Control Valves

Original Operating Instructions

Process Automation

User Guide

Festo Didactic

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By the staff of Festo Didactic

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e-mail: services.didactic@festo.com

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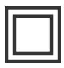
Safety Symbols and Procedures

The following table lists the safety and common symbols that may be used in this document and on the equipment. Before performing procedures with the equipment, you should read all sections regarding safety in the User Guide accompanying the equipment. Additional safety procedures are given before any task requiring specific safety precautions.

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.
NOTICE	**NOTICE** indicates a hazard with a potentially hazardous situation, which, if not avoided, may result in property damage.
	Caution, risk of danger. Consult the relevant user documentation.
	Caution, risk of electric shock.
	Caution, lifting hazard.
	Caution, hot surface.
	Caution, risk of fire.
	Caution, risk of explosion.

Symbol	Description
	Caution, belt drive entanglement hazard.
	Caution, chain drive entanglement hazard.
	Caution, gear entanglement hazard.
	Caution, hand crushing hazard.
	Static sensitive contents. Observe precautions for handling electrostatic discharge sensitive devices.
	Notice, non-ionizing radiation.
	Consult the relevant user documentation.
	Radio Equipment Directive (RED) geographical restrictions – consult the relevant user documentation.
	Direct current.
	Alternating current.
	Both direct and alternating current.
	Three-phase alternating current.
	Earth (ground) terminal.

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.

Preface

Introduction to the learning system

Automated process control provides many advantages over manual control and is therefore used in most modern industrial processes. Breweries, wastewater treatment plants, mining operations, and the automotive industry are examples of industries that rely on automated process control systems.

Keeping process variables such as pressure, flow, level, temperature, and pH within defined operating ranges is essential to produce products with consistent composition and quality.

The Instrumentation and Process Control Training System reproduces an industrial environment using modern, industrial-grade equipment. Throughout the course, students develop skills in installing and operating process control equipment, combining theoretical knowledge with hands-on practice.

The system's modular design allows instructors to select equipment that matches specific course objectives. Two mobile workstations form the core of the system. Optional components for pressure, flow, level, temperature, and pH control, as well as valves, calibration equipment, and software, can replace basic components with the same function as needed. Different controllers can be used interchangeably during control exercises, depending on instructional needs.

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

LVProSim, a software application used in the system's courses, can be downloaded here:

LVProSim

http://bit.ly/LVPROSIM32600

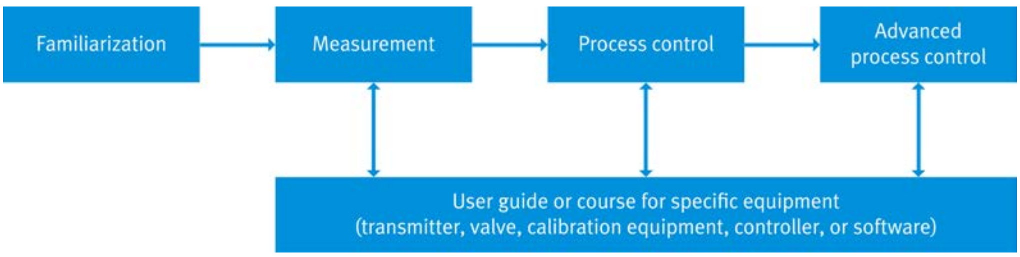


Figure 1: Standard learning path for the Instrumentation and Process Control Learning System.

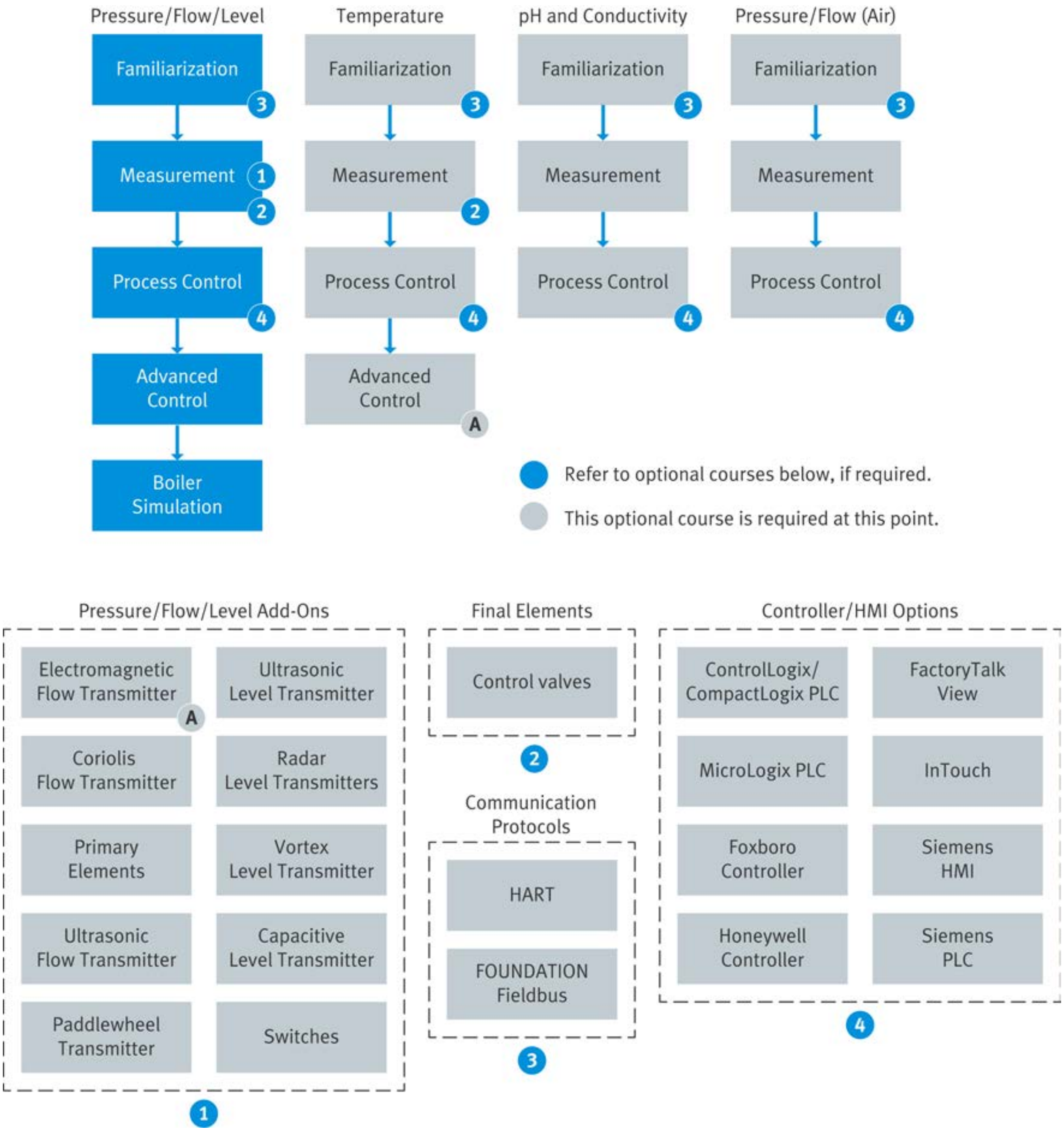


Figure 2: Instrumentation and Process Control Learning System.

Basic Control Valve Theory

Introduction

A control valve is a final control element that regulates the flow of a liquid or gas in a process loop to keep a determined process variable at a desired set point. The effect of a valve on the process fluid can ultimately be on variables such as pressure, flow, level, or temperature in a system. Consequently, the same control valve can be used to regulate any of these variables provided the appropriate variable is measured and monitored by a controller.

The opening or closing of control valves is achieved by means of electrical, hydraulic or pneumatic actuators. A control valve fully or partially opens or closes in response to a command, analog or digital, received from a controller. A transducer then converts this signal into another one suitable to the valve actuator. An example would be an electrical signal converted to pressurized air in the case of a pneumatic actuator.

The topic of control valves is broad and rife with details and tricks of the trade. This section aims to give you a basic understanding of control valves in their different variations.

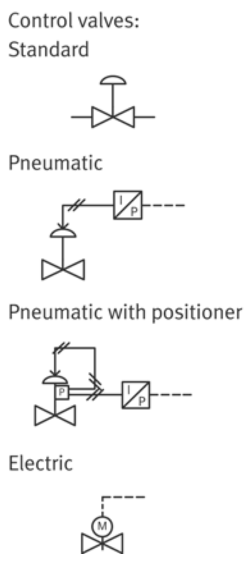


Figure 3: Instrument symbols.

The anatomy of a control valve

A control valve has at least one fluid inlet and one outlet; mixing or diverting valves have multiple inlets and/or outlets. It includes a flow-restricting element, which can be adjusted to limit flow to the outlet(s), and an actuator that applies mechanical power to this element as either linear (sliding-stem) or rotary (angular) motion.

The different types of control valves

Control valves come in many types, each with specific characteristics and applications. The most common is the globe valve, which uses a plug to restrict fluid flow in a passage. The plug is often designed so that the maximum flow through the valve has a defined relationship to the stem travel, typically linear or equal-percentage. Other common types are gate, ball, and butterfly valves. A gate valve is used mainly for simple on/off flow control. A ball valve offers excellent shutoff but poor throttling performance. A butterfly valve, like a globe valve, is used for throttling but uses a rotating circular disc to restrict flow.

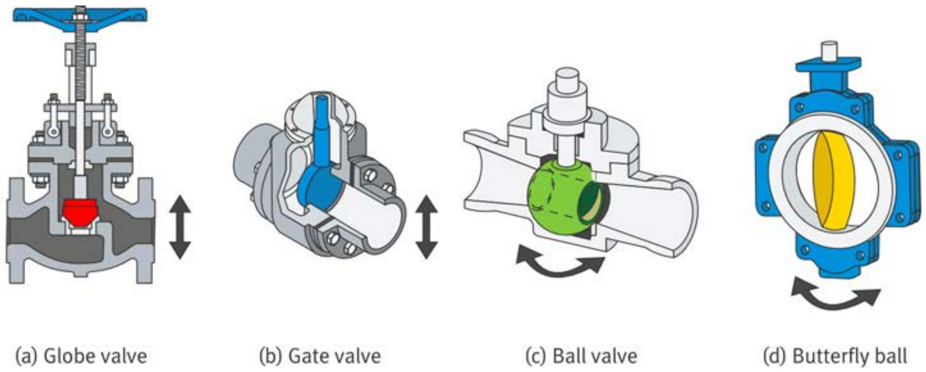


Figure 4: Main types of valves.

The Instrumentation and Process Control Training System uses globe valves for all models, except for the V-Ball Valve (model 46954), which uses a ball valve.

The following figure shows the components of a basic control valve with a pneumatic spring-and-diaphragm actuator.

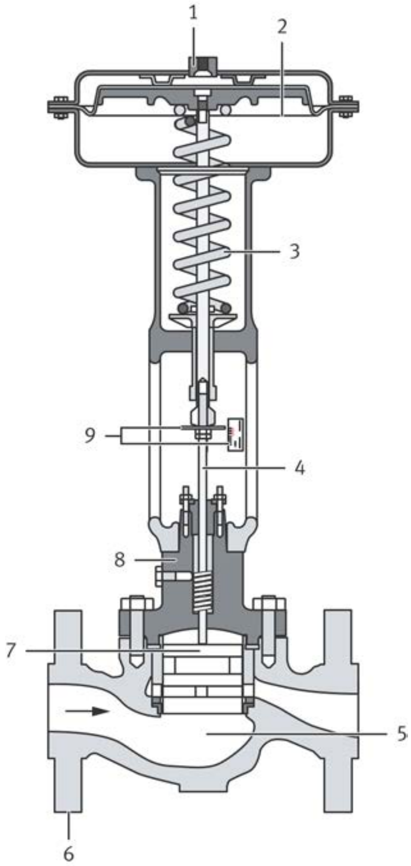


Figure 5: Typical spring-and-diaphragm pneumatic control valve.

1. **Pressure signal input.** This connection supplies pressurized air to the valve actuator.

2. **Diaphragm plate.** A flexible plate that transmits vertical movement to the valve stem when pressurized air is applied to its surface.

3. **Actuator spring.** Maintains the valve in its normally open or normally closed position.

4. **Valve stem.** Part that connects the actuator with the valve closure member.

5. **Inlet/Outlet.** Fluid passageways. Note that a control valve is generally directional.

6. **Body.** Contains the fluid flow passageway, the pipe connectors, and the valve plug.

7. **Valve plug.** This is the closure member of the valve that is in direct contact with the fluid.

8. **Bonnet.** Contains the packing box and stem seal, and guides the valve stem.

9. **Travel indicator and scale.** A pointer and scale used to show the position of the valve.

The pneumatic actuator

One of the most common types of control valves is the pneumatically operated control valve with a spring-and-diaphragm actuator. The construction details of this type of valve are shown in Figure 5 and in Figure 6 below.

A spring-and-diaphragm pneumatic actuator consists of two chambers separated by an airtight diaphragm. One chamber is open to the atmosphere and contains a spring acting on the diaphragm. The other chamber is pressurized with air supplied to control the valve opening. This pressurized air exerts a force on the diaphragm that opposes the spring force. The diaphragm moves linearly with the pressure of the control air (because the spring behaves according to Hooke's law). As the diaphragm moves, it moves a stem that displaces the flow-restricting device. This linear motion is converted into rotation by mechanical means if the flow-restricting element requires rotational movement.

When the spring is in the lower chamber, its force tends to move the stem up, while the force due to the air pressure moves the stem down. For a valve like the first one shown in Figure 6, this behavior is called "air-to-close" or fail-open, because the valve will be open if air pressure is lost. If the spring is in the upper chamber, it pushes the stem down, while the force due to the pressurized air in the lower chamber counteracts this force by pushing up. The valve is then of the "air-to-open" type or fail-close (see, for example, the second valve in Figure 6).

The designation of a valve as "fail-open" or "fail-close" depends on the combined action of the actuator and the valve. An actuator is a direct actuator when the stem moves down as the air pressure increases, and a reverse actuator when the stem moves up as the air pressure increases. The valve has direct action when a downward-moving stem restricts the fluid flow, and reverse action when a downward-moving stem increases the fluid flow. See the following figure for the different combinations and their overall effect.

Table 1: Fail-open and fail-close designation based on actuator and valve action.

Spring Action	Direct	Reverse	Direct	Reverse
Valve Action	Direct	Direct	Reverse	Reverse
Designation	Fail Open	Fail Closed	Fail Closed	Fail Open
	Air-to-close	Air-to-open	Air-to-open	Air-to-close

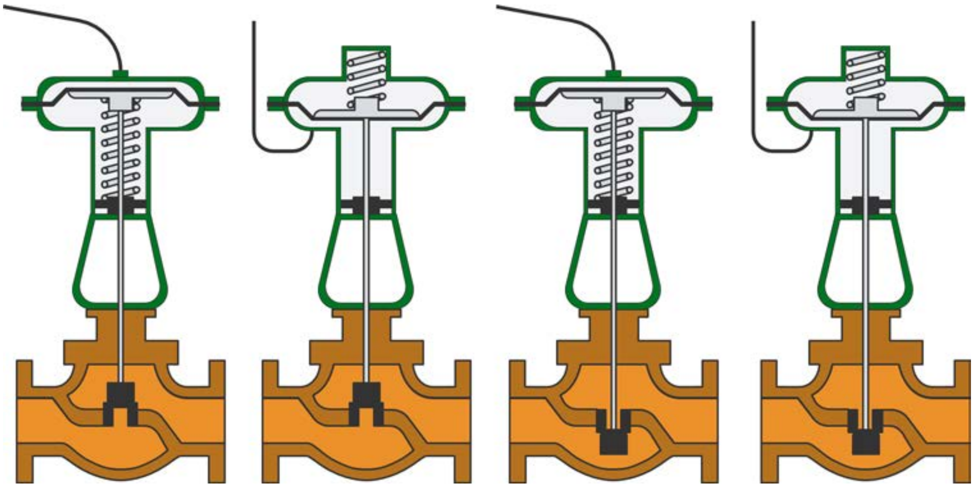


Figure 6: Different valve and actuator actions.

The spring in a pneumatic actuator must have precisely calibrated stiffness and length to ensure an adequate response of the diaphragm-and-spring system to the control signal. The **bench rate** is the pressure span that can be applied to an actuator to change the valve opening. A 20-90 kPa (3-13 psi) range is a typical bench rate. The spring inside the actuator can be replaced by one with a different stiffness if the bench range needs to be changed.

Table 2: State of opening of a control valve for a typical bench rate.

Control Signal	Type of Valve	
	Air-to-open	Air-to-close
0 to 20 kPa (0 to 3 psi)	closed	open
20 to 90 kPa (3 to 13 psi)	partly open	partly open
above 90 kPa (above 13 psi)	open	closed

This means that an air-to-close control valve is fully open for a control signal between 0 and 20 kPa (0-3 psi) and fully closed when the control signal is equal to or above 90 kPa (equal to or above 13 psi). When the control signal is within the bench rate, the stem is between its origin and its maximum displacement. The displacement is a linear function of the control signal between the lower and upper limits of the bench rate. Do not send too high a pressure to an actuator, as this could irreversibly damage the mechanism.

Current-to-pressure (I/P) converter

A typical control valve is equipped with a current-to-pressure converter, often abbreviated I/P, that receives a command as a 4 to 20 mA analog signal and linearly converts it into a 20 to 100 kPa (3 to 15 psi) pressurized air signal. This pressurized air signal is applied to the diaphragm surface, producing a force that overcomes the spring force and moves the valve closure member up or down.

An I/P converter must be connected to a pressurized air supply to perform the conversion between current and pressure. A functional diagram of a typical I/P converter is shown below:

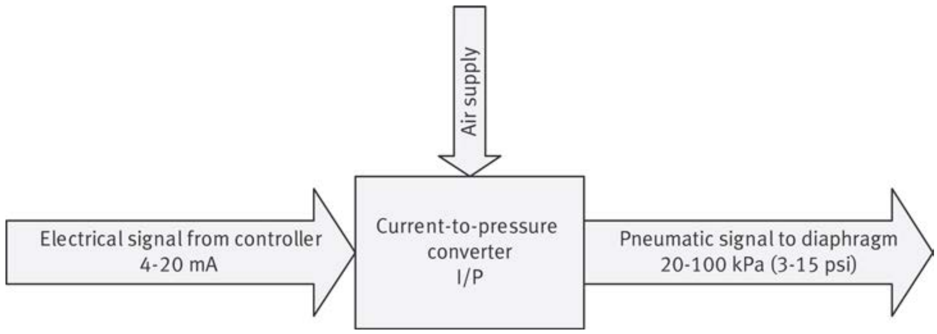


Figure 7: Functional diagram of a typical I/P converter.

Globe-valve flow characteristics

A globe valve always contains a valve member (the plug) designed to provide a defined relationship between the flow and the percentage of stem travel. The characteristics of a valve plug are obtained by plotting the fluid flow as a function of the stem travel for a fixed pressure drop across the valve.

The sensitivity S is defined as the ratio of the change in fluid flow over the change in stem travel L.

$$S = \frac{dQ}{dL} \approx \frac{\Delta Q}{\Delta L}$$

- **Linear characteristic (curve A)**

  A valve has linear characteristics when $S = \dfrac{dQ}{dL} = C$, where C is a constant.

  This means that the slope of the curve is constant, so that a given change in the distance traveled by the stem always yields the same change in flow.

- **Equal-percentage characteristic (curve B)**

  In an equal-percentage valve, the plug is shaped so that the relative change $(\Delta Q/Q)$ is constant at any value of L. The sensitivity then follows: $S = \dfrac{dQ}{dL} = CQ$, where C is a constant. The relationship between Q and C is, in this case, of the exponential form.

- **Quick-opening characteristic (curve C)**

  This type of valve is primarily used in conjunction with on-off control where a rapid increase in flow for a small stem travel distance is desirable (safety system for instance).

