6.2 Accessories and Positioners

B. G. LIPTÁK (1995)

Types:
Air accumulators, air sets, handwheels, I/P transducers, limit stops, limit switches, positioners, relays (biasing, booster, lock-up, quick-exhaust, reversing), smart (microprocessor-based) valve electronics, solenoid pilots, stem position transmitters, servo solenoid valve.

Materials of Construction:

Supply Pressure (Gauge):
Varies from 20 to 25 PSIG (140 to 170 kPa) for signal relays to 60 to 100 PSIG (400 to 700 kPa) for positioners or boosters, some to 150 PSIG (1000 kPa).

Inaccuracy:
Positioners: repeatable to ±0.1 to 1% and accurate to ±0.5 to 2% of span. Transducers: ±0.5 to 1% of span. Boosters: ±0.1 to 1% of span.

Signal Ranges (Gauge Pressure):
Pneumatic: 3–9, 3–15 (preferred), 6–30, and 9–15 PSIG (20–60, 20–100, 40–200, and 60–100 kPa). Electronic: Digital Fieldbus and other, 1–5, 4–20 (preferred), and 10–50 mA DC. Others are used such as 0–10 and 1–10 VDC.

Costs:
Air sets, $40; handwheels, $500 for larger size; I/P transducers, $300; limit stops, $100; limit switches, $50 to $150; positioners, $400 (pneumatic), $600 (electronic); $1500 (special) solenoid pilots, $80; stem position transmitter, $250 to $500.

Partial List of Suppliers:
Air Sets:
Adams Valve Inc. (www.adamsvalves-usa.com/page.cfm?name=welcome)
ControlAir Inc. (www.controlair.com/news/index.htm)
Cashco Inc. (www.cashco.com/)
Fisher Controls (www.emersonprocess.com/fisher)
ITT Conoflow (www.conoflow.com/)
Masoneilan Dresser (www.masoneilan.com/internet/businessunits/measurement/subunits/masoneilan/index.cfm)
Moore Products Co. (www.sea.siemens.com/default.asp)

Flow sheet symbols
Handwheels and Limit Stops:
Anchor/Darling Valve Co. (see Flowserve)
Auma Actuators Inc. (www.auma-usa.com/)
Copes-Vulkan Inc. (www.dezurik.com/)
Daniel Valve Co. (www.danielvalve.com/)
Duriron Co. (www.flowserve.com/valves/index.htm)
Fisher Controls (www.emersonprocess.com/fisher/)
Grinnell Supply Sales Co. (www.grinnell.com/)
Keystone Controls Inc. (www.tycovalves.com/)
Leslie Controls Inc. (www.lesliecontrols.com/)
Limitorque Corp. (www.flowserve.com/valves/index.htm)
Pacific Valves (www.cranevalves.com/pv.htm)
Mastergear Div. (www.regal-beloit.com/)
Neles-Jamesbury Inc. (www.metsoautomation.com/)
PBM Inc. (www.pbmvalve.com/)
Rotork Controls Inc. (www.tycovalves.com/)
Velan Valve Corp. (www.velan.com/)
Valtek (www.flowserve.com/valves/index.htm)
Xomox (www.xomox.com/Xomox/hdocs/)

I/P Transducers, Positioners, Stem Position Transmitters:
ABB Kent Inc. (www.abb.com/)
Bailey Controls Co. (see ABB)
Bray Valve and Controls (www.bray.com/)
DeZurik (www.dezurik.com/)
Fisher Controls International Inc. (www.emersonprocess.com/fisher/)
Foxboro Co. (www.foxboro.com/)
Honeywell Industrial Controls (www.honeywell.com/)
ITT Conoflow (www.conoflow.com/)
Jordan Controls Inc. (www.jordancontrols.com/home_default.asp)
Kammer Valves Inc. (www.flowserve.com/valves/index.htm)
Leslie Controls Inc. (www.lesliecontrols.com/)
Moore Products Co. (www.sea.siemens.com/default.asp)
Neles (METSO) Controls (www.metsoautomation.com/)
Valtek Inc. (www.flowserve.com/valves/index.htm)

Limit Switches:
Allen Bradley (www.ab.com/)
Go Switch Inc. (Topworx) (www.topworx.com/)
Micro Switch/Honeywell (content.honeywell.com/sensing/)
Pepperl + Fuchs Inc. (www.pepperl-fuchs.com/pa/welcome_e.html/)
Proximity Controls Inc. (www.proximitycontrols.com/products.htm)

Relays (Biasing, Booster, Reversing):
Bailey Controls Co. (www.abb.com/)
Fairchild Industrial Products Co. (flu.com/fairchild/)
Fisher Controls International (www.emersonprocess.com/fisher/)
Foxboro Co. (www.foxboro.com/)
Moore Products Co. (www.sea.siemens.com/default.asp)
Robertshaw Controls Co. (www.robertshawindustrial.com/)

Smart (Microprocessor-Based) Valve Electronics:
EIM Controls (www.eim-co.com/eimweb.nsf/pages/company)
Kaye & MacDonald (www.kayemacdonald.com)
Limitorque (www.flowserve.com/valves/index.htm)
Rotork Controls (www.tycovalves.com/)
Valtek (www.flowserve.com/valves/index.htm)

Solenoid Pilot:
Automatic Switch Co. (www.asco.com/)
INTRODUCTION

This section describes some of the traditional valve accessories, including positioners. For the valve accessories that provide self-diagnostic capability or can communicate on the fieldbuses, the reader is referred to Section 6.12, which is fully devoted to an in-depth discussion of intelligent valves, positioners, and accessories.

The word “accessories” applies to the many devices added to control valves. Many of these are more necessities than accessories, depending on the application. This section lists and discusses some of the many accessory devices that can be attached to both throttling and on/off valves. The purpose is to improve their performance or to obtain remote feedback on their status. The positioner is the single most important valve accessory, and this section will emphasize the design and the application of positioners. Before starting that discussion, a brief summary will consider the contribution of microprocessors to the development of smart valve accessories. See also Section 6.9, Dynamic Performance of Control Valves, for a more detailed look at valve dynamics.

