gauges.....	44
	Strain-gauge pressure sensing devices.....	45
	How to install a pressure-sensing device to measure a pressure	46
	What is bleeding?.....	47
	PROCEDURE	48
	Pressure gauge measuring	48
	Measuring pressure with a differential-pressure transmitter	50
	Transmitter calibration	51
	Comparison between PI and PT	52
	Verifying the accuracy of a pressure gauge with a liquid manometer	53
	End of the exercise	57

Table of Contents

Ex. 2-2	Pressure Losses	59
	DISCUSSION	59
	Pressure loss	59
	Major losses	59
	Minor losses	60
	PROCEDURE	61
	Pressure loss versus orifice size.....	61
	Pressure loss versus flow rate	63
	End of the exercise	66
Ex. 2-3	Centrifugal Pumps.....	69
	DISCUSSION	69
	Pumps	69
	Basic operation of a liquid pump.....	70
	Types of liquid pumps	70
	The centrifugal pump	71
	Velocity head.....	72
	System curve.....	73
	Performance chart	75
	Cavitation.....	77
	NPSHR and NPSHA.....	79
	PROCEDURE	81
	Set up and connections	81
	Measuring the pressure-versus-flow curve of the pump for different rotation speeds	82
	End of the exercise	86
Ex. 2-4	Centrifugal Pumps in Series and in Parallel (Optional Exercise).....	89
	DISCUSSION	89
	Centrifugal pumps in series	89
	Centrifugal pumps in parallel	90
	PROCEDURE	92
	Set up and connections – centrifugal pumps in series	92
	Upstream pumping unit operating alone.....	93
	Upstream and downstream pumping units both operating.....	94
	Set up and connections – centrifugal pumps in parallel	96
	Upstream pumping unit operating alone	98
	Two pumping units operating at the same time	99
	End of the exercise	101

Table of Contents

Unit 3	Flow Processes.....	107
	DISCUSSION OF FUNDAMENTALS.....	107
	Fluid dynamics	107
	Flow rate.....	107
	Volume flow rate	107
	Mass flow rate.....	108
	Types of pressure	108
	Bernoulli equation	110
	Bernoulli equation applications	110
	Laminar and turbulent flows	112
	Reynolds number.....	113
	EXAMPLE.....	114
	Solution	114
Ex. 3-1	Rotameters and Paddle Wheel Flowmeters.....	117
	DISCUSSION	117
	Rotameters.....	117
	Measuring principle of rotameters.....	117
	Correct installation of rotameters	118
	Advantages and limitations of rotameters	118
	Paddle wheel flow transmitters	119
	Industrial applications of paddle wheel flowmeters	120
	Advantages and limitations of paddle wheel flowmeters.....	120
	Description of the supplied paddle wheel flow transmitter	120
	PROCEDURE	122
	Preparation question	122
	Set up and connections.....	123
	Operation of a paddle wheel flow transmitter.....	124
	Current-versus-flow curve of a paddle wheel flow transmitter	124
	End of the exercise	127
Ex. 3-2	Orifice Plates.....	129
	DISCUSSION	129
	Orifice plates	129
	Measuring principle	129
	Industrial applications.....	131
	Advantages and limitations	131
	Description of the supplied orifice plate	132
	Permanent pressure loss	133
	PROCEDURE	133
	Preparation question	133
	Set up and connections.....	133
	Transmitter calibration	134

Table of Contents

	Measuring the pressure drop-versus-flow curve of the orifice plate	135
	Linearizing the orifice plate curve	138
	Permanent pressure loss of the orifice plate	139
	End of the exercise	143
Ex. 3-3	Venturi Tubes.....	145
	DISCUSSION	145
	Venturi tubes	145
	Measuring principle	145
	Permanent pressure loss	147
	Correct installation of venturi tubes.....	147
	Industrial applications.....	147
	Advantages and limitations of venturi tubes	147
	Description of the supplied venturi tube.....	147
	Power in a flow system	148
	Units of power.....	148
	Power conversion in a flow system.....	149
	Efficiency	150
	Dissipated power in a flow system.....	151
	Yearly electricity cost of a differential-pressure flowmeter	151
	Selection of a differential-pressure flowmeter.....	151
	EXAMPLE 1.....	152
	Solution (SI units)	152
	EXAMPLE 2.....	153
	Solution (US customary units)	153
	PROCEDURE	154
	Set up and connections	154
	Transmitter calibration	155
	Measuring the pressure drop-versus-flow curve of the venturi tube	155
	Linearizing the venturi tube curve.....	159
	Permanent pressure loss of the venturi tube	160
	Electricity cost of flowmeters.....	163
	End of the exercise	164
Ex. 3-4	Pitot Tubes and Industrial DP Transmitters (Optional Exercise).....	167
	DISCUSSION	167
	Introduction	167
	Industrial applications.....	168
	Measuring principle	169
	Advantages and limitations	170
	Description of the supplied pitot tube assembly	170

Table of Contents

	PROCEDURE	172
	Set up and connections.....	172
	DP transmitter commissioning	172
	Measuring the pressure drop-versus-flow curve.....	173
	Measuring flow rates using a pitot tube	175
	End of the exercise	177
Unit 4	Level Processes.....	183
	DISCUSSION OF FUNDAMENTALS.....	183
	Level measurement.....	183
	Point-level detection.....	183
	Continuous level detection.....	184
Ex. 4-1	Float Switches.....	185
	DISCUSSION	185
	Introduction	185
	Reed switch float switches	186
	How a reed switch works	186
	The float and the stem	187
	Construction and operation	187
	Industrial applications.....	188
	Advantages and limitations	188
	Installing the float switch	188
	PROCEDURE	190
	Set up and connections.....	190
	Level regulation.....	191
	End of the exercise	192
Ex. 4-2	Differential Pressure Level Meters.....	195
	DISCUSSION	195
	Measuring hydrostatic pressure in order to infer level	195
	Measurement of the level in open vessels.....	196
	Advantages and limitations	197
	PROCEDURE	198
	Set up and connections.....	198
	Transmitter calibration.....	199
	Relationship between level and pressure transmitter output	201
	Level measurement using the Industrial DP Transmitter (optional section).....	203
	Set up and connections	203
	Transmitter calibration	203
	Relationship between level and pressure transmitter current ..	203
	End of the exercise	206

Table of Contents

Ex. 4-3	Zero Suppression and Zero Elevation.....	209
	DISCUSSION	209
	Range with an elevated or suppressed zero	209
	Suppressed-zero range	209
	Elevated-zero range.....	211
	PROCEDURE	213
	Set up and connections	213
	Purging the air from the bottom hose (column pressurization).....	214
	Transmitter calibration.....	214
	Effect of lowering the transmitter on the measurable level range	215
	Zero suppression	218
	End of the exercise	219
 Ex. 4-4	 Wet Reference Legs (Optional Exercise)	 221
	DISCUSSION	221
	Measuring level in closed tanks	221
	Dry reference leg.....	222
	Measurement errors	223
	Wet reference leg.....	223
	Measurement errors	224
	PROCEDURE	225
	Set up and connections	225
	Setting the wet reference leg	226
	Transmitter calibration.....	226
	Measuring the level of the liquid in a pressurized column	226
	End of the exercise	229
 Ex. 4-5	 Bubblers (Optional Exercise)	 231
	DISCUSSION	231
	Bubblers	231
	How to measure liquid level using a bubbler	232
	Advantages and limitations.....	232
	Description of the supplied bubbler.....	233
	PROCEDURE	234
	Set up and connections	234
	Transmitter calibration.....	236
	Relationship between level and bubbler air pressure	237
	End of the exercise	239