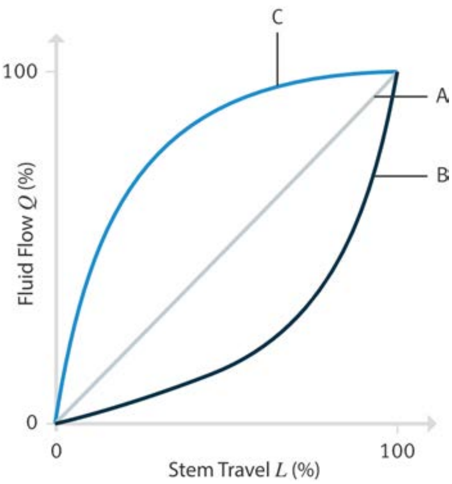


Figure 8: Typical flow characteristics of the valve plug.

Note that all the globe valves used with the Instrumentation and Process Control Training System are of the equal-percentage type.

Valve sizing and selection – a quick overview

Choosing the right valve for an application is an art, which involves experience and many rules of thumb. This section aims to present a simplified method for doing so, and introduces a few important valve characteristics along the way, such as C_v, the flow coefficient.

1. The system you are going to use must first be completely defined and the requirements of your process must be known. An example is given for a flow loop on the Instrumentation and Process Control Training System:

   - **Total head available.** About 240 kPa (34.5 psi). This is the maximum pressure the pump can deliver.
   - **Pressure drop (without the control valve in place).** In the case of a simple flow loop, the loss of pressure is very small, a pessimistic estimate could be 34.5 kPa (5 psi).
   - **Maximum flow rate.** The maximum flow rate given by the pump is about 56.8 l/min (15 gal/min).
   - **Typical operating flow rate.** The usual flow rate of our application is 30.3 l/min (8 gal/min).
   - **Minimum flow rate.** Let's assume we need a minimum flow rate of 15.1 l/min (4 gal/min).
   - **Diameter of the pipes.** The hoses have an internal diameter of 1.9 cm (0.75 inches).

The first rule of thumb states that your valve (while completely open) should use 10% of the total pressure drop or 69 kPa (10 psi), whichever is greater. Since the pressure drop is about 35 kPa (5 psi), the allowable pressure drop across the valve is 69 kPa (10 psi). The total pressure head (240 kPa (34.5 psi)) is sufficient to accommodate this added pressure drop across the valve.

2. The flow coefficient of the valve is now calculated. The flow coefficient C_v is always calculated in US customary units and its units are oftentimes ignored. An SI version exists and is noted K_v. Note that the relationship between the two is C_v = 1.16 K_v.

$$C_v = Q\sqrt{\frac{SG}{\Delta P}}$$

where

Q	is the flow rate in **US gal/min**
SG	is the specific gravity of the fluid (= 1 for water at 60°F)
ΔP	is the pressure drop across the valve in **psi**

The flow factor K_v, is the SI equivalent of C_v. This equation is built to mirror the C_v version and deals cavalierly with its various dimensional units as the resulting number is considered unitless. It is calculated in the following way (be careful to use the units as indicated):

$$K_v = Q\sqrt{\frac{SG}{\Delta P}}$$

where

Q	is the flow rate in **m³/hour**
SG	is the specific gravity of the fluid (= 1 for water at 20°C)
ΔP	is the pressure drop across the valve in **bar** (1 bar = 100 kPa)

So, the flow coefficient at maximum flow in our example is (notice that C_v = 1.16 K_v):

$$C_v = Q\sqrt{\frac{SG}{\Delta P}} = 15\sqrt{\frac{1}{10}} = 4.74 \text{ or } K_v = 56.8 \cdot \frac{60\ m^3}{1000\ min} \cdot \sqrt{\frac{1}{0.69\ bar}} = 4.10$$

The flow coefficient can also be calculated for the minimum and the normal operating condition. Note that the same pressure drop (10 psi) is used in the calculation as an approximation. The actual pressure drop would actually be larger, which would result in a smaller K_v. The level of precision considered here is sufficient for our needs.

Normal flow conditions $C_v = 8\sqrt{\frac{1}{10}} = 2.53$ -> $K_v = 2.18$

Minimal flow conditions $C_v = 4\sqrt{\frac{1}{10}} = 1.26$ -> $K_v = 1.09$

3. It is important at this point to consider two more rules of thumb:

- The diameter of the inlet/outlet ports on a control valve should never be smaller than half the size of the pipes used. The hoses used in the system have a diameter of 1.9 cm (3/4 in). This implies that the control valve should have a diameter of at least 0.95 cm (3/8 in). So, a control valve with a diameter of 1.3 cm (1/2 in) complies with this rule.
- One should strive to avoid using the lower 20% and the upper 20% of the stem stroke since a valve is much simpler to control in its middle range (20 to 80%) than at its extremes. Of course, this is not always possible; think of an application where the flow requires being completely stopped from time to time (valve stem at 0%). Nonetheless, it is poor practice to use the extremes of a valve's range to exert everyday control on a process.

You must then decide which type of valve will be used (in our case: an equal-percentage globe valve). Keeping in mind the C_v (or K_v) values obtained in the previous step, we can head to a manufacturer's chart. Here is some technical information about the chosen valve:

Table 3: C_v (and K_v) coefficients of the control valve as a function of its opening.

Valve Opening (%)	C_v	K_v
5	0.16	0.14
10	0.24	0.21
20	0.38	0.33
30	0.5	0.43
40	0.7	0.61
50	1.0	0.87
60	1.4	1.21
70	2.1	1.82
80	2.9	2.51
90	4.1	3.55
100	6.0	5.19

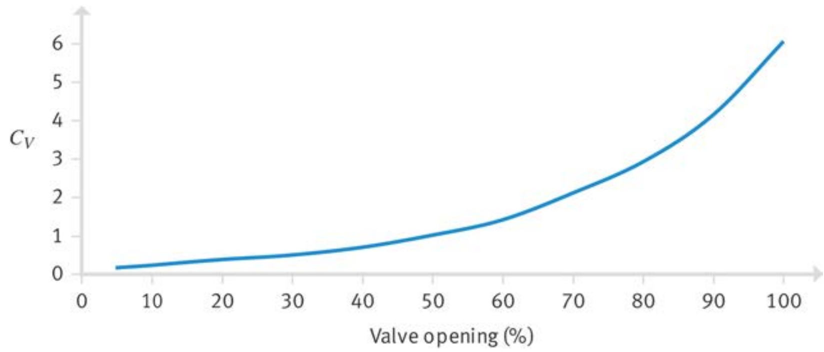


Figure 9: Valve coefficient C_v as a function of the valve opening.

We see from the graph that a C_v of 1.26 corresponds roughly to an opening of the valve of 55%. In the same way, a C_v of 2.18 corresponds to an opening of about 72% and a C_v of 4.74 (maximum flow) to a valve opening of 94%.

The rule of avoiding the use of the lower 20% range of the valve is easily obeyed. On the other hand, the upper 20% is used for high-flow control. A judgment call must be made at this point. Is the system likely to operate at the maximum flow rate during control experiments for extended periods of time? The answer is no. In fact, the highest flow rate you are likely to encounter during well-tuned control experiments will correspond to an opening of 85%, which is still acceptable. On top of that, an approximation was used in the calculation of C_v. The actual pressure drops are larger than the ones used in the calculations. Consequently, the valve openings would be smaller than the ones obtained.

The essential point to remember is that the valve you select must be sized so that it accommodates your process as much as possible, without resorting to using its extreme ranges excessively. In our case, the valve is appropriate.

Accessories

Valves may be equipped with many accessories. A few of them are briefly described here:

Positioner: A positioner is a mechanical device that is used to make sure the valve stem is where the controller wants it to be. The positioner corrects for errors due to factors such as changes in packing friction (due to dirt, corrosion, or lack of lubrication), changes in the dynamic forces of a process, dead band, or nonlinearities. It works as the slave loop (usually a high-gain proportional controller) of a cascade controller which measures the position of the stem and compares it to the desired position (the set point). For this reason, a positioner is adequate when the time constant of the slave loop is much shorter than the time constant of the master loop. This means that the positioner must be able to respond much faster than the master process variable which the valve controls.

DVC: A DVC stands for Digital Valve Controller. It is a current-to-pressure device equipped with a microprocessor. This type of accessory allows automatic calibration and configuration as well as digital positioning. Certain models are capable of communication via either HART or Fieldbus communication protocols.

Booster: A booster is a device that amplifies a pneumatic signal to improve the performance of a control valve. It is, in essence, a feedforward amplifier and is typically used in conjunction with a positioner.

Types of valve positioner

Valve positioners are available in a large variety of models, depending on the type of input and output signals used to operate the valve stem.

- Pneumatic (both signals are pneumatic). This is the case with the Fisher 3660 positioner.
- Electro-pneumatic
- Digital-pneumatic. A DVC uses this type of positioner.
- Electro-hydraulic
- Electrical (both signals are electrical). The electric control valve is an example of a valve with an electrical positioner.

Advantages and disadvantages of valve positioners

The advantages of valve positioners include:

- Their ability to convert the type of control signal.
- Their ability to reduce friction and, therefore, the hysteresis and the dead band. The resolution and response time is also enhanced.
- Their ability to increase the stability of valve operation in the presence of viscous or sticky fluid.
- Their ability to modify the behavior of a valve according to the requirements of a process, or to correct for the non-linearity of a valve.
- The possibility to equip them with safety devices to protect the equipment in case of signal failure or abnormal situations.

The disadvantages of valve positioners include:

- Their high cost.
- They are not as useful for a process with a quick response time (flow or pressure processes for instance).
- They can produce undesired oscillations in some improperly tuned systems.

More information about the valves

Cavitation

The phenomenon of cavitation (from the Latin verb cavitare, which means to hollow out) is an undesirable and destructive process in valves. Cavitation occurs as a fluid is caused to evaporate locally thus creating cavities (small bubbles filled with steam). Those cavities are formed in areas where the speed of the fluid becomes so high the local hydrostatic pressure decreases below the vapor pressure of the fluid (i.e., the pressure at the vena contracta of the valve is below the vapor pressure). The cavities are carried away by the flow and soon collapse (implode) when they reach areas where the pressure is higher. As they collapse, the cavities produce shockwaves that can cause damage to nearby surfaces.

Cavitation can be identified by its typical sound, which is similar to that of boiling water. At higher levels of cavitation, the sound may make you think of gravel trying to pass through the valve. As damage resulting from cavitation can be quite serious, it is important to avoid it as much as possible. This is done by properly designing the valve and by avoiding situations where the drop of pressure due to the valve is large (i.e. situations where the control valve is almost closed).

This phenomenon does not manifest itself much, if at all, with the Instrumentation and Process Control Training System, even as control valves are almost closed. It is nonetheless crucial to recognize cavitation in an industrial setting in order to minimize its effects. For more information and illustrations of cavitation in action, please refer to the Measurement manual.

Flashing

Flashing is similar to cavitation as it occurs when the local pressure drops below the vapor pressure of the fluid, forming gaseous bubbles. The difference is that the pressure remains below the vapor pressure after the restriction. The bubbles consequently do not implode as in cavitation, but persist and are carried with the flow at high velocities. This can cause damage akin to sand-blasting on the surface of the equipment.

Choked flow

An incompressible liquid passing in a control valve may result in the choking of the valve as the pressure drop caused by the restriction in the valve brings the liquid pressure below its vapor pressure. At this pressure, the liquid starts to form bubbles which take up space in the vena contracta of the valve and force the molecules to crowd. This prevents additional increases of flow as the downstream pressure is further decreased (the upstream pressure remains constant).

The choked flow pressure drop is a parameter often given in technical publications on control valves which indicates the minimal pressure drop required to cause choking. At maximum flow rate, that minimal pressure drop is about 240 kPa (35 psi). This is very close to the total pressure head supplied by the pump so that the valve does not choke unless almost closed. A choked flow also produces either cavitation or flashing.

Safety Considerations

⚠ CAUTION

To avoid injuries to you or your teammates and to avoid damage to the equipment, always follow the safety guidelines listed below:

- Always wear personal protective equipment, especially steel cap shoes, when manipulating the control valve.
- Control valves are heavy. Request the help of your teammates to lift and install one.
- Disconnect the electrical connections, the pneumatic connection, and relieve the pressure in the valve before displacing it.

Using the control valve

To ensure good performance, some precautions must be taken when installing and using any of the control valves presented in this manual. The procedures detailed in the following subsections underline the most important aspects.

Installation on the process workstation

Follow the guidelines listed below when installing the valve on the process workstation:

- Make sure the strut on which you plan to install the control valve is firmly attached to the structure of the process workstation.
- Always secure the control valve assembly to a strut with screws and spring nuts.

⚠ CAUTION

The control valve could fall and cause injuries to you or your teammates or damage equipment if it is not secured with spring nuts and screws.

- Make sure the valve body does not freely rotate. If it does rotate, tighten the locknut that secures the body to the yoke.

Flow direction

Notice the flow-direction arrow located on the brass valve body (look behind the valve if you do not see it). This arrow must always point in the direction of the flow. You may need to rotate the valve body to orient the arrow properly. To do so, locate the locknut along the stem of the control valve (you might need to use an access window at the back of the control valve) and:

⚠ CAUTION

Never turn a normally open valve when pressure is applied to the air inlet as it might cause permanent and extensive damage to the valve seat. Always disconnect the pressurized air source from a normally open control valve before performing this procedure.

For the same reason, a normally closed valve should be opened with the proper control signal when changing its direction of flow.

Note that three-way valves are different. Such valves are resting on either one of their seats when the pressure is maximal (100%) or minimal (0%). Consequently, it is mandatory to send a pressure of 50% to the actuator when the direction of flow is to be changed. This prevents damage to the valve due to friction on the seats.

1. Use a hammer and a suitable screwdriver to unscrew the actuator locknut that secures the valve body to the yoke as shown in the following figure. It is recommended that a piece of rag be placed on the locknut to avoid damaging its finish with the screwdriver and you should only use light hammer blows.

2. Hand-rotate the valve body until the arrow points in the same direction as the flow.

3. Tighten the locknut until the valve body cannot rotate anymore.

Figure 10: Unscrewing the actuator locknut to loosen the valve body.

Basic Control Valve (46950-B)

Description of the basic control valve

The basic control valve, model 46950-B0, is a pneumatically operated control valve of the globe type equipped with a spring-and-diaphragm actuator. The actuator is controlled by an I/P that receives an analog signal from a controller which is linearly converted into a pneumatic signal. This signal is applied to the surface of the diaphragm to overcome the retaining force of the spring.

Construction details of the basic control valve are shown below:

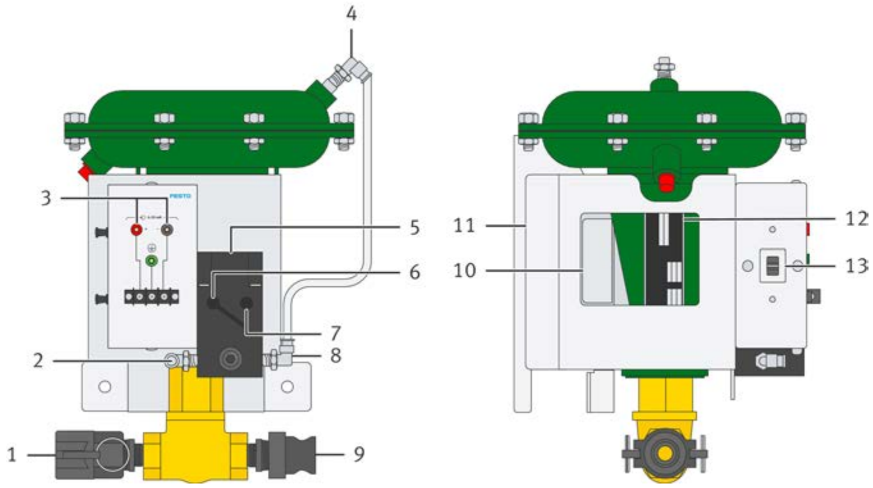


Figure 11: Pneumatic control valve, model 46950-B.

1. **Outlet:** Fluid must exit from the female fitting (the valve is directional).

2. **I/P pressurized air inlet:** This port connects to a pressurized air outlet on the pneumatic unit.

	⚠ CAUTION
⚠	The maximum pressure allowed at this inlet is 550 kPa (80 psi). A pressure exceeding this value could damage the I/P.

3. **4-20 mA connectors:** The control signal is picked up at these connectors. For a typical wiring example involving the control valve, see the Current loop example section.

4. **Actuator pressurized air inlet:** The pneumatic signal from the I/P pressurized air outlet is picked up at this inlet.

	⚠ CAUTION
⚠	The maximum pressure allowed at this inlet is 240 kPa (35 psi). A pressure exceeding this value could damage the actuator.

5. **Current-to-pressure converter (I/P):** Linearly converts the 4-20 mA control signal into a 20-100 kPa (3-15 psi) pneumatic signal.

6. **RANGE adjustment screw:** Used to adjust the pressure range that corresponds to the 4-20 mA control signal. Remove the v-shaped plastic cover to access the adjustment screw.

7. **ZERO adjustment screw:** Used to adjust the pressure value that corresponds to a 4 mA signal. The ZERO and RANGE adjustment screws are interacting.

8. **I/P pressurized air outlet:** This port connects to the pressurized air inlet of the actuator.

9. **Inlet:** Fluid must enter from the male fitting (the valve is directional).

10. **Mirror:** Use this mirror to view the position of the travel indicator and scale.

11. **Mounting bracket:** Always use the mounting bracket to securely install the control valve assembly to a strut on the process workstation.

12. **Nameplate:** Shows the main technical information about the control valve. Note that the nameplate may be located somewhere else on the valve, such as on the top of the actuator.

13. **Fault switch:** There is one available fault switch that can be activated by the instructor to insert an electrical fault. The fault is activated when the switch is in the on position (I). Ensure that the fault is in the off position (O) if you are not performing a troubleshooting exercise.

Below is a summary of the main characteristics of the control valve and of the current-to-pressure converter:

Table 4: Control valve.

Valve type	globe type plug valve, equal percentage
Actuator	normally open (air-to-close), spring-and-diaphragm
Valve size	13 mm (0.5 in)
C_V (fully open)	6
Actuator pressure range	20-90 kPa (3-13 psi)
Maximum pressure at actuator inlet	240 kPa (35 psi)

Table 5: I/P.

Current input range	4-20 mA
Pressure output range	20-100 kPa (3-15 psi)
Maximum pressure at inlet	550 kPa (80 psi)
Available pressure adjustments	range and zero

Connecting and adjusting the valve

Pressure connections

There are three pressure connection points on the basic control valve. Follow the procedure detailed below to make all the necessary connections using impulse lines. Do not power the control valve with any electrical current during this procedure.

1. Connect the 0-200 kPa (0-30 psi) pressurized air outlet located on the pneumatic unit to the I/P pressurized air inlet.

⚠ CAUTION

Do not use the 0-700 kPa (0-100 psi) pressurized air outlet of the pneumatic unit. This ensures that the supplied pressure never exceeds the maximum pressure the I/P can withstand: 550 kPa (80 psi).

2. Use the regulator on the pneumatic unit to set the pressure to approximately 170 kPa (25 psi).

3. If it is not already done, interconnect the I/P pressurized air outlet with the actuator pressurized air inlet using impulse lines.

⚠ CAUTION

The pressure at these ports must never exceed 240 kPa (35 psi).

Range and zero adjustment

After a long period of downtime, or if it is the first time the I/P is used, it should be adjusted to ensure that the conversion between electrical and pneumatic control signals is linear and similar to the curve shown below:

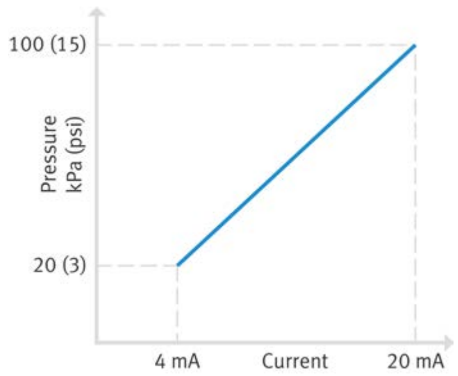


Figure 12: Conversion between electrical and pneumatic control signals.