SMART VALVES

Section 6.3 discusses some of the more common applications of intelligent actuator systems, and Section 6.12 is fully devoted to an in-depth discussion of intelligent valves, positioners, and accessories.

The microprocessor can provide logic to improve the positioning and the performance of the valve. Additional services may include operational and maintenance communications with the valve.

Microprocessor-based systems are available in watertight or explosionproof (NEMA 6 or 7) construction and can tolerate ambient temperatures from −40 to 185°F (−40 to 85°C). They can also be used where any or all of high humidity, fungus, or dust are present. As shown in Figure 6.2a, these devices have become quite complex, and any proposed application for “smart” positioners should review the operating conditions and the application requirements with the manufacturer. Some of the positioners emphasize maintenance services; some make improved control their main goal.

Microprocessor-based systems can incorporate self-tuning and self-calibrating electronic positioners or electronic proportional, integral, derivative (PID) controllers, which respond to a digital or analog external set point and commands. Locating the controller logic at the valve and dedicating it to full-time control is an advantage on critical loops, providing fast response for applications such as compressor surge protection, where speed of response is a major consideration.

There may also be an improvement in control robustness and reliability if the system can continue to control without the central control system. This does not mean that positive control is lost, because the system is still “under orders” from the central system, only the continuous cycle of measure-compute-act-feedback is local. Commands for set point, mode of operation, and data collection reside in the central system. Local control eliminates the time lost during communications and response of the central control system like a programmable logic controller (PLC) or distributed control system (DCS).

Smart positioners can modify the characterization of the valve to reduce control nonlinearities in the valve and actuator and to provide special action. It is possible to match the valve to the process requirements to reduce the change in process gain over the range of operation or to provide special response or action as required.

Smart actuator circuitry can also protect electric motor operators from electrical overload when the valve is jammed or from reverse phase operation. Smart systems can also take advantage of the lower cost of digital communications over a single loop of two-conductor or fiber-optic cable. This method of communications can substantially reduce the wiring cost of installations that can control a number of actuators, pumps, and other devices.

The smart valves can have calibration changed and reconfigured and can detect such performance changes as pressure drop changes resulting from a fouled pump or pipeline. They can also limit the valve travel to stay within the range where the required characteristics (gain) are guaranteed or to limit maximum or minimum flows.

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Some of the smart valve packages incorporate additional sensors installed on or in the valve. These measurements may include upstream and downstream process pressure, pressure difference, flow, process fluid temperature, stem position, and actuator operating pressures (Figure 6.2a). This allows both for total distributed control and for the flexibility of manipulating the valve to control any one of the variables.

These valves may also include local indicators and the capability of calibration or reconfiguration of the valve, transmitters, or controller. Diagnostic capabilities include self-tuning and the ability to evaluate the valve and process responses to step or to ramp changes in the valve position. Upon failure of the electrical power supply the valve functions can be supported by battery backup.

The user is cautioned that some of these more sophisticated accessories may require more than the usual two-wire 4–20 mA DC power/signal wiring. Some are “four-wire” with separate power required. Some are two-wire, but may present a higher impedance load to the system than the simpler field instruments. This higher source voltage requirement may prevent wiring two positioners in series for split ranging.

Primarily used with on/off valves, on-line partial stroke testing may be provided for safety applications to provide verification of the valve actuation system. The user is advised to check the current versions of applicable standards because there is significant interest and activity in this area.

**POSITIONERS**

The positioner along with the associated actuator constitutes a simple position control loop. The valve begins to act only after the error is detected and the controller output has changed. Inherently, this is a lagging action.

With the typical air supply pressure used, 15–100 PSIG (100–700 kPa), any large change in valve signal will result in a critical pressure drop within the positioner. When the internal flow restriction has a pressure drop ($\Delta P$) greater than 50% of the absolute inlet pressure, then sonic flow velocities will exist. This sets a constant and limiting flow rate through the pilot valve.

This maximum flow rate capacity is probably the one listed in the product specifications. As the valve stem approaches the desired position, the $\Delta P$ decreases and the flow decreases to be more nearly proportional to the signal error. This results in some slowing of the response at the end of the stroke change and may help to stabilize response.
When to Use Positioners

The purpose of a positioner is to improve the accuracy of control valve response. This means that the valve position will more closely approach the position commanded by the control system. A positioner can reduce the effects of many dynamic variations. These include changes in packing friction due to dirt, corrosion, lubrication, or lack of lubrication; variations in the dynamic forces of the process; sloppy linkages (causing dead band); and nonlinearities in the valve actuator.

The dead band of a good valve/actuator is 2% (Section 6.4), but it has been measured at up to 5%. Large plug valves and ball valves with less than perfect linkages and inadequate actuators may be far worse. A better positioner with the proper actuator can often have a dead band of less than 0.5% of stroke.

The positioner increases the actuator speed or thrust by increasing the actuator pressure or airflow volume, and can modify the valve characteristics through the use of mechanical links and cams or electronic function generators. While these positioner capabilities are very important, some of these capabilities can also be obtained or approximated with other accessories.

For example, split-ranging is possible using pneumatic relays. Multiplier/biasing relays in the air signal line to the valve modify the relationship between controller output and actuator air pressure. The response speed/thrust of the valve can be increased with the use of airflow booster relays, and changes to the control valve characteristics can be obtained, not only with a different plug characteristic shape, but also by pneumatic or electronic characterizing of the controller signal. Consider that the computing relays may have a lower flow capacity than a positioner and the speed of response may be affected.

When the valve is in remote manual (open-loop) operation, the positioner will reduce the effects of the valve hysteresis and dead band and improve the accuracy of the response. When the valve is under automatic (closed-loop) control, the positioner will normally improve control, but will do that only if the loop response is slow when it is compared to the control valve response (analysis, temperature, liquid level and blending, slow flow, large volume gas flow).

An imperfect positioner may degrade loop response, contribute to proportional offsets, and cause limit cycling in fast loops where the valve cannot keep up (fast flow, liquid pressure, small volume gas pressure). Older and simpler positioners did limit response and create problems.

