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Smart Valves and Positioners

6.1 Process Control

6.1.1 Introduction to Process Control

Until recently, the majority of valves and actuators were used as part of analog systems. Today, as the process industry enters a new millennium, the face of process control is changing such that smart technology is quickly overtaking those antiquated analog systems, which were once so prevalent. Smart final control elements—such as intelligent systems mounted on valves or digital positioners used with actuators—have fewer or no moving parts to fail, and the performance associated with digital communications is far and away better than the 4- to 20-mA signal found with I/P analog systems. Plus, today's smart final control elements offer a whole host of new functionalities once thought futuristic—such as automatic loop tuning, self-diagnostics, information processing, planned maintenance, and warning/alarm management.

To understand the terminology and abilities of smart products, a number of common instrumentation and control principles and terms must be generally understood.

6.1.2 Controllers and Distributive Control Systems

A wide majority of control systems that link process sensors and final control elements, such as control valves and actuators, use controllers or distributive control systems to provide intelligence in the control loop. A *controller* is a microprocessor that receives input from a process

sensor—such as a pressure or temperature sensor or flow meter—and compares that signal against a predetermined value. After the comparison is made, it sends a correcting signal to a final control element until the predetermined value is reached. A common controller seen in today's systems has a three-way mode that allows for loop tuning—in other words, the adjustment by the user of the proportional, integral, and derivative settings, which is commonly called *PID control*. With PID control, these three settings can be adjusted to optimize the control loop or to provide certain control loop characteristics. For example, variations between the set-point and process variable can be automatically corrected or the system speed can be increased to improve system response.

Related to a controller, but on a much larger scale, is the *distributive control system* (or DCS). The DCS is a central microprocessor designed to receive data from a number of devices and control the feedback to several final control elements. With a DCS, all wiring for the input devices and final control elements lead to one central area, usually in a control room where the DCS is located.

6.1.3 Analog Process Control Systems

The analog process control system has had a long history—beginning in the mid-1970s—as the industry standard. However, by the year 2000, analog process control systems generally had been replaced by the digital process control system as the industry standard. Regardless of this shift, a sizeable number of process control plants still rely on this technology, and its operation should be understood.

With a conventional analog system, the process sensing device transmits a 4- to 20-mA signal to a controller or DCS. The signal is sent through a dedicated line, which is typically a shielded two-wire line. Because the controller or DCS is simply a process computer that utilizes digital signals, the analog information coming from the field must be converted to a digital signal for the controller or DCS to use. This is accomplished through an analog input/output interface card, which converts the analog signal to a digital signal for the microprocessor to use, as shown in Fig. 6.1. If the information received from the transmitted signal is different from the value needed by the process, the controller or DCS sends a correcting signal to the final control element, which can be a control valve. Once again, because of the analog communication lines involved, the controller or DCS will send a digital signal, which is then converted to an analog signal and transmitted across a dedicated analog line to the control valve. The control valve responds by moving its position until the correct process value is achieved.

Analog devices—such as a flow meter, a limit switch, or a positioner—are used to generate process information or react to feedback from the controller and create an analog signal through mechanical means. For example, a limit switch depends on the mechanical movement of the shaft to make contact with the lever arm of the limit switch, which causes the contacts of the switch to meet and send the analog signal.

The main advantage of an analog process control system is that, because of the analog input/output interface, any analog device—whether it is a flow meter or control valve—can communicate with the controller or DCS, making equipment interchangeability easy. A secondary advantage is that the analog system has general acceptance around the world. Instrumentation people are familiar with it and the majority of process devices still use it.

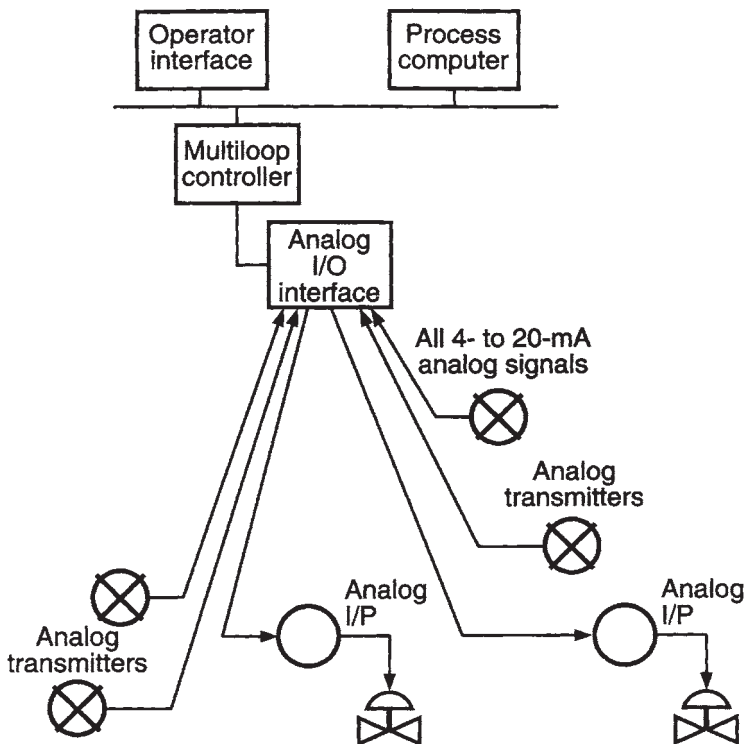


Figure 6.1 Analog process communication network. (Courtesy of Fisher Controls International, Inc.)