Table of Contents

Ex. 4-6	Ultrasonic Level Transmitters (Optional Exercise).....	241
	DISCUSSION	241
	Introduction	241
	How does an ultrasonic level sensor work?.....	242
	Relay control	243
	Example 1 – Water supply	244
	Example 2 – Overflow control	244
	Characteristics of ultrasonic level sensors	244
	What is the influence of the temperature?	245
	What are the factors influencing the intensity of the echo?	246
	Advantages and limitations	246
	Description of the supplied ultrasonic level transmitter.....	246
	Summary of technical specifications	248
	PROCEDURE	248
	Set up and connections.....	248
	General arrangement.....	248
	Commissioning the ultrasonic level transmitter.....	250
	Varying the column level.....	252
	Measuring the water level	254
	Using the relays	259
	End of the exercise	261
Unit 5	Process Characteristics.....	265
	DISCUSSION OF FUNDAMENTALS.....	265
	Dynamics	265
	Resistance	265
	Capacitance	266
	Inertia.....	266
	Types of processes	266
	Single-capacitance processes	267
	The mathematics behind single-capacitance processes	269
	The mathematics behind electrical RC circuits	270
	Process characteristics	271
	Dead time	272
	Time constant	272
	The mathematics behind the time constant	273
	Process gain	273
	Other characteristics	274
Ex. 5-1	Determining the Dynamic Characteristics of a Process	275
	DISCUSSION	275
	Open-loop method	275
	How to obtain an open-loop response curve	276
	Steps to obtain the response curve.....	276

Table of Contents

	Preliminary analysis of the open-loop response curve	277
	Determine the process order	277
	Determine the process gain	277
	Prepare the response curve for analysis	278
	Analyzing the response curve	279
	Graphical method (Ziegler-Nichols)	279
	2%–63.2% method	280
	28.3%–63.2% method	281
	PROCEDURE	281
	Set up and connections	281
	Transmitter calibration	282
	Characterization of the pressure process	283
	Curves analysis	285
	End of the exercise	286
Unit 6	PID Process Control	291
	DISCUSSION OF FUNDAMENTALS	291
	Feedback control	291
	Reverse vs. direct action	292
	On-off control	293
	On-off controller with a dead band	295
	PID control	297
	Proportional controller	299
	Tuning a controller for proportional control	301
	Proportional and integral controller	301
	The influence of the integral term	302
	Tuning a controller for PI control	304
	The integral in the integral term	304
	Proportional, integral, and derivative controller	305
	Tuning a controller for PID control	306
	Proportional and derivative controller	306
	Comparison between the P, PI, and PID control	306
	The proportional, integral, and derivative actions	307
	Structure of controllers	310
	Non-interacting	310
	Interacting	311
	The mathematical link between the non-interacting and the interacting algorithm	311
	Parallel	312
Ex. 6-1	Pressure Process Control	313
	DISCUSSION	313
	Recapitulation of relevant control schemes	313
	Tuning with the trial-and-error method	313
	A procedure for the trial and error method	314
	A complementary approach to trial and error tuning	316

Table of Contents

	PROCEDURE	317
	Set up and connections.....	317
	Transmitter calibration.....	318
	P control of the pressure process	319
	PI control of the pressure process	321
	PID control of the pressure process.....	323
	Fine tuning	323
	End of the exercise	325
Ex. 6-2	Flow Process Control.....	327
	DISCUSSION	327
	Brief review of new control modes	327
	Tuning with the ultimate cycle method.....	327
	Quarter-amplitude decay ratio.....	329
	Limits of the ultimate-cycle method.....	330
	PROCEDURE	331
	Set up and connections.....	331
	Transmitter calibration.....	332
	PID control of the flow process	332
	PI control.....	336
	PID control	337
	End of the exercise	340
Ex. 6-3	Level Process Control.....	343
	DISCUSSION	343
	The open-loop Ziegler-Nichols method.....	343
	PROCEDURE	344
	Set up and connections.....	344
	Purging air from the pressure line.....	346
	Transmitter calibration.....	346
	Level process characterization	347
	Calculation of PI and PID parameters.....	348
	PID control of the level process	349
	PI control.....	349
	PID control	350
	End of the exercise	353
Ex. 6-4	Cascade Process Control (Optional Exercise)	355
	DISCUSSION	355
	Cascade control	355
	Tuning a cascade control system	357
	Secondary control modes	357

Table of Contents

PROCEDURE	358
Set up and connections	358
Transmitters calibration.....	359
Calibration of transmitter FT1	359
Calibration of transmitter LT1	360
Single-loop control of a level process	360
Cascade control of the level process	362
Addition and tuning of a flow (slave) loop	362
Cascade control	365
End of the exercise	367
 Ex. 6-5 Second-Order Process Control (Optional Exercise).....	369
DISCUSSION	369
PID control of second-order processes.....	369
PROCEDURE	371
Set up and connections	371
Transmitters calibration.....	372
Calibration of transmitter LT1	372
Calibration of transmitter LT2	373
Setting up a second-order level process.....	374
Open-loop step response of the second-order process.....	375
PID control of the second-order process	377
End of the exercise	379
 Appendix A Equipment Utilization Chart	385
 Appendix B Using LVProSim	387
About LVProSim.....	387
Connecting LVProSim for data acquisition	387
Data acquisition mode.....	387
User interface	388
Recording a signal from a transmitter.....	390
Configuring and using the trend recorder	391
Meters and totalizers	394
Using and configuring the PID controllers.....	395
User defined functions	398
Simulation mode	400
User interface	400
Running a process simulation.....	401
 Appendix C Pumping Unit Construction and Maintenance	407
Pump components	407
Maintenance and changing the water	408

Table of Contents

Appendix D ISA Instrumentation Symbols	409
Introduction	409
Tag numbers.....	410
Function designation symbols.....	413
General instrument symbols	414
Instrument line symbols	415
Other component symbols	416
 Appendix E Selecting a Sensing Element.....	 421
 Appendix F Conversion Table.....	 423
 Appendix G List of Variables	 425
 Appendix H Using the Pumping Unit Variable-Speed Drive.....	 427
 Appendix I Using the Industrial Differential-Pressure Transmitter.....	 429
Introduction	429
Description of the supplied differential-pressure transmitters	429
Display and operating keys.....	431
Using the DP transmitter.....	433
Setting language	433
Resetting to factory settings.....	434
Bleeding the impulse lines	434
Commissioning for differential pressure measurements	435
Commissioning for flow rate measurements	436
Commissioning for level measurements	438
 Appendix J Using the Paperless Recorder	 441
Introduction	441
Description of the supplied paperless recorder.....	441
Using the paperless recorder	442
Starting-up the recorder	442
Configuring an analog input	443
Testing an analog input.....	444
Configuring and using relays.....	445
Deleting the internal memory	447
Connecting the recorder to a computer for the first time	447
Launching ReadWin® 2000 for the first time	448
Remote set up.....	453
Downloading recorded data	455
Data transfer via USB flash drive.....	456
Typical setup (HART).....	458
Screen capture via USB flash drive	459

Table of Contents

Appendix K Simplifying Equations for US Customary Units	461
Appendix L Process Control Analysis Using the Laplace Transform	463
Laplace transforms.....	463
Transfer functions.....	464
Poles of a transfer function	465
Block diagrams	466
Structure of controllers	468
Transfer function and block diagram of an interacting controller.....	468
Transfer function and block diagram of a non-interacting controller.....	468
Transfer function and block diagram of a parallel controller	469
Transfer function of a general process	469
Transfer function of a first-order linear process	469
Transfer function of a second-order linear process	471
Transfer function for a second-order non-interacting level process	473
Transfer function for a second-order interacting level process	474
The special case of two identical tanks.....	475
 Index	 477
Bibliography	481

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.

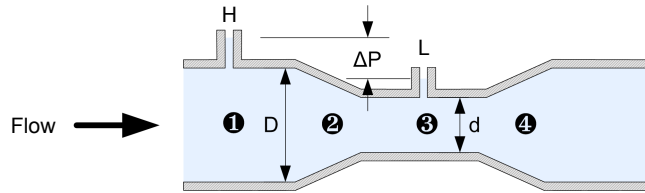


Figure 3-18. Flow measurement using a venturi tube.

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:

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

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.