Follow the procedure described below to adjust the I/P:

1. Connect the impulse line from the I/P pressurized air outlet to the 0-700 kPa (0-100 psi) digital pressure gauge, model 46761-B0, supplied with the system.

2. Connect the 0-200 kPa (0-30 psi) pressurized air outlet on the pneumatic unit to the I/P pressurized air inlet. Set the pressure to 170 kPa (25 psi).

3. Set your calibrator to work as a current source. Connect the leads to the 4-20 mA connectors located to the left of the I/P.

4. Remove the V-shaped protective plastic piece to access the RANGE and ZERO adjustment screws.

5. Set the calibrator output to 4 mA and turn the ZERO adjusting screw to obtain a reading of 20 kPa (3 psi) on the digital pressure gauge.

Turn the ZERO adjusting screw counterclockwise to increase the pressure or clockwise to decrease the pressure at the I/P pressurized air outlet.

6. Set the calibrator output to 20 mA and adjust the RANGE adjusting screw, located in the range access hole, to obtain a reading of 103.4 kPa (15 psi) on the digital pressure gauge.

It may be necessary to repeat the last two steps several times due to the interaction between the ZERO and RANGE adjustments.

Current loop example (HART only)

The following procedure details the steps to make a typical connection involving the basic control valve (any correctly calibrated control valve can be used), the paperless recorder (also known as a trend recorder) and a current calibrator. Here the current calibrator will simulate a controller.

1. Locate the 4-20 mA icon on the upper part of the black connection box of the control valve assembly. The connectors located below will receive the 4-20 mA signal from the calibrator.

2. Connect the + connector of your calibrator to the + connector of the CH1 connector on the paperless recorder front panel.

3. Connect the – connector of CH1 to the + connector of the black connection box of the control valve assembly.

4. The current loop must be closed to obtain a complete circuit. To do so, connect the – connector of the black connection box to the – connector of your calibrator.

5. Connect the recorder to a 24 V source on the electrical unit.

6. Switch on the electrical unit. The paperless recorder should boot.

7. To test your connection, configure the recorder to measure and display a 4-20 mA current on CH1. Refer to the Familiarization manual for details.

8. Use the calibrator to send a 12 mA current to the I/P transducer.

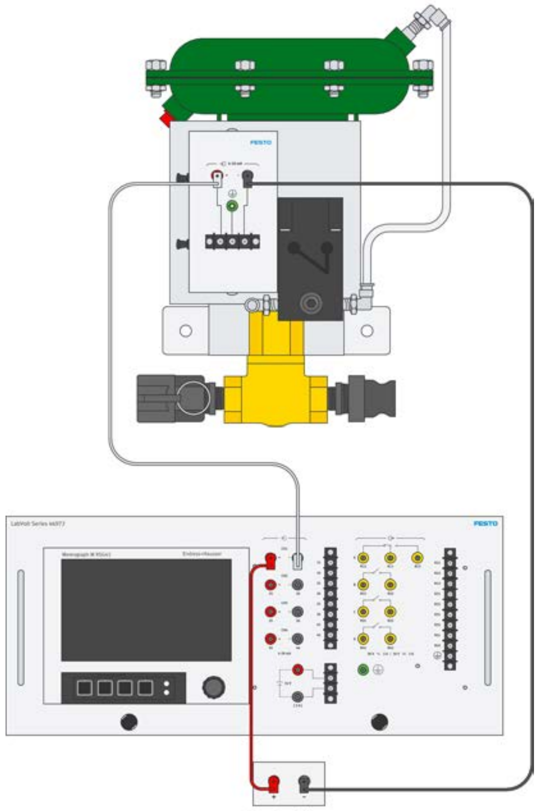


Figure 13: Typical current loop with the control valve and recorder.

9. Observe the travel indicator on the valve. It should indicate approximately one half (1/2), meaning the valve is half closed. Make sure the recorder's screen indicates 12 mA.

10. Now send a 4 mA current and then a 20 mA current. The valve should respectively be completely open and completely closed.

11. Power off the calibrator and disconnect it from the control valve assembly. In a real process loop, you would replace the calibrator with a controller and use it in manual mode to verify the position of the valve.

Pneumatic Control Valve with a Positioner (46950-A)

Description of the control valve

The pneumatic control valve with a positioner, model 46950-A, is a pneumatically operated control valve of the globe type equipped with a spring-and-diaphragm actuator. The valve itself is identical to the basic control valve presented in Learning Unit 1, but also includes a positioner and a pressure regulator.

Construction details of the pneumatic control valve with a positioner are shown below:

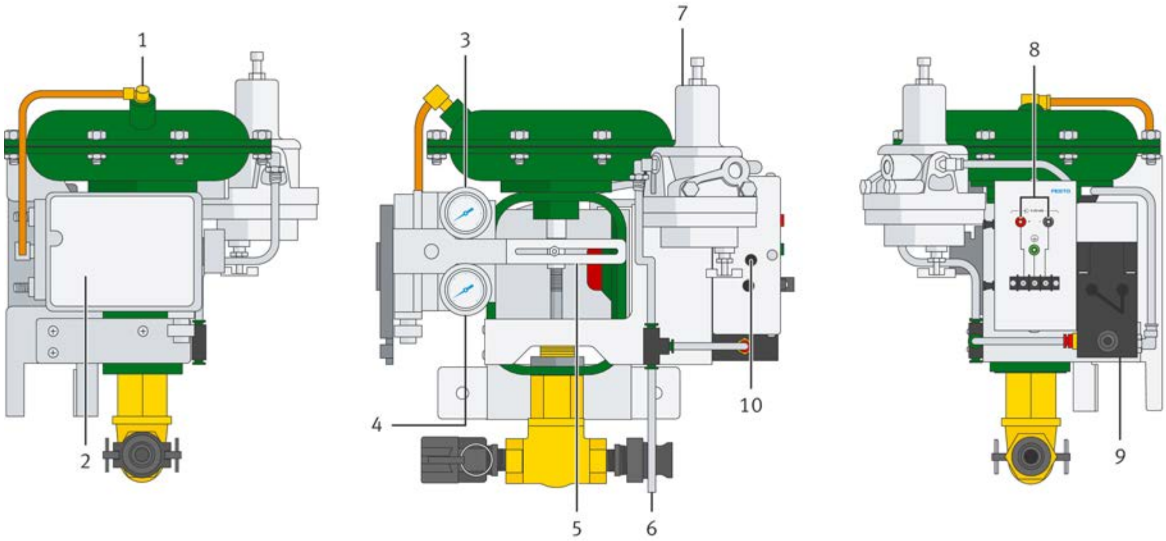


Figure 14: Pneumatic control valve with a positioner, model 46950-A.

1. **Actuator pressurized air inlet.** Pneumatic signal from the I/P pressurized air outlet is picked up at this inlet and is used to actuate the position of the stem.

⚠ CAUTION
The maximum pressure allowed at this inlet is 240 kPa (35 psi). A pressure exceeding this value could damage the actuator.

2. **Pneumatic positioner.** The positioner is a mechanical device that provides a pressure to the valve actuator based on the input pressure and on the feedback it receives from the valve stem.

3. **Input signal pressure gauge.** Provides a reading of the pressure sent by the I/P converter that corresponds to the desired position of the valve stem.

4. **Output signal pressure gauge.** Indicates the actual pressure sent to the actuator of the valve by the positioner.

5. **Feedback plate.** The feedback plate and the graduated scale provide a visual reference of the stem position. Notice how the lever of the positioner is linked to the feedback plate.

6. **Air supply Inlet.** Connect the air supply to T-shaped connector. The supplied air is fed to both the I/P converter and to the pressure regulator.

⚠ CAUTION

The maximum pressure allowed at this inlet is 550 kPa (80 psi). A pressure exceeding this value could damage the I/P.

A pressure of 170 kPa (25 psi) is recommended.

7. **Pressure regulator.** The regulator cleans up the air supplied to the valve with its filters and ensures a continuous air pressure is fed to the positioner.

8. **4-20 mA connectors.** The control signal is picked up at these connectors. For a typical wiring example involving the control valve, see the Current loop example section in Learning Unit 2.

9. **Current-to-pressure converter (I/P).** Linearly converts the 4-20 mA control signal into a 20-100 kPa (3-15 psi) pneumatic signal.

10. **Fault switch panel.** There is one fault switch behind the panel that can be activated by the instructor to insert an electrical fault. The fault is activated when the switch is in the on position (I). Ensure that the fault is in the off position (O) if you are not performing a troubleshooting exercise.

This control valve is **directional**: Fluid must enter from the male fitting and exit from the female fitting. Below is a summary of the main characteristics of the control valve and of its current-to-pressure converter:

Table 6: Control valve.

Valve type	globe type plug valve, equal percentage
Actuator	normally open (air-to-close), spring-and-diaphragm
Valve size	13 mm (0.5 in)
C_V (fully open)	6
Actuator pressure range	20-90 kPa (3-13 psi)
Maximum pressure at actuator inlet	240 kPa (35 psi)

Table 7: I/P.

Current input range	4-20 mA
Pressure output range	20-100 kPa (3-15 psi)
Maximum pressure at inlet	550 kPa (80 psi)
Available pressure adjustments	range and zero

Valve positioner

This control valve is equipped with a Fisher 3660 positioner. A positioner is a mechanical and pneumatic device which permits the accurate positioning of the actuator stem. In short, a valve positioner can be viewed as a high-gain proportional controller that compares a desired valve stem position to its actual position and makes the necessary modifications to correct for any error between the two.

A valve positioner works in the following way:

- A pneumatic signal coming from the I/P converter is sent to the positioner and corresponds to the desired position of the valve. This signal is the position set point.
- The positioner sends a pressure signal proportional to the set point to the valve actuator. This forces the valve stem to move either upward or downward.
- At the same time, a signal indicating the actual position of the stem is fed back to the positioner via the feedback lever. As long as an error exists between the feedback signal and the set point, the pressure sent to the actuator is readjusted. This is done until the stem position corresponds to the set point.

In the two following figures show the different external components of a positioner and how the positioner is connected to the control valve.

In Figure 15, the upper pressure gauge indicates the pressure sent by the I/P converter. This pressure corresponds to a specific opening of the control valve. The lower pressure gauge displays the pressure sent to the actuator in order to attain the desired stem travel.

A plate is fixed perpendicularly on the valve stem and is linked to the feedback lever via a rod. This rod rests under the plate and it can be moved along the lever to adjust the span of the positioner. The zero-adjustment screw is located under a protective cover and is used to modify the zero of the positioner.

Figure 15: Front view of a valve with a positioner.

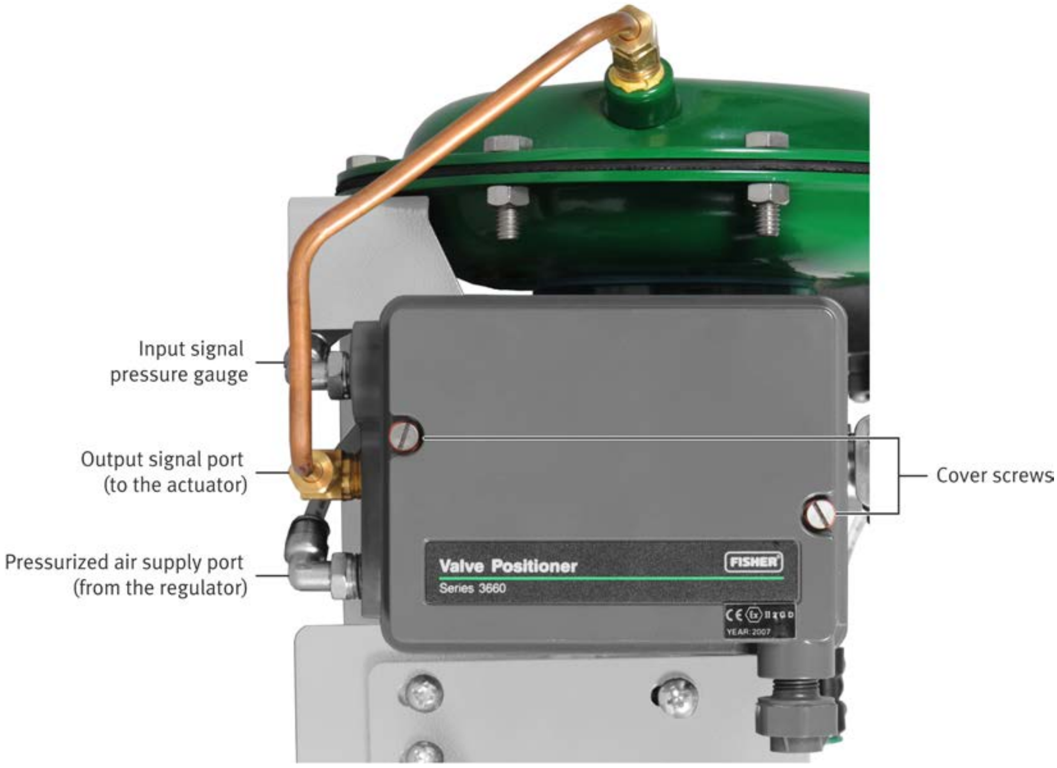


Figure 16: External view of the positioner.

Operation of a positioner

The following figure shows details of the positioner with its cover removed. Unscrew the two screws on the cover to gain access to the inner mechanism.

The first thing to notice is that the relay receives a constant input pressure supplied by the regulator. The output pressure of the relay is governed by the opening of a nozzle. This output is at its maximum when the nozzle is completely closed and it is reduced as air is allowed to flow out from the nozzle. This output signal is sent to the actuator of the valve and ultimately controls the opening of the valve. There is however an elegant mechanism which acts on the nozzle to control the pressure signal sent to the valve.

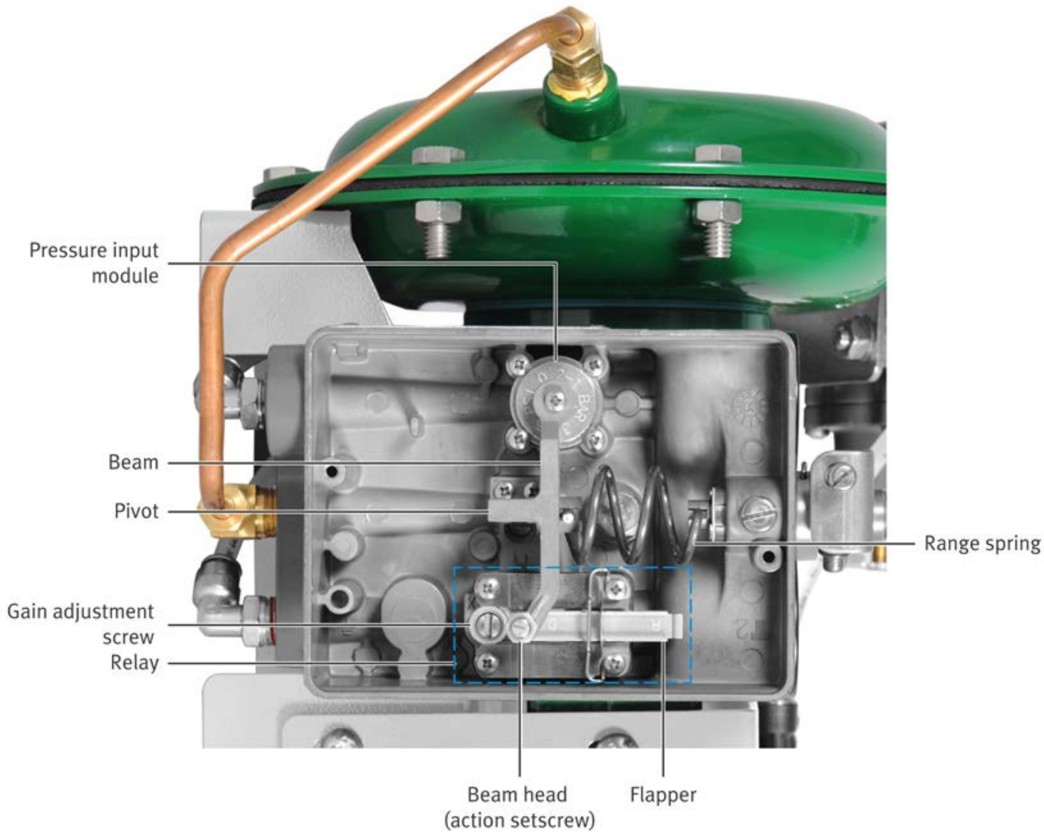


Figure 17: Internal view of the positioner.

The set point signal from the I/P comes into the positioner and is applied to an input module which moves up and down according to the pressure applied. As the head of the input module moves, it makes a beam rotate around the pivot. The beam has a head (action setscrew) at its other extremity which moves the flapper-nozzle system.

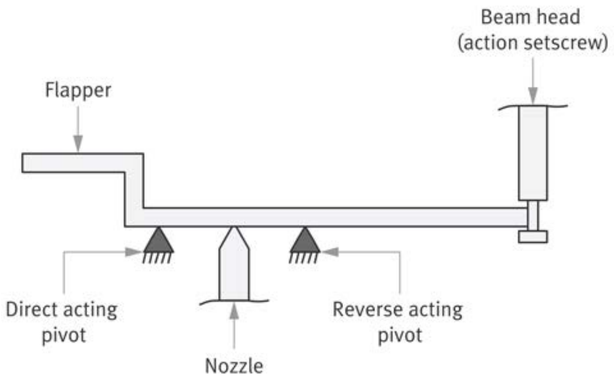


Figure 18: Cross section of the flapper/nozzle system.

The motion of the flapper changes the output pressure sent to the actuator. It is so because the obstruction of the nozzle depends on the position of the flapper. Note that the flapper uses one of two available pivots. When the D (direct) symbol of the flapper is close to the beam head, the direct acting pivot is used. The reverse acting pivot is used when the flapper is turned so that the R (reverse) symbol is closest to the beam head.

In principle, the action of the control valve can be inverted with the positioner. This is done by turning the flapper so that the R symbol is closest to the beam head. This changes the direction of rotation of the flapper and consequently inverts the action on the nozzle, ultimately reversing the action of the valve. To revert the motion of the feedback lever, it is necessary to move the entire positioner assembly to the other side of the actuator structure. For this reason, reversing the action is not possible on model 46950-A, as the bracket used to secure the valve on the workstation cannot accommodate a positioner at a location different from the intended one.

The most important aspect of a positioner comes from the fact it uses feedback to match the actual position of the stem with the desired position. This is performed by another part of the mechanism shown in Figure 17 which couples to the beam and adds its effect to the overall action. A feedback lever is attached to a plate which follows the travel of the stem at all times. The lever transmits a torque to the range spring which is then relayed to the beam. This torque is proportional to the error between the displacement of the stem and its desired position, and it acts to force the stem towards the set point.

Connecting and adjusting the valve

The valve can be connected to a process loop in the same way as the Basic Control Valve. The pressure connection and the calibration of the I/P converter should be performed as explained in the subsection entitled Connecting and adjusting the valve in Learning Unit 1. The only difference is that the pressurized air supply coming from the Pneumatic Panel at 170 kPa (25 psi) must be connected to the T-shaped connector, which sends air to both the regulator and to the I/P converter.

The pneumatic control valve with a pneumatic positioner can be used in a control loop once it has been calibrated. It works in the same way as the basic control valve and could be used in situations such as the one presented in Figure 13.