Analog systems have a number of disadvantages, as well. First, they must have dedicated lines—or in other words, one line per device. If two devices are placed on one 4- to 20-mA line, the signals are apt to interact adversely with one another and confuse the controller or DCS. Of course, electrical lines can be influenced adversely by magnetic fields and radio frequencies. In addition, wires can be damaged or broken. Analog devices must have moving parts to create the analog signal, which can wear, fail, or hang up. Also, because analog devices have mechanical adjustments, calibration can wander or drift from the necessary settings, especially where vibration occurs.

6.1.4 HART Field Communication Protocol Development

Control valves installed in analog process control systems have benefited by development of the HART® field communication protocol and a wide assortment of HART field instruments. The acronym HART stands for *highway addressable remote transducer* and began as the brainchild of the instrument manufacturer Rosemount in the late 1980s. Rosemount opened up the protocol to other developers and a user group was formed in 1990. In 1993, this user group evolved into the HART Communication Foundation, which was established to support the application of HART protocol to the process industry.

Because of the existence of hundreds of plants with conventional analog process control systems, HART protocol has allowed the use of digital technology within their 4- to 20-mA wired infrastructures, allowing digital communication with HART-designed control valves and other HART devices.

By design, HART protocol preserves the 4- to 20-mA signal, while allowing two-way digital communication to work within the 4- to 20-mA line without disrupting the original purpose of the signal line. HART protocol is developed around a slave/master environment, where the control valve and positioner (with digital capabilities) or other smart device (referred to as the *slave*) only communicates when communicated to by the *master*, which may be a personal computer or handheld communicator. (A typical handheld communicator is depicted in Figure 6.2.)

Typically, HART protocol (when used in conjunction with a smart valve or digital positioner) provides greater functionality or improved performance over conventional 4- to 20-mA devices. In addition, it allows for other information-gathering and performance-based functions, such as calibration, diagnostics, setting device parameters, and data storage.



Figure 6.2 Two-way communications link with a digital positioner, using a HART Handheld Communicator. *(Courtesy of Fisher Controls International)*

6.1.5 Digital Process Control Systems

Because of the disadvantages of the analog process control system, coupled with the recent advent of microprocessor-based controllers, distributive control systems, and fieldbus communications, the demand for digital communication has grown significantly throughout the 1990s and into the new millennium. A digital process control system not only utilizes the digital communications associated with the controller or DCS, but also uses the same digital communications with the process sensors and final control elements. This eliminates the analog-to-digital interface conversion as well as some of the mechanical parts and motion associated with analog devices. It greatly improves product reliability, with a minimal amount of moving parts to fail or wires to break. It also ensures that exact information is received by the controller and that the final control element follows the feedback perfectly. With digital systems, hysteresis, repeatability, and other control problems are minimal when compared to analog systems. Although physical lines are usually still required between the

controller or DCS, as well as the process sensor and final control element, digital communications allow a number of devices to use a single line. This is because each device can have an electrical signature that would allow it to identify itself to the DCS or controller without signal interference.

Digital communications are dependent on a standardized communication all-digital language, called *fieldbus*. With a standardized fieldbus, field devices not only communicate with the controller or DCS, but also with other field devices. The fieldbus also provides a reasonable power supply to run the complex functions of smart equipment.

With a digital system, analog input/output interfaces are replaced by a fieldbus digital interface, which can receive a number of signals from multiple devices connected to one digital line. The main advantage of digital communications is that the signals sent by any device are easily identified through an instrument signature and can be separated from competing signals. This allows the DCS to sort the information according to one device and send feedback input to another device, all on one line, as shown in Figure 6.3.

The most obvious advantage of a digital system is the improved accuracy and response of the system. With digital communications, no portion of a signal is lost. The lack of moving parts or linkages means better performance, less maintenance and recalibration, and lower spare part inventories. Once a full digital communication link is in place, interchangeability between all devices is possible, which was one of the benefits of the analog system. If PID control is included with the system, the digital system will allow for automatic loop-tuning, improving the performance of the control loop. Information about the performance of equipment can lead to equipment and process diagnostics, which assists with planned maintenance and eliminates maintenance surprises. With fieldbus technology, power is available within the communication lines to run the digital equipment, eliminating outside power sources.