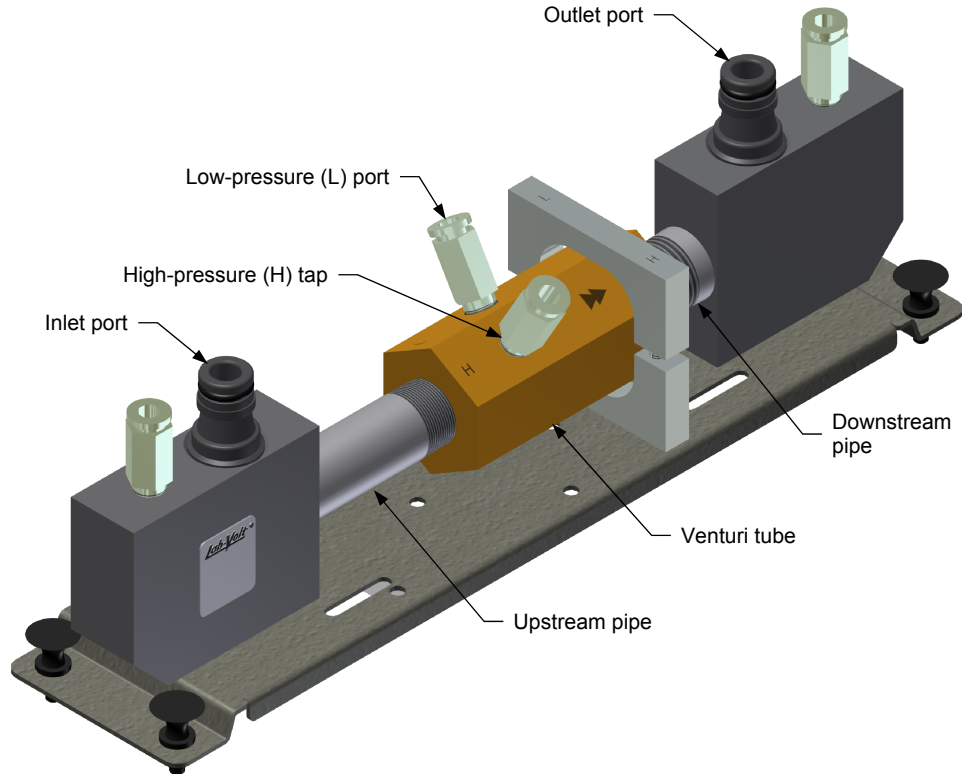


Figure 3-19. Venturi tube, Model 6551.

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 $1 \text{ kg}\cdot\text{m}^2/\text{s}^3$. 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 $550 \text{ ft}\cdot\text{lbf}/\text{s}$, 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.

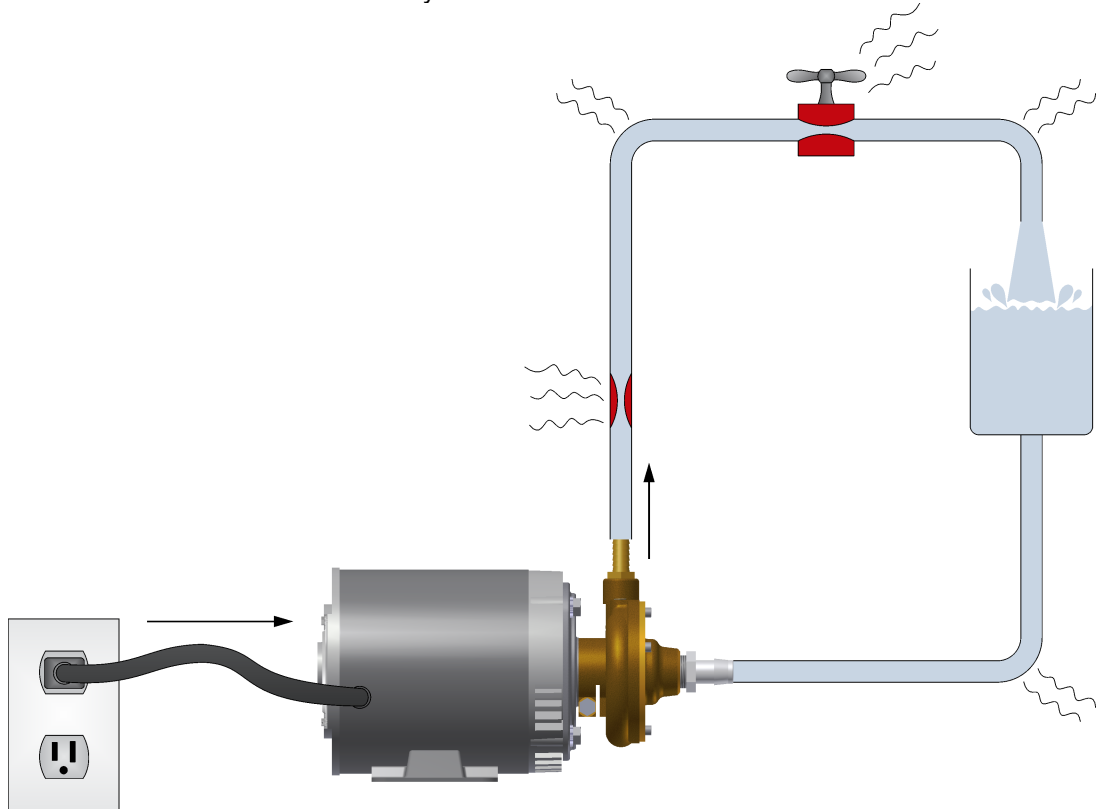


Figure 3-20. Power conversion in a water system.

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:

$$P_p = p_p Q_p \quad (3-15)$$

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:

$$\eta_m = P_{out}/P_{in} \quad (3-16)$$

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:

$$\eta_p = P_p/P_{out} \quad (3-17)$$

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:

$$\eta_o = \eta_m \eta_p \quad (3-18)$$

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:

$$P_c = p_c Q_c \quad (3-19)$$

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:

$$C_y = \frac{P_c T_u R_e}{\eta_o} \quad (3-20)$$

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)

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

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

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

$$C_y = \$3127$$

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.

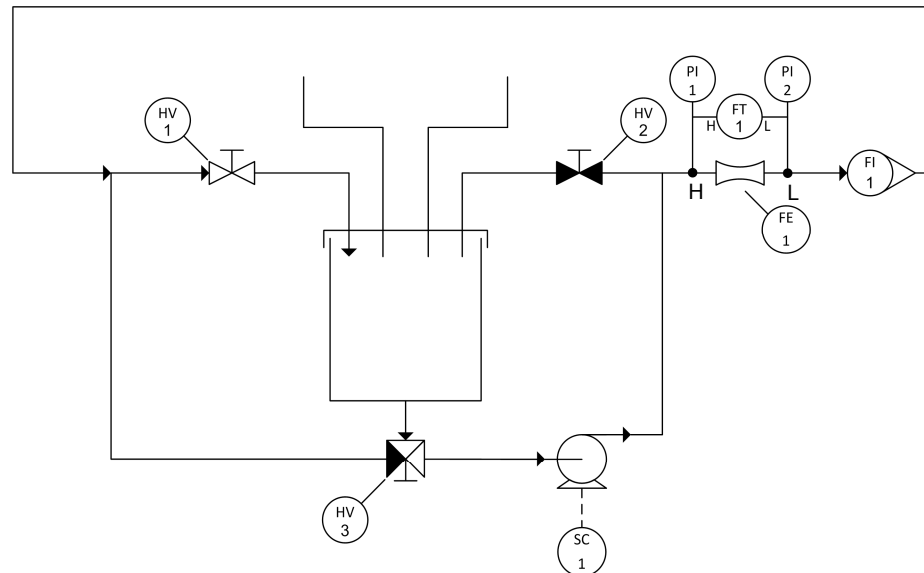


Figure 3-21. Measuring flow rate with a venturi tube.