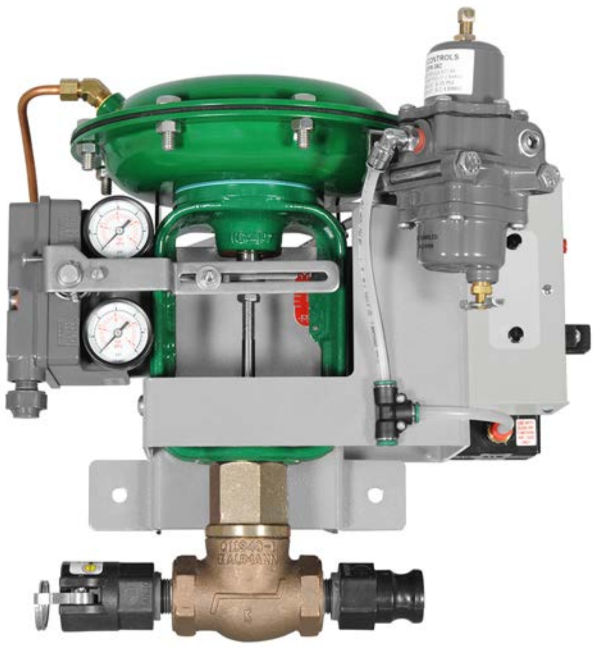


Figure 19: Connection of the pressurized air supply line to the valve.

Calibrating the zero and the span of the positioner

The pneumatic positioner must be calibrated when the valve is first used or whenever its configuration is modified. The calibration does not typically drift much over time, but it is always a good idea to monitor the calibration and to take corrective action when required. The procedure below outlines the steps for performing a calibration of the zero and of the span of a Fisher 3660 positioner. Note that it is assumed that the I/P converter is properly calibrated.

1. Secure the valve on a strut of the workstation with spring nuts and bolts. Connect the pressurized air supply (170 kPa (25 psi)) to the control valve and turn the pneumatic panel on. It is not required to connect the valve to a process for the calibration. Do not activate the pump during this procedure.

2. Remove the cover of the positioner. Make sure the flapper is positioned so that the engraved letter "D" for direct (not "R" for reverse) is nearest the action setscrew (See Figure 17). With the action set to direct, the pressure output of the positioner increases as the 4-20 mA signal sent to the valve increases. It is the only mode of action supported on this model.

3. Locate the gain adjustment screw, which is next to the action setscrew (see Figure 17). Turn the gain adjustment screw fully clockwise (without forcing the screw!), then turn it three turns counterclockwise. This sets a gain which is typically adequate for most setups.

   The recommended position given below for the span adjustment nut is only valid for the suggested gain. Note that you can use a different gain for an application, but doing so implies performing a complete readjustment of both the zero and the span settings.

4. The span (travel) of the valve positioner must now be adjusted. Locate the span adjustment nut on the feedback lever assembly. Loosen the nut and make the rod slide along the lever until the center of the rod is at approximately 2 cm (0.8 in) from the point of reference.

   Set the input pressure to 100 kPa (15 psi). This can be done either by connecting a pressure line at the appropriate pressure from the pneumatic panel to the input of the positioner or by sending a 20 mA signal to the I/P (assuming it is properly calibrated). The input pressure is read with the input pressure gauge.

   Check that the reading of the output pressure gauge is equal to or slightly higher than 100 kPa (15 psi).

   - If so, the span is properly adjusted. The valve is fully closed and the feedback plate of the positioner is level with the lowermost mark on the position indicator. Tighten the span adjustment nut and proceed to the next step.
   - If not, readjust the span adjustment nut so that the output pressure gauge reads a pressure equal to or slightly higher than 100 kPa (15 psi). Tighten the span adjustment nut and proceed to the next step.

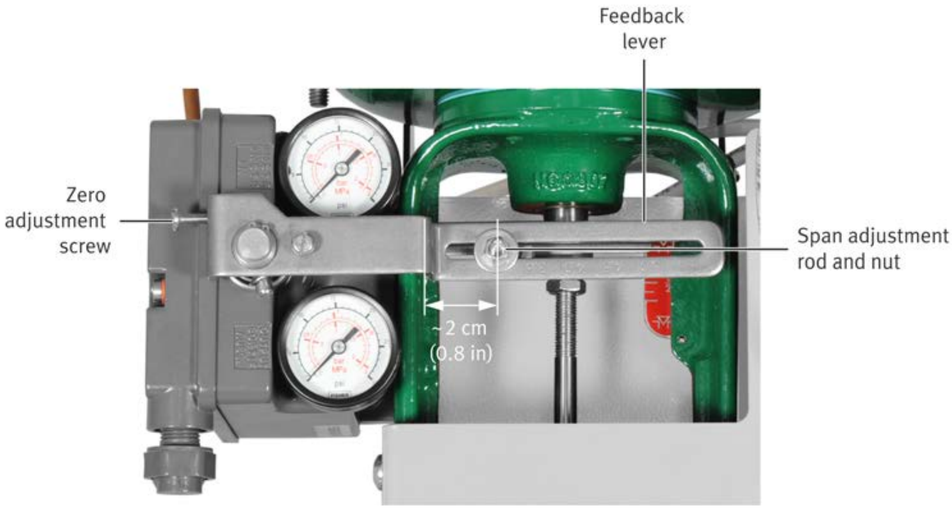


Figure 20: Suggested position of the span-adjustment rod and nut.

5. The zero of the positioner can now be adjusted. Start by locating the zero-adjustment screw. It is situated at the far left of the feedback lever and is normally shielded from unintentional modifications by a protective cover. Remove the protective cover with the help of a flat-bladed screwdriver.

   Set the pressure applied to the input of the positioner to 20 kPa (3 psi). You can do so either by adjusting the pressure line from the pneumatic panel at the proper value or by sending a 4 mA signal to the I/P (assuming it is properly calibrated).

Very slowly increase the pressure applied at the input of the positioner to 24 kPa (3.5 psi) - you can send a signal of about 4.6 mA if you use an I/P to generate the required pressure. Check that this causes the needle of the output pressure gauge to move from almost zero to a slightly higher reading:

- If it is the case, the zero is properly adjusted. The valve is fully open and the feedback plate of the positioner is level with the uppermost mark on the position indicator. Proceed to the next step.
- If not, the zero must be adjusted by turning the zero-adjustment screw (either clockwise or counterclockwise, depending on the situation). Adjust the screw until the needle of the positioner output gauge starts to move from the minimum reading to a slightly higher one. Proceed to the next step.

6. Set the input pressure sent to the positioner back to 100 kPa (15 psi) to see if the output pressure of the positioner is still equal to or slightly higher than 100 kPa (15 psi). If not, move the span adjustment nut to reach this condition.

7. Set the input pressure sent to the positioner back to 20 kPa (3 psi) to see whether the output pressure is still slightly above the zero graduation. If not, readjust the zero-adjustment screw until this condition is met.

8. If necessary, repeat steps 6 and 7 until the span and zero adjustments are properly set.

The gain, zero, and span adjustments are interacting. Therefore, if you modify the zero adjustment, you will need to readjust the span adjustment, and vice-versa. Those readjustments must be performed until both parameters converge to yield the desired behavior. Also, changing the gain requires a readjustment of both zero and span settings.

9. Place the protective covers back over the zero-adjustment screw and over the valve positioner. If you connected an impulse line from the pneumatic panel directly to the positioner input, disconnect the impulse line (turn off the air supply while you do so) and reconnect the output of the I/P to the positioner input.

   The positioner is now calibrated and the valve is ready to be used.

Control Valve with DVC2000 (46950-0)

Description of the control valve

The control valve with a digital valve controller (DVC2000), model 46950-0, is a pneumatically operated control valve of the globe type equipped with a spring-and-diaphragm actuator. The valve itself is identical to the basic control valve, but also includes a digital controller and a pressure regulator.

Construction details of the control valve with a DVC2000 are shown below:

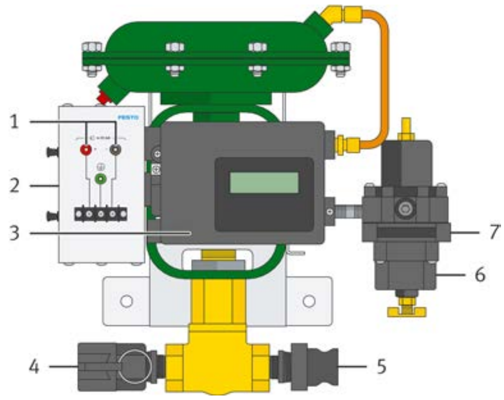


Figure 21: Control valve with a digital valve controller (DVC2000), model 46950-0.

1. **4-20 mA connectors:** The control signal is picked up at these connectors. A minimum of 4 mA is required to power the DVC. This valve can use HART communication.

2. **Fault switch:** There is one available fault switch that can be activated by the instructor to insert an electrical fault. The fault is activated when the switch is in the on position (I). Ensure that the fault is in the off position (O) if you are not performing a troubleshooting exercise.

3. **DVC2000:** The DVC2000 is a digital valve controller. It is the digital equivalent of a pneumatic positioner and can be programmed either manually or via the HART protocol. It is linked to a feedback plate attached on the valve stem. The control keys can be accessed by removing the protective cover.

4. **Outlet:** Fluid must exit from the female fitting (the valve is directional).

5. **Inlet:** Fluid must enter from the male fitting (the valve is directional).

6. **Regulator:** The regulator cleans up the air supplied to the valve with its filters and ensures that a continuous air pressure is fed to the DVC air supply input.

7. **Actuator pressurized air inlet:** The pneumatic signal from the pneumatic panel is picked up at this inlet. A pressure of 175 kPa (25 psi) is recommended.

⚠ CAUTION

A pressure supply of 175 kPa (25 psi) is sufficient. The regulator and the DVC can withstand higher pressures (up to 690 kPa (100 psi) for the DVC), but the actuator of the valve requires a mere 90 kPa (13 psi) to close and will be damaged by pressure above 240 kPa (35 psi).

Below is a summary of the main characteristics of the control valve and of its controller:

Table 8: Control valve.

Actuator	normally open (air-to-close), spring-and-diaphragm
Valve size	13 mm (0.5 in)
C_v **(fully open)**	6
Actuator pressure range	20-90 kPa (3-13 psi)
Maximum pressure at actuator inlet	240 kPa (35 psi)

Table 9: DVC2000.

Current input range	4-20 mA
Pressure output range	0-140 kPa (0-20 psi)
Maximum pressure at inlet	690 kPa (100 psi)

Digital valve controller (DVC2000)

This control valve is equipped with a digital valve controller. A digital valve controller is a microprocessor-based current-to-pressure valve positioner designed to replace mechanical and pneumatic devices. Its digital nature permits the accurate positioning of the actuator stem and offers many settings as well as the possibility of communicating directly with the controller via the HART protocol.

The following subsections explain how to calibrate and change the options of the DVC2000. Before using the valve, always perform the following steps:

1. Secure the valve on a strut of the workstation with spring nuts and bolts. Connect the pressurized air supply (170 kPa (25 psi)) to the control valve and turn the pneumatic panel on. It is not required to connect the valve to a process for the calibration. Do not activate the pump during this procedure.

2. Remove the protective cover to gain access to the control keys.

3. Connect a calibrator to the control valve. Sending an output of 4 mA powers the valve and the LCD shows its main display.

   Assuming the valve is calibrated as required, you can use a 4-20 mA signal to control its opening.

Changing the language of operation

1. From the main display, press and hold all four arrow keys for three seconds.

2. You will be prompted upon release of the arrow keys to choose the language you wish to use. Scroll the list of languages with the up and down arrows and press the right arrow to select the highlighted one.

Performing a quick setup

The quick setup option performs a calibration and a tuning of the instrument automatically. It usually does a satisfactory job. It is, however, possible to perform either a calibration of the travel of the valve or a tuning of the controller response separately (see below). To perform a quick setup:

1. From the main display, press the down arrow once to highlight the quick setup option. Press the right arrow.

2. The DVC will issue a warning reminding you that the valve will move during this procedure. If it is safe to perform this procedure at this point (i.e., the process is not running), press and hold the right arrow for three seconds. (Press the left arrow to go back to the menu).

3. The valve will automatically perform the setup (this should last about 2 minutes). You can press both the left and right arrows for three seconds if you wish to stop this procedure.

   Once completed, the controller will prompt you to press the right arrow, which will bring you back to the main display.

The control valve should now be correctly configured.

Travel calibration

You can use this procedure if you want to calibrate the instrument without changing the tuning values. This can be done either manually or automatically.

1. From the main display, press the down arrow key twice to highlight the travel calibration option. Press the right arrow.

2. The DVC will prompt you to select either automatic or manual (using the up and down arrows). Make your selection and press the right arrow.

3. The DVC will issue a warning reminding you that the valve will move during this procedure. If it is safe to perform this procedure at this point (i.e., the process is not running), press and hold the right arrow for three seconds. (Press the left arrow to go back to the menu).

4. If you choose the automatic mode, the controller will automatically perform the necessary adjustments. This lasts about two minutes. A message will tell whether the procedure has succeeded or failed.

   If you choose the manual mode, you will be asked to send a 4 mA current to make the valve travel to its fully open position. Press the right arrow key. You will be asked next to move the valve to its fully closed position by sending a 20 mA current. Press the right arrow key once the valve has settled in its fully closed position. The DVC will then finish the procedure (this may last a minute or two). You will be prompted to save and exit or to exit without saving. Highlight your choice (up and down arrow keys) and press the right arrow key.

The calibration of the travel of the stem is now completed.

Tuning the digital valve controller

Using this procedure allows you to change the response of the controller without changing the calibration. This can be done either manually or automatically.

1. From the main display, press the down arrow key three times to highlight the tuning option. Press the right arrow.

2. The DVC will prompt you to select either automatic or manual (using the up and down arrows). Make your selection and press the right arrow.

3. The DVC will issue a warning reminding you that the valve will move during this procedure. If it is safe to perform this procedure at this point (i.e., the process is not running), press and hold the right arrow for three seconds. (Press the left arrow to go back to the menu).

4. If you choose the automatic mode, the controller will automatically perform the necessary adjustments. This lasts about two minutes. A message will tell whether the procedure has succeeded or failed.

If you choose the manual mode, you will be prompted to select one of eleven tuning sets. Each tuning set provides specific gain settings for the valve. They range from set C (the slowest) to set M (the fastest). It is normally recommended to start from C and to increase as required. A tuning set becomes activated as soon as it is displayed in the menu (using the up and down arrows). Test the tuning by changing the 4-20 mA signal sent to the valve. Press the right arrow to confirm your choice.

Select the amount of damping you wish to use. Pressing the up or down arrow keys applies more or less damping. Press the right arrow to confirm your choice. You will then be prompted to save and exit or to exit without saving. Highlight your choice (up and down arrow keys) and press the right arrow key.

The tuning of the valve controller is now completed.

Detailed setup

This procedure allows you to change a number of important characteristics such as the pressure units, the default state of the valve, the input range and the characteristic.

1. From the main display, press the down arrow key four times to highlight the detailed setup option. Press the right arrow.

2. The DVC will prompt you to select the Zero Control Signal parameter. This parameter is used to specify whether the valve is fully open or fully closed when the input is 0%. You can choose either open or close (using the up and down arrows) – the default value for this valve is open. Make your selection and press the right arrow.

3. The DVC then asks you to select the Pressure Units it will display. Choose either bar, psi, or kPa (using the up and down arrows). Make your selection and press the right arrow.

4. The DVC then asks you to specify the Input Range Low parameter. This is the current value which corresponds to the minimum displacement (the default is 4 mA). Make your selection (using the up and down arrows) and press the right arrow.

5. You are next prompted to specify the Input Range High parameter. This is the current value which corresponds to the maximum displacement (the default is 20 mA). Make your selection (using the up and down arrows) and press the right arrow.

6. The next parameter to specify is the Characteristic parameter. This specifies the relationship between the travel of the stem and the 4-20 mA signal sent to the controller. Make your selection from the available options: Quick Open, Linear, Equal %, or Custom (using the up and down arrows) and press the right arrow. The default value is Linear.

   Note that the Custom function requires a HART based connection to be reconfigured.

7. You will then be prompted to save and exit or to exit without saving. Highlight your choice (up and down arrow keys) and press the right arrow key.

   If you save, the DVC will issue a warning reminding you that the valve may move during this procedure. If it is safe to perform this procedure at this point (i.e., the process is not running), press and hold the right arrow for three seconds.

Analog input calibration

This procedure allows you to calibrate the current measurement of the controller with a precise calibrator. This procedure is performed on your valve before delivery and should not require any adjustments. In case it becomes necessary to perform a recalibration, follow the steps below:

1. From the main display, press the down arrow key five times to highlight the detailed setup option. Press the right arrow.

2. The DVC will issue a warning reminding you that the valve will move during this procedure. If it is safe to perform this procedure at this point (i.e., the process is not running), press and hold the right arrow for three seconds. (Press the left arrow to go back to the menu).

3. Apply a precise 4 mA signal. Press the right arrow.

   Apply a precise 20 mA signal. Press the right arrow.

4. You will then be prompted to save and exit or to exit without saving. Highlight your choice (up and down arrow keys) and press the right arrow key.

This concludes the analog input calibration procedure.

Reversing the action of the control valve (using the HART protocol)

The DVC2000 offers the possibility of using the HART communication protocol to gain access to all the parameters of the DVC, including many advanced ones not accessible manually. One of the most interesting features made available by the HART protocol is the possibility of reversing the action of the valve. This is done entirely by the controller and makes the valve operate as an air-to-open one (e.g., fully closed for a 4 mA signal and fully open for a 20 mA signal). Of course, the valve opens completely if the controller becomes unpowered at any time.

The following procedure assumes you are familiar with the HART protocol and with the Fieldcare software. Refer to the manual entitled HART Device Configuration, (P/N 86050), for details.

1. Connect the DVC2000 on a current loop with a 4-20 mA source and the Commubox. Connect the Commubox to a PC and launch the Fieldcare software. Take the necessary steps to communicate with the DVC2000

2. It is mandatory to put the valve in the "Out of Service" mode before attempting to change any parameter. This can be done by accessing the Instrument Mode menu. This menu can be found by following this path: Online -> Setup & Diag. -> Basic Setup -> Manual Setup -> Instrument Mode. Click on the button and choose "Out of Service".

3. You can now go to the following menu: Online -> Setup & Diag. -> Detailed Setup -> Measured Var. to change the Input Range Hi and the Input Range Lo parameters. The trick to setting the valve in reverse action is to set the Input Range Hi parameter to a value smaller than the Input Range Lo parameter.

To invert the action of the valve you can set the parameters (Input Range Hi: 4 mA and Input Range Lo: 20 mA). Note that the default values for normal valve action are:

Input Range Hi: 20 mA

Input Range Lo: 4 mA

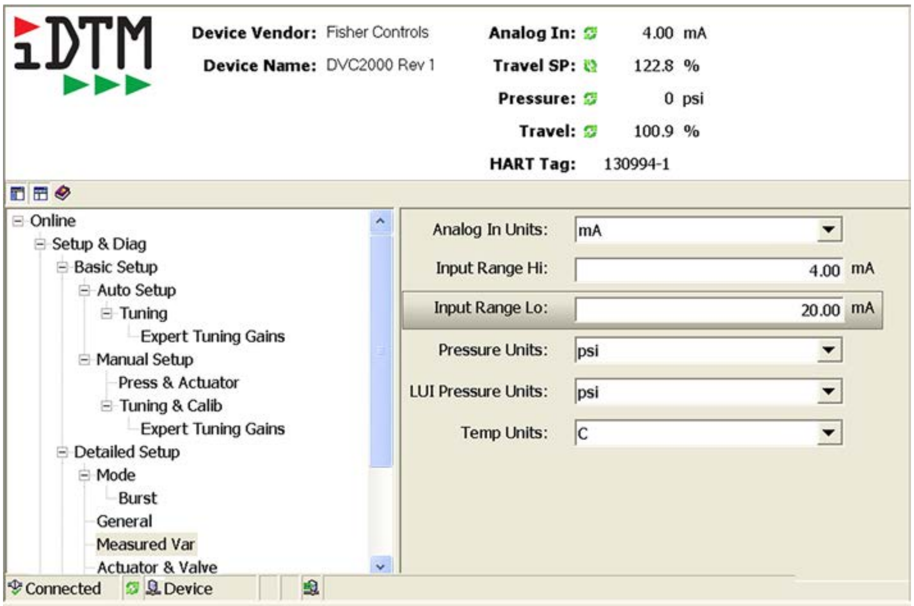


Figure 22: Configuring the DVC2000 to reverse the action of the valve.