6.1.6 Fieldbus Standardization

Up until the late 1990s, the problem with a standardized fieldbus was the lack of a general agreement by the process industry as to which communication language would best serve its global needs. Early fieldbus developers each produced a different communication language. However, for a user to have full digital communication, all the smart devices must operate off of the same fieldbus; this limits the options of the user since several fieldbus standards were proposed by

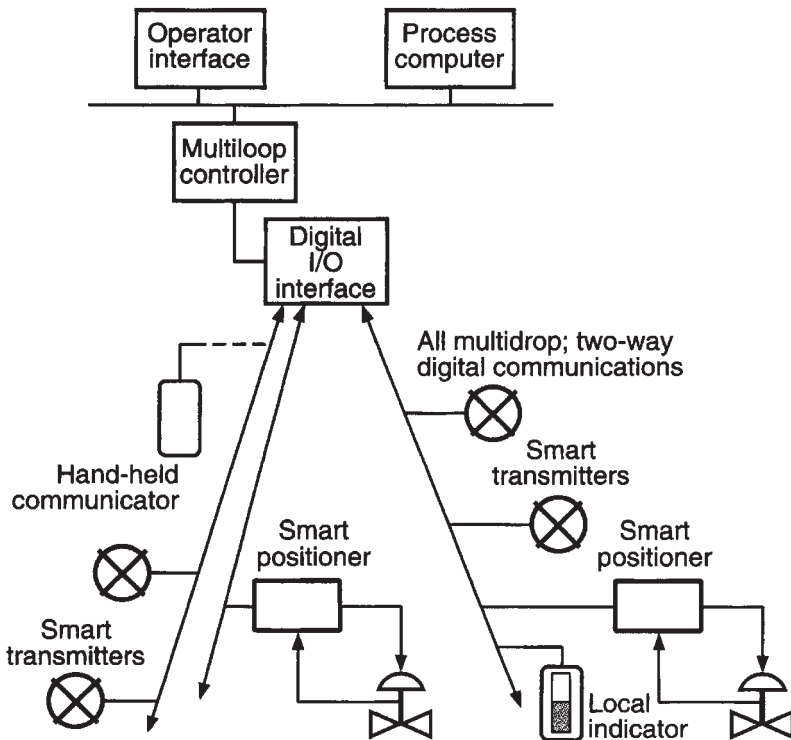


Figure 6.3 Digital fieldbus communications network. (Courtesy of Fisher Controls International, Inc.)

different competing sources. This debate is finally being resolved among those promoting various fieldbus languages, with the Foundation fieldbus technology (developed by the Fieldbus Foundation) seen as the primary leader. With the emergence of a true standardized fieldbus, all smart process equipment and its associated software can then be developed to use the same language, creating a true digital relationship among all digital devices.

Established in 1994, the Fieldbus Foundation brings together over 100 developers and manufacturers of digital process control products. Working together under the Fieldbus Foundation umbrella, these companies have supported a global fieldbus protocol with contributions and product development, although the Foundation fieldbus technology is not owned by any one company. The overwhelming volume of support for this field has driven its acceptance by the process industry, and standardization to the Foundation fieldbus is expected in the near

future. Foundation fieldbus is an interoperable system based on the seven-layer communications model established by the International Standards Organization's Open System Interconnect (OSI/ISO), as shown in Table 6.1. Its specifications are also compatible with the ISA's SP50 standards project and the International Electrotechnical Committee (IEC).

6.1.7 Development of Smart Valves

Prior to the 1990s, control valve design and functionality had remained relatively stable. While some new control valve designs, such as the eccentric plug valve and the spring cylinder actuator, were deemed "advances," it was widely accepted that the primary role of the control valve as a final control element had not changed in over 30 years.

The idea of integrating digital communications and intelligence with control valves first surfaced in the early 1990s with early prototypes being heralded by industry experts as the future of process control. However, these early prototypes were designed primarily as self-sustaining devices because the process industry did not have access to a uniform fieldbus standard to link and utilize these valves with the DCS.

However, over the next 10 years (with the aggressive development of fieldbus communications, wireless Internet technology, condition monitoring, Ethernet systems, and field communication devices), the control valve industry has been re-energized by a spurt of digital product development. In 2004, an entire subindustry of digital prod-

Table 6.1. OSI 7-Layer Model

OSI layer	Function
1. Physical	Transmitting raw bit stream through existing mechanical and electrical connections
2. Data link	Establishing data packet structure, bus arbitration, error detection, and framing
3. Network	Routing of all packets and resolving of all network addresses
4. Transport	Providing transparent message transfer, which is independent of the network
5. Session	Providing connection management services for all applications
6. Presentation	Converting data from applications between the local format and the network
7. Application	Providing network-capable applications

ucts and software for control valves has been realized and has driven growth for the entire control valve industry.

6.1.8 Role of Smart Valves

The term *smart valves* has been applied to those control valves that use on-board microprocessors or digital positioners to communicate with either analog or digital systems. As final control elements, control valves must have the ability to communicate digitally with the controller or DCS, as well as to interact with other digital field instruments, to take advantage of the positive aspects of digital communications. As a minimum, this requires a digital positioner.

This development of smart products, however, was slowed initially by the lack of a standardized fieldbus—although a number of smart valves and positioners available today have been developed so that they can handle a number of proposed fieldbus versions (each requiring unique software and hardware versions). Today's smart valves vary widely according to the capabilities of microprocessor and design. For example, intelligent systems provide complete single-loop control when placed on a valve—which requires process sensors, a controller, and a digital positioner.