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

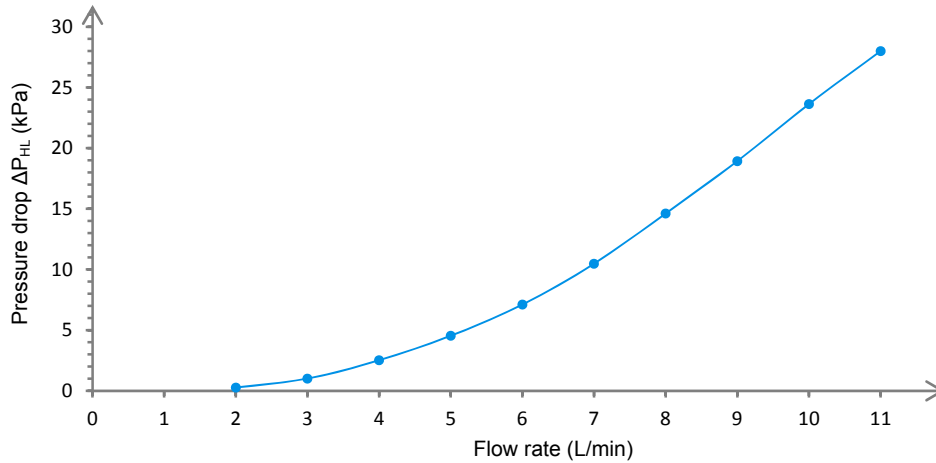
Venturi tube data (US customary units).

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

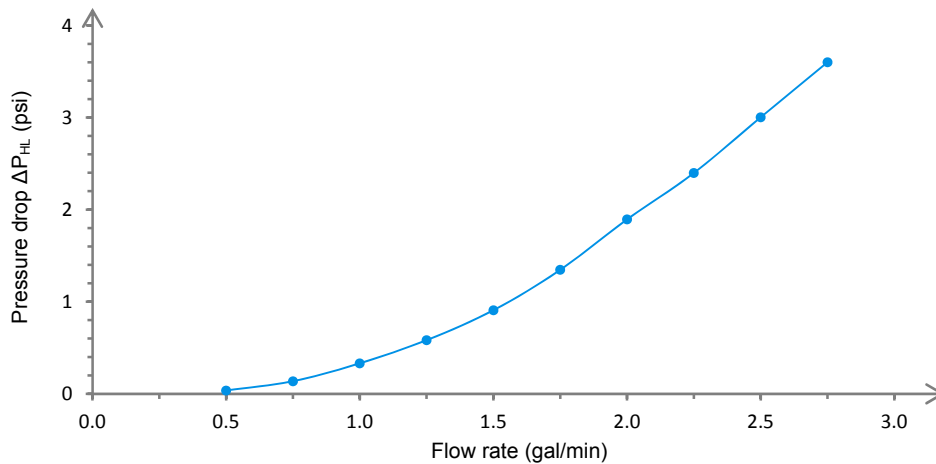
16. Stop the pump.

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).



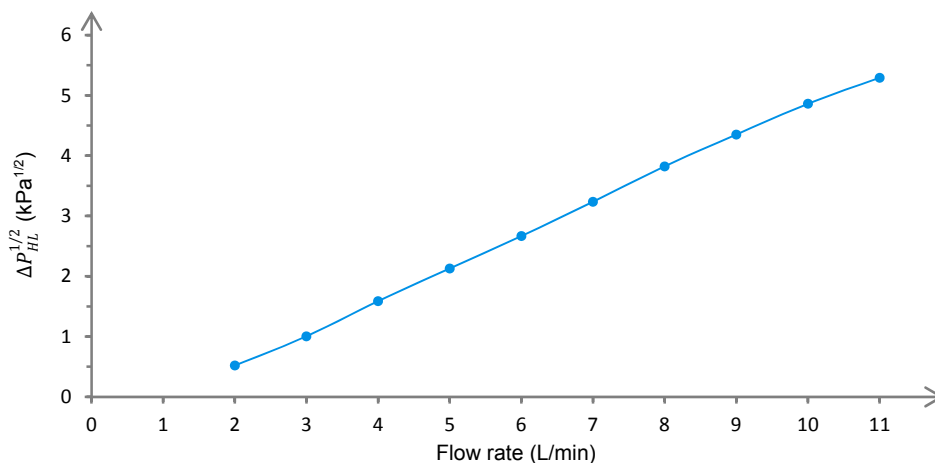
Flow rate and differential pressure produced by a venturi tube (US customary units).

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

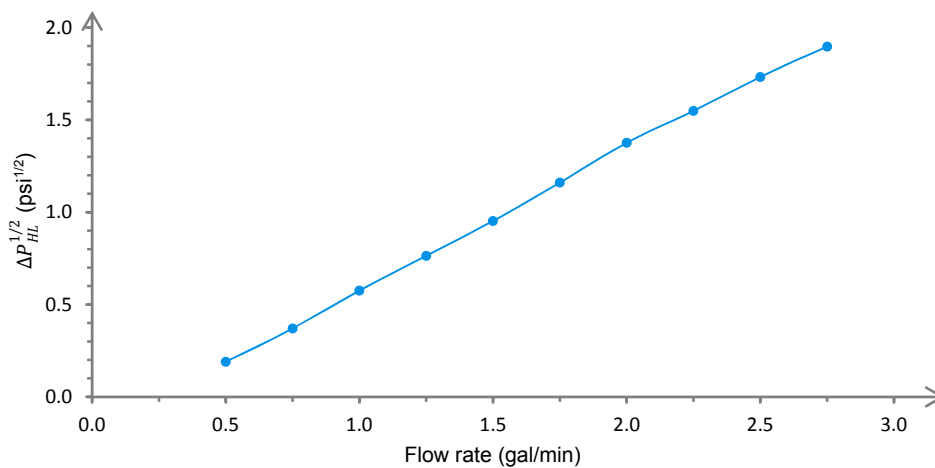
No. The relationship between the flow rate and the pressure drop produced by the venturi tube is not linear, as indicated by the parabolic shape of the curve. This occurs because the pressure drop is proportional to the square of the flow rate.

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.

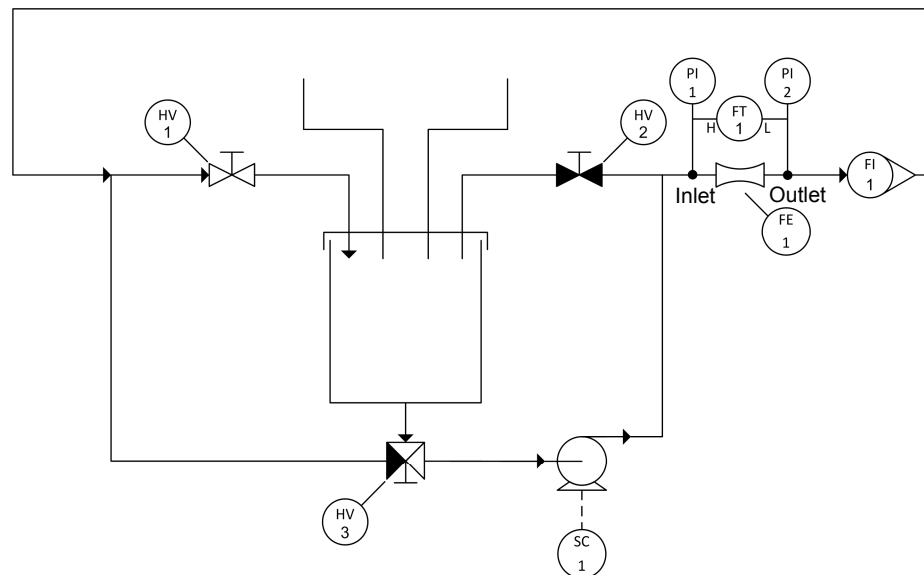


Figure 3-22. Measuring flow rate with a venturi tube.

- 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_{10} 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_{I0} 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_{I0} 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_{I0} 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?

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

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

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

$$C_y = \$1.64$$

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.

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

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

$$C_y = \$4.50$$

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.

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.