4. Make sure the Control Mode parameter is set to Analog. This parameter can be found in this menu: Online -> Setup & Diag. -> Detailed Setup -> Mode.

5. Put the valve back in the "In Service" mode by accessing the Instrument Mode menu. This menu can be found by following this path: Online -> Setup & Diag. -> Basic Setup -> Manual Setup -> Instrument Mode. Click on the button and choose "In Service".

   The valve is now inverted.

Control Valve with DVC6000 – HART/FF (46950-E/-D)

Description of the control valve

The control valve with a digital valve controller (DVC6000), model 46950-D or -E, is a pneumatically operated control valve of the globe type equipped with a spring-and-diaphragm actuator. The valve itself is identical to the basic control valve presented in Learning Unit 1, but also includes a digital controller and a pressure regulator.

Note that the FOUNDATION Fieldbus version, while almost identical to the HART version, requires some knowledge of the FOUNDATION Fieldbus communication protocol to be able to use it. Refer to this section for a basic description of the valve and to manuals 86002 and 86003-E0 for more information on the Fieldbus protocol.

Construction details of the control valve with a DVC6000 are shown below:

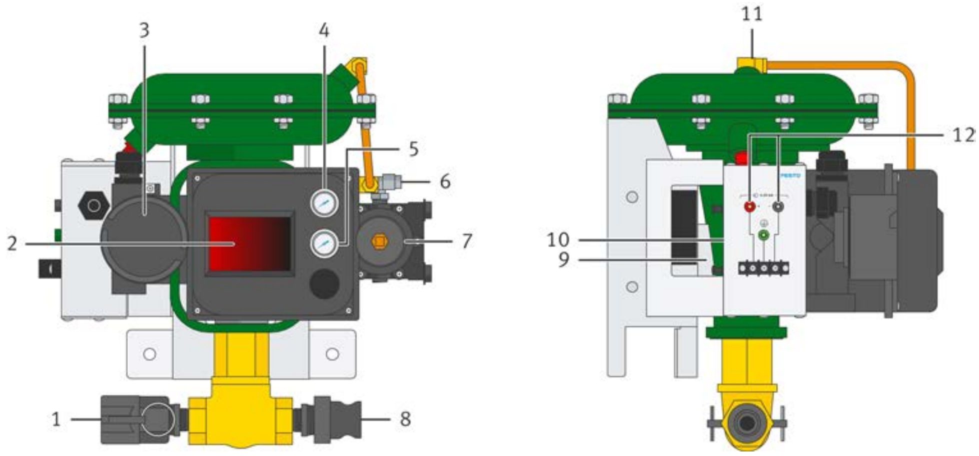


Figure 23: Control valve with a digital valve controller (DVC6000), model 46950-E.

1. **Outlet:** Fluid must exit from the female fitting (the valve is directional).

2. **DVC6010:** The DVC6010 is a digital valve controller of the DVC6000 family designed for sliding-stem valves. It is the digital equivalent of a pneumatic positioner and can be programmed via the HART protocol. A DVC is linked to a feedback plate attached to the valve stem and is thus able to track the opening of the control valve.

3. **Terminal box:** The terminal box contains the electrical terminals for the power input to the DVC (Loop +/-). There is also an auxiliary loop (Aux. +/-) which is used to disengage the Protection mode.

4. **Upper gauge:** Measures the output pressure sent to the valve actuator.

5. **Lower gauge:** Measures the pressure supplied to the DVC out of the pressure regulator.

6. **Pressurized air supply inlet:** The pneumatic signal from the pneumatic panel is picked up at this inlet. A pressure of 175 kPa (25 psi) is recommended.

	⚠ CAUTION
	A pressure supply of 175 kPa (25 psi) is sufficient. The regulator and the DVC can withstand higher pressures (up to 1000 kPa (145 psi) for the DVC6010), but the actuator of the valve requires a mere 69 kPa (10 psi) to close and will be damaged by pressure above 240 kPa (35 psi).

7. **Regulator:** The regulator cleans up the air supplied to the valve with its filters and ensures that a continuous air pressure is fed to the DVC air supply input.

8. **Inlet:** Fluid must enter from the male fitting (the valve is directional).

9. **Graduated scale:** A graduated scale can be seen through the view window and is used as an indicator of the opening of the valve.

10. **Fault switch:** There is one available fault switch that can be activated by the instructor to insert an electrical fault. The fault is activated when the switch is in the on position (I). Ensure that the fault is in the off position (O) if you are not performing a troubleshooting exercise.

11. **Actuator air inlet:** The pressurized air signal from the DVC6000 output comes into the actuator from this port.

12. **4-20 mA connectors:** The control signal is picked up at these connectors.

    HART version: The unit is powered and controlled through a 4-20 mA current loop and features the required + and - connectors. A minimum of 4 mA is required to power the DVC.

    FOUNDATION Fieldbus version: The unit red and black jacks must be connected to corresponding H1 segment jacks on the FF bridge. The H1 cable pair supplies 24 V dc and permits digital data transfer with the control valve.

Below is a summary of the main characteristics of the control valve and of its controller.

Table 10: Control valve.

Valve type	globe type plug valve, equal percentage
Actuator	normally open (air-to-close), spring-and-diaphragm
Valve size	13 mm (0.5 in)
C_v **(fully open)**	6
Actuator pressure range	20-69 kPa (3-10 psi)
Maximum pressure at actuator inlet	240 kPa (35 psi)

Table 11: DVC6010.

Current input range	4-20 mA
Pressure output range	0-69 kPa (0-10 psi)
Maximum pressure at inlet	1000 kPa (145 psi)

Digital valve controller (DVC6000)

This control valve is equipped with a digital valve controller. A digital valve controller is a microprocessor-based current-to-pressure valve positioner designed to replace mechanical and pneumatic devices. Its digital nature permits the accurate positioning of the actuator stem and offers access to a large number of settings as well as the possibility of communicating directly with the controller via a communication protocol such as HART (the FOUNDATION Fieldbus protocol is supported with model 46950-D).

The following paragraphs explain how to calibrate and change the relevant options of the DVC6000. The procedures assume you are familiar with the HART protocol used in conjunction with the Fieldcare software. Refer to the appropriate manual for details (titled HART Device Configuration, P/N 86050).

Always perform the following steps when using the valve:

1. Secure the valve on a strut of the workstation with spring nuts and bolts. Connect the pressurized air supply (170 kPa (25 psi)) to the control valve and turn the pneumatic panel on. It is not necessary to connect the valve to a process for the calibration.

2. Connect the DVC6000 to a current loop with a 4-20 mA source and send a 4-20 mA signal to power the DVC6000.

Assuming the valve is calibrated as required, you can use a 4-20 mA signal to control its opening.

Using a communication protocol and putting the valve out of service

The DVC must take advantage of a communication protocol to modify any of its parameters. It is also necessary to put the valve in the "Out of Service" mode before any change can be made to the settings of the valve. Note that the valve must be returned to its "In Service" mode before normal control operations can resume. This procedure is explained in the following steps.

1. Connect the DVC6000 to a current loop with a 4-20 mA source which also includes the HART Commubox if your valve is HART compliant. If your valve works with the FOUNDATION Fieldbus protocol, make sure to connect the valve correctly to the Fieldbus Bridge.

   Connect the communication device to a PC and launch the Fieldcare software. Take the necessary steps to communicate with the DVC6000.

2. It is mandatory to put the valve in the "Out of Service" mode before attempting to change any parameter. This can be done by accessing the Instrument Mode menu. This menu can be found by following this path: Online -> Configure/Setup -> Detailed Setup -> Mode and Protection -> Instrument Mode. Click on the button and choose "Out of Service".

3. You can now change the different parameters of the DVC6000. Consult one of the procedures written below to perform a specific change or simply explore the different menus and parameters of the controller.

4. Once you are done making changes, put the valve back in the "In Service" mode by accessing the Instrument Mode menu. This menu can be found by following this path: Online -> Configure/Setup -> Detailed Setup -> Mode and Protection -> Instrument Mode. Click on the button and choose "In Service".

   The changes made will now be taken into account by the DVC6000.

Using the Setup Wizard

The setup wizard can be used anytime to restore the parameters to their original values. The wizard will guide you through a series of questions to adjust the parameters of the DVC.

1. Click on the Setup Wizard button from Online -> Configure/Setup -> Basic Setup to launch the wizard. A window will appear, reminding you to put the valve out of service in order to make changes to the configuration. Acquiesce to this request if your valve is not already out of service.

2. The wizard will ask you a series of questions. It may ask you (after a reset for instance) what type of control you want to use (answer Analog if the question arises). Here is a list of answers to the questions of the setup wizard:

   The wizard will inform you that the configuration is ready to be sent. Choose Send or Review if you wish to examine the configuration (Once done, send the configuration to the DVC or edit your answers).

Table 12: Recommended setup wizard answers.

Wizard's question	Recommended answer
Tvl/Press Select?	Travel Control
Pressure Units?	Your choice of kPa, psi, or bar
Maximum Supply Pressure?	138 kPa (20 psi) – This is the pressure out of the regulator
Actuator Manufacturer?	Baumann
Actuator Model?	Air to extend
Actuator Size?	32
Is a Volume Booster or Quick Release present?	No

3. The wizard asks you next whether you would like to use a plethora of factory default parameters for the DVC. It is recommended that you select Yes. You may wish to inspect the different parameters by choosing Review (You can then decide if you accept or wish to edit them).

   The Setup Wizard has then completed its task. Click on Ok.

4. You will next be informed that the Auto Tvl Calib procedure should be run to complete the setup. Click on Ok, then choose Yes.

   You will be asked to set the Crossover Adjust parameter. Choose Default.

   The valve stem must be moved to set the Pressure Range Hi and Lo parameters. Signify your agreement to the wizard and wait while the valve automatically moves its stem and calibrates itself.

5. The setup is now completed. Remember to set the valve back in the "**In Service**" mode if you do not plan to change more parameters at this point.

Tuning the response of the controller

The response of the DVC can be adjusted to optimize the behavior of the control valve. You must choose between control of either travel or pressure.

1. Put the valve in the "**Out of Service**" mode.

2. Go in the Tvl/Press Control menu and choose either Travel Control or Pressure Control. This menu can be found by following this path: Online -> Configure/Setup -> Detailed Setup -> Response Control -> Tvl/Press Control.

- If you chose Travel Control, go in the Travel Limits submenu and verify that both the Tvl Limit Hi and Tvl Limit Lo are set to 125% and -25%, respectively. This deactivates the travel limits. Go in the Tvl/Press Cutoffs submenu and set the Tvl/Press Cut Hi and the Tvl/Press Cut Lo parameters to 99.5% and 0.5%.

- If you chose Pressure Control, go in the Pressure Control submenu and verify that both the Press Range Lo and Press Range Hi are set to the appropriate bench rate, i.e., 20-69 kPa (3-10 psi). Go in the Tvl/Press Cutoffs submenu and set the Tvl/Press Cut Hi and the Tvl/Press Cut Lo parameters to 99.5% and 0.5%.

3. Go to the menu corresponding to the type of control you chose in the previous step (Travel or Pressure): Online -> Configure/Setup -> Detailed Setup -> Response Control -> Tuning-> Travel or Pressure Tuning.

   From there you can set the tuning parameter used by the DVC to control either the travel or the pressure. Choose a letter from B (C in the case of travel) to M (where B is the slowest setting and M the fastest).

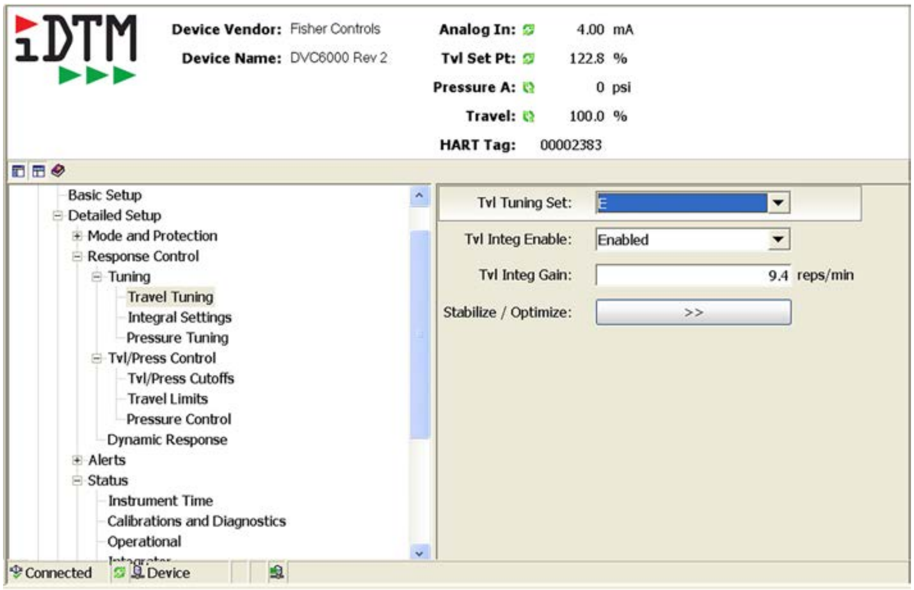


Figure 24: Tuning of the Travel control on a DVC6000.

You can also specify if integral gain is used as well as the value of that gain.

4. Put the valve back in the "In Service" mode.

   A series of more advanced tuning options are available with a DVC6000. Consult the manufacturer's documentation for all the details.

Inverting the action of the valve

The action of the control valve can be inverted with the assistance of the DVC by changing the appropriate parameters. The inversion is done entirely by the controller and makes the valve operate as an air-to-open one (e.g., fully closed for a 4 mA signal and fully open for a 20 mA signal). Of course, the valve opens completely if the controller becomes unpowered at any time.

1. Put the valve in the "Out of Service" mode if necessary.

2. You can now go to the following menu: Online -> Configure/Setup -> Detailed Setup -> Instrument -> Analog Input Range to change the Input Range Hi and the Input Range Lo parameters. The trick to setting the valve in reverse action is to set the Input Range Hi parameter to a value smaller than the Input Range Lo parameter.

   To invert the action of the valve, you can set the parameters as shown in the following figure (Input Range Hi: 4 mA and Input Range Lo: 20 mA). Note that the default values for normal valve action are:

   Input Range Hi: 20 mA

   Input Range Lo: 4 mA

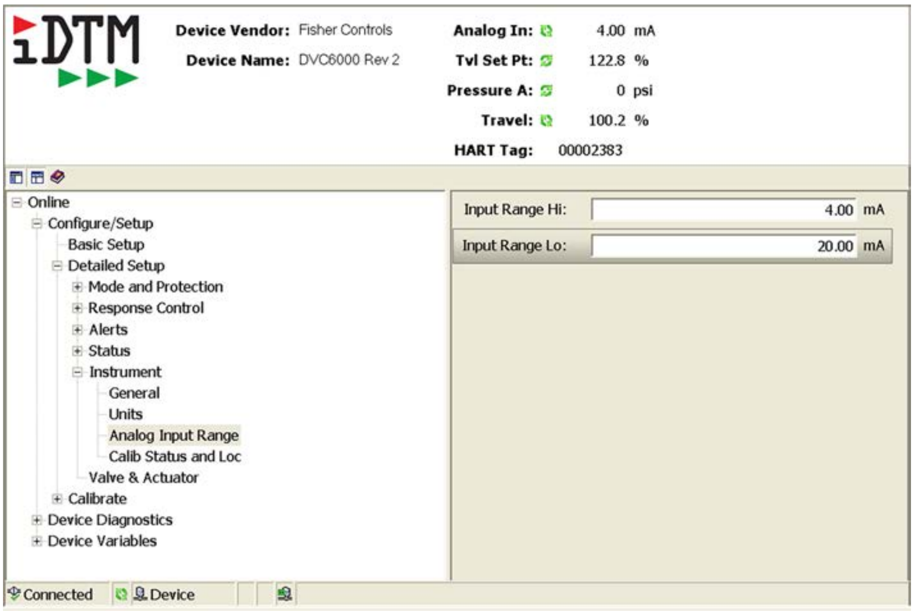


Figure 25: Configuring the DVC6000 to reverse the action of the valve.

3. Make sure the Control Mode parameter is set to Analog. This parameter can be found in this menu: Online -> Configure/Setup-> Detailed Setup -> Mode and Protection -> Control Mode.

4. Put the valve back in the "**In Service**" mode.

   The valve is now inverted.

Protection mode of the DVC

The DVC has a mode which can be activated to prevent changes to the parameters of the DVC. This can be quite useful in an industrial context to prevent tampering, but it is not so appropriate when the configuration needs to be modified often. It is also worthwhile to know that while the protection mode is easily engaged, it requires connecting a jumper in the terminal box to disengage.

To engage the protection mode, access the Protection menu by following this path: Online -> Configure/Setup -> Detailed Setup -> Mode and Protection -> Protection. Click on the button, follow the instructions, and choose "Config. & Calib.". The protection mode is now engaged.

To disengage the protection mode, click on the same button, but choose None. You will then need to remove the cover of the terminal box to access the auxiliary loop jacks. Turn the cover counterclockwise to remove it. The dialog window will ask you to make sure the auxiliary loop is open (nothing connected to the jacks). Make sure this is the case and click on Ok. You will next be asked to connect a jumper to the auxiliary jacks. Connect the two jacks with a short electrical cable and click on Ok. The final step is to disconnect the jumper and to click on Ok. The protection mode will then be deactivated.

Control Valve with DVC6200 – HART/FF (46950-E/-D)

Description of the control valve

The control valve with a digital valve controller (DVC6200), model 46950 D or E, is a pneumatically operated control valve of the globe type equipped with a spring-and-diaphragm actuator. The valve itself is identical to the basic control valve presented in Learning Unit 1, but also includes a digital controller and a pressure regulator.

Note that the FOUNDATION Fieldbus version, while almost identical to the HART version, requires some knowledge of the FOUNDATION Fieldbus communication protocol to be able to use it. Refer to this section for a basic description of the valve and to manuals 86002 and 86003-E0 for more information on the Fieldbus protocol.

Construction details of the control valve with a DVC6200 are shown below:

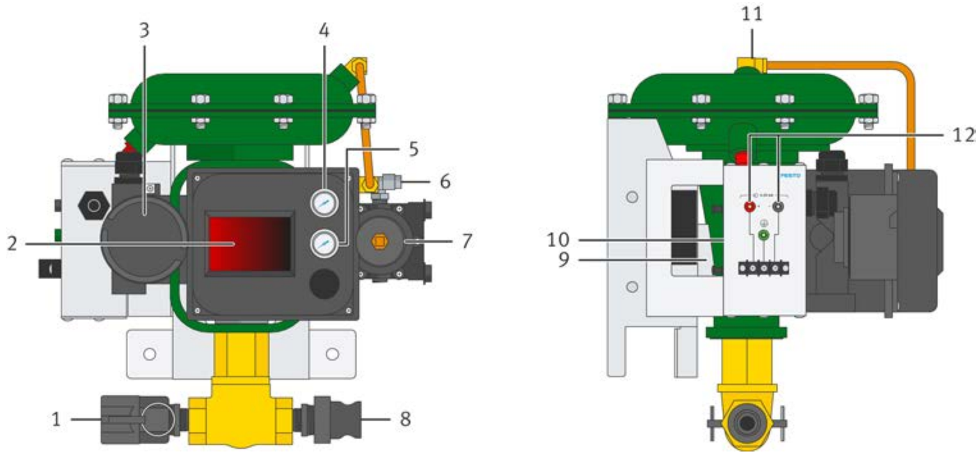


Figure 26: Control valve with a digital valve controller (DVC6200), model 46950-E.

1. **Outlet:** Fluid must exit from the female fitting (the valve is directional).

2. **DVC6200:** The DVC6200 is a digital valve controller designed for sliding-stem valves. It is the digital equivalent of a pneumatic positioner and can be programmed via the HART protocol. The DVC6200 utilizes a magnetic assembly for linkage-less, non-contacting position measurement and is thus able to track the opening of the control valve.

