

# 5

## Manual Operators and Actuators

### **5.1 Introduction to Manual Operators and Actuators**

#### **5.1.1 Purpose of Manual Operators and Actuators**

With most valves, some mechanical device or external system must be devised to open or close the valve, or to change the position of the valve if it is to be used in throttling service. Manual operators, actuators, and actuation systems are those mechanisms that are installed on valves to allow this action to take place.

#### **5.1.2 Definition of Manual Operators**

A *manual operator* is any device that requires the presence of a human being to provide the energy to operate the valve, as well as to determine the proper action (open, closed, or a throttling position). Manual operators require some type of a mechanical device that allows the human being to easily transfer muscle strength to mechanical force inside the valve, usually through a handwheel or lever that provides mechanical leverage. Since the beginning of process industry, manual operators have been in use and are very commonplace, although over the past three decades, their use has declined somewhat in favor of automatic control actuators. The reason is simply the cost as well as imperfections of the human operator. A human being must be dispatched to the valve with a manual operator and complete the action on the valve. With simple on-off control, this action may be adequate. However, with the accuracy required in today's process systems, the

human operator may not be fast enough to reach a valve—or stroke it—when an action is required. With throttling situations, a human operator can only guess at an approximate position of the valve's closure element, which may not be exact enough for a critical service. Even an extra half turn of a handwheel may create too much or too little flow, pressure, or temperature for some applications, especially with some inherent or installed flow characteristics. In addition to the slowness and inaccuracies of human beings, some applications have high internal forces that manual operators cannot overcome because of the physical limitations of the human being, even with extraordinarily long levers or wide handwheels. Also, in business terms, human beings are expensive. The days are over when runners on bicycles were dispatched from the control room to turn handwheels. Nearly all plants today are looking for technology to replace human beings, not only because of the human resource cost, but also for the greater accuracy, efficiency, and productivity associated with higher technology.

### 5.1.3 Definition of Actuators and Actuation Systems

Automatic control of valves requires an *actuator*, which is defined as any device mounted on a valve that, in response to a signal, automatically moves the valve to the required position using an outside power source. The addition of an actuator to a throttling valve, which has the ability to adjust to a signal, is called a *control valve*. Some say that by the pure definition of actuator, a manual operator is an actuator. However, when most people associated with valves discuss the term actuator, they are referring to a power-actuated operator using an outside signal and power source rather than a human being. Typical classifications of actuators include pneumatic actuators (diaphragm, piston cylinder, vane, etc.), electronic motor actuators, and electrohydraulic actuators. *Actuation systems* are special actuators that are commonly mounted on manually operated valves and can be used in either on-off or throttling applications.

Actuators are critical elements in the *control loop*, which consists of a sensing device, controller, and an actuator mounted on a valve. With a control loop, a sensing device in the process system—such as a temperature sensor or a flow meter—is installed downstream from the control valve and is set to measure a particular variable in the process. The sensor reports its finding to a controller, which compares the actual data against the predetermined value required by the process. If the measured value is different from the predetermined value, the con-

troller sends a correction signal to control valve's actuator. This signal can be sent using one of three methods: increasing or decreasing air pressure, varying electric voltage, or increasing or decreasing hydraulic pressure. The actuator receives this signal and moves accordingly to vary the position of the closure element until the controller determines that the measured value is equal to the predetermined value. At that point, the signal increase or decrease stops, and the actuator—and subsequently, the closure element—holds its position.

Not only must the actuator have the ability to adjust to a changing signal, but it must also have enough power to overcome the internal forces of the process, the effects of gravity, and friction in the valve itself. The majority of applications requiring actuators today require the use of compressed air, with nine out of ten actuators pneumatically driven. Air is by far the preferred power medium, since it is relatively cheap and is available in nearly all plants. In addition, it does not contaminate the environment and can be regulated easily. Typical plant compressed air supply is generally between 60 and 150 psi (between 4 and 10 bar), which is sufficient to run a large portion of the pneumatic actuators available today. When a valve must overcome exceptionally high pressures or when the valve must stroke quickly, bottled nitrogen is often used, allowing pressures up to 2200 psi (150 bar). Not only does a bottle allow for high pressures of nitrogen, it also relatively moisture-free and extremely free of particulates and other foreign material. In general, the disadvantage of air-driven actuators is that, because of the compressibility of gases, some exactness is lost through that medium.

Other power sources can include electrical (both ac and dc power) as well as hydraulics (and to a far lesser extent, steam). Although electro-mechanical and electrohydraulic actuators are more expensive than pneumatic actuators, they do have the advantages of extremely good accuracy and the ability to operate in environments experiencing low temperatures (where typical air lines can freeze from condensed water) or when high thrusts are required.

If a signal is sent separately from the power supply, pneumatic or electric signals are the industry preference. Prior to 1980, the majority of actuators received pneumatic signals. These signals were typically 3 to 15 psi (0.2 to 1 bar), although 3 to 9 psi (0.2 to 0.6 bar) and 9 to 15 psi (0.6 to 1 bar) were also commonplace. However, with the arrival of the precise control associated with electropneumatic and digital control systems, the pendulum has swung in favor of the electric signals (4 to 20 mA or 10 to 50 mA).

Actuators are described as either single or double acting. A *single-acting actuator* uses a design in which the power source is applied to only one side of an *actuator barrier* (piston, diaphragm, vane, etc.) and the opposite side is not opposed by the power sources. A spring may be added to the opposite side to counteract the single action. A related term is the *direct-acting actuator*, which refers to a design in which the power source is applied to extend the stem. On the other hand, a *reverse-acting actuator* refers to an actuator where the power source causes the actuator stem to retract. *Double-acting actuator* is a term used for actuators that have power supplied to both sides of an actuator barrier. By varying the pressure on either side of the actuator barrier, the barrier moves up or down. Pneumatic double-acting actuators nearly always require the use of a positioner to provide the varying power to the chambers above and below the barrier.

An actuator is normally a separate subassembly from the body, meaning it can be removed from the body for servicing without disassembly of the body subassembly. On the other hand, the body can be serviced without disassembly of the actuator.

## 5.2 Manual Operators

### 5.2.1 Introduction to Manual Operators

As discussed in Sec. 5.1, manual operators require the strength and positioning ability of a human being in order to operate the valve. Generally, manual operators are associated with the operation of on-off applications, as well as simple throttling applications not requiring undue accuracy or immediate feedback. The majority of the valves described as manual valves in Chap. 3 uses manual operators.