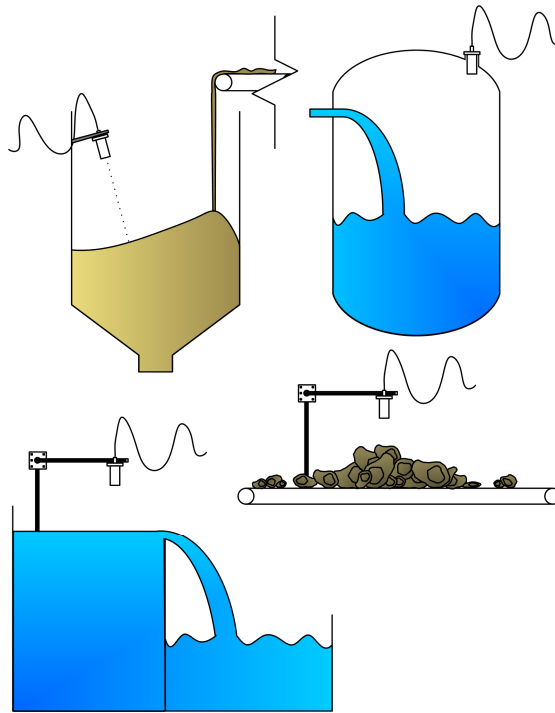


Figure 4-23. Typical applications of ultrasonic sensors.

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.

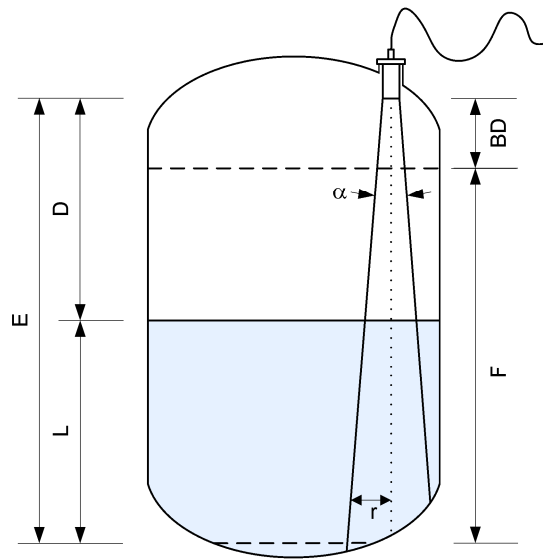


Figure 4-24. Relevant dimensions for a typical ultrasound set up.

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.

$$D = \frac{c_{air} t}{2} \quad (4-13)$$

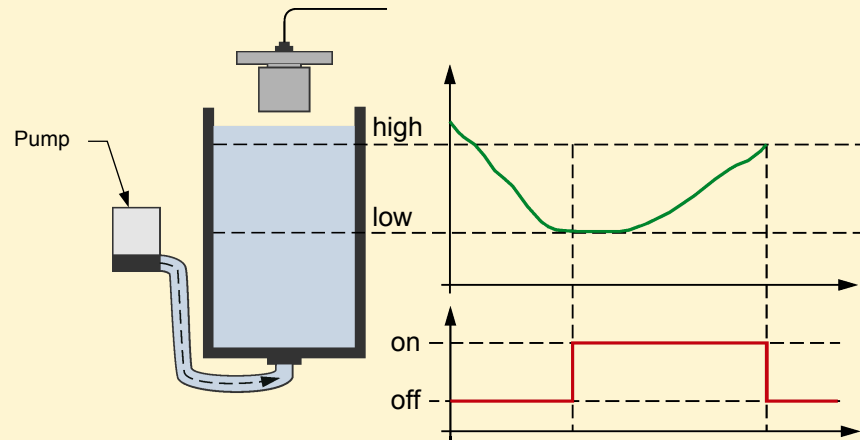
where D is the distance between the ultrasonic sensor and the surface of the product
 c_{air} is the speed of sound in the air
 t is the time taken by the ultrasonic pulse to travel to and from the surface of the product

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.

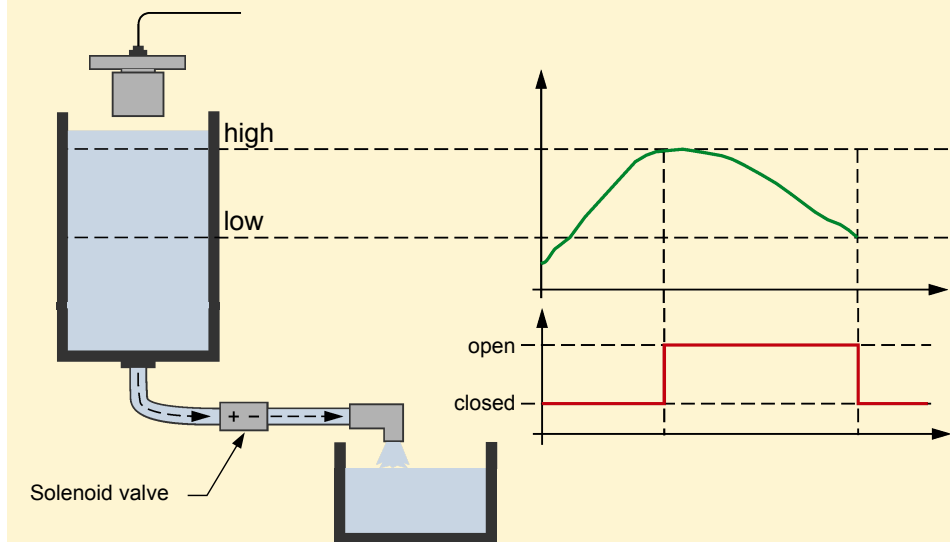
Example 1 – Water supply

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.

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

where c_{air} is the speed of sound (m/s)
 $c_{air(0^{\circ}C)}$ is 331.3 m/s, the speed of sound at 0°C
 $T_{^{\circ}C}$ 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 $T_{^{\circ}C}$ much smaller than 273.15°C.

$$c_{air} \approx c_{air(0^{\circ}C)} + 0.606 T_{^{\circ}C} \quad (4-15)$$

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

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

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

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

$$c_{air} \approx 1051.5 + 1.11 T_{^{\circ}F} \quad (4-17)$$

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.

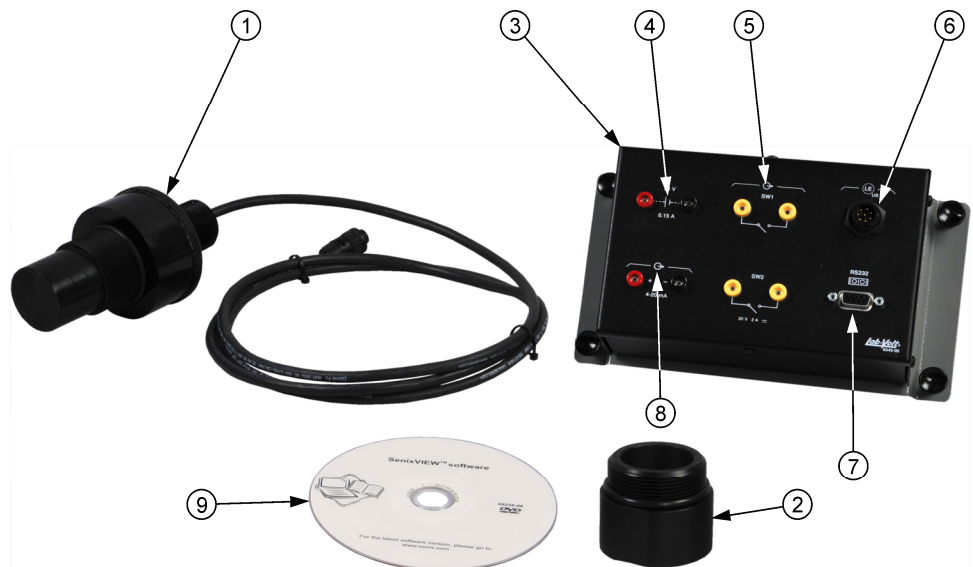


Figure 4-25. Ultrasonic level transmitter (Model 6545).

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.

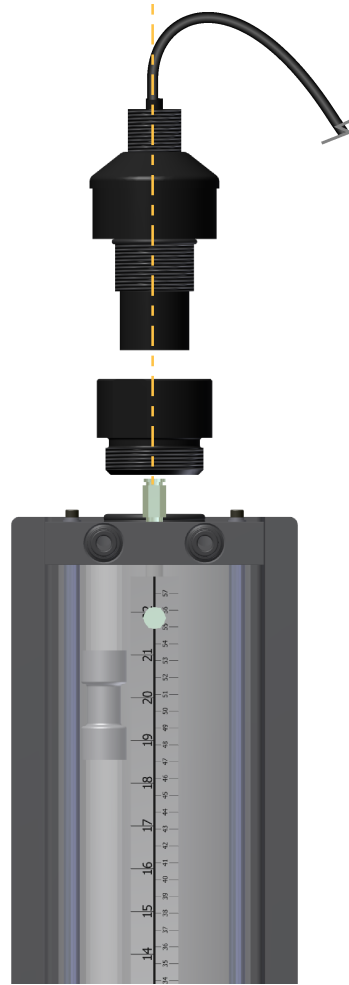


Figure 4-26. Installing the sensor on the column.