3. **Terminal box:** The terminal box contains the electrical terminals for the power input to the DVC (Loop +/-). There is also an auxiliary loop (Aux. +/-) which is used to disengage the Protection mode.

4. **Upper gauge:** Measures the output pressure sent to the valve actuator.

5. **Lower gauge:** Measures the pressure supplied to the DVC out of the pressure regulator.

6. **Pressurized air supply inlet:** The pneumatic signal from the pneumatic panel is picked up at this inlet. A pressure of 175 kPa (25 psi) is recommended.

> ⚠ **CAUTION**
>
> A pressure supply of 175 kPa (25 psi) is sufficient. The regulator and the DVC can withstand higher pressures (up to 1000 kPa (145 psi) for the DVC6200), but the actuator of the valve requires a mere 69 kPa (10 psi) to close and will be damaged by pressure above 240 kPa (35 psi).

7. **Regulator:** The regulator cleans up the air supplied to the valve with its filters and ensures that a continuous air pressure is fed to the DVC air supply input.

8. **Inlet:** Fluid must enter from the male fitting (the valve is directional).

9. **Graduated scale:** A graduated scale can be seen through the view window and is used as an indicator of the opening of the valve.

10. **Fault switch:** There is one available fault switch that can be activated by the instructor to insert an electrical fault. The fault is activated when the switch is in the on position (I). Ensure that the fault is in the off position (O) if you are not performing a troubleshooting exercise.

11. **Actuator air inlet:** The pressurized air signal from the DVC6200 output comes into the actuator from this port.

12. **4-20 mA connectors:** The control signal is picked up at these connectors.

    HART version: The unit is powered and controlled through a 4-20 mA current loop and features the required + and - connectors. A minimum of 4 mA is required to power the DVC.

    FOUNDATION Fieldbus version: The unit red and black jacks must be connected to corresponding H1 segment jacks on the FF bridge. The H1 cable pair supplies 24 V dc and permits digital data transfer with the control valve.

Here is a summary of the main characteristics of the control valve and of its controller:

Table 13: Control valve.

Valve type	globe type plug valve, equal percentage
Actuator	normally open (air-to-close), spring-and-diaphragm
Valve size	13 mm (0.5 in)
C_v **(fully open)**	6
Actuator pressure range	20-69 kPa (3-10 psi)
Maximum pressure at actuator inlet	240 kPa (35 psi)

Table 14: DVC6200.

Current input range	4-20 mA
Pressure output range	0-69 kPa (0-10 psi)
Maximum pressure at inlet	1000 kPa (145 psi)

Digital valve controller (DVC6200)

This control valve is equipped with a digital valve controller. A digital valve controller is a microprocessor-based current-to-pressure valve positioner designed to replace mechanical and pneumatic devices. Its digital nature permits the accurate positioning of the actuator stem and offers access to many settings as well as the possibility of communicating directly with the controller via a communication protocol such as HART (the FOUNDATION Fieldbus protocol is supported with model 46950-D).

The following paragraphs explain how to calibrate and change the relevant options of the DVC6200. The procedures assume you are familiar with the HART protocol used in conjunction with the Fieldcare software. Refer to the appropriate manual for details (titled HART Device Configuration, P/N 86050).

Always perform the following steps when using the valve:

1. Secure the valve on a strut of the workstation with spring nuts and bolts. Connect the pressurized air supply (170 kPa (25 psi)) to the control valve and turn the pneumatic panel on. It is not necessary to connect the valve to a process for the calibration.

2. Connect the DVC6200 to a current loop with a 4-20 mA source and send a 4-20 mA signal to power the DVC6200.

Assuming the valve is calibrated as required, you can use a 4-20 mA signal to control its opening.

Using a communication protocol and putting the valve out of service

The DVC must take advantage of a communication protocol to modify any of its parameters. It is also necessary to put the valve in the "Not in Service" mode before any change can be made to the settings of the valve. Note that the valve must be returned to its "In Service" mode before normal control operations can resume. This procedure is explained in the following steps.

1. Connect the DVC6200 to a current loop with a 4-20 mA source which also includes the HART Commubox if your valve is HART compliant. If your valve works with the FOUNDATION Fieldbus protocol, make sure to connect the valve correctly to the Fieldbus Bridge.

   Connect the communication device to a PC and launch the Fieldcare software. Take the necessary steps to communicate with the DVC6200.

2. It is mandatory to put the valve in the "Not in Service" mode before attempting to change any parameter. This can be done by accessing the Instrument Mode menu. This menu can be found by following this path: Setup -> Detailed Setup -> Overview -> Overview -> Mode. Click on the button and choose "Not in Service".

3. You can now change the different parameters of the DVC6200. Consult one of the procedures written below to perform a specific change or simply explore the different menus and parameters of the controller.

4. Once you are done making changes, put the valve back in the "In Service" mode by accessing the Instrument Mode menu. This menu can be found by following this path: Setup -> Detailed Setup -> Overview -> Overview -> Mode. Click on the button and choose "In Service".

   The changes made will now be taken into account by the DVC6200.

Using the Setup Wizard

The setup wizard can be used anytime to restore the parameters to their original values. The wizard will guide you through a series of questions to adjust the parameters of the DVC.

1. Click on the Setup Wizard button from Setup -> Basic Setup -> Basic Setup -> Step 1 to launch the wizard. A window will appear, reminding you to put the valve out of service in order to make changes to the configuration. Acquiesce to this request if your valve is not already out of service.

2. The wizard will ask you a series of questions. It may ask you (after a reset for instance) what type of control you want to use (answer Analog if the question arises). Here is a list of answers to the questions of the setup wizard:

   The wizard will inform you that the configuration is ready to be sent. Choose Send or Review if you wish to examine the configuration (Once done, send the configuration to the DVC or edit your answers).

Table 15: Recommended setup wizard answers.

Wizard's question	Recommended answer
Relay Type	A or C
Instrument Family	DVC6200
Tvl/Press Select?	Travel Control
Pressure Units?	Your choice of kPa, psi, or bar
Travel Limit Hi?	138kPa (20 psi) – This is the pressure out of the regulator
Actuator Manufacturer?	Baumann
Actuator Model?	Air to extend
Actuator Size?	32
Is a Volume Booster or Quick Release present?	No

3. The wizard asks you next whether you would like to use a plethora of factory default parameters for the DVC. It is recommended that you select Yes. You may wish to inspect the different parameters by choosing Review (You can then decide if you accept or wish to edit them).

   The Setup Wizard has then completed its task. Click on Ok.

4. You will next be informed that the Auto Tvl Calib procedure should be run to complete the setup. Click on Ok, then choose Yes.

   The valve stem must be moved to set the Pressure Range Hi and Lo parameters. Signify your agreement to the wizard and wait while the valve automatically moves its stem and calibrates itself.

5. The setup is now completed. Remember to set the valve back in the "**In Service**" mode if you do not plan to change more parameters at this point.

Tuning the response of the controller

The response of the DVC can be adjusted to optimize the behavior of the control valve. You must choose between control of either travel or pressure.

1. Put the valve in the "**Not in Service**" mode.

2. Go in the Travel or Pressure Select menu and choose either Travel Control or Pressure Control. This menu can be found by following this path: Setup ->

Detailed Setup -> Response Control -> Travel or Pressure Control -> Travel/ Pressure Select.

- If you chose Travel Control, go in the Travel Control submenu and verify that both the Travel Limit Hi and Travel Limit Lo are set to 125% and -25%, respectively. This deactivates the travel limits. Go in the Tvl/ Press Cutoffs submenu and set the Tvl/Press Cut Hi and the Tvl/Press Cut Lo parameters to 99.5% and 0.5%.

- If you chose Pressure Control, go in the Pressure Control submenu and verify that both the Press Range Lo and Press Range Hi are set to the appropriate bench rate, i.e., 20-69 kPa (3-10 psi). Go in the Travel or Pressure Control submenu and set the Cutoff Hi and the Cutoff Lo parameters to 99.5% and 0.5%.

3. Go to the menu corresponding to the type of control you chose in the previous step (Travel or Pressure): Setup -> Detailed Setup -> Response Control -> Tuning-> Travel or Pressure Tuning.

   From there you can set the tuning parameter used by the DVC to control either the travel or the pressure. Choose a letter from B (C in the case of travel) to M (where B is the slowest setting and M the fastest).

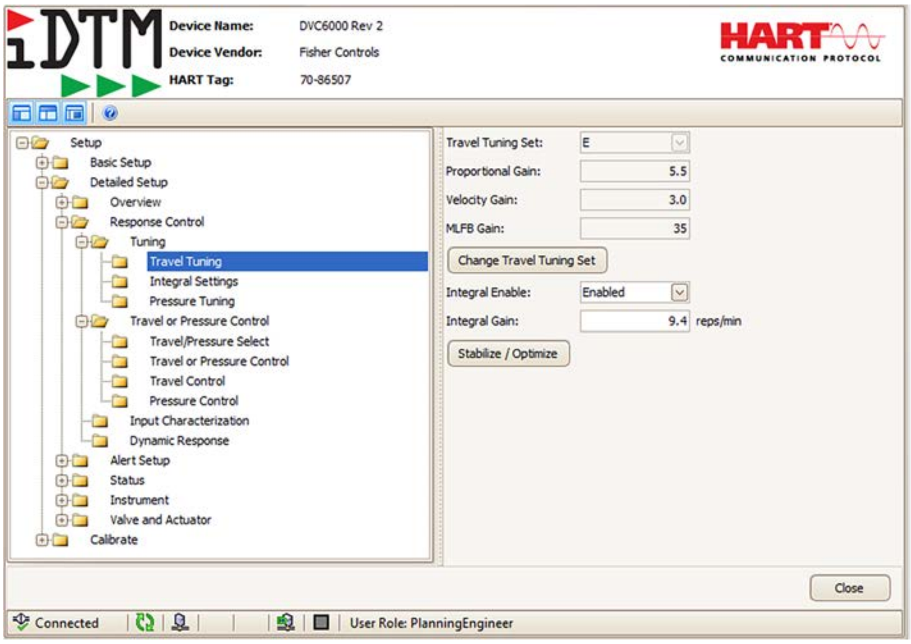


Figure 27: Tuning of the Travel control on a DVC6200.

You can also specify if integral gain is used as well as the value of that gain.

4. Put the valve back in the "**In Service**" mode.

   A series of more advanced tuning options are available with a DVC6200. Consult the manufacturer's documentation for all the details.

Inverting the action of the valve

The action of the control valve can be inverted with the assistance of the DVC by changing the appropriate parameters. The inversion is done entirely by the controller and makes the valve operate as an air-to-open one (e.g., fully closed for a 4 mA signal and fully open for a 20 mA signal). Of course, the valve opens completely if the controller becomes unpowered at any time.

1. Put the valve in the “Not in Service” mode if necessary.

2. You can now go to the following menu: Setup -> Detailed Setup -> Instrument -> Instrument -> Analog Input Range to change the Input Range Hi and the Input Range Lo parameters. The trick to setting the valve in reverse action is to set the Input Range Hi parameter to a value smaller than the Input Range Lo parameter.

   To invert the action of the valve, you can set the parameters (Input Range Hi: 4 mA and Input Range Lo: 20 mA). Note that the default values for normal valve action are:

   Input Range Hi: 20 mA

   Input Range Lo: 4 mA

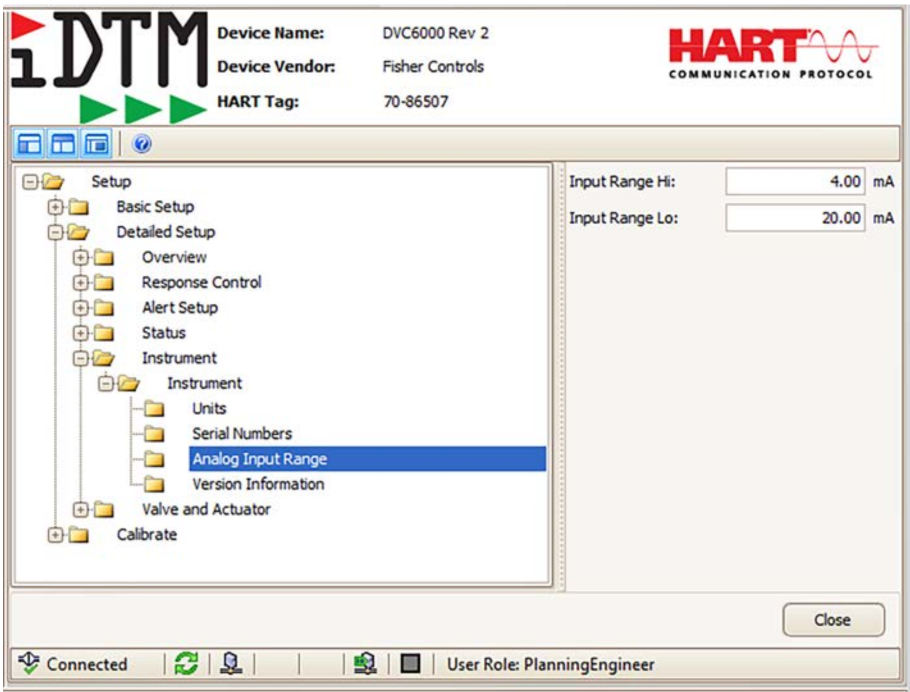


Figure 28: Configuring the DVC6200 to reverse the action of the valve.

3. Make sure the Control Mode parameter is set to Analog. This parameter can be found in this menu: Setup -> Detailed Setup -> Overview -> Overview -> Mode.

4. Put the valve back in the "In Service" mode.

   The valve is now inverted.

Protection mode of the DVC

The DVC has a mode which can be activated to prevent changes to the parameters of the DVC. This can be quite useful in an industrial context to prevent tampering, but it is not so appropriate when the configuration needs to be modified often. It is also worthwhile to know that while the protection mode is easily engaged, it requires connecting a jumper in the terminal box to disengage.

To engage the protection mode, access the Protection menu by following this path: Setup -> Detailed Setup -> Overview -> Overview -> Protection. Click on the button, follow the instructions, and choose "Config. & Calib.". The protection mode is now engaged.

To disengage the protection mode, click on the same button, but choose None. You will then need to remove the cover of the terminal box to access the auxiliary loop jacks. Turn the cover counterclockwise to remove it. The dialog window will ask you to make sure the auxiliary loop is open (nothing connected to the jacks). Make sure this is the case and click on Ok. You will next be asked to connect a jumper to the auxiliary jacks. Connect the two jacks with a short electrical cable and click on Ok. The final step is to disconnect the jumper and to click on Ok. The protection mode will then be deactivated.

Electric Control Valve (46950-C)

Description of the control valve

The electric control valve, model 46950-C, is an electrically operated control valve of the globe type equipped with an electric actuator. The electrical actuator offers a reliable and precise control over the position of the valve stem. Its main drawback is its slower response, especially compared to pneumatic actuators.

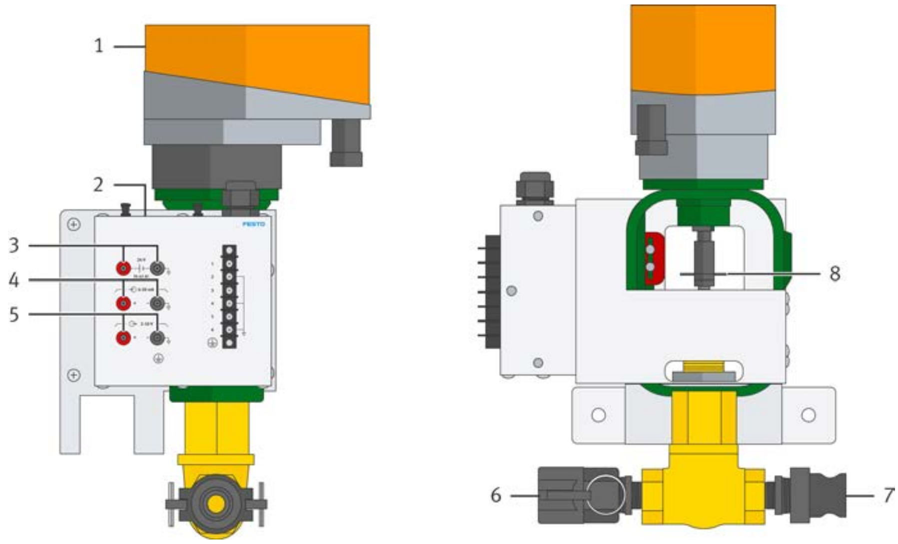


Figure 29: Electric control valve, model 46950-C (old variant).

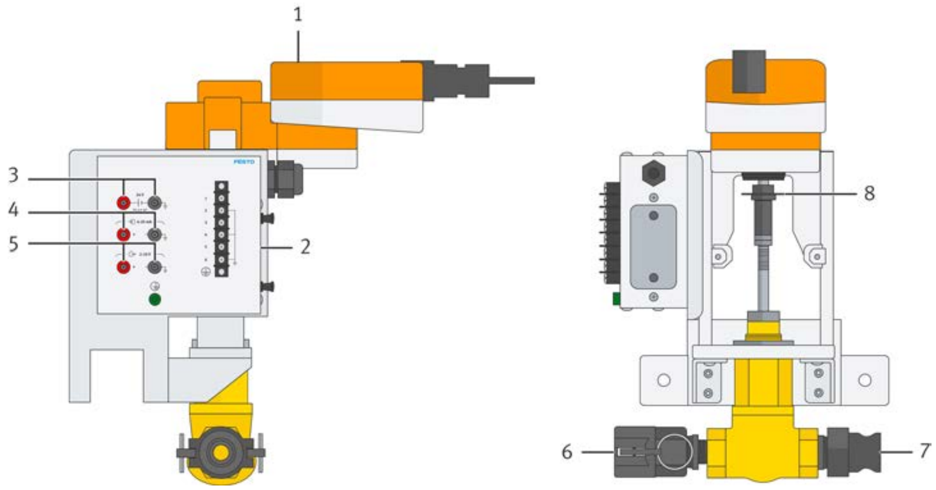


Figure 30: Electric control valve, model 46950-C (new variant).

1. **Electrical actuator:** The electrical actuator (model NVF24-MFT-50) contains an electrical motor which moves the stem up and down according to the control signal received.

   It is normally open and is restored to that state by a spring in case of power failure. A hexagonal key can be used to manually change the position of the stem. The hexagonal socket is located on the top of the electric actuator.

	⚠ CAUTION
⚠	Always disconnect the power from the electrical valve before attempting to manually override the actuator.

2. **Fault switches:** There are two available fault switches that can be activated by the instructor to insert electrical faults. A fault is activated when the switch is in the on position (I). Ensure that the faults are in the off position (O) if you are not performing a troubleshooting exercise.

3. **24 V dc power input connectors:** Power input connectors used to supply electrical power to the motor of the electrical actuator.

4. **4-20 mA control signal connectors:** The control signal is picked up at these connectors. A 4 mA signal results in a completely open valve and a 20 mA signal corresponds to a completely closed one.

5. **2-10 V dc feedback signal output connectors:** Supply a 2-10 V dc signal that is proportional to the position of the stem.

6. **Outlet:** Fluid must exit from the female fitting (the valve is directional).

7. **Inlet:** Fluid must enter from the male fitting (the valve is directional).

8. **Travel indicator and plate:** A plate fixed to the valve stem is used in conjunction with the travel indicator to quickly obtain a visual measure of the current opening of the valve.

Below is a summary of the main characteristics of the control valve and of its actuator:

Table 16: Control valve.

Valve type	Globe type plug valve, equal percentage
Actuator	Electric (Fail-safe open)
Valve size	13 mm (0.5 in)
C_v (fully open)	6

Table 17: Electric actuator.

Current input range	4-20 mA
Full course duration (electrical motor)	75 s (old variant) 35 s (new variant)
Full course duration (fail-safe)	30 s (old variant) 35 s (new variant)

Using the electric control valve

Standard operation

The electric valve is very straightforward to use:

1. Connect the actuator to a 24 V dc power source. This is necessary to power the electric motor which drives the displacement of the stem. Note that if the actuator becomes unpowered at any time, a spring will bring back the valve to its fully open position (unless manually locked).

2. Send a 4-20 mA control signal to the input of the electric actuator. The electrical motor will automatically place the stem at a position proportional to the control signal.

   The total displacement from the fully-open position to the fully-closed one takes a relatively long time. Consequently, the electric valve is not appropriate for fast-changing processes and is much more suited to the ones with long time constants.

Manual operation (old variant only)

Perform the following procedure to manually override the valve:

1. Disconnect the power (24 V dc) from the valve before proceeding further. Having the spring operate while you try to manually control the valve is detrimental to the mechanism of the valve.

2. Insert the 5 mm (3/16 in) hex key in the manual override socket.

3. The mechanism is locked when the manual override socket is lowered (i.e., not level with the orange cover). To unlock the mechanism, turn the hex key counterclockwise for about 1/8 of a turn. Let the socket rise.
You can now turn the hex key in the clockwise direction to close the valve.

4. Letting go of the hex key while the mechanism is unlocked will cause the spring to return to its fully open position. Lock the mechanism to keep it in place.

   To lock the mechanism, turn the key about 3/4 of a turn counterclockwise, press down lightly with the hex key to bring the socket down, then turn lightly in the clockwise direction. The mechanism should now be locked in the desired position.

5. The mechanism unlocks when you restore the 24 V dc power to the valve, except if you locked the valve in the fully open position. In this case, you need to unlock the mechanism yourself (unplug the power supply to the valve first).

Description of the main buttons and switches (new variant only)

The electric actuator of the new variant of the control valve is shown in the following figure, with its main buttons and switches.

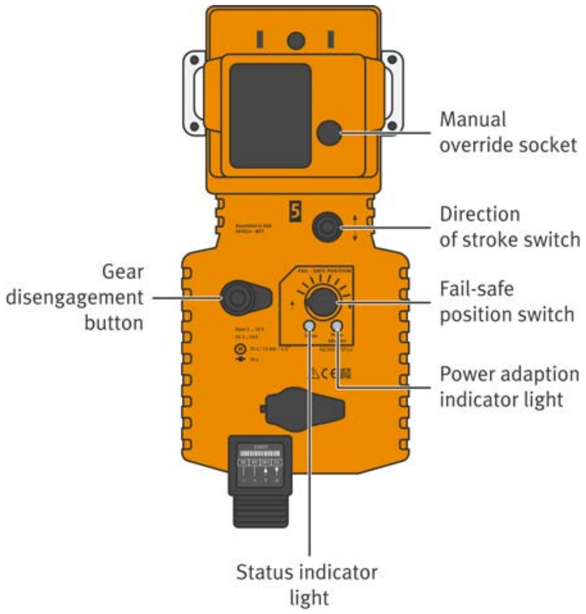


Figure 31: Electric actuator of the new variant of the control valve.

A summary description of the buttons and switches of the electric actuator is given below.

- Gear disengagement button: when this button is pressed, the gear is disengaged and manual operation becomes possible. This button is used for the manual override of the electrical actuator. See the Manual operation (new variant only) section below.
- Manual override socket: used for the manual override of the electrical actuator. See the Manual operation (new variant only) section below.
- Direction of stroke switch: determines the direction of stroke during normal operation. The default position is with the arrow pointing up.
- Fail-safe position switch: determines the position of the valve when the fail-safe activates. The default position is fully open (arrow pointing up).
- Power adaption indicator light: pressing this button for three seconds activates the stroke adaption, in which both mechanical end stops are detected (entire setting range). The indicator light also indicates the actuator status (see status indicator light below).
- Status indicator light: indicates the status of the electric actuator. The different statuses are indicated below.

Table 18: Status of the electric actuator.

Yellow light	Green light	Status
Off	On	Ready for operation
Off	Flashing	Fail-safe activated
On	Off	Capacitor pre-charging, capacitor fault, or writing error in supply
Off	Off	Not in operation
On	On	Adaption process running

Manual operation (new variant only)

Perform the following procedure to manually override the valve:

1. Disconnect the power (24 V dc) from the valve before proceeding further. Having the spring operate while you try to manually control the valve is detrimental to the mechanism of the valve.

2. Insert the 5 mm (3/16 in) hex key in the manual override socket.

3. To unlock the mechanism, press and hold the gear disengagement button.

4. While holding the gear disengagement button pressed, turn the hex key in the clockwise direction to close the valve or in the counterclockwise direction to open it.

5. When the valve is in the desired position, let go of the gear disengagement button.

Default reset (new variant only)

Perform the following procedure to reset the electric actuator to default:

1. Set the direction of stroke switch to the position with the arrow pointing up.

2. Set the fail-safe position switch to the position with the arrow pointing up. This corresponds to the fully open position.

3. Power up the electric actuator using the 24 V power supply. Wait for the stroke adaption process to run its course, if applicable.

4. If not already done, press on the power adaption indicator light for about three seconds, then wait for the stroke adaption process to complete. Both mechanical end stops should be detected (entire setting range).

5. When the yellow indicator light turns off and the green indicator light is on, the electric actuator is ready for operation.

Feedback signal

An output of the actuator provides a feedback signal proportional to the position of the valve stem. The feedback is provided in the form of a 2-10 V dc signal where a value of 2 V means the valve is fully open and a value of 10 V means that it is completely closed.

This feedback can be used to keep track of the stem position from a remote location or to provide information to a controller. Be careful: Many controllers use 4-20 mA inputs, whereas the feedback is a 2-10 V dc signal.

Lists of Faults on the Control Valves

Table 19: List of faults – Control valve with a DVC2000, Model 46950-0.

Fault	Fault description
1	Opens analog input circuit.

Table 20: List of faults – Pneumatic Control Valve with a Positioner, Model 46950-A.

Fault	Fault description
1	Opens analog input circuit.

Table 21: List of faults – Control valve with a DVC6010, Model 46950-D & -E.

Fault	Fault description
1	Opens analog input circuit.

Table 22: List of faults – Basic control valve, Model 46950-B.

Fault	Fault description
1	Opens analog input circuit.

Table 23: List of faults – Electric control valve, Model 46950-C.

Fault	Fault description
1	Opens analog input circuit.
2	Opens the 24 V dc power input circuit.

Note that the faults for the air control valves and the three-way control valves are the same as those listed above. Refer to the list of faults of a standard control valve with a particular accessory for the faults of the air or three-way control valve with that same accessory.

Appendix B

Air Control Valves

A smaller version of the main control valve is available for controlling compressed air on the Instrumentation and Process Control Training System. Although the characteristics of this air control valve differ, it offers many of the same options as the valve presented in this course. This appendix outlines the key features of the valve without repeating the operating instructions, which are similar for both models. Refer to the main sections of this course for instructions on operating a specific digital valve controller or positioner that can be used with your air control valve.

The main difference of the air control valve is its smaller diameter (6.35 mm or 0.25"). Also, since it is designed to control compressed air, the valve is normally closed. Here is a list of the main characteristics of the air control valve:

Table 24: Control valve – main characteristics.

Valve type	globe type plug valve, equal percentage
Actuator	normally closed (air-to-open), spring-and-diaphragm
Valve size	6.35 mm (0.25")
C_v **(fully open)**	0.2
Actuator pressure range	30-90 kPa (4-13 psi)
Maximum pressure at actuator inlet	240 kPa (35 psi)

The basic control valve for air is illustrated below. Please refer to Table 26 for indications on the section to consult for more information regarding the different models.

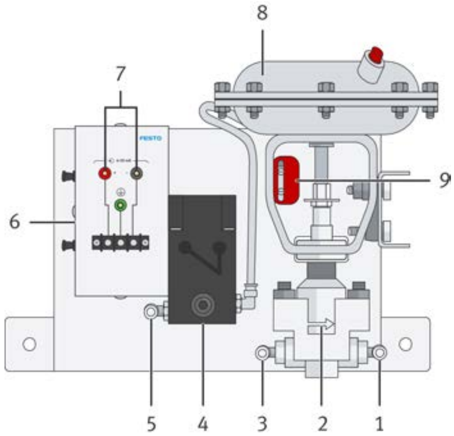


Figure 32: Pneumatic control valve for air, model 46953-0.

1. **Outlet.** Fluid must exit from the proper pressure port (the valve is directional). Refer to the direction arrow. Only pneumatic tubing is to be used with this valve.

2. **Direction arrow.** The arrow indicates the direction of flow of this directional valve.

3. **Inlet.** Fluid must enter from the proper pressure port (the valve is directional). Refer to the direction arrow. Only pneumatic tubing is to be used with this valve.

4. **Current-to-pressure converter (I/P).** Linearly converts the 4-20 mA control signal into a 30-90 kPa (4-13 psi) pneumatic signal.

   The I/P converter must be calibrated from time to time, as indicated in Learning Unit 2.

Table 25: Current-to-pressure converter (I/P).

Current input range	4-20 mA
Pressure output range	20-100 kPa (3-15 psi)
Maximum pressure at inlet	550 kPa (80 psi)
Available pressure adjustments	range and zero

5. **I/P pressurized air inlet.** This port connects to a line of pressurized air coming from the pneumatic unit. A pressure of 170 kPa (25 psi) is quite sufficient and insures suitable operation of the I/P.

⚠ CAUTION

The maximum pressure allowed at this inlet is 550 kPa (80 psi). A pressure exceeding this value could damage the I/P.

A pressure of 170 kPa (25 psi) is recommended.

6. **Fault switch.** There is one available fault switch that can be activated by the instructor to insert an electrical fault. The fault is activated when the switch is in the on position (I). Ensure that the fault is in the off position (O) if you are not performing a troubleshooting exercise.

7. **4-20 mA connectors.** Control signal is picked up at these connectors. When the I/P converter or digital controller is properly calibrated, a 4 mA signal results in a closed valve while a 20 mA signal corresponds to a fully open one.

8. **Actuator.** The actuator contains the mechanism (springs and the diaphragm) required to move the valve stem when pressurized air is applied at its inlet.

⚠ CAUTION

The maximum pressure allowed at the inlet of the actuator is 240 kPa (35 psi). A pressure exceeding this value could damage the actuator.

9. **Graduated scale and indicator plate**

   Graduated scale and indicator plate. The graduated scale and its associated indicator plate can be used as a quick visual reference of the opening of the valve.

Table 26: Correspondence table for the air control valves.

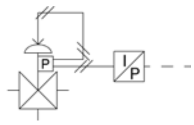
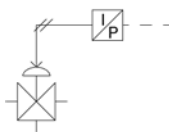
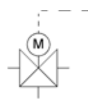
Model	Name	Similar to	Refer to
46953-0	Pneumatic Control Valve for air	46950-B	Learning Unit 2
46953-A	Pneumatic Control Valve for air with a DVC 2000 (HART)	46950-0	Learning Unit 4
46953-B	Pneumatic Control Valve for air with a Positioner	46950-A	Learning Unit 3
46953-C	Pneumatic Control Valve for air with a DVC 6000 (HART)	46950-E	Learning Unit 5
46953-D	Pneumatic Control Valve for air with a DVC 6000 (Fieldbus)	46950-D	Learning Unit 5

Three-Way Control Valves

Three-way control valves contain three ports and are used in many industrial processes to either mix fluids together or to divert a fluid to two different destinations. They can be put to multiple uses in a plant, but such valves are typically used on the Instrumentation and Process Control Training System to regulate the flow of water sent to the heat exchanger when performing temperature experiments.

The characteristics of the three-way control valves are slightly different, but they come with many of the same options as the standard two-port valve presented in this manual. This appendix aims to outline the important features of the three-way valve without repeating the operating instructions which are similar for the two models. Please refer to the main sections of this manual for instructions on the operation of a specific digital valve controller or positioner which could complement your three-way control valve.

Table 27: Instrument symbols for three-way control valves.

 Figure 33: Standard.	 Figure 34: Pneumatic with positioner.
 Figure 35: Pneumatic.	 Figure 36: Electric.

Principle of operation of a three-way control valve

The three-way control valve works on the same basic principle as the two-port valve studied in this manual: A stem is moved up and down by an actuator, thus moving a specially designed two-sided valve plug. The key point is that the valve plug has a direct effect on the flow of one port while it has the inverse effect on the other one. The three ports of the valve are identified by letters. Those letters are: C (Common), U (Upper), and L (Lower).

In (a) of the following figure, we see that when the stem is at its higher position, the plug completely blocks the access to the U port while the C-L path is open. When the stem is lowered to its full extent as in (b), the plug rests on the lower seat and blocks the L port, leaving the C-U path fully open. When the plug is in an intermediate state as in (c), both the C-U and C-L paths are open to different extents.

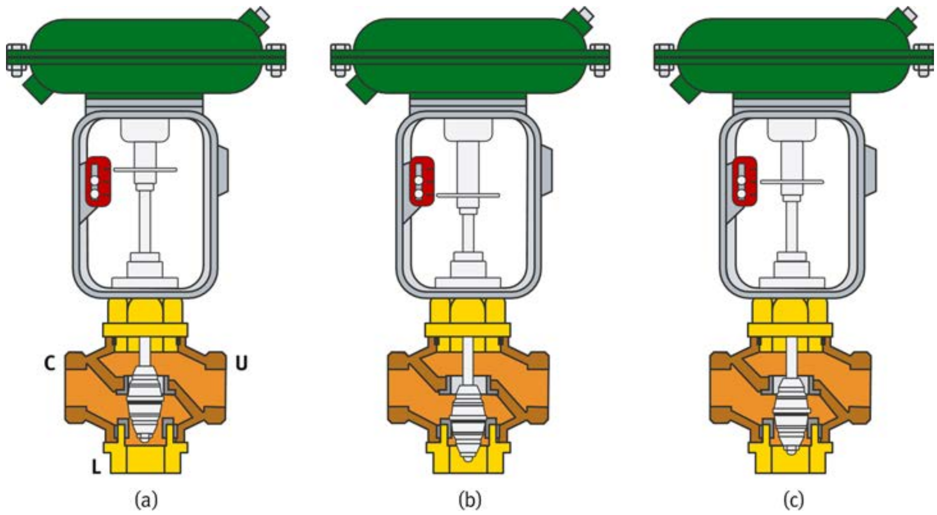


Figure 37: Operation of a three-way control valve.

Modes of operation

A three-way control valve can be used in one of two main modes: diverting or mixing. The construction of three-way valves differs slightly for the two modes. The three-way valve selected for the training system uses the mixing mode.

The **diverting** mode uses the common port (C) as the input and the lower and upper ports as outputs (L and U). The valve is used to control the proportions of the incoming fluid sent to each of the two outputs.

The **mixing** mode uses both the lower and upper ports as inputs (L and U) and the common port (C) as a single output. The valve is used to control the composition of the output fluid by fixing the proportions of the two incoming fluids which are mixed together.

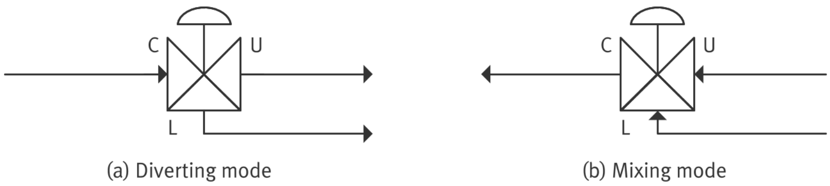


Figure 38: Possible modes of a three-way valve.

The three-way control valve makes the C_v coefficients for the different ports evolve with the travel of the stem as illustrated in the following figure. This figure illustrates the experimental results in the case of the valve used in mixing mode. Observe how the C_v of the U port increases while the coefficient of the L port decreases as the stem moves from 0% of its travel to 100%. The C_v coeffcient of the C port remains the same throughout the course of the stem. This comes from the fact that the fluid exiting the valve at port C is the sum of the fluid entering from ports U and L.

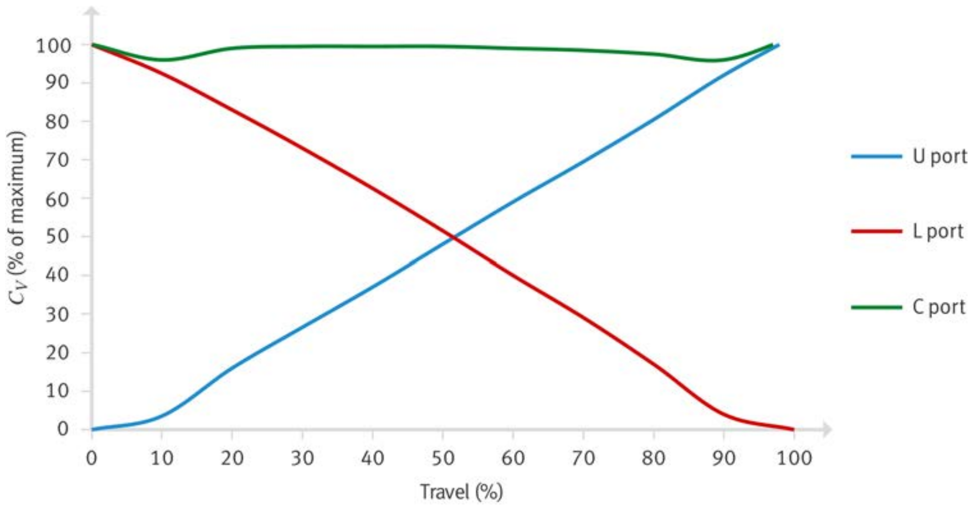


Figure 39: Flow characteristics of the three-way valve (mixing mode).

In the context of temperature experiments, the three-way valve will be used to control the flow of cold water going to the heat exchanger. A simplified setup, shown in the following figure, explains how the hot water is circulated toward the heat exchanger. If the three-way valve is fully closed on L, then the C-U path is fully open and a maximum flow of water goes through the heat exchanger. If the valve is fully open on L, then the C port is closed and all the water flows through the C-L path, completely avoiding the heat exchanger. Note that the heat exchanger is always subject to water pressure (static and/or dynamic) in this type of configuration.

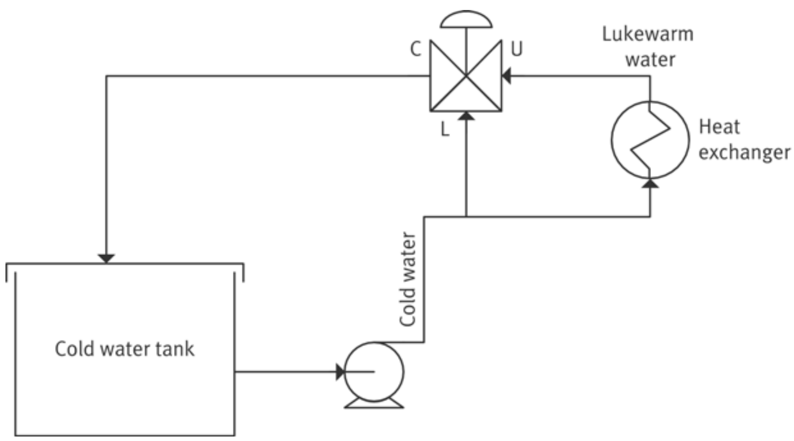


Figure 40: Mixing mode as used in temperature experiments.

Description of the basic three-way control valve

The basic three-way valve is similar in design and construction to the two-way valve. The most notable differences are the use of a double-sided plug and the three ports. The following table lists the main characteristics of the three-way control valve.

The basic three-way control valve is illustrated below. Please refer to Table 30 for indications on the section to refer to for more information regarding the different models.

Table 28: Control valve.

Valve type	Globe-type plug valve,linearMixing type
Actuator	Fail open on port L,spring-and-diaphragm
Valve size	12.7 mm (0.5 in)
C_V (Maximum rated value)	4
Actuator pressure range	34.5-90 kPa (5-13 psi)
Maximum pressure at actuator inlet	240 kPa (35 psi)

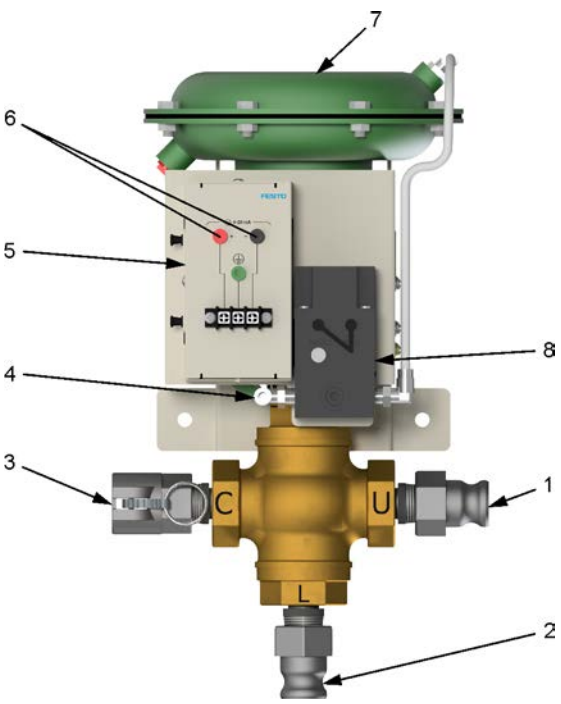


Figure 41: Three-way pneumatic control valve, model 46955-B.

1. **Upper port (U).** This port is one of the two inlet ports of the valve. It is equipped with a male connector.

2. **Lower port (L).** This port is one of the two inlet ports of the valve. It is equipped with a male connector.

3. **Common port (C).** The C port is the outlet of the valve and the port where the flows from ports U and L mix. The sum of the flows at ports U and L is equal to the flow passing by port $C(|Q_U + Q_L| = |Q_C|)$. This port is equipped with a female connector.

4. **I/P pressurized air inlet.** This port connects to a line of pressurized air coming from the pneumatic unit. A pressure of 170 kPa (25 psi) is quite sufficient and insures suitable operation of the I/P.

⚠ CAUTION

The maximum pressure allowed at this inlet is 550 kPa (80 psi). A pressure exceeding this value could damage the I/P.A pressure of 170 kPa (25 psi) is recommended.

5. **Fault switch.** There is one available fault switch that can be activated by the instructor to insert an electrical fault. The fault is activated when the switch is in the on position (I). Ensure that the fault is in the off position (O) if you are not performing a troubleshooting exercise.

6. **4-20 mA connectors.** Control signal is picked up at these connectors. When the I/P converter or digital controller is properly calibrated, a 4 mA signal results in a valve fully open on port L (closed on port U) while a 20 mA signal corresponds to a fully closed port L (open port U).

7. **Actuator.** The actuator contains the mechanism (springs and the diaphragm) required to move the valve stem when pressurized air is applied at its inlet.

8. **Current-to-pressure converter (I/P).** Linearly converts the 4-20 mA control signal into a 34.5-90 kPa (5-13 psi) pneumatic signal.

   The I/P converter must be calibrated from time to time as indicated in Learning Unit 2.

Table 29: Current-to-pressure converter (I/P).

Current input range	4-20 mA
Pressure output range	20-100 kPa (3-15 psi)
Maximum pressure at inlet	550 kPa (80 psi)
Available pressure adjustments	range and zero

As mentioned previously, the orientation of the three-way valve can be changed by turning the body of the valve (follow the steps beginning on Step 1). Keep in mind that a pressure of about 62 kPa (9 psi) must be applied to the valve while turning the valve body so as to prevent permanent damage. This corresponds to a control signal of 12 mA.

Table 30: Correspondence table for the three-way control valves.

Model	Name	Similar to	Refer to
46955-0	Three-Way Pneumatic Control Valve with a DVC 2000 (HART)	46950-0	Learning Unit 4
46955-A	Three-Way Pneumatic Control Valve with a Positioner	46950-A	Learning Unit 3
46955-B	Three-Way Pneumatic Control Valve	46950-B	Learning Unit 2
46955-C	Three-Way Electric Control Valve	46950-C	Learning Unit 7
46955-D	Three-Way Pneumatic Control Valvewith a DVC 6000 (Fieldbus)	46950-D	
46955-E	Three-Way Pneumatic Control Valvewith a DVC 6000 (HART)	46950-E	Learning Unit 5

Appendix D

Using Fieldcare via the HART Protocol

The capacitive level transmitter can be configured and used remotely from a computer as can most devices using the HART protocol. An optional toolkit (Model 46982) including the Fieldcare software and the communication box is required to perform the operations described in this section. Note that this section is an overview. Documentation provided with the toolkit should be consulted for comprehensive information.

1. Turn on the computer and prepare a process loop which includes the control valve, a 4-20 mA calibrator, and the commubox. Connect the commubox (making sure its internal resistance is activated) to the current loop as shown on the following figure. Connect the commubox to the USB port of your computer.

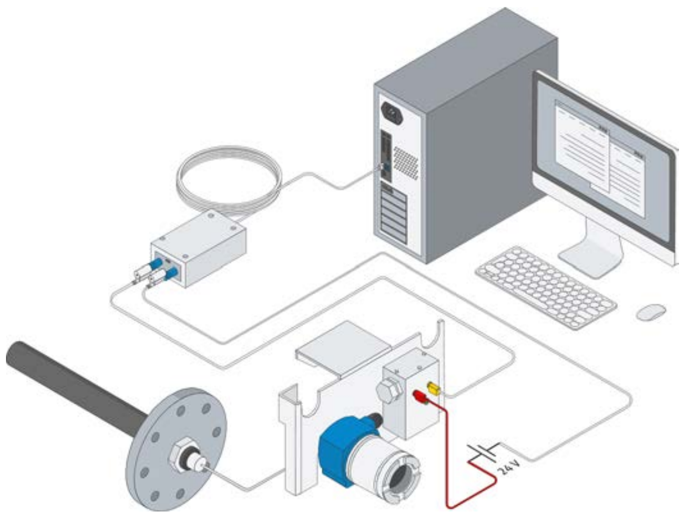


Figure 42: Connection of the capacitive level transmitter for the HART protocol.

2. Launch the Fieldcare software and select point-to-point HART communication.

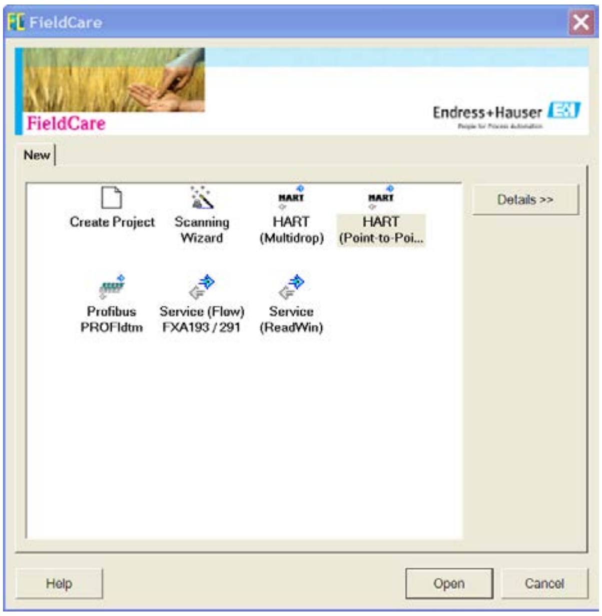


Figure 43: Choose HART (Point-to-Point) in the menu.

3. The software offers to run a scanning macro to find the device connected via the HART protocol. Click Yes to have the software detect the device.

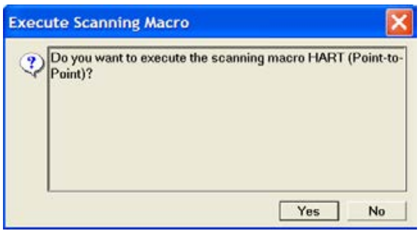


Figure 44: Choose Yes to execute the scanning macro.

4. The Fieldcare software displays relevant information about the device at the top of its window and a list of menus and sub-menus on the left-hand side in the Label window.

   The device may be locked from configuration modification. In such a case, enter the code 100 in safety settings ▶ code. To lock the device, simply change the code to something different than 100.

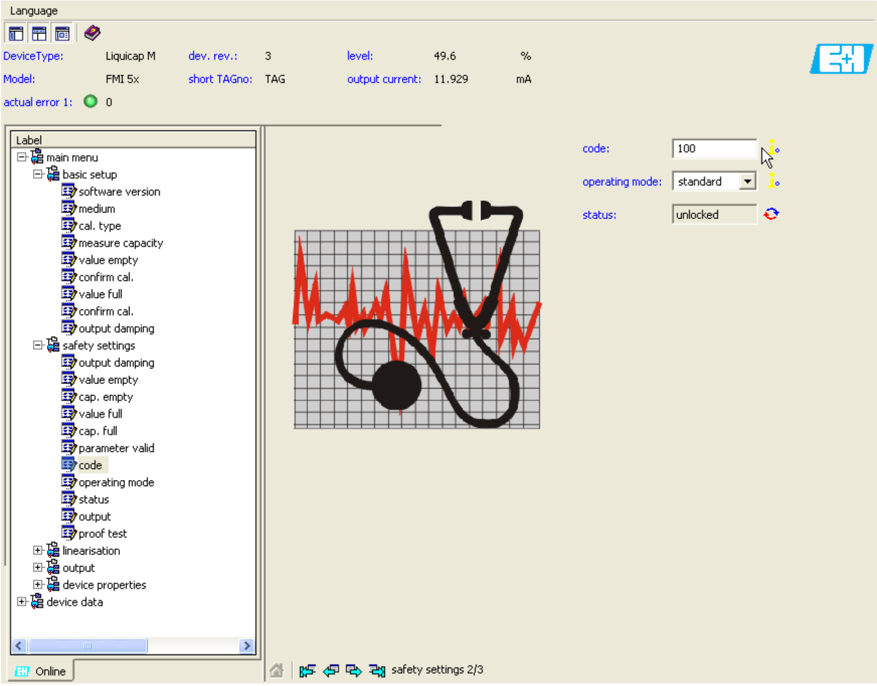


Figure 45: Locking or unlocking the capacitive level transmitter.

5. Choose the basic setup sub-menu from the main menu. Set the parameters as shown in the following figure.

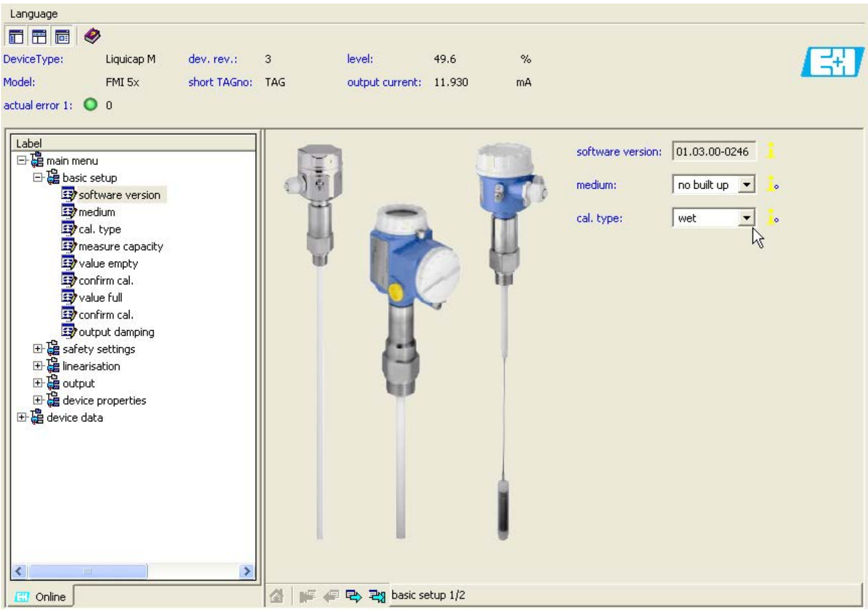


Figure 46: The basic setup sub-menu, part I.

6. Go to the second part of the basic setup sub-menu and set the different parameters as shown in the following figure.

Make sure the column is empty, then confirm the calibration of the device for the (1) value empty parameter. Then, fill the column up to the point where you want the reading to correspond to 100% and confirm the value of the (2) value full parameter.

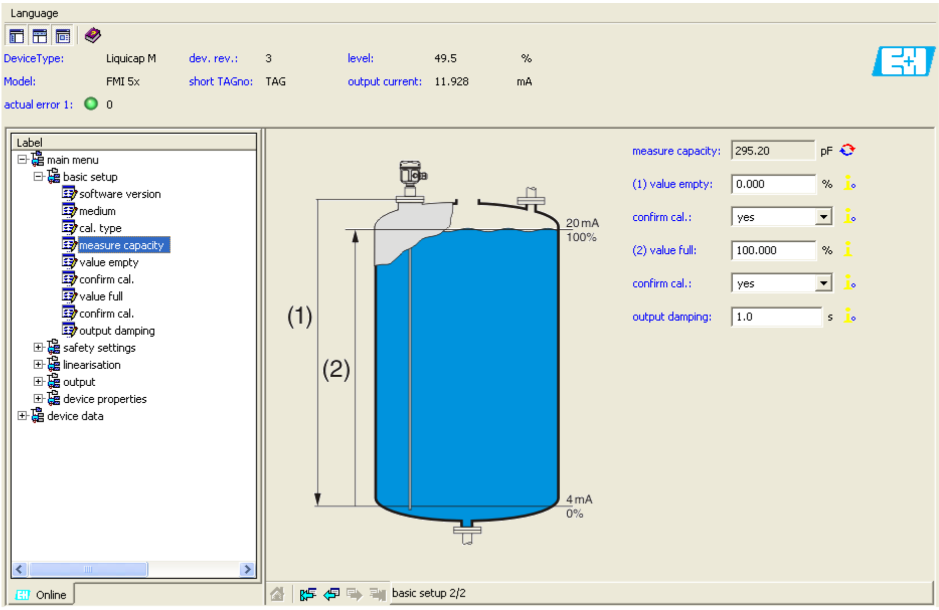


Figure 47: The basic setup sub-menu, part II.

7. Go into the linearisation sub-menu to set the units to the value of your choice. The default values are shown in the following figure.

8. Explore the menus and sub-menus to learn about the different possibilities and settings of the device. More information is available in the manufacturer's documentation for each option.

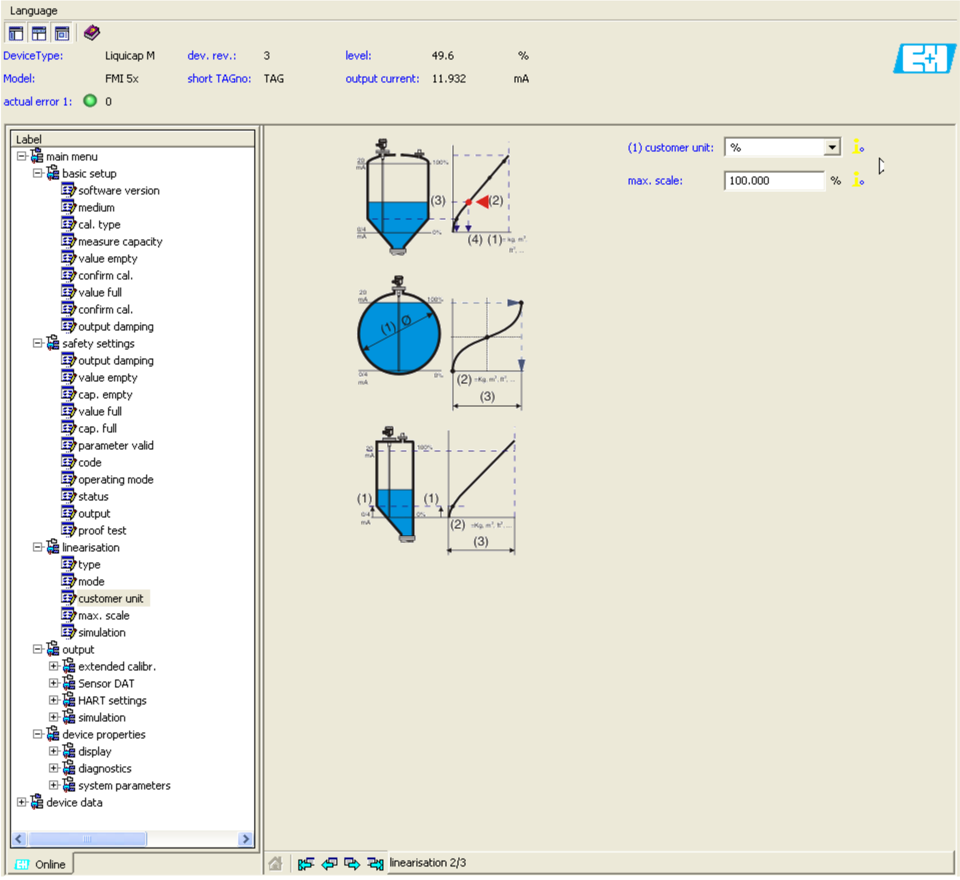


Figure 48: The customer unit sub-menu.

Appendix E

Unit Conversion Table

Table 31: Conversion from SI/Metric units to U.S. customary units.

To convert	from	to	Multiply by
Density	kg/m³	lb/ft³	6.243×10^{-2}
Heat transfer rate	W	BTU/h	3.412
Force	N	lbf	2.248×10^{-1}
Length	m	ft	3.281
Mass	kg	lb	2.205
Pressure	Pa	inHg (60°F)	2.961×10^{-4}
	Pa	lbf/in² (psi)	1.450×10^{-4}
Specific weight	N/m³	lbf/ft³	6.366×10^{-3}
Temperature	°C	°F	$T_F = \frac{9}{5} T_C + 32$
	K	°F	$T_F = \frac{9}{5}(T_K - 273.15) + 32$
Velocity	m/s	ft/s	3.281
Viscosity (dynamic)	N·s/m²	lbf·s /ft²	2.089×10^{-2}
Volume flow rate	L/min	ft³/s	5.886×10^{-4}
	L/min	gal/min (gpm)	2.642×10^{-1}
	m³/s	ft³/s	35.31
	m³/s	gal/min (gpm)	1.585×10^{4}

Table 32: Conversion from U.S. customary units to SI/Metric units.

To convert	from	to	Multiply by
Density	lb/ft^3	kg/m^3	16.02
Heat transfer rate	16.02	W	0.293
Force	lbf	N	4.448
Length	ft	m	3.048×10^{-1}
Mass	lb	kg	4.536×10^{-1}
Pressure	inHg (60°F)	Pa	3.377×10^{3}
	lbf/in^2 (psi)	Pa	6.895×10^{3}
Specific weight	lbf/ft^3	N/m^3	1.571×10^{2}
Temperature	°F	°C	$T_C = \frac{5}{9}(T_F - 32)$
	°F	K	$T_K = \frac{5}{9}(T_F - 32) + 273.15$
Velocity	ft/s	m/s	3.048×10^{-1}
Viscosity (dynamic)	$lbf \cdot s/ft^2$	$N \cdot s/m^2$	47.88
Volume flow rate	ft^3/s	L/min	1.699×10^{3}
	gal/min (gpm)	L/min	3.785
	ft^3/s	m^3/s	2.832×10^{-2}
	gal/min (gpm)	m^3/s	6.309×10^{-5}

CE Importer:
Festo Didactic SE
Rechbergstr. 3
73770 Denkendorf
Germany
Tel.: +49 711 3467-0
did@festo.com

US Importer:
Festo Didactic Inc.
607 Industrial Way West
Eatontown, NJ 07724
United States
Tel.: +1 732 938-2000
Toll Free: +1-800-522-8658
services.didactic@festo.com

CA Manufacturer:
Festo Didactic Ltée/Ltd
675, rue du Carbone
Québec (Québec) G2N 2K7
Canada
Tel.: +1 418 849-1000
Toll Free: +1-800-522-8658
services.didactic@festo.com

UK Importer:
Festo Ltd
Applied Automation Centre
Brackmills
Northampton, NN4 7PY
United Kingdom
T +44 800 626 422
info_gb@festo.com

www.festo.com

User Guide

Control Valves

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