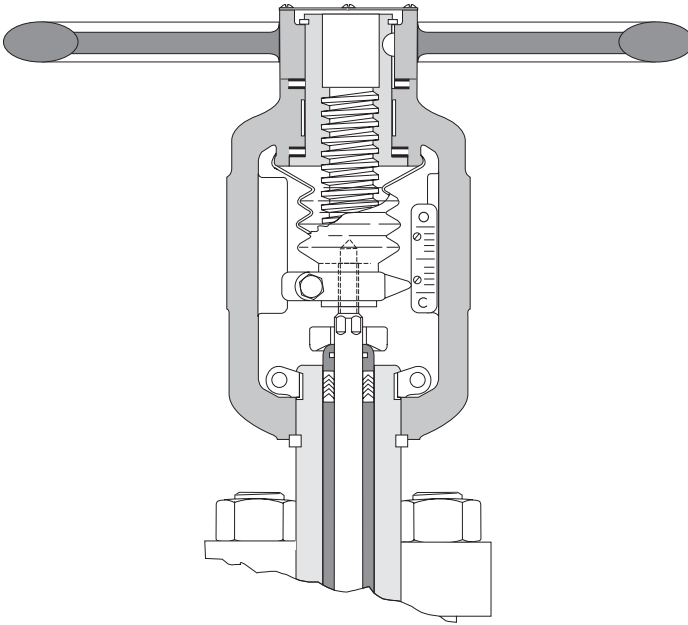
The advantage of a manual operator lies in its mechanical simplicity—minimal moving parts and no sealed chambers to leak or fail. A human being moves one part (such as a handwheel or a lever) and the valve is opened, closed, or placed in a midstroke position. Design simplicity also means that troubleshooting, maintenance, and disassembly are easier. The disadvantage of manual operators is slow response, since response depends upon a human being operating the manual operator—which in some cases may take some time. For example, a linear handwheel may require 30 or more revolutions to close a valve with a 4-in stroke. And, because a human being must be dispatched to a manually operated valve, the travel time to the valve makes for even

slower response. Also, if the valve requires throttling (a midstroke) position, the position of the valve depends upon the judgment of the operator, which may vary widely. In some applications this may not be a problem, but as systems have become more exact over the years, finding the right throttling point has become much more difficult with a manual operator.

### 5.2.2 Manual Operator Design

Generally, manual operators are divided into two categories: linear motion and rotary motion. Linear-motion manual handwheels use a threaded connection between a fixed-position part of the handwheel assembly, such as a yoke or housing, and a dynamic part (usually a handwheel stem). Multiple turns of a hand-held part mechanism—in most cases, a handwheel—cause linear movement of the dynamic stem, which is connected to a linear-motion closure element.

One of the more common designs is shown in Fig. 5.1, which shows an independent linear handwheel operator that is mounted directly to a body subassembly and is not an integral part of the valve. The actuator uses a yoke to support the handwheel mechanism and to attach the operator to the valve. The connection to the body is made with an inside diameter of the lower portion of the yoke, called the *spud*. The yoke's spud fits over the bonnet and is secured with a yoke nut or other clamping device. The closure device's stem—such as a plug stem, compressor stem, or gate stem—is threaded to the bottom of the handwheel stem. The upper portion of the yoke houses the handwheel nut, which turns with the handwheel. Some designs allow the handwheel and nut to be one integral part, while others make them separate because of material considerations. When the handwheel is separate, a key or locking bolt is used to secure the handwheel to the handwheel nut. The handwheel nut is retained in position, allowing rotational movement, and is internally drilled and tapped to receive the handwheel stem. The matching external threads of the handwheel stem are threaded into the handwheel nut, allowing for several threads to be engaged at any given position. Generally, ACME threads are used for manual operators. To avoid problems with constant contact between similar metals, which can lead to galling, the handwheel stem and handwheel nut are made from dissimilar materials. The most common combination is brass or bronze for the nut and stainless steel for the stem. As the handwheel is turned, the retained handwheel nut turns the engaged threads of the handwheel stem, extending or retracting the stem, depending on which direction the handwheel was



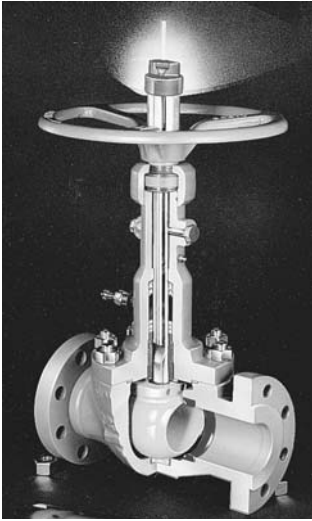
**Figure 5.1.** Independent linear handwheel operator. (Courtesy of Valtek International)

turned. The extension or retraction of the stem then operates the linear motion of the closure element. In some larger designs or high-pressure applications, rollers or races are placed between the handwheel and the upper portion of the yoke to minimize friction between mating parts, providing easier turning of the handwheel.

The chief advantage of the independent operator is that the valve does not need to be disassembled to service the operator. The disadvantage is that the overall valve has a greater height than other designs.

The other common linear manual-operator design is the dependent linear handwheel operator, which has the handwheel mechanism built directly into the bonnet cap of the valve, as shown in Fig. 5.2. In this case, instead of a yoke, the bonnet cap retains the handwheel nut. The one-piece stem has dual duty of operating both the closure element and the handwheel. The obvious advantage of this design over the independent operator is that the height of the valve is far lower. The disadvantage is that operator problems require some valve disassembly.

Linear operators are also divided into two design categories: the rising-stem and nonrising-stem designs. The *rising-stem* design uses a

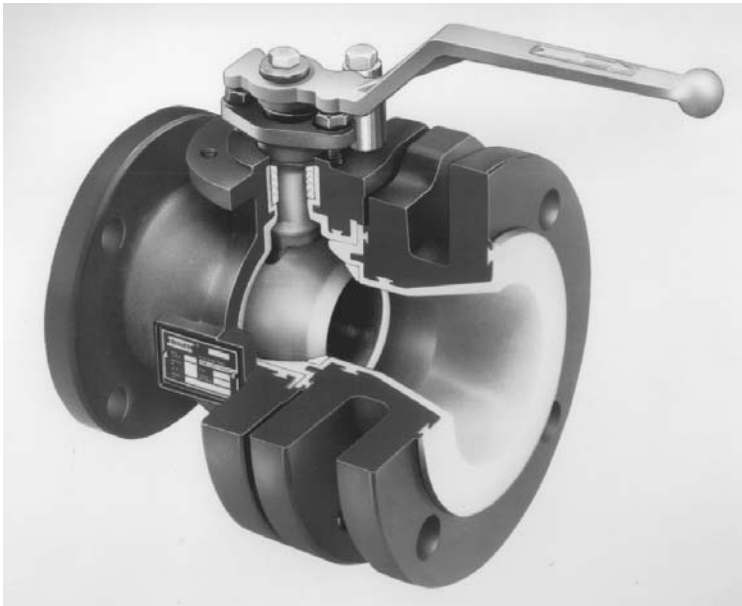


**Figure 5.2.** Integral linear handwheel operator.  
(Courtesy of Orbit Valve Company)

handwheel nut to retract the handwheel stem. As the handwheel nut is turned, the handwheel stem rises above the handwheel. A majority of manual linear-motion valves use rising-stem operators. On the other hand, the *nonrising-stem* design is typically used with dependent operators. The handwheel turns the retained and threaded stem, which engages the closure element (such as a wedge gate). As the handwheel is turned, the stem turns with it. The closure element is designed to be fixed by guiding so that it cannot rotate; therefore the closure element has a tendency to rise or lower with the stem rotation.

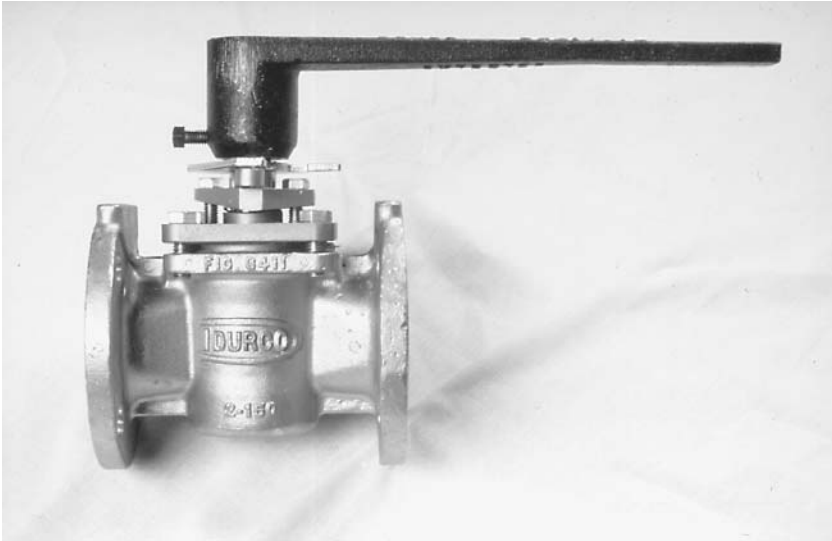
As noted earlier, the most common way of handling a linear manual operator is through a handwheel. Handwheels come in all different surface finishes, from smooth to rough, depending on the work conditions and the type of construction. Many are spoked to save weight, although some petroleum and refining applications require solid handwheels to ensure that they stay intact during a fire. Spoked handwheels have the added advantage of greater security, by allowing a locking mechanism to be placed on the operator to prevent accidental or intentional tampering with the valve's position. Another common handwheel design is the chain wheel. A *chain wheel* is a handwheel with teeth or grooves to accommodate a circular length of chain, allowing for the user to operate an out-of-reach valve.

Rotary-motion manual operators are used with quarter-turn valves, such as plug, ball, and butterfly valves. The most efficient method to turn a quarter-turn closure element is through a right-angle extension of the stem, which allows for better leverage. The two most common types of rotary-motion manual operators are the *handle* and the *wrench*. Many technicians refer to the two terms interchangeably, but a difference does exist. Handles are bolted to the stem of the closure element (Fig. 5.3) and are commonplace with smaller sizes in the lower-pressure classes. Handles are specified with soft-seated ball valves in sizes up to 6 in (DN 150) and butterfly valves in sizes up to 8 in (DN 200). On the other hand, wrenches are not permanently secured to the stem and can be moved from valve to valve (Fig. 5.4), allowing for the operator to place the valve in a particular position and leave it alone without fear of accidental or intentional tampering. Wrenches are normally equipped with plug valves up through 4 in (DN 100) with sleeved plugs and 6 in (DN 150) with lubricated plugs. In some ball and butterfly manual-valve designs, the handle is integral to the stem, but the most common and inexpensive design is a separable handle in which the handle (or wrench) has an opening that is cut to the shape of the



**Figure 5.3.** Quarter-turn handle mounted on lined ball valve.  
(Courtesy of Atomac/The Duriron Company, Valve Division)





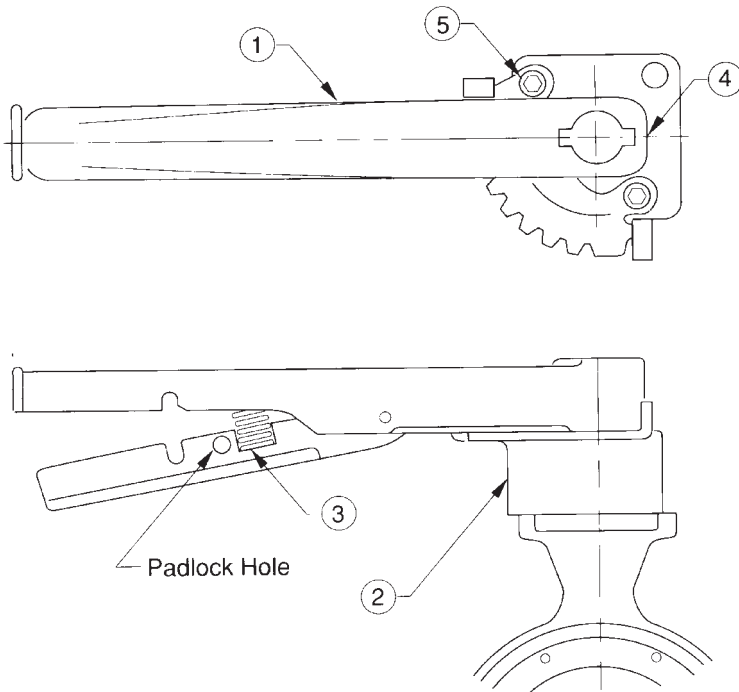
**Figure 5.4.** Quarter-turn wrench mounted on plug valve. (Courtesy of The Duriron Company, Valve Division)

plug stem. A square stem allows for the positioning of the handle or wrench in any one of the four quadrants, while a two-sided flatted stem allows for positioning in one of two positions, front and back. Handles are secured to the stem using a bolt and locking washer.

Handles and wrenches are usually made from ductile iron, although stamped stainless-steel plate is used also. A plastic or rubber grip is placed on the end for comfortable turning. Most manufacturers supply a standard length that handles most applications within the pressure or temperature range of the valve, although longer lengths are sometimes offered to allow for easier operation. Longer lengths, however, may cause problems where space is restricted, not allowing the full quarter-turn motion.

Below the wrench is a *collar-stop* that is used to limit the motion of the closure element to a  $90^\circ$  (or quarter-turn) range. Turning the wrench moves the stem, which in turn moves the plug, ball, or disk, until the collar stops the travel. When the travel is stopped, the closure element should either be in its full-open or full-closed position.

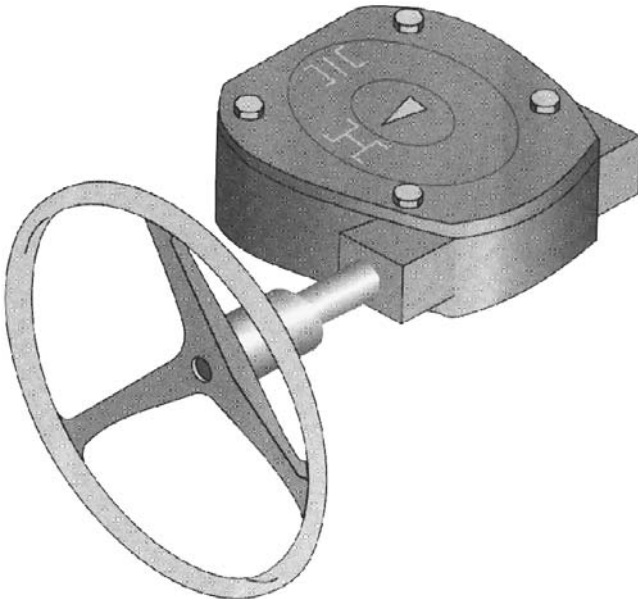
Because of the large forces that can act upon a disk in some applications, butterfly valves may require handlevers for manual operation. A *handlever* is a two-piece, spring-loaded operator that can be positioned in a number of preset slots (Fig. 5.5). The handlever has a fixed upper



**Figure 5.5.** Quarter-turn lever operator. Numbered parts are as follows: (1) lever, (2) ratchet plate, (3) spring, (4) set screw, (5) socket head cap screw. (Courtesy of Flowseal, a unit of the Crane Valve Group)

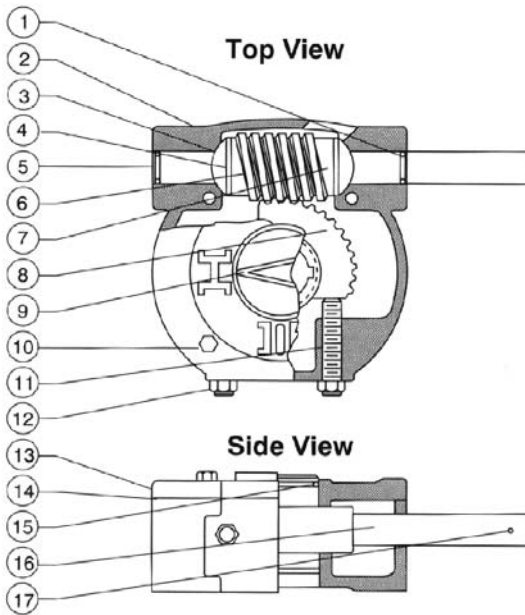
lever and a movable lower lever. In the static position, the spring loading of the lower lever allows it to seat in one of multiple slots in the collar. By squeezing the upper and lower levers, the lower lever disengages the slot, allowing rotational movement to another desired slot. When the handlever is released, the lower lever seats into the slot, locking the valve in that particular position. The range of slots can vary according to the number of positions required. A typical handlever has a minimum of three positions, full-open, full-closed, and midstroke position, although any number of positions can be planned for as long as room exists for the desired number of slots in the collar.

In larger linear and rotary valves, or in higher-pressure classes, the use of conventional handwheels, handles, and wrenches is not desirable. The circumference of the handwheel or length of the wrench or handle would be so long to handle the leverage that the arc and the



**Figure 5.6.** Quarter-turn worm-gear operator. (Courtesy of Flowseal, a unit of the Crane Valve Group)

weight of the operator would be impractical. In this case, gear operators are used. As shown in Figs. 5.6 and 5.7, *gear operators* (sometimes called *gearboxes*) use gearing to translate handwheel torque into high-output thrust, which is necessary to overcome the greater thrust requirements of larger flows or higher pressures. Linear-motion gearboxes use spur or beveled gearing, while rotary-motion gearboxes use rack-and-pinion or worm gearing. Gear operators use gears with ratios anywhere between 7:1 and 3:1. Both handwheels and cranks are used to turn the gears. The gearing is protected by the gearbox, which not only protects nearby personnel from the turning gears but also minimizes contact with atmospheric or outside conditions. Gear operators are normally bolted onto the bonnet or bonnet cap of linear-motion and some quarter-turn valves and bolted onto the body of butterfly and some ball valves. With linear-motion valves, the stem is threaded directly to the operator stem. With rotary-motion valves, the shaft end may be splined or squared and may intersect with the internal opening of a gear inside the gearbox. When a valve is installed in the line, its position may be difficult to determine without some type of positioner indicator. Most operators have a position indicator consisting of an



**Figure 5.7.** Internal view of quarter-turn worm-gear operator. Numbered parts are as follows: (1) seal-input shaft, (2) housing, (3) bearing, (4) washer, (5) plug, (6) worm gear, (7) worm pin, (8) gear segment, (9) indicator cap, (10) cover bolt, (11) stop adjustable screw, (12) hex nut, (13) cover, (14) gasket cover, (15) O-ring, (16) worm shaft, (17) roll pin. (Courtesy of Flowseal, a unit of the Crane Valve Group)

arrow and a matching position plate, which shows the position of the valve.

## 5.3 Pneumatic Actuators

### 5.3.1 Introduction to Pneumatic Actuators

The most commonly applied actuator is the pneumatically driven actuator, because the power source—compressed air—is relatively inexpensive when compared to a human resource or electrical or hydraulic power sources. For that reason, approximately 90 percent of all actuators in service today are driven by compressed air. When com-

pared to the cost of electromechanical and electrohydraulic actuators, pneumatic actuators are relatively inexpensive as well as easy to understand and maintain. Most are available as standard off-the-shelf products in a number of predetermined sizes corresponding to maximum thrust. Only in special services are special-engineered actuators produced, such as those applications requiring exceptionally long strokes, high stroking speeds, or severe temperatures. From a maintenance standpoint, pneumatic actuators are more easily serviced and calibrated than other types of actuators. Some pneumatic actuators are designed to be *field-reversible*, meaning that they can be converted from air-to-extend to air-to-retract (or visa versa) in the field without special tools or maintenance procedures. Although not as powerful as hydraulic actuators, pneumatic actuators can generate substantial thrust to handle a majority of applications, including high-pressure and high-pressure-drop situations. While air lines are not easy to install, the cost is less than installing electrical conduit and electrical lines as well as hydraulic hoses. Pneumatic actuators also bleed compressed air to atmosphere, which is environmentally safe, when compared to hydraulics. When pneumatic positioners are used with a pneumatic actuator, they are ideal for use in explosive and flammable environments since they do not depend upon electrical signals or power, which could potentially spark a fire if not explosion-proof or intrinsically safe.

The chief disadvantage of pneumatic actuators is that some response and stiffness are lost because of the compressibility of gases—especially with pneumatic actuators that use elastomers with large areas, such as diaphragms. This is not a factor, however, in the majority of applications that do not require a high degree of stiffness or response. With larger actuators, speed is an issue since the volume of the actuator must be filled with compressed air and/or bled to atmosphere to move. For this reason, larger actuators take longer to stroke from full retraction to full extension than smaller actuators, as shown in Table 5.1. Also, pneumatic actuators must be close to an air supply and are dependent upon the continued operation of a compressor unless a separate backup system or volume tank arrangement is installed. Although some designs are better than others, pneumatic actuators do have limits on the amount of thrust available, making some designs unlikely choices for high-pressure applications in large line sizes. Low thrust is commonly associated with diaphragm actuators since the diaphragms can only handle so much air pressure without failing, thus limiting their thrust capabilities.

**Table 5.1.** Actuator Stroking Times\*

Actuator Size (piston area in inches <sup>2</sup> /cm <sup>2</sup> )	Seconds to Maximum Stroke (0.25-inch/6 mm tubing)	Stroke Length (inches/cm)	Seconds Per Inch (2.5 cm) of Stroke
25/161	1.2	1.5/3.8	0.8
50/323	3.5	3/7.6	1.2
100/645	9.6	4/10.2	2.4
200/1290	20.8	4/10.2	5.2
300/1936	31.3	4/10.2	7.8

\*Data courtesy of Valtek International. Data based upon cylinder actuator design.



**Figure 5.8.** Single-acting diaphragm actuator.  
(Courtesy of Fisher Controls International, Inc.)

### 5.3.2 Pneumatic Actuator Design

The most commonly applied pneumatic actuator over the past 40 years has been the *diaphragm actuator* (Fig. 5.8). Most diaphragm actuators are designed for linear motion, although some rotary-motion designs exist. By definition, a typical diaphragm actuator is a single-acting actuator that provides air pressure to one side of an elastomeric barrier (called the *diaphragm*) to extend or retract the actuator stem, which is connected to the closure element. The diaphragm is sandwiched between upper and lower casings, either of which can be used to hold air pressure, depending on the style of the actuator.

In the single-acting design, the air chamber on one side of the diaphragm is opposed on the other side of the diaphragm by an internal spring, called the *range spring*, that allows the actuator to move in the opposite direction when the air pressure in the chamber is lessened. The range spring also acts as a fail-safe mechanism, allowing the actuator to return to either an open or closed position when the air supply to the actuator is interrupted. Depending on the configuration, the spring is installed next to the diaphragm or the diaphragm plate. The actuator stem is connected to the diaphragm plate and is supported through the top of the yoke with the assistance of a guide. As the diaphragm moves with increasing air pressure, the plate moves in a corresponding manner. That linear motion is directly transferred to the actuator stem, which moves the closure element in the valve. A *yoke* attaches the actuator to the valve body to show the position of the actuator and valve, to support the actuator stem, and to make the actuator-stem to valve-stem connection. It also provides a convenient place to attach accessories. With diaphragm actuators, the most common connection between the body and the actuator is a threaded yoke nut. A clamp is used to prevent the accidental rotation of the actuator stem with the valve stem. The clamp can also be equipped with a pointer that can indicate actuator or valve position.

With conventional single-acting diaphragm actuators, the air signal from the controller to the actuator has a dual role. First, it provides a positioning signal. Second, it provides the power to generate the thrust necessary to overcome the process forces, friction, gravity, the weight of the closure element, and the opposing force generated by the range spring.

Diaphragm actuators have both direct-acting and reverse-acting designs. With the direct-acting design (Fig. 5.9), air pressure is sent to the actuator, which extends the actuator stem and allows the valve to close. This also means that the actuator will retract its stem upon loss of air, allowing the valve to open and remain open. With the reverse-acting design (Fig. 5.10), as the air pressure is sent to the actuator, the



**Figure 5.9.** Direct-acting diaphragm actuator.  
(Courtesy of Fisher Controls International, Inc.)

stem retracts and the valve opens. If the supply or signal air pressure is interrupted, the actuator moves to the extended position, allowing the valve to close.

With the direct-acting design, air is introduced to the upper casing located above the diaphragm. Beneath the diaphragm are the diaphragm plate and the range spring. The range spring bottoms out in the bottom of the yoke, allowing the upper end of the spring to push against the diaphragm plate and subsequently the diaphragm. In this relaxed (or failure) position, the diaphragm is pushed into the area of the upper casing. As air is introduced into the upper casing and pressure builds, the diaphragm and plate push against the spring. As the signal pressure increases, the air pressure overcomes the opposing forces and the diaphragm and plate move downward. This movement allows the actuator stem to extend and the valve to move toward the closed position. Eventually as the full signal air pressure is reached and the resulting air pressure is introduced into the chamber, the diaphragm and plate reach their full travel. On the other side of the plate, the range spring is nearly fully compressed. At this point, the stem is at its full extension and the valve is closed at the full pressure end of the signal.





**Figure 5.10.** Reverse-acting diaphragm actuator. (Courtesy of Fisher Controls International, Inc.)

As the signal is lessened, resulting in lower air pressure in the chamber, the counterforce of the range spring begins to take effect, and the actuator moves to its relaxed state and the valve is opened.

With the reverse-acting design, the lower chamber is used to provide the air pressure to retract the actuator stem, while a reverse-acting spring is used to provide the counterforce, as well as the failure mode. The upper casing is static and only needs to retain the diaphragm and to vent displaced air volume to atmosphere. With this configuration, the lower casing is pressure retaining and requires an air connection to inject air into that chamber. The diaphragm plate is installed above the diaphragm. The range spring, which is still located below the diaphragm, is seated below the lower casing and is not in direct contact with the diaphragm and plate assembly. Instead, the range spring is seated on a retainer on the lower portion of the actuator stem. Because the range spring bottoms out (or in this case, tops out) at the bottom of the lower casing, as the actuator stem retracts with air to the lower chamber, the spring's resistance increases proportionately. As the actuator stem retracts, the valve begins to open. When the air sig-

nal is at the high end of the range, the actuator stem is fully retracted, and the range spring is almost completely compressed. When the signal changes and moves to the lower end of the range, the air pressure to the lower chamber is lessened. At that point, the range spring's counterforce begins to push the actuator stem to the relaxed (extended) state until the full extension is reached and the valve closes.

When positioners are used to improve the overall response of the actuator, three-way positioners can be installed that supply or exhaust air pressure to only one side of the diaphragm. Three-way positioners can be mounted on the actuator's yoke leg or can be integrally mounted inside the actuator, as shown in Fig. 5.11.

Diaphragm actuators are produced in several sizes, with a different diaphragm area for each size as well as several range-spring options. Each size has a given range of thrust that is available to overcome process forces, frictional forces, gravitational forces, and the range spring. Therefore, the actuator size has less to do with the process' line size than the service conditions. Whether the valve is used primarily for on-off service or throttling service has some bearing on the actuator size. With diaphragm actuators, the instrument signal can vary



**Figure 5.11.** Diaphragm actuator with integral three-way positioner. (Courtesy of Kammer Valves)

widely to accommodate power considerations. Although 3 to 15 psi (0.2 to 1.0 bar) is considered standard, diaphragm actuators can have signal ranges as high as 3 to 27 psi (0.2 to 1.9 bar) or 6 to 30 psi (0.4 to 2.1 bar). Diaphragm actuators are sized according to the square inches of the diaphragm. For example, a size 125 diaphragm actuator has a diaphragm of 125 square inches (in<sup>2</sup>).

The chief advantage of diaphragm actuators is that they are relatively inexpensive to produce and are commonly seen through the entire process industry. Although limited in high-thrust requirements, they are well suited to a good portion of applications in lower-pressure ranges, where thrust requirements are not so demanding. The basic single-acting design and method of operation are simple to understand. Because the positioning signal is also conveniently used to power the actuator, the expense of a positioner and tubing is not necessary. Without a positioner, an involved calibration process and the potential for mechanical difficulties associated with that device are not necessary. The lack of positioner also means that less moving parts, such as a positioner-to-actuator linkage, are involved that may cause potential maintenance problems. When used with linear-motion valves, the entire movement of the actuator stem is transferred directly to the valve's closure element. Because no tight dynamic seals, such as O-rings, are involved with the diaphragm, no breakout force is necessary during positioning, providing immediate and accurate response. Generally, diaphragm actuators are ideal for those applications in which precise positioning and immediate response are important and in which medium to low thrust is acceptable to overcome the process and valve forces.

Several disadvantages of the design should be noted. Because the diaphragm is relatively large, the subsequently large casing may present weight and height problems, especially when mounted on smaller valve sizes. This can cause problems with stress at the connection point between a small valve and an oversized actuator. Because of the restrictions in the elasticity of the diaphragm, its stem travel is limited. Strokes are somewhat short, when compared to other types of actuators. This poses a problem with special severe service trims in which a long stroke is necessary to provide a particular flow characteristic or provide a greater flow capacity through a stack or other trim device. Most diaphragm actuators have strokes of 2 in (5.1 cm) or less, although 4-in (10.2-cm) strokes are possible in some special designs. The largest drawbacks are the thrust and air-pressure restrictions of the diaphragm itself. Because the amount of force produced by the diaphragm actuator is proportional to the size of the actuator, the

physical size required for high thrusts is limited by the size of the diaphragm. Most diaphragms are rated for operation in the 20- to 30-psi (1.4- to 2.1-bar) range, therefore limiting the amount of air pressure acting on the diaphragm. For example, a size 125 diaphragm actuator operating with 30 psi (2.1 bar) air pressure can produce a maximum of 3750 lb of thrust (1700 kgf). For that reason, the only way to increase the thrust is to increase the size of the diaphragm, which results in a larger actuator and air chamber. In turn, this larger volume produces slower actuator speed and decreases overall response. The air-pressure limitations of the diaphragm also require the use of air regulators because the air pressure supplied by most plant compressors is between 80 and 125 psi (between 5.5 and 8.6 bar). If diaphragms could handle such high air pressures, the thrust capabilities of the example above would increase dramatically to 10,000 lb (4400 kgf) of thrust. Unfortunately, no diaphragm material has been developed that can provide such strength yet provide the required resilience to move through the full stroke. The thrust limitations of a diaphragm actuator can be overcome by using it with valve designs that can balance the process flow conditions, such as double-seated valves or pressure-balanced trim. Although the cost of such valve bodies may be higher than unbalanced designs, the cost may be negated by the smaller actuator.

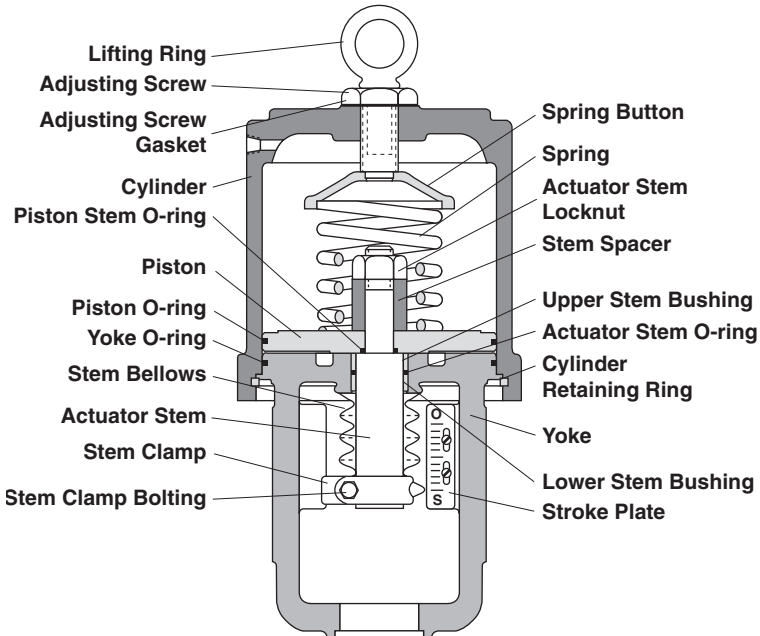
Generally, diaphragm actuators—because of the limitations of the diaphragm—do not provide exceptional stiffness and therefore have problems with fluctuations in the process flow. They also experience problems when throttling close to the seat, not having enough power to prevent the closure element from being pulled into the seat. The stiffness value of a diaphragm actuator is usually constant throughout the entire stroke. When the closure element is close to the seat, a sudden change or fluctuation in the process flow can cause the valve to slam shut, causing water-hammer effects.

From a maintenance standpoint, the life of diaphragm actuators is somewhat limited by the life of the diaphragm. If the diaphragm develops even a minor failure, the actuator is inoperable. Since the two casings are bolted together with numerous bolts, disassembly can be somewhat laborious and time consuming. Diaphragm actuators are not field-reversible, because different parts are required for the direct- and reserve-acting designs. Diaphragm actuators have about one-third more parts than other types of pneumatic actuators, which increases their cost somewhat.

Although the diaphragm actuator is the most common pneumatic actuator, the piston cylinder actuator (Fig. 5.12) is gaining widespread acceptance, especially as processes become more advanced and



**Figure 5.12.** Piston cylinder actuator. (Courtesy of Valtek International)

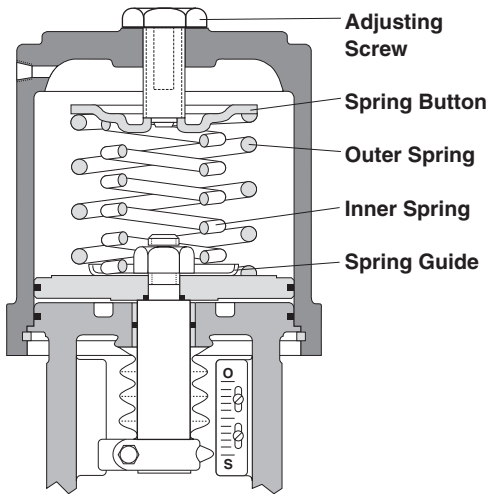


**Figure 5.13.** Internal view of piston cylinder actuator. (Courtesy of Valtek International)

demanding. As shown in Fig. 5.13, the *piston cylinder actuator* uses a sliding sealed plate (called the *piston*) inside a pressure-retaining cylinder to provide double-acting operation. With the double-acting design, air is supplied to both sides of the piston by a positioner. As with all double-acting actuators, a positioner must be used to take the pneumatic or electric signal from the controller and send air to one side of the piston while bleeding the opposite side until the correction position is reached. An opposing range spring is not necessary with the piston cylinder actuator, although a spring may be included inside the cylinder to act as a fail-safe mechanism. More information about the use and operation of positioners is found in Sec. 5.6.

Like diaphragm actuator designs, piston cylinder actuators can be used with either linear or rotary valves. Linear designs are the most efficient since the entire movement of the actuator stem is transferred directly to the valve stem. On the other hand, the rotary design must use some type of linear- to rotary-motion linkage. This can create some hysteresis and dead band because of the lost motion caused by the use of linkages or slotted levers.

The design of the linear cylinder actuator involves a cast yoke, which is used to make the connection to the valve body. It also provides room for the connection between the valve's stem and the actuator stem, attaches the cylinder mechanism to the valve, supports the actuator stem, and allows the installation of the positioner and other accessories. The cylinder can be made from either aluminum (for weight and machining considerations) or steel, based on the application. Fire-sensitive applications prefer the higher melting point of steel over aluminum. The inside of the cylinder is machined to a polished finish to allow for a good seal. The piston itself is a flat disk that is machined nearly to the inside diameter of the cylinder. An O-ring (or similar elastomer seal) fits inside a groove along the sealing edge of the piston. When the O-ring and piston are installed inside the cylinder, the cylinder wall is lubricated to allow a strong, sliding seal. If a fail-safe spring is required, it can be installed either above or below the piston. Unlike the diaphragm actuator that requires a different range spring for different opposing forces, the piston cylinder actuator spring is only needed for fail-safe operation. Therefore, only one heavy-duty spring is needed to cover most applications with the thrust requirements of that actuator size. For extremely high-pressure-drop-applications, a nested spring configuration (one spring inside another) can be used, as shown in Fig. 5.14. Spring compression is applied by the introduction of an adjusting bolt, which compresses the spring to the required return force. Adjusting bolts of different lengths can be used to vary the spring compression. The cylinder is installed above the yoke with either a snap-ring arrangement or bolting.



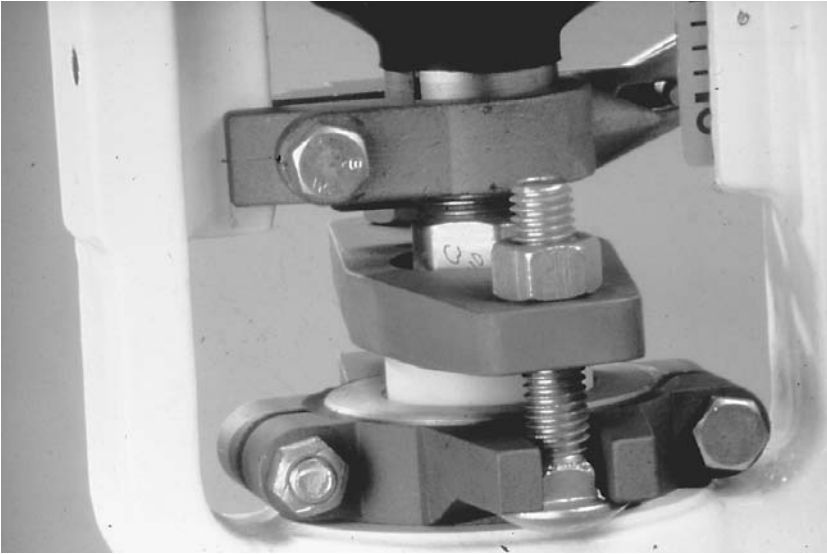
**Figure 5.14.** Piston cylinder actuator with dual springs. (Courtesy of Valtek International)

The actuator stem is attached to the piston and is supported by the top of the yoke with guides. It is sealed from the lower chamber with an O-ring. With piston cylinder actuators, the most common connection between the body and the actuator is a two-piece yoke clamp (Fig. 5.15). This permits a tight connection without larger threads to contend with, which can be a problem with atmospheric corrosion. A clamp is used to prevent the accidental rotation of the actuator stem with the valve stem. The clamp can also be equipped with a pointer to indicate actuator or valve position.

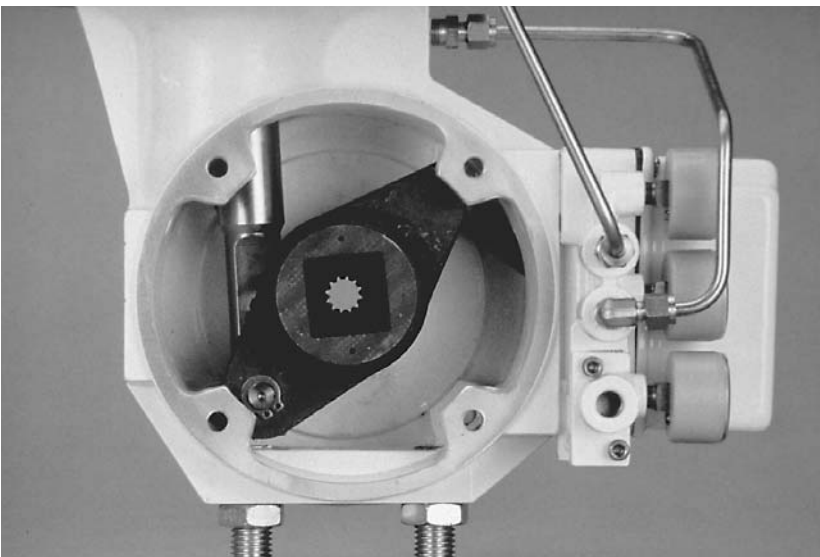
Most rotary designs use some type of linkage to transfer linear motion to rotary action. Figure 5.16 shows one common design in which a splined lever is attached to the valve's shaft and has a pivot point on the actuator stem to minimize hysteresis. Such a design requires a sliding seal to allow for the rocking motion of the piston, which will rock slightly as the actuator stem rotates with the travel of the lever. As shown in Fig. 5.17, another common rotary piston cylinder design uses a slotted lever that intersects a pinned actuator stem. This design avoids the rocking piston and its requirement for a sliding seal, although it does have potential for some slight hysteresis and dead band because of the slotted-lever design. With this design, the heavy-duty return spring is placed in a separate housing, opposite the cylinder.

Piston cylinder actuators are reversible, meaning that the same actuator can be modified for either air-to-close (actuator stem extends) or air-



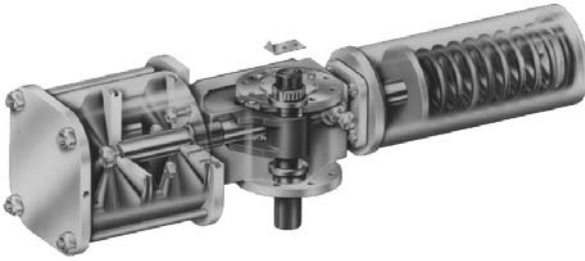


**Figure 5.15.** Two-piece yoke clamp connection between yoke and bonnet.  
(Courtesy of Valtek International)

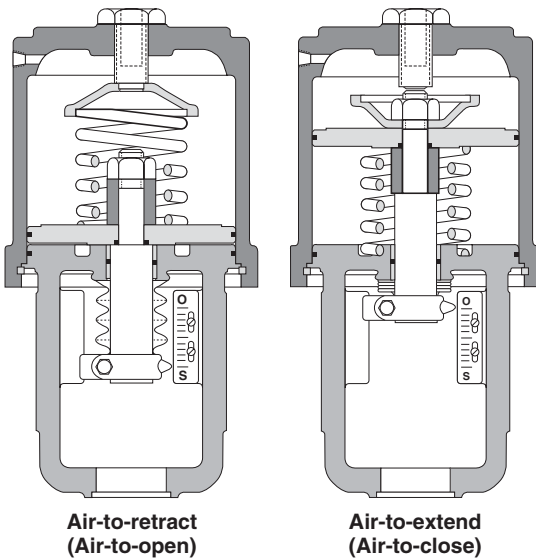


**Figure 5.16.** Splined clamp connection between rotary actuator and shaft.  
(Courtesy of Valtek International)





**Figure 5.17.** Slotted-lever and pinned actuator-stem connection between rotary actuator and shaft. (Courtesy of Automax, Inc.)



**Figure 5.18.** Air-to-retract and air-to-extend configurations for piston cylinder actuators. (Courtesy of Valtek International)

to-open (actuator stem retracts), as shown in Fig. 5.18. With air-to-close designs, the spring is placed below the piston and is held in place by a ringed groove in the top of the yoke.

The operation of piston cylinder actuators is quite simple. As an air-to-close signal is sent from the controller to the positioner, the positioner sends air to the cylinder's upper chamber above the piston, while the positioner bleeds a comparable amount of air from the lower

chamber below the piston. The changing pressures in these two chambers cause the piston to move downward. Subsequently the actuator stem moves downward, as does the valve stem. As the signal changes to “open,” the air pressure in the lower chamber builds, while the air pressure in the upper chamber is bled off, allowing the piston to move upward. Therefore the valve’s closure element opens. If the signal or power supply is lost, the piston is assisted by the fail-safe spring and moves to its relaxed position. In air-to-close configurations, the relaxed state is with the stem retracted. In air-to-open configurations, the relaxed state is with the stem extended.

The primary advantage of cylinder actuators is the higher thrust capability, size for size, over comparable diaphragm actuators. Because the cylinder actuator with a positioner does not need to use air supply as a signal, the plant’s full air-supply pressure can be used to power the actuator. The piston with its sliding O-ring seal is much more capable of handling greater air pressure than the diaphragm. To demonstrate the significance of this difference, a piston cylinder actuator with a piston of 25 in<sup>2</sup> (161 cm<sup>2</sup>) used with an 80-psi (5.5-bar) air supply is capable of producing 2000 lb of thrust (910 kgf). Assuming a 6- to 30-psi (0.4- to 2.1-bar) range, a comparable diaphragm actuator would only generate 750 lb (340 kgf) of thrust using the 30-psi (2.1-bar) air supply. A far larger diaphragm actuator would be needed to provide the same thrust requirement as the piston cylinder actuator.

Piston actuators, which have smaller chambers to fill with higher pressures of air, have faster stroking speeds than diaphragm actuators, which must fill larger chambers with lower pressures of air. For example, a size 25 piston cylinder actuator can stroke 1.5 in (3.8 cm) in less than 1 s, while a diaphragm actuator takes over 2 s to stroke the same distance.

Generally, cylinder actuators can be operated with air supplies as high as 150 psi (10.3 bar) or as low as 30 psi (2.1 bar). A side benefit to a piston cylinder actuator handling up to 150-psi (10.3-bar) plant air is that air regulators are not required. For diaphragm actuators such regulators are necessary since they cannot handle plant air normally beyond 40 psi (2.8 bar).

Placing air pressure on both sides of the piston also permits greater actuator stiffness, meaning that the actuator can hold a position without being influenced by fluctuation of the process flow. This is especially important with globe or butterfly valves when the plug or disk is being throttled close to the seat and the “bathtub stopper effect” (Sec. 9.6) can take place. Single-acting actuators have difficulty with the bathtub stopper effect because the range spring (which provides

the counterforce) may not be strong enough to prevent it from happening. Stiffness of piston cylinder actuators can be calculated by using the following equation:

$$K = \frac{kPA^2}{v}$$

where  $K$  = stiffness

$k$  = ratio of specific heat

$P$  = supply pressure

$A^2$  = piston area

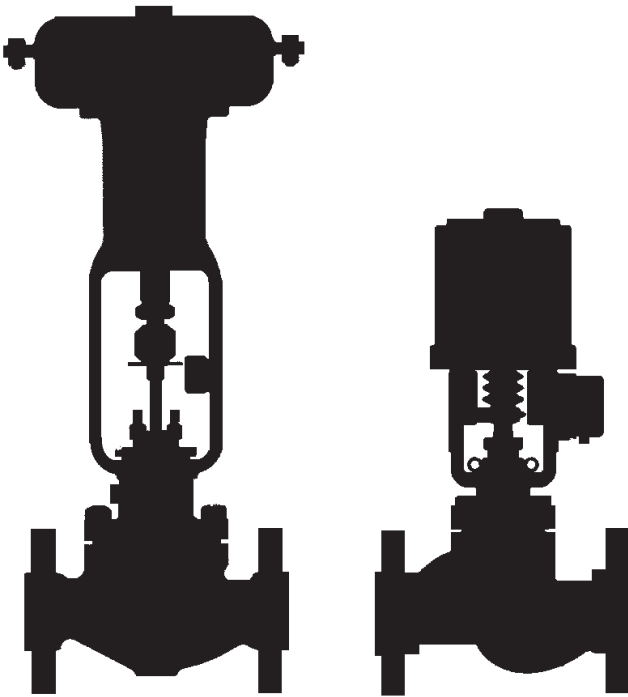
$v$  = cylinder volume under the piston

To illustrate how drastic the stiffness rates vary between piston cylinder actuators and diaphragm actuators, a comparison can be made using a piston cylinder actuator with a 25-in<sup>2</sup> (161-cm<sup>2</sup>) piston, which is typical for a 2-in (DN 50) globe valve. With a supply pressure of 100 psi (6.9 bar) and a 0.75-in (1.9-cm) stroke, the stiffness value at midstroke would be 9333 lb/in (1667 kg/cm). In comparison, a diaphragm actuator with a 46-in<sup>2</sup> diaphragm (296 cm<sup>2</sup>), which is required for a 2-in valve, only has a stiffness value of 920 lb/in (164 kg/cm). In addition, as the closure element approaches the closed position with a very close throttling position, the reduced volume in the bottom of the cylinder provides for increased and exceptional stiffness. With the 25-in actuator example used earlier, if the plug in a globe valve is 0.125 in (0.3 cm) away from the seat, the piston is only 0.375 in (1 cm) away from the top of the yoke. That would yield over 18,000 lb/in (3214 kg/cm) of stiffness. For that reason, piston cylinder actuators are preferred when process fluctuations occur or if throttling close to the seat is required by the application.

As a general rule, piston cylinder actuators are much more compact, being smaller in height and weight, than diaphragm actuators—an important consideration with installation, maintenance, and seismic requirements. Of course, the size difference is highly accentuated when larger-diaphragm actuators are needed to generate higher thrusts. A height comparison of comparable actuators is shown in Fig. 5.19.

Another consideration is the length of the stroke. With spring cylinder actuators, the stroke is only limited by the height of the cylinder, permitting longer strokes than diaphragm actuators, which are restricted by the resilience limitations of a diaphragm.

Due to the accuracy associated with the positioner, piston cylinder actuators generally perform better than diaphragm actuators, with virtually no hysteresis, highly accurate signal response, and excellent linearity.



**Figure 5.19.** Height comparison between comparable diaphragm (left) and piston (right) cylinder actuators. (Courtesy of Valtek International)

Piston cylinder actuators have some drawbacks. First, if the actuator remains in a static position for some time, some breakout force may be necessary to move the piston when a signal is eventually sent. When considering the added thrust and response associated with piston cylinder actuators, this breakout torque may not be noticeable. The requirement of a positioner does add expense to the actuator—although with less parts, the actuator itself is less expensive than a diaphragm actuator. A positioner also requires calibration. As discussed in Sec. 5.6, positioners can present problems with exposed linkage and fouled air passages.

A recent modification of the piston cylinder actuator, a similar design that features a canister assembly and an integral positioner, is shown in Fig. 5.20. Instead of using a dynamic piston, the piston is static and the chambers are dynamic. As shown in Fig. 5.21, the entire