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

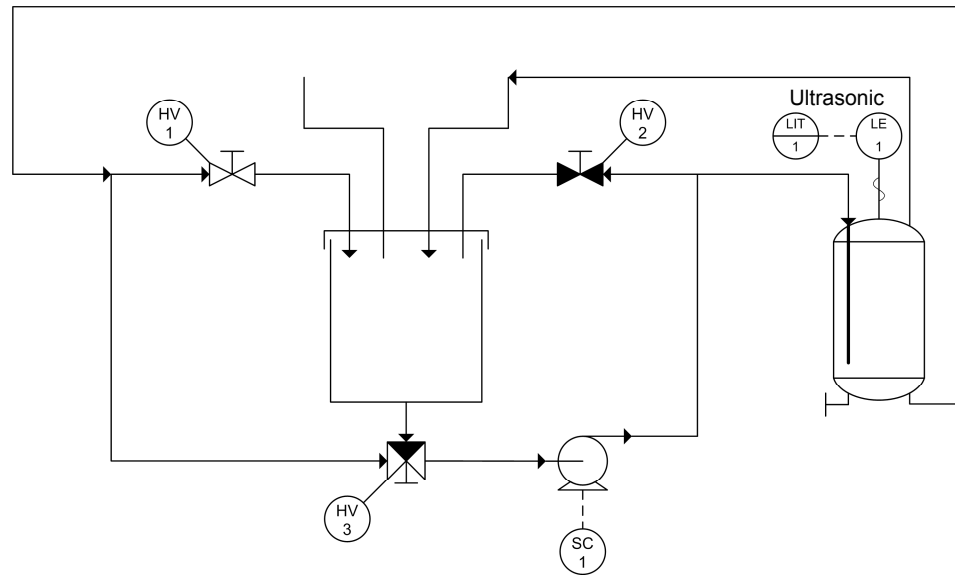


Figure 4-27. Measuring the water level using an ultrasonic level transmitter.

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.

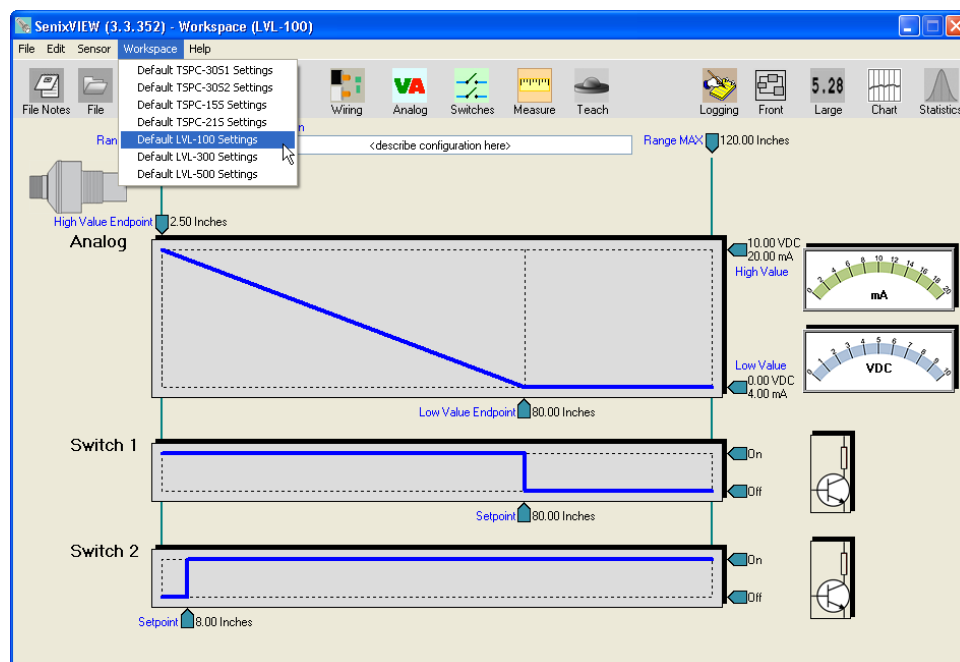


Figure 4-28. Loading default LVL-100 settings.

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.

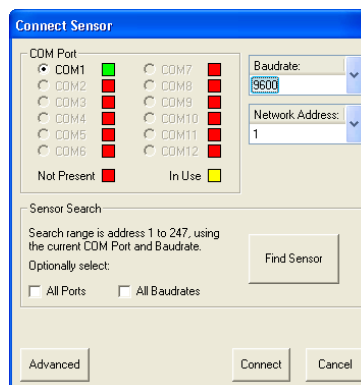


Figure 4-29. Connect Sensor window.

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).

Black border indicates which set of parameters is displayed

Not equal symbol indicates that workspace and sensor parameters are different

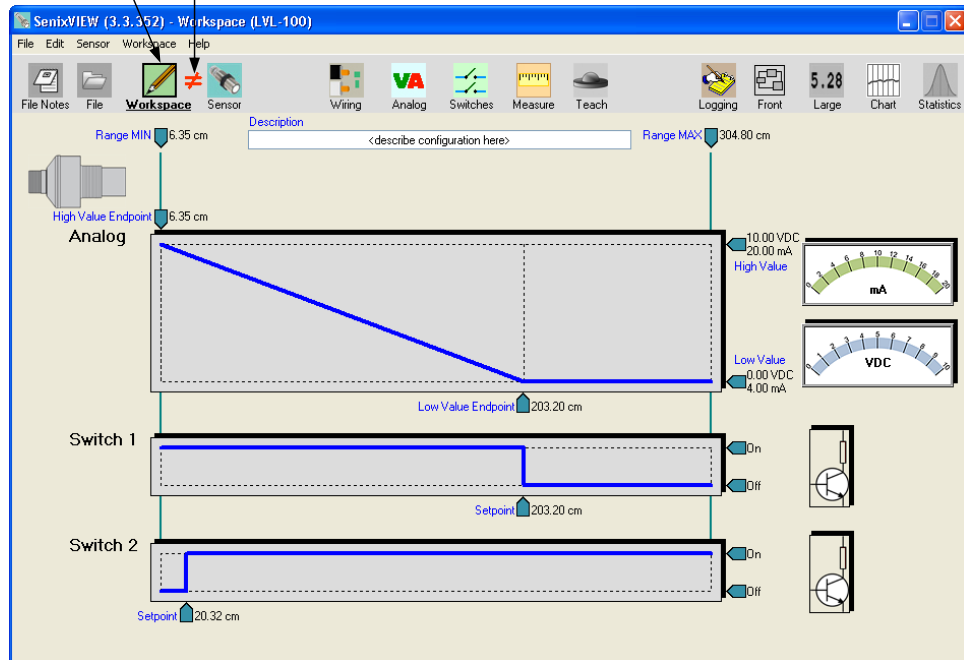


Figure 4-30. Default workspace.

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:

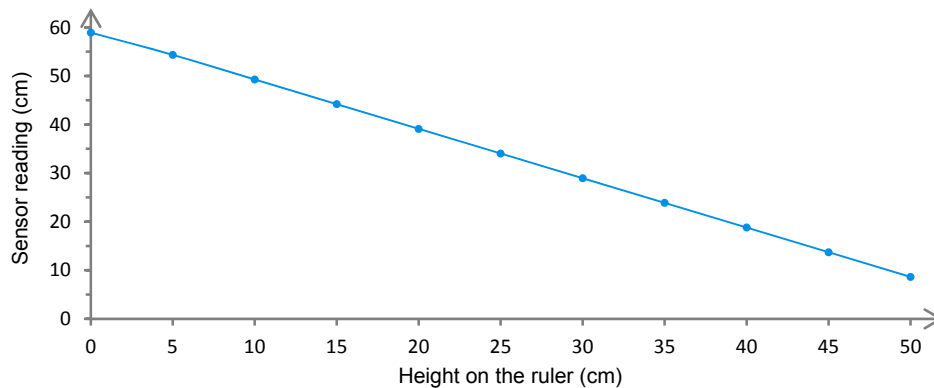
Comparison between readings.