This allows for a wide range of functions, from process control to data acquisition to self-diagnostics. In addition, with some smart valve designs, PID control can be added to automatically loop tune the process so that it is more efficient. On the other hand, a digital positioner has the microprocessor included with the positioner and is used only to assist the valve with its ability to act as the final control element. Overall, both smart valves and positioners can provide various levels of valve self-diagnostics and management of safety systems, such as a controlled shutdown.

Many existing plants today remain wired with analog lines, each attached to an individual input device or final control element. To replace these analog lines with digital lines is time-consuming and expensive; thus this conversion has been somewhat delayed due to economic concerns. For this reason, an open protocol has been developed. The open protocol allows smart products to utilize existing analog lines for both communication and power needs. This means that those smart devices that use the existing 4- to 20-mA lines must use the worst case scenario—4 mA—as the main power source. The problem with such low power is that the device can only have a limited amount of electronics and, therefore, the smart capabilities of such devices are limited. As mentioned earlier, one advantage of a fieldbus

is that the power could be increased to expand the capabilities of smart devices in general.

Smart valves are primarily linear-motion valves, with globe valves being the primary focus, although some rotary-motion designs have been modified to smart service. An advantage of using smart products with a rotary valve—which has an inherent flow characteristic—is that a modified flow characteristic can be custom programmed, providing better flow control for the user. Also, a smart valve can correct the problems associated with a positioner's linear-to-rotary motion, which does not produce a true linear signal because of the swing arc of the positioner take-off arm.

6.2 Intelligent Systems for Control Valves

6.2.1 Introduction to Intelligent Systems

As discussed earlier, the most sophisticated smart valve is a control valve that is equipped with an intelligent system with process sensors. The *intelligent system* is a microprocessor-based controller that is capable of providing local process control, diagnostics, and safety management. Process input to the intelligent system comes through process sensors mounted on the body, as shown in Fig. 6.4. The system also has internal sensors to monitor valve stem position and pressures on both sides of the pneumatic actuator.

Placing a controller and process sensors on a control valve allows for *single-loop control*—defined simply as an input sensor sending information to the controller, which sends a correcting signal to a final control element until the correct value is achieved. By monitoring the upstream pressure, downstream pressure, temperature, and the stem position, the intelligent system can calculate the flow rate for the valve and compare that against the predetermined setpoint—and make any necessary position adjustments to provide the correct flow rate. The intelligent system can be configured to handle single-loop control for the pressure differential, upstream pressure, downstream pressure, temperature, flow rate, stem position, or another auxiliary process loop. Because the intelligent system can be programmed to handle local control and measurement of the process, the DCS can be used to handle more demanding control situations elsewhere in the plant or to provide an overall process supervising function. With its local controller, the intelligent system is then capable of monitoring and creat-



Figure 6.4 Intelligent control system with an integral digital positioner mounted on a globe control valve. (Courtesy of Valtek International)

ing a record of the upstream and downstream pressure, differential pressure, process temperature, and the flow rate. The controller of intelligent systems can be equipped with PID control that uses a value from an external transmitter or internal process parameters as the control variable. This allows the process to be tuned for more efficient process control in a number of wide-ranging applications.

Intelligent systems can be used in either analog or digital systems with digital or conventional analog positioners (Fig. 6.5). They can respond to PID operation with a 4- to 20-mA analog signal, a digital signal, or through a preprogrammed set-point. Intelligent systems sometimes require the use of a personal computer or the DCS to set the tuning and operating parameters of the smart valve—although some of the newer versions come equipped with an on-board keypad, which allows for direct operation.

The user communicates with the intelligent system through a number of operator interfaces: DCS input/output interface card, hand station and recorder, or personal computer. When a personal computer is used to communicate with the intelligent system, interface software (provided by the manufacturer) must be installed.



Figure 6.5 Intelligent control system combined with an analog positioner mounted on a globe control valve. (Courtesy of Valtek International)

The close proximity of the process sensors and control valve to the controller greatly reduces the dead time or lag time, significantly increasing the response to process changes. When a digital positioner is included in the intelligent system, the problems associated with hysteresis, linearity, and repeatability are greatly reduced. The intelligent system has the capability of collecting and issuing flow and process data to the DCS, which provides the user with a current engineering analysis of the process. Remote sensors can also be tied to the intelligent system for improved control of the other parameters of the process without having to channel the data through the DCS.

An important side benefit of an intelligent system is that line penetrations are reduced significantly—an important consideration in this age when fugitive emissions are a critical concern. Because the process sensors are installed on the valve itself, the single-point installation of the valve eliminates separate line penetrations for the flow meters as well as the temperature and pressure sensors. Therefore, instead of having four or five line penetrations as part of the control loop, only one (the smart valve) exists, which eliminates a number of potential leak paths as well as decreasing EPA (or other governing body) reporting functions.

Intelligent systems allow for valve and process self-diagnostics through their ability to record a signature of the valve or process. When the valve is first installed, a signature can be taken of the valve's initial start-up performance or of the process itself by plotting the flow against certain travel characteristics. As the valve continues in operation, periodic monitoring of the valve's and system's performance can be compared against the initial start-up signature. When this performance begins to falter through normal wear or through an unexpected failure, the intelligent system can warn the user of pending or existing problems, allowing for preventative maintenance or corrective action to take place before a major system or valve failure. For example, the system can take a signature of the leakage through the seat in a closed position (by monitoring the downstream pressure). Over time the intelligent system can compare the initial signature against the current body leakage signature. If the current reading exceeds the ANSI leakage class (a preset condition) due to a damaged or worn closure or regulating element, the system can warn the user that servicing of the closure element is needed. By monitoring the upper and lower pressure chambers of the actuator, intelligent systems can also evaluate a loss of packing compression and actuator seals or recognize jerky stem travel, which may point to a problem with the closure or regulating element. If an analog positioner is used with the system, hysteresis, repeatability, and linearity can be monitored.

Since a process signature is possible, the system's overall performance, which can be affected by associated upstream or downstream equipment, can be monitored and evaluated as well. For example, if an upstream pump begins to slow, the upstream pressure will decrease and fall below acceptable limits at a certain point. When the intelligent system finds the pressure dropping below the preset value, it can alert the user, who can then schedule the necessary valve or actuator maintenance.

Safety management is another use for intelligent systems, since they are capable of programmable settings that can notify the user when process limits are violated by a system upset. In addition, the systems can be used to monitor and analyze the process during start-up and shutdown, warning of any sudden departures from the normal service conditions. Multiple failure modes can be programmed into the intelligent system, which will provide a different mode for a variety of failures: loss of air supply or power, process failure, loss of command signal, etc.

Data logging is another advantage of intelligent systems, as they have the ability to record process conditions through user-specified

intervals. For example, some intelligent systems are capable of recording up to 300 lines of process conditions at intervals anywhere between a second to three hours apart. This data log is normally provided so that the user can evaluate the process, looking for any abnormalities or upsets.

The wide range of benefits of an intelligent system is often reflected in the price of the intelligent system, which may produce some “sticker shock” to those accustomed only to the cost associated with other actuator accessories. However, the user should look at the larger picture: The intelligent system takes the place of a controller, individual pressure and temperature sensors, a flow meter, limit switches, tubing and wiring, etc. Taken together, the cost of an intelligent system mounted directly on a control valve is less than the sum of the individual pieces of equipment. The only evident problem with an intelligent system is that it requires a separate 24-V dc power supply to run the electronics, which may require some additional wiring and a conversion box if only standard ac power is available.

A simplification of the intelligent system is to install the system to the actuator without including the process sensors in the body (using existing sensors already installed in the system)—in essence, creating a very powerful digital positioner. This allows the intelligent system to function with many of the advantages discussed earlier, but without the on-board single-loop control. The advantage is that the cost is less, yet offers many of the smart technology benefits associated with the full intelligent system.

6.2.2 Intelligent System Design

Shown in Fig. 6.6 is a schematic of a typical intelligent system. Power is supplied by a separate 24-V dc source as well as a compressed air source. Pressure sensors are mounted directly to the body on the upstream and downstream sides of the closure element. The location of the pressure sensors on the body is critical to ensuring proper pressure readings without being affected by an increase of velocity as the flow moves through the closure or regulating element or any other narrowed section of the body. The temperature sensor is placed between the pressure sensors and as close to the closure or regulating element as necessary to determine the best process temperature reading. The wiring for the sensors is tubed directly to the intelligent system. Pneumatic lines feed air from the digital positioner (in this case, the digital positioner is part of the intelligent system) to the upper and lower chambers of the actuator.

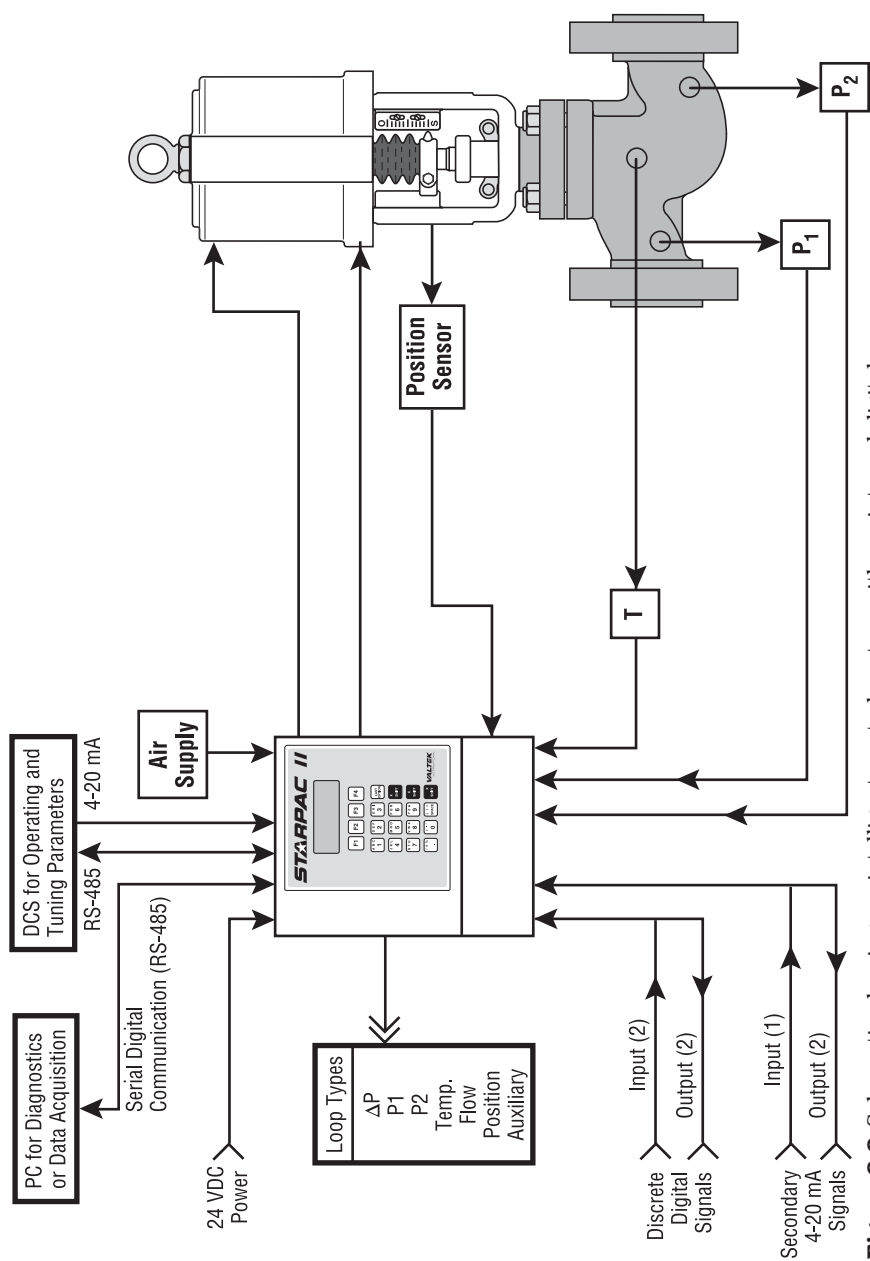


Figure 6.6 Schematic showing an intelligent control system with an internal digital positioner. (Courtesy of Valtek International)

Operating or tuning input, as well as data acquisition, takes place through either the supervisory DCS or through a personal computer via a serial digital communication line, which is a designated electrical signal, such as RS-485. A separate 4- to 20-mA line is linked from the DCS to the intelligent system for any standalone command signals. With the single-loop control associated with an intelligent system, this line is often not necessary but is available if needed.

Input and output lines are provided for discrete digital signals that act as switches, allowing the user to toggle between manual and automatic operation of the intelligent system or for other custom configurations. The secondary 4- to 20-mA signal inputs are used for any auxiliary input, such as from a remote flow meter to control downstream pressure. The secondary 4- to 20-mA outputs are used to communicate with another supervisory device, such as another controller.

As noted earlier, intelligent systems can be used with standalone positioners. A schematic of an intelligent system with an analog positioner is shown in Fig. 6.7.

6.3 Digital Positioners

6.3.1 Introduction to Digital Positioners

Following the introduction of the intelligent system for control valves, a logical step was to move toward *digital positioners*, which are devices that use a microprocessor to position the pneumatic actuator and to monitor and record certain data (Fig. 6.8).

Digital positioners do not provide single-loop control as intelligent systems do; therefore, they must be installed in a more conventional process loop, with a controller and process sensors. Although they are not equal to intelligent systems, digital positioners can perform some of the same functions. For example, a digital positioner can measure and transmit actuator stem position, providing alarm signals (similar to limit switches) when a certain position is reached or exceeded and eliminating any requirement for an independent position transmitter. PID control and tuning are also possible.

Because the pressures to the actuator are monitored, changes in actuator operation pressures can allow self-diagnostics of the actuator and certain aspects of the valve, such as changes in packing compression or a binding closure element. As with all smart devices, digital positioners have an electronic signature that allows for remote identification. The positioner can be characterized and calibrated remotely through input

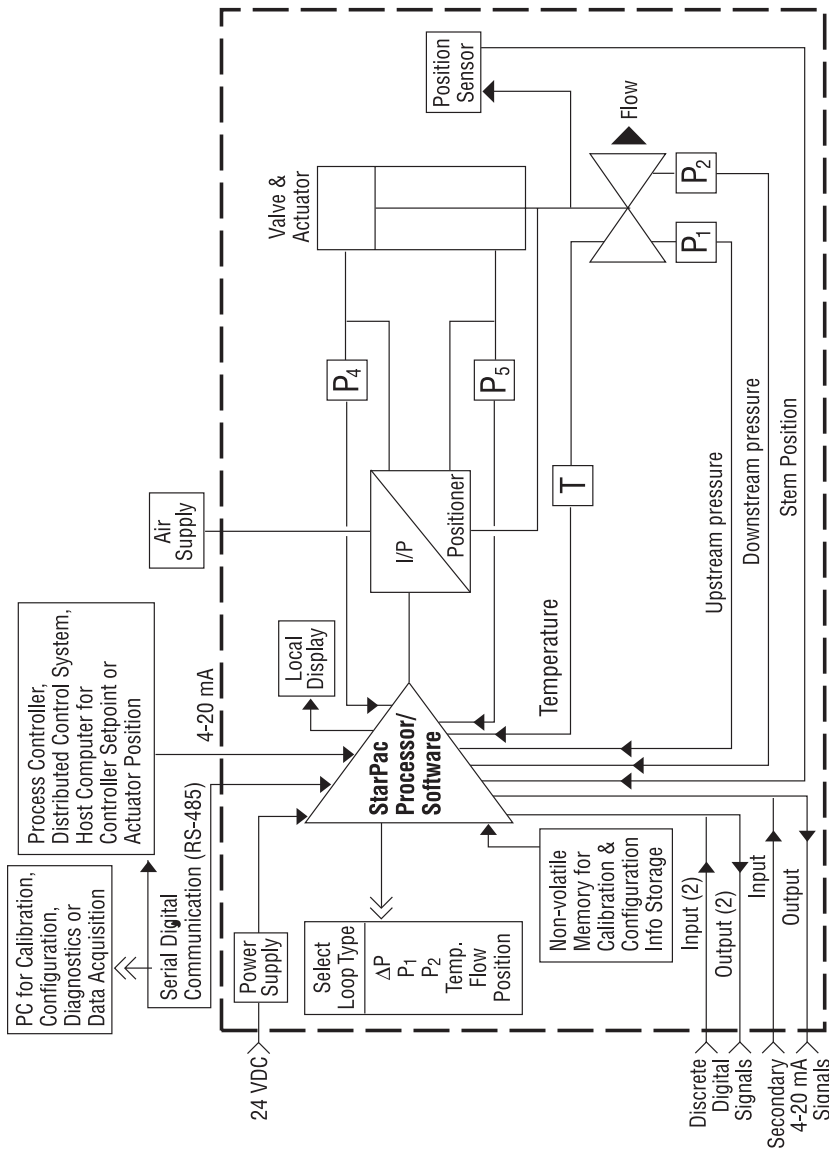


Figure 6.7 Schematic showing an intelligent control system with separate electro-pneumatic positioner. (Courtesy of Valtek International)

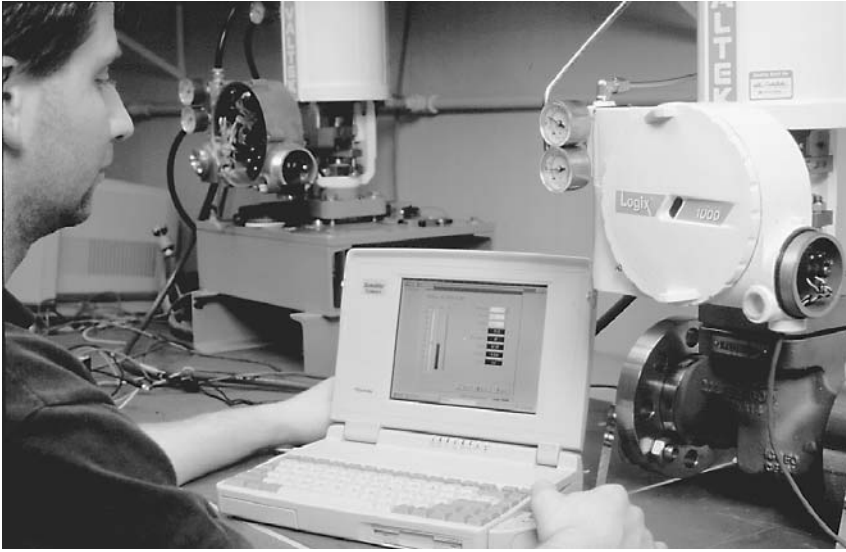


Figure 6.8 Computer interface with a digital positioner. (Courtesy of Valtek International)

from the DCS or a personal computer. No characterizable cam is required to modify an inherent valve characteristic; instead, the electronics can be used to provide a modified or customized flow characteristic.

As stated earlier, digital positioners have far lower hysteresis and better repeatability and linearity than analog positioners. However, because digital positioners still have some moving parts—such as a spool valve and a linear-to-rotary linkage at the actuator stem—some hysteresis, repeatability, and linearity problems can exist. The advantage to using smart electronics is that such errors can be zeroed out, allowing the positioner to take such problems into account. Both an advantage and disadvantage of the digital positioner is its reliance upon two-wire 4- to 20-mA signal and power sources. The obvious advantage is that an analog positioner receiving an electrical signal could be replaced with a digital positioner. The disadvantage is that only 4 mA is available to run the positioner, which limits the amount of electronics that can be run through the power source.