The issue is more of the speed of the valve relative to the controlled process rather than absolute speed (Figure 6.2b). It is not uncommon for the valve to be the slowest part of the loop and limit process response. This may be a problem, or it may be perfectly acceptable. The needs of the process should be the basis for determining the performance requirements of the control system. The very worst situation occurs when the valve system and the process have equal or similar time constants.

Actuators without springs or equivalent padding pressure to provide the spring return function will usually require positioners with dual outputs to drive both sides of the diaphragm or piston. The spool valve or relay valve will have a second output, with its action the reverse of the first one. Because the opposing air pressure below the diaphragm decreases when the air pressure above the diaphragm increases, the actuator has a greater net force available without the opposing spring force.

It is necessary to have a packing gland or O-ring seal around the valve stem for the lower air pressure. A positioner with only a single output can be used with a reversing relay to provide the second output.

A number of different control design requirements can be accomplished with positioners. A reverse-acting positioner (increase in input causes a decrease in output) makes an air-to-open, spring-to-close valve function as an air-to-close, spring-to-close valve.

This combination may be specified for systems with interlocks or batch operations. The use of reverse acting positioners is discouraged by some users for maintenance reasons. Beware of terminology here: “Fail Open” has been...
confused with “Flow to Open,” and “Fail Closed” has been confused with “Flow to Close.” These are different and must be defined and understood especially in safety applications.

Heating, ventilation, and air-conditioning (HVAC) systems with low-pressure pneumatic thermostats may use some sort of simple positioner to increase actuator pressures. The alternative is electric signals and electric motor-activated valves. These services rarely need fast response or tight control.

**Split-Range Operation** Split-ranging is the use of two valves controlled from one controller output signal. With positioners, each positioner moves its valve over only a part of the controller output range.

One typical application is for temperature control. Here, the cooling valve is full open at 0% controller signal and closed at 50% signal and beyond, while the heating valve is closed over the 0–50% range and begins to open at 50% controller signal and fully opens at 100%. See Figure 6.2c and Table 6.2d.

The example is a simple one and has many possible difficulties. The specific application may require a different sort of calibration. A dead zone with both valves closed at a controller output of 50% will have no total flow over that dead band. This may be used to reduce costs of heating and cooling.

Other applications may require that both valves be partly open at the 50% controller output point. For a system where the valves add the temperature control fluid into a circulating system, it might work well. But, as an example, if the system is “once through” where the heat transfer rate is proportional to the heating/cooling fluid velocity, the valves are usually set up with some overlap in valve position. That is, the cooling flow might not shut off until the Controller Output (CO) is 75%, and the heating flow might start at 25% CO. The total flow and thus heat transfer rate will remain more nearly constant and stabilize the operation.

With this approach, maintenance is simplified because standard positioner calibrations are used and the full positioner accuracy is retained. Note that the specifications for the positioner are defined for the full range of the positioner and that if only half the output range is used, the effective dead band for each valve is doubled. For a maximum in flexibility, control each valve from a separate control system output.

### Table 6.2d

**As it is Shown in Figure 6.2c, it is Possible to Use Relays instead of Split-Range Positioners**

<table>
<thead>
<tr>
<th>Controller</th>
<th>Output</th>
<th>Output</th>
<th>Output</th>
<th>Control</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valve 1</td>
<td>Valve 1</td>
<td>Valve 2</td>
<td>Valve 2</td>
<td>Valve 2</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
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</tr>
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<td>50</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

**Signals in PSIG (bar)**

<table>
<thead>
<tr>
<th>Controller</th>
<th>Output</th>
<th>Output</th>
<th>Output</th>
<th>Control</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valve 1</td>
<td>Valve 1</td>
<td>Valve 2</td>
<td>Valve 2</td>
<td>Valve 2</td>
</tr>
<tr>
<td>3 (0.2)</td>
<td>15 (1.0)</td>
<td>3 (0.2)</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>9 (0.6)</td>
<td>3 (0.2)</td>
<td>3 (0.2)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>15 (1.0)</td>
<td>3 (0.2)</td>
<td>15 (1.0)</td>
<td>0%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Signals in % (with overlapping flows)**

<table>
<thead>
<tr>
<th>Controller</th>
<th>Output</th>
<th>Output</th>
<th>Output</th>
<th>Control</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valve 1</td>
<td>Valve 1</td>
<td>Valve 2</td>
<td>Valve 2</td>
<td>Valve 2</td>
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<tr>
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<tr>
<td>25</td>
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<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

**Tight Shut-Off** In some applications, there is a need for special tight shut-off. A positioner calibration can provide the full actuator pressure applied to the valve stem when the valve is commanded to be closed.

**High Rangeability** A special application might require accurate flow control for a small percentage valve opening. The positioner calibration can provide that the valve moves very little for a large fraction of the low end of the signal range but still opens fully at 100% of signal. Examples include a drastic difference between operating conditions and start-up or emergency shutdown, or a large butterfly valve.

An application as simple as a level control may be very poor because the valve is oversized for special operating problems. A very simple flow control loop will add considerable accuracy at a modest cost. The primary requirement for the flow sensor is to be reliable; even poor accuracy is adequate. A simple field controller, even pneumatic, will constitute an inexpensive secondary control loop requiring little attention.

**Gap Action** If there is a great problem with packing wear, it is possible to set up the controller or the positioner for “gap action.” Here, the valve signal changes only when the controller error exceeds a certain limit.
Condensate pots that accumulate steam condensate are an example of this. A partly opened valve will experience damaging cavitation. A valve that quickly switches between fully open at a high condensate level and fully closed at a low level will avoid cavitation. Boiler blowdown valves are a similar application.

**When Not to Use a Positioner**

The positioner/actuator can be defined as the secondary control loop in the cascade loop, working with the process controller output providing the control signal. In order for a cascade secondary to improve control, it must respond more quickly than the primary loop. The ideal situation would be if the time constant of the secondary was one tenth (open-loop speed of response ten times as fast) of that of the primary and if the period of oscillation of the secondary loop was three times that of the primary.

Even if the valve response is not as fast as these ideals, there still may be very helpful isolation of the process from process fluid changes. No process control response time can be faster than the slowest element in the control loop. The advantages of a cascade system are achieved with good secondary response.