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)

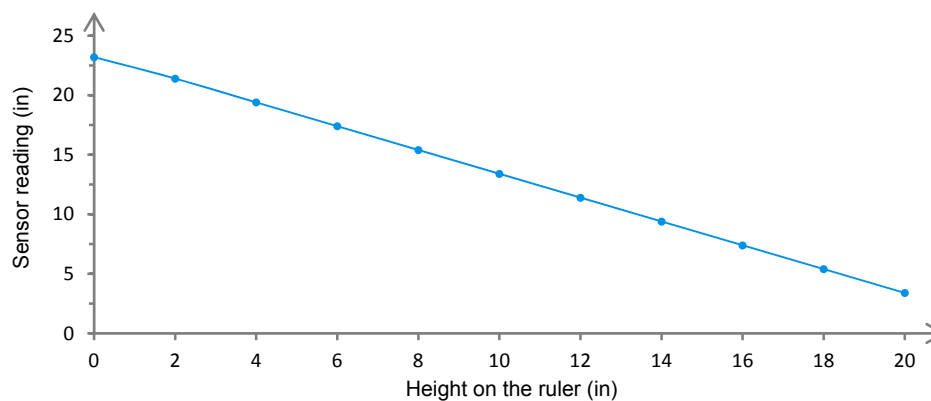
22. Stop the pump.

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

Low Adaptor:

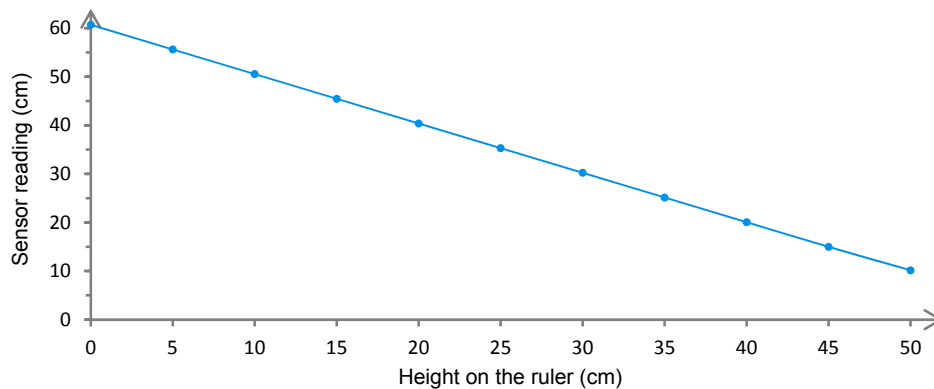


Ruler and transmitter readings (SI units).

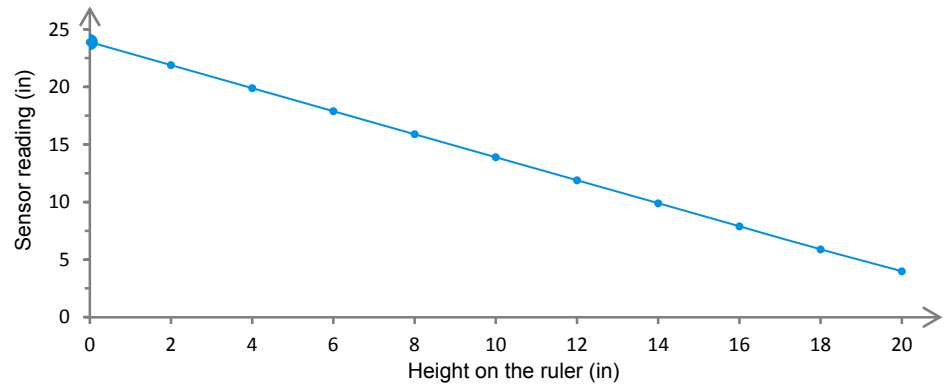


Ruler and transmitter readings (US customary units).

High Adaptor:



Ruler and transmitter readings (SI units).



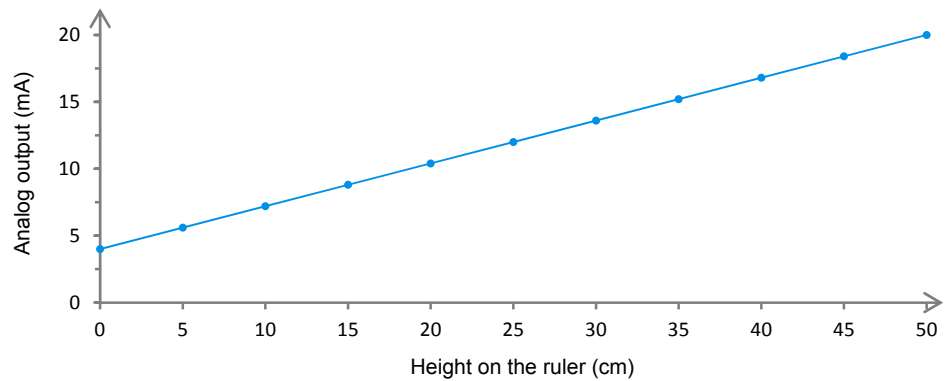
Ruler and transmitter readings (US customary units).

24. How would you characterize this relationship?

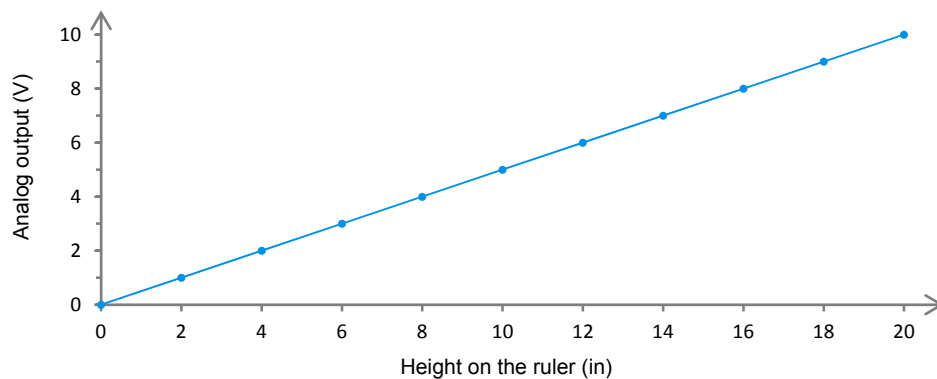
Inversely proportional

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

Low Adaptor:

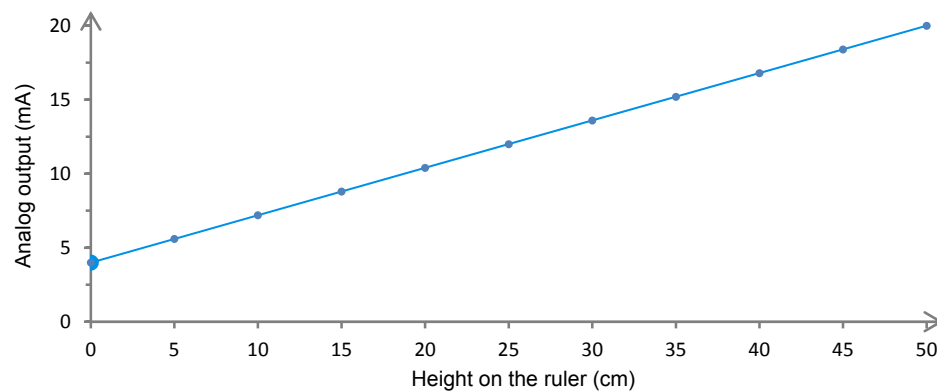


Height and analog output (cm and mA).