6.3.2 Digital Positioners Design and Operation

A typical digital positioner schematic is shown in Fig. 6.9. The command 4- to 20-mA signal provides the power source to the electronics.

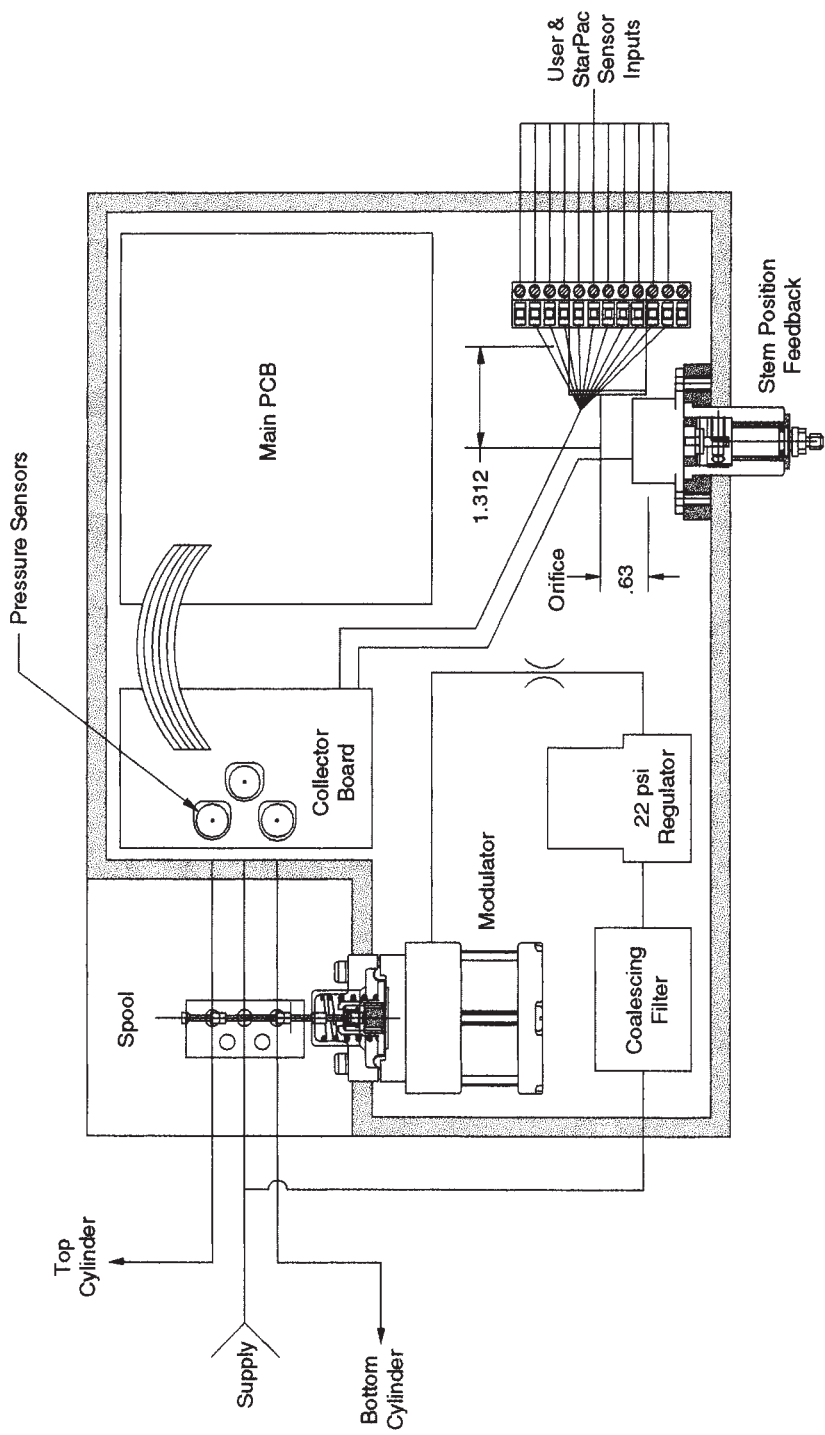


Figure 6.9 Digital positioner schematic. (Courtesy of Valtek International)

Compressed air is also required to provide the power to the pneumatic actuator. The actuator's feedback position is provided by a special take-off arm that provides a mechanical-to-electronic function: The linear motion of the actuator stem turns a rotating potentiometer, which provides position feedback to the positioner's electronics and compares that feedback to the signal. If a discrepancy occurs either through a changing signal or through an incorrect actuator position, a correcting electronic signal is sent to a pressure modulator. The pressure modulator then positions an inner spool, which sends air to one side of the actuator and exhausts the other side. This action moves the position of the actuator and continues until the correct position is reached. At this point, the feedback is equal to the signal and the pressure modulator places the inner spool in a holding position.

A key element in the correct operation of digital positioners is the placement of pressure sensors in the electronics that can monitor the air pressure sent to the actuator. This information is important in recording an initial signature for the actuator's function, as well as providing future signatures that can be used for self-diagnostics.