A general principle is to use a cascade system when the advantages of isolating the primary control loop from the nonlinearity, and variations in the secondary system, justify the added cost and complexity. In such installations (B in Figure 6.2b shows a gas pressure control process), the addition of a positioner increases the open-loop (steady state) gain and improves the loop response. For this situation, the process response may be further improved because the primary controller can be tuned with increased gain (narrower proportional band) and increased integral action (reset) to speed up the integral action.

It is clear that poor valve response reduces the quality of control much more than the poor valve response would imply. In this situation the controller tuning must be modified (gain reduced, integral lengthened) to avoid oscillation due to dead band and response delay. In typical real applications controller tuning is conservative and avoids any hint of oscillation, and the response is even worse than it might be. Operators usually object to cycling processes.

Part A in Figure 6.2b illustrates a fast liquid flow process, where the loop without a positioner can be tuned more tightly (for higher gain and more repeats/minute); such a loop responds better without a poor positioner. It might also be noted that after a new state is reached, the positioned installation gives better and noisier control because of increased speed of response.

Some argue that all loops can be (and should be) controlled with positioned valves “because they provide improved response.” This is true, but there are situations where the positioner will add unjustified cost. The very fast flow loop of Figure 6.2b is one example.

Another is a small valve with a relatively large actuator and good available force; it has a small valve stem and little friction and a small plug with low fluid forces. Situations where cost is primary and quality of control is not highly important may also omit positioners. Examples are HVAC where forces are low and signal changes are slow, but there is a desire to control the cost. Positioners are not normally required for on/off service.

**Positioner Performance**

The valve positioner is a servo-amplifier acting with the valve actuator to control the position of the valve stem. Without a positioner, the stem position may be changed or motion restrained by varying fluid pressures on the plug and by unpredictable friction forces. See Section 6.9 for more details on control valve response.

The pneumatic input signal is typically 3–15 PSIG (20–100 kPa), and the typical stroke is between 1/2 and 3 in. (12–75 mm). Errors of 0.05 in. (0.1 mm) are typical. The usual input air signal is the output of a pneumatic controller in the field or from a control panel or control system. The controller signal is the result of comparing a set point pressure to a measured variable as presented by a 3–15 PSIG value and the output is intended to reduce the error.

Most positioners use air both as the operating fluid and as the source of power. Hydraulic actuator/positioners use high-pressure oil and are used on applications requiring large valves for high differential pressure services. These are units requiring actuator pressures higher than the normally available 60–100 PSIG (0.4–0.7 MPa) instrument air supply pressure. Hydraulic actuators are considerably more expensive; and they may be acoustically noisy and require specialized maintenance.

Electric motor operators are also available (Section 6.3). They are used where air is not available and where their typically slow operating speed is acceptable. There are some specialized electric valve actuators that can provide very high position precision; others can provide very fast response.

The analog electropneumatic positioner input section responds to a standard milliamperes signal. Such units usually consist of a pneumatic positioner plus an integral I/P. Some users prefer to use a pneumatic positioner with a separate I/P (current to pressure converter), usually located near the valve. A few systems provide for packaging all of these accessories into one unit.

An all-electric server solenoid motor-type positioner/actuator valve is also available. At least one control valve design uses a servo solenoid valve (SV) to achieve very fast and accurate response using the process fluid pressure for actuation. This approach requires a relatively clean fluid.

The positioner normally provides a substantial improvement in valve and control loop performance, with the greatest improvement realized on slow control loops with low controller gains typically level, temperature, or analytical control (Figure 6.2c).
Positioners have typical open-loop gain (change in output pressure per change in input signal, with the valve stem locked in position) of 10:1 up to 200:1. Dead band (the minimum input change for a detectable output change) is claimed as 0.1–0.5% of span. Vendors claim positioning accuracy of 0.002–0.005 in. (0.05–0.13 mm) under bench test conditions.

**Positioner Designs**

The control valve positioner as used with a globe-style valve is typically mounted on the valve yoke and has mechanical linkage, which is connected to the valve stem to sense position. The pneumatic positioner is powered by compressed air at pressures between 25 and 150 PSIG (170 and 1000 KPa).

Tubing conveys the positioner output air to and from the actuator. There are some standards defining standardized mounting details for positioners, solenoid valves, and other accessories.

Other designs mount the positioner directly in line with the valve stem, and installed on the end of the actuator. In this design the linkage to the valve stem is direct in a straight line. In this scheme, the positioner provides air directly to the top of the actuator. Figure 6.2e illustrates such a force-balance positioner design.

For rotary valves, the positioner is mounted above the valve body. In every case, the mountings must be solid and not allow any relative motion, which adds directly to the dead band. The installation should be so arranged that there is little temptation for workers to damage the connecting tubing and linkages by climbing on the valve. The exterior of the positioner should have a finish compatible with the chemical environment.

The interior is (mostly) protected from corrosion by the steady bleed of dry clean air from the pilot valve. If the valve will be exposed to a very high level of vibration or acoustic noise, the purchase specifications should note this. Some positioner designs will withstand vibration better than others.

Pipeline applications may use the pipeline gas to operate the pneumatic instruments. For these applications, the instrument vents are purchased with tapped connections to carry the vented gas to a safe location. Because the gas used may not be totally dry, there may be a need for filters and separators to protect the instruments. Consult the valve and instrument manufacturers for requirements. Also consider the area electrical classification for electropneumatic positioners.

Because all positioners use small restrictions to reduce the air consumption at steady state, it is vital that the air be clean. Some positioner designs include a small integral filter. Satisfactory long-term operation of the instruments is considerably improved if all the dirt and moisture are removed in a good external supply filter before it reaches the positioner.

Liquids are efficient transporters of dirt and solids in supply lines to places where they will cause trouble. Liquids also can lead to ice, which can block flow in restrictors resulting in positioner malfunction, and then it may vanish without a trace after causing an unexplained upset. A simple mechanical separator will normally not remove enough moisture to properly protect the instruments.

**Force-Balance Positioners** The force-balance positioner shown in Figure 6.2e has an element that compares the force generated by the input signal with the force generated by the feedback spring connected to the valve stem. Figure 6.2f shows the electropneumatic force-balance positioner.

**Motion-Balance Positioners** The motion-balance positioner in Figure 6.2g compares the motion of an input bellows or diaphragm with linkage attached to the valve stem. Either can be very accurate. Bellows-type input elements are generally thought to be more accurate than diaphragms, and although slightly more likely to fail in fatigue, both types are used successfully. New and mostly electronic positioners differ widely in design and performance.

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**FIG. 6.2e**

*Force-balance positioner.*

**FIG. 6.2f**

*Electropneumatic force-balance positioner.*

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6.2 Accessories and Positioners

Electrohydraulic Positioners

The electrohydraulic positioner addresses the need to control actuators on very large valves and for high-pressure differential applications. These systems typically require an external motor-driven pump, reservoir, pressure control regulators, high-pressure accumulators, and filters. The positioners may use high pressure oil jet tubes that are directed by linkages to regulate the oil pressure in the actuator.

Hydraulic pressures are typically 750–1,500 PSIG (5,000–10,000 kPa). A hydraulic pressure accumulator is often provided to store the energy for peak requirements. The valve vendors can suggest or supply the hydraulic system packages. Specification issues to be determined include the use of flammable or nonflammable oils, electrical classification, peak needs, noise, space required, costs, and maintenance. If the area has several large valves, a larger central hydraulic system may be used.

Digital to Pneumatic Positioners

The digital valve actuators are described in Section 6.3. Some of the digital to pneumatic positioner designs have used rotary motors to control the pilot system. These tend to feature lock-in-place on loss of input signal. Others use a small fast solenoid valve that switches rapidly between open and closed to create an average air pressure for the actuator.

Still others may use a piezoelectric valve (electrical signals cause a deflection in a special crystal structure), either proportional or pulsating. A pulse stepping motor may rotate a shaft to set a follower, which develops an input signal force or position (Figure 6.2h). The remainder of the positioner is pneumatic. Stroke speed may be limited by stepping motor response. The only way to make decisions during the selection process with the many different designs with their many subtle differences may be to rely on proven performance.

Positioner Accessories

A number of options are available for most positioner designs, such as gauges to display the supply, signal, and output pressures. These add little cost but are a great help during checkout and maintenance.

Bypass air switches will connect the controller output directly to the actuator. These were once popular when 15 PSIG (100 kPa) pressure was adequate to move the spring-diaphragm actuator if the positioner was direct acting (increase input—increase output). The bypass is rarely specified now because this feature permits only very limited maintenance on the positioner and most modern high-performance positioners do not offer this option.

There are also safety implications in providing the possibility of changing the valve response. At one time, the usual justification for the bypass valve was to provide a way to get a poor performing positioner out of the loop for field troubleshooting. In some corporations the only control valves now purchased without positioners are small (1 in. [25 mm] and less), for low-pressure differential (0–20 PSIG [0–140 kPa]), and less critical service (comfort heating and ventilation), and where absolutely minimum cost is required.

Mechanical switches are used to provide a signal to the operator or control system that the valve stem is at or beyond a specified position. The specifications for these switches should consider the voltage and current surges caused by lightning strikes on long wire runs. These are available to suit the local electrical classification requirements. For some manufacturers of piston-type actuators, springs to provide for fail-safe action on loss of air are considered an accessory and are not supplied except as specified.

Position Indicators

Globe-style valves normally have a simple stem position pointer mounted on the stem with a simple scale on the yoke. A local valve position indicator may be mounted on rotary valves to
allow the operator to see the state of the valve. Stem position transmitters, usually derived from positioner designs, are used to provide independent remote indication of valve stem position.

**TRANSUCERS**

**I/P (Electropneumatic) Transducers**

A large variety of converters (transducers) are discussed in detail in Section 3.3. The electropneumatic transducer (I/P) converts electrical signals (usually 4–20 mA DC) into a pneumatic signal, usually 3–15 PSIG (0.2–1.0 barg). The most common application is the interface between an electronic controller output and the pneumatic control valves. It is also used between digital control systems and control valves. A few designs use signal feedback to improve accuracy (Figure 6.2i).

Most I/P transducer designs are of the “motion-balance” type (Figure 6.2j), where the small force developed by the milliampere current through a coil in a magnetic field causes motion in a nozzle-baffle assembly, resulting in a changing pneumatic pressure. The nozzle-baffle system is an amazingly accurate mechanism for measuring small distances.

When an I/P is used within a control loop between the controller and the control valve, its error is combined with the valve error, which is detected by the loop controller and then driven towards zero error. Repeatability and reasonable linearity are required, and most I/Ps have advertised accuracies of 0.35–1.0% of full scale. Most I/Ps have relatively low air capacity, and a booster relay may be needed to drive a pneumatic actuator unless a positioner is used.

**Digital Electropneumatic Transducers**

A variety of devices are used to convert digital signals in addition to the electronic digital-to-analog converter. One device uses a stepper motor, as in the digital positioner mentioned above.

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**FIG. 6.2i**
Electropneumatic force-balance transducer design and components.

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**FIG. 6.2j**
In a motion-balance electropneumatic transducer, the coil is of similar construction to the voice coil of a loudspeaker. Leads are arranged to go through a pivot point to reduce their effect on output.

A second device has a number of wires connected to it and receives data on all these wires simultaneously. This “parallel” data signal is converted to an analog current, and this controls the output pressure. Another device responds to a string of pulses (“serial” data) to set the output pressure.

**RELAYS**

**Booster Relays**

A “booster” relay, Figure 6.2k, is a device that amplifies pneumatic signals in volume (capacity) or in pressure, or both. Most booster designs were derived from a pressure regulator, with the input signal providing the loading force in place of the regulator spring. Internal pressure feedback...
may improve accuracy. The downstream-facing pitot tube compensates for flow-related pressure drop.

The feedback diaphragm has a smaller area than the input diaphragm so that greater pressure is required to achieve force balance. Volume boosters with a pressure ratio of 1:1 (gain of 1) are sometimes used to speed up a valve actuator response if a positioner is not used. The booster cannot overcome inaccuracies due to friction or forces on the valve plug, but it will reduce their effects because of faster response.

The stroking times of pneumatic piston actuators (Section 6.4) are a function of their size and of the size of the connecting tubing. A size 300 actuator with \( \frac{3}{8} \) in. (9.5 mm) tubing has a stroking time of 27.7 sec. If the output of the positioner operating that actuator is piped to one booster on each side of the piston, the stroking time is reduced to 5.4 sec, and if two boosters in parallel are used on each side, the striking time is reduced to 2.7 sec.

Large control valves and large actuators may require flow or pressure boosters installed between the positioner and the actuator to achieve the required speed. One special “dead band booster” design, Figure 6.2l, does not respond until an (approximately) 1 PSIG (6.9 kPa) difference between input and output is exceeded.

A built-in needle valve allows a limited airflow to bypass the booster gain portion and provides adjustable damping. Springs provide the 1 PSIG dead band with this relay. Very large volume amplification occurs for fast input signal change, but it does not amplify a slow change.

One common application for this relay is the centrifugal compressor antisurge control, where the control valve must open very quickly (1–3 sec) but then is required to throttle smoothly. The needle valve is adjusted with the complete control system assembled and operating. Careful tuning is vital to proper operation. With the booster needle valve fully closed, the positioner-valve system may be unstable.

Best operation occurs when the needle valve is open only enough to smoothly dampen the oscillations. If more than one of these relays is used to add capacity for one side of the piston actuator, it is absolutely necessary to set the needle valves as identically as possible to avoid a complex and probably unstable interaction between the relays.

It is worth repeating here that no air device will operate properly without an adequate air supply. With their large air-handling capacities, valve booster relays require 0.5–0.75 in. (12–20 mm) air supply and output tubing to the valve operator. Large filters are used to minimize any air supply restriction. In one special case, a large air tank 10 ft \(^3\) (0.3 m\(^3\)) was installed near the valve in order to provide adequate local air surge capacity.

**Reversing and Other Relays**

Besides the booster function, pneumatic relays can meet other control valve requirements. The fixed-gain-plus-adjustable-bias relay for split-ranging was mentioned in connection with Figure 6.2c. Another 1:2 reversing relay is shown in Figure 6.2m. This design has a reverse gain of two (0% input results in 100% output, 50% input results in 0% output). It will reverse the operation of a valve and provide the gain and bias needed for split-ranging, while retaining the native failure action on loss of the supply air.

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**FIG. 6.2l**
The design of a dead band booster in which the springs provide the 1 PSIG (6.9 kPa) dead band.

**FIG. 6.2m**
2:1 reversing relay.
The relay is a force-balance device. The output pressure generates a force on a diaphragm with one half the area of the input diaphragm so that the output pressure must be twice the input pressure. A wide variety of relays are available, amplifying, “reducing” (gains of less than one), computing (averaging, square root, and so on.), selecting (highest, lowest), some with provision for biasing the output.

Complex control concepts have been implemented entirely with pneumatic logic. This functionality is more commonly accomplished today with electronic circuits or in the control system. Very successful override control systems have been designed with one valve position controlled by several process variables such as pressure, level, and temperature.

Table 6.2n lists the air capacity for a few selected pneumatic components to show the range of typical devices. The data was found in various places and some is old. If the exact capacity of a relay or the stroking speed of a valve is important, it would be wise to check with the manufacturer.

### Quick-Exhaust Relays

The quick-release valve or quick-dump valve, Figure 6.2o, is a pilot valve that opens a high-capacity vent when the input pressure drops below a set pressure. This is used where it is needed to quickly open a valve that vents a vessel or system during a shut-down.

It is not unusual for a positioner to bleed excess air from the actuator for some seconds before a valve begins to move, because the actuator is completely filled (saturated) with supply pressure air. The quick exhaust helps reduce the lost time. The controller continues to call for valve action after it reaches its mechanical stop.

<table>
<thead>
<tr>
<th>Model</th>
<th>Air Capacity</th>
<th>PSI Supply</th>
<th>Function</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moore 750E</td>
<td>7.5 SCFM</td>
<td>60 PSIG</td>
<td>Positioner</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 71</td>
<td>4 sec, 3-15, 350 in³</td>
<td>18 PSIG</td>
<td>Positioner (1)</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore I/P</td>
<td>0.1 SCFM</td>
<td>20 PSIG</td>
<td>I/P converter</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 50M</td>
<td>3.7/2.1 SCFM</td>
<td>20 PSIG</td>
<td>Controller</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 61H</td>
<td>10.5 SCFM</td>
<td>9 PSIG</td>
<td>Booster relay</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 61L</td>
<td>4.5 SCFM</td>
<td>9 PSIG</td>
<td>Booster relay</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 61F</td>
<td>2.4 SCFM</td>
<td>9 PSIG</td>
<td>Booster relay</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 610F</td>
<td>2.4 SCFM</td>
<td>9 PSIG</td>
<td>Booster relay</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 612</td>
<td>0.12 SCFM</td>
<td>9 PSIG</td>
<td>Multi-input low-signal select</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 66BA2</td>
<td>2.2 SCFM</td>
<td>9 PSIG</td>
<td>1:2 A relay (2)</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore GC 66l</td>
<td>2.2 SCFM</td>
<td>9 PSIG</td>
<td>Amp + bias relay</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 68</td>
<td>2.4 SCFM</td>
<td>9 PSIG</td>
<td>Computing relays (1)</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore GC 77</td>
<td>NA (low)</td>
<td>E/P transverter</td>
<td></td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 750 I/P</td>
<td>7.5 SCFM</td>
<td>60 PSIG</td>
<td>I/P positioner</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 750</td>
<td>7.5 SCFM</td>
<td>60 PSIG</td>
<td>Positioner</td>
<td>Catalog</td>
</tr>
<tr>
<td>Moore 72</td>
<td>0.7 SCFM (3)</td>
<td>25 PSIG</td>
<td>Positioner</td>
<td>Moore paper</td>
</tr>
<tr>
<td>ASCO 8320</td>
<td>24 SCFM(4)</td>
<td>30 PSIG</td>
<td>Solenoid valve</td>
<td>Catalog</td>
</tr>
<tr>
<td>Valtek Booster</td>
<td>2300/1350(5)</td>
<td>60 PSIG</td>
<td>High capacity</td>
<td>Catalog</td>
</tr>
<tr>
<td>Fisher 3710</td>
<td>8 SCFM</td>
<td>60 PSIG</td>
<td>Standard capacity</td>
<td>Catalog</td>
</tr>
<tr>
<td>Fisher 3710</td>
<td>14 SCFM</td>
<td>60 PSIG</td>
<td>High capacity</td>
<td>Catalog</td>
</tr>
<tr>
<td>Valtek Beta</td>
<td>11 SCFM</td>
<td>60 PSIG</td>
<td>Positioner</td>
<td>Catalog</td>
</tr>
</tbody>
</table>

**Notes:**
1. Typical
2. Typical for family of amplifying and reducing relays
3. Higher available as option
4. Typical three-way, “universal,” no minimum pressure difference requirement, used for valve interlock
5. Supply/exhaust

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Quick-exhaust three-way solenoid valves having a large exhaust port for a similar effect can also be used.

**Relays to Lock-up Valve Position**

A lock-up relay or “fail in last position” relay, Figure 6.2p, is available to seal in the existing actuator pressures if the air supply is lost. It is intended to hold the valve in the last controlled position. If the valve is partly open at the time of air failure, this “frozen” position is not absolutely predictable because the servo-action is lost, variable plug forces may move the stem, and air may leak out in an unpredictable manner.

When a piston actuator is to be locked in its last position when the air supply fails, it is necessary to install two lock-up valves at the two ends of the piston and use a three-way switching valve to vent their actuators when the air supply pressure drops to some preset limit (Figure 6.2q).

**FIG. 6.2o**
Quick-exhaust valve in which the elastomer flapper normally allows air to flow to the actuator while sealing the exhaust; if the inlet pressure is below that in the actuator, it allows the air from the actuator to be exhausted.

**FIG. 6.2p**
Lock-up relay: If control pressure drops below the spring setting of this relay, then the relay valve closes and seals in the last air pressure in the actuator.

**FIG. 6.2q**
A valve with piston actuator, which is provided with fail-in-place lock-up controls. (Courtesy of Valtek, Flowserve Corp.)
Control Valve Selection and Sizing

Failure Position Guaranteed by Stored Air

In piston-operated valves, the air stored within the piston can also be used as the energy source to move the valve to a safe position when the air supply is lost. This can be achieved by locking the air in on one side of the piston while venting the other, when the air supply pressure drops to a predetermined value.

If there is concern that the piston volume is insufficient to fully stroke the valve under all conditions when the air supply might fail, an external tank can be used as the source of driving energy. Figure 6.2r illustrates such an installation for a fail-closed (air-to-open) valve.

Some piston-type actuators have no spring, and others have a spring too weak to guarantee valve action on loss of air supply. For these, an air tank (typically 0.5 ft\(^3\), or 0.014 m\(^3\)) with a check valve on the inlet may be used to allow limited operation or orderly shutdown (Figure 6.2s). Because everything leaks, this will only be reliable for a reasonable time. Longer term requirements may be satisfied if the process pressure tends to hold the valve plug in the desired direction.

ENERGY SUPPLIES

Air Sets

The “air set” is the air regulator with filter and drip pot used to supply air to the positioner or other instrument. It is often purchased with the valve, mounted, and piped. The regulator must have the pressure range to cover the spring range of the actuator, and it should have a built-in overpressure vent to protect the actuator; a gauge is valuable to aid in setting the output pressure and for discovering a failed or plugged supply.

Flow capacity is a problem only with very large valves. Some piston actuators and positioners will operate with up to 150 PSIG (1 MPa) supply, and there is a trend toward eliminating the regulator, but the filter is retained for reliable valve operation. Most manufacturers recommend that each control valve have its own individual air set.

The risk in providing air sets for high-pressure actuators such as air cylinders is that field operators can thereby limit the supply pressure, which in turn reduces actuator stiffness (resistance to the dynamic forces of the process). An air set must be used when the pressure rating of the actuator or positioner is lower than the air supply pressure.

The use of air filters is always recommended. They should be installed in the air supply serving the positioner...
and should be designed for the maximum air supply pressure. Their purpose is to remove moisture, oil, and all particles that are 5 µ or larger. In industry it is axiomatic that dirt is everywhere, and it will always find small restrictions to plug.

**Hydraulic (High-Pressure) Operation**

High-pressure, high-performance, hydraulic oil-filled systems are used for special needs, such as very large valves or those that require forces beyond 150 PSIG air supply. These function much like larger versions of the hydraulic power steering used on automobiles.

Very high speed performance and power is available, all at added cost. Most of the accessories and functions commonly found in pneumatic systems are available. These include: positioners, flow boosters, and pressure regulators.

**Hydraulic (Water) Operation**

There are two sorts of “hydraulic” operations. The first was addressed above. The second “hydraulic” system is the ubiquitous but rarely considered municipal water supply and wastewater systems, which have their own special set of requirements and solutions.

Actuators, pilot valves, regulators, and control relays are available that operate using water pressure just like the pneumatic systems used elsewhere. These control the water to fill elevated storage tanks and stop flow when the tanks are filled, and then implement the desired operating logic when water pressure is lost. Even fluid flow rate flow control is possible.

Self-contained water operation eliminates the need for electrical or air power and signals. Relays and valves to control water pressure surges can be provided. Users should contact the appropriate specialized suppliers for further information.

**LIMIT SWITCHES**

Switches are installed on electric motor-driven valves to open the circuit and stop driving the motor when the valve is at its limit (fully open or closed) or on motor over-torque. The name “limit switch” is also used to describe switches installed to signal when a valve is at or beyond a predetermined position. These switches are used for operator information, interlock inputs, or computer feedback.

It is necessary to consider the mounting problems, electrical classification of the area, the electrical characteristics of circuit, overtravel of actuating arm, and corrosive nature of the area. Usually, it is easiest to purchase the valve complete with the required switches already installed.

Because of environmental problems, some users have been using sealed magnetically actuated or proximity switches. Note that it is difficult to adjust limit switches closer than ±5–10 % and that dead bands of 2–5% can occur. Problems with failure of small contacts have been traced to voltage surges picked up on long field wiring.

Plantwide standardization on limit switch specifications for makes and model number will reduce spare part storage and simplify maintenance. When specifying the limit switches, one should specify the required contact ratings, the contact configurations (SPDT, DPDT, and so on), and the type of housing required. Typical choices include weatherproof, explosionproof, or hermetically sealed explosionproof.

Figure 6.2t illustrates a proximity switch installed on a linear actuator. The maximum spacing allowable between the switch and the sensed surface is 0.11 in. (3 mm). The switch is available in UL- and CSA-approved explosionproof designs.

**SOLENOID VALVES**

The solenoid valve (see Section 6.3 for more details) as a control valve accessory is used (1) to operate on/off pneumatic actuators or (2) to interrupt the action of modulating valves by switching air or hydraulic pressures. It is common practice to use a solenoid valve as the pilot for a pneumatically operated on/off valve because of the wide choice of features and capabilities available in the solenoid valve.

Solenoid valves are primarily used as parts of start-up or shutdown, interlock, or batch systems to cause the control valve to take some predetermined action under certain conditions. Three philosophies are in common use.

**Three-Way Solenoids**

In the first, the 3–15 PSIG (0.2–1.0 bar) signal to the positioner is blocked and the downstream tubing either vented or connected to some other preset pressure (Figure 6.2u).

This approach is reliable because the solenoid valve is lightly stressed, the positioner and valve have been in continuous use, and any failure or poor operation should have been detected during normal operation. With this scheme, the substituted signal can be any value over the operating range, the
Control Valve Selection and Sizing

valve will go to the desired opening, and the advantages of the positioner are retained. If the actual positioner input is fed back to the controller external feedback connection, then a smooth return to normal control may be expected when the control loop is returned to normal operation.

In the second philosophy, the solenoid valve is installed in the tubing between the positioner and the actuator (Figure 6.2v). Solenoid valves with adequate pressure rating and flow capacity are required. Only three control valve actions are possible: fully closed, fully open, or lock-up existing pressures.

A third philosophy is to shut off the air supply to the positioner and let the valve act as designed on loss of air supply. This is one scheme used in batch operations where the valves are switched into service when a process unit or pump is turned on.

In order for the system to shut down (valve to close) in case of loss of power or emergence of an unsafe condition, it is desirable for the solenoid valve to be continuously energized during normal operation. This will guarantee that any failure, loss of power, or a broken wire will cause a fail-safe action.

As a control valve accessory, usually a three-way (three ports) solenoid valve is required. Some designs require that pressure be always applied to one certain port and that another certain port always be used as the vent. This does not always suit the required logic, but valves can be found designed for “universal” operation where there is more freedom in assigning port function.

Also, note that clean, dry, oil-free instrument air provides no lubrication, and some types of solenoid valves (spool-type) will have a short life or become unreliable without lubrication. See also the discussion of the impact of solenoid valve operation on valve response in Section 6.9.

Four-Way Solenoids

For on/off cylinder-operated valve actuators, four-way solenoids are often used (Figure 6.2w). They are fast, provide positive operation, and are available for a variety of AC or DC voltage services and with Class F coils for up to 310°F (154°C) temperature services.

Solenoid Capacity

Each approach must consider the flow capacity of these solenoid valves. The desired solenoid valve $C_v$ must be greater than the $C_v$ of the positioner to avoid a reduction in stroke speed. If they are equal, then the valve speed will be roughly half of that without the solenoid.

It is typical of solenoid valves that small valves are directly operated and the larger ones are pilot operated. In pilot-operated valves, a small direct-operated valve uses air pressure to switch the larger main valve. Pilot-operated valves require a certain minimum air pressure differential in order to operate the main valve.

If the solenoid valve is tripped while the air pressure is less than this pressure, the main valve will not change state and tripping the pilot will have no effect. The valve will trip later when the pressure differential becomes high enough to operate it. Where full pressure is always present this is not an issue.

HANDWHEELS

Handwheels are used to provide for partial or complete manual control of the valve and to override the pneumatic actuator. Some, mounted on top of the actuator, Figure 6.2x, can only push on the valve stem to close (or open with inverted trim).

Others can be configured for continuous, bidirectional operation with force amplification ratios from 40:1 up to over 100:1. These top-mounted designs are illustrated in Figure 6.2y.
Side-mounted handwheels have engagement clutches to allow the handwheel to fully stroke the valve open and closed, Figure 6.2z. In the continuously connected handwheel design, the handwheel is provided with a “neutral” position. When placed in that position, the handwheel does not interfere with automatic operation of the valve.

Turning the handwheel one way forces the stem to extend, and turning it the other way forces the stem to retract. Adjusting the handwheel screw away from the “normal” position introduces a “limit stop” on the valve travel in one direction or the other, but not both. Consider that some handwheels may interfere with interlock shutdown operation of the valve.

For the manual operation of rotary valves, either hand levers 15–22 in. (38–56 cm) in length or clutch-equipped gearbox-type handwheels are used.

If manual throttling control is intended, the plant design must consider how the human operator will know how to set the valve and if the process can be safely controlled manually. This is not always the case, and handwheels have limited application in modern continuous process plants.

**LIMIT STOPS**

It is possible to install fixed limit stops to limit valve stem motion to either ensure a minimum opening or limit a maximum opening (Figure 6.2aa). These are usually purchased with the valve. Consider how to document the purpose and settings for these for maintenance purposes.

**BYPASS VALVE**

Perhaps not thought of as an accessory, the manual bypass for steam shut-off valves are critical to start-ups. The manual valves are “cracked open” to pressurize and heat up the steam.
header. Opening the large valve could result in serious damage downstream as slugs of water are propelled into equipment. Other applications may have similar issues.

References

5. ANSI/TSA-75.25.01, “Test Procedure for Control Valve Response Measurement from Step Inputs.”

Bibliography