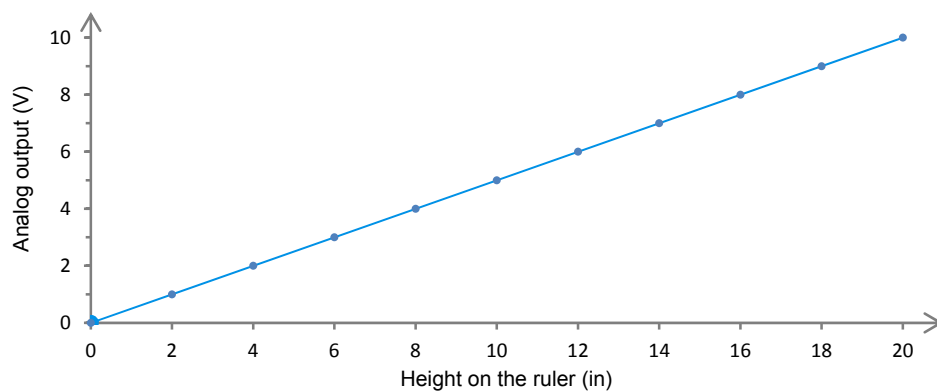


Height and analog output (in and V).

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.

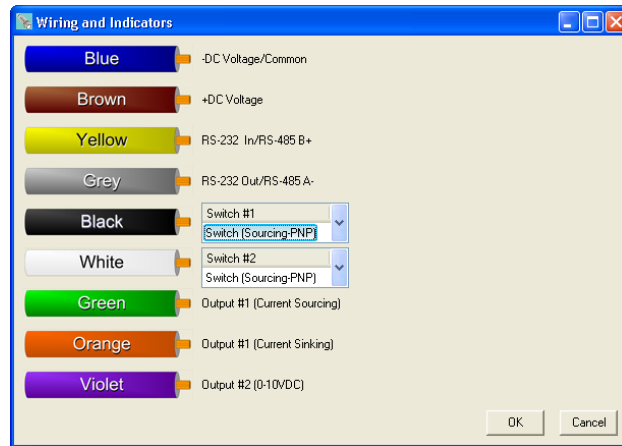


Figure 4-31. Configuring switch #1 and switch #2.

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.

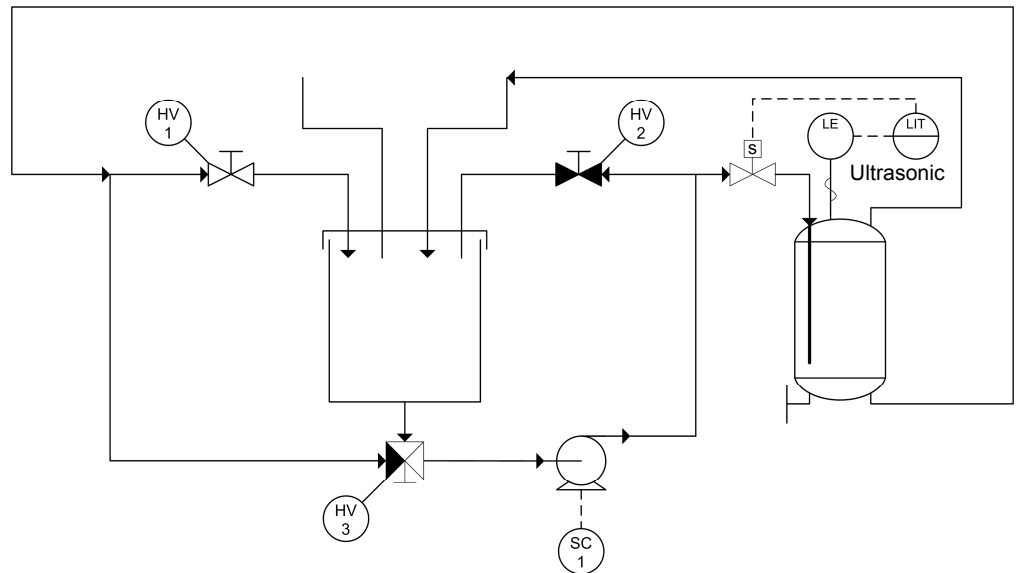


Figure 4-32. Simple On-Off control scheme using the transmitter.

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**.

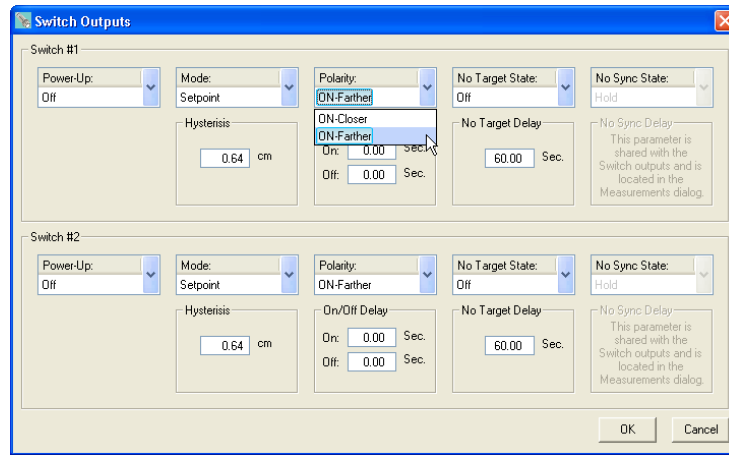


Figure 4-33. Switch #1 polarity.

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.

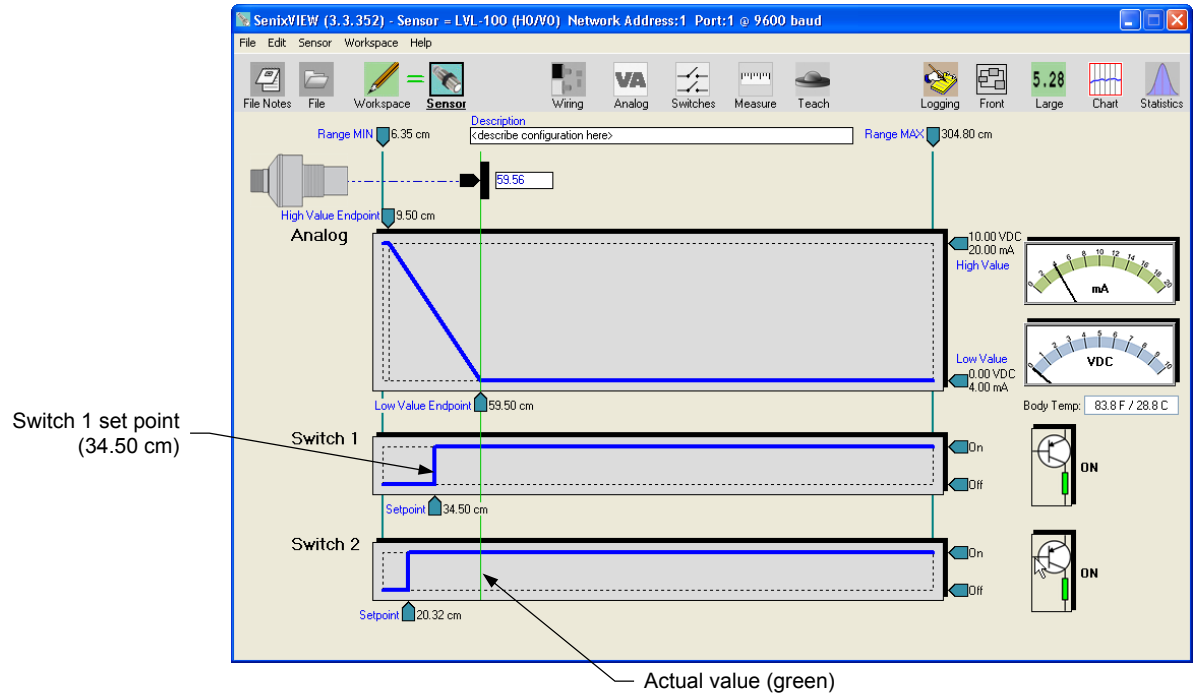


Figure 4-34. Switch 1 set point.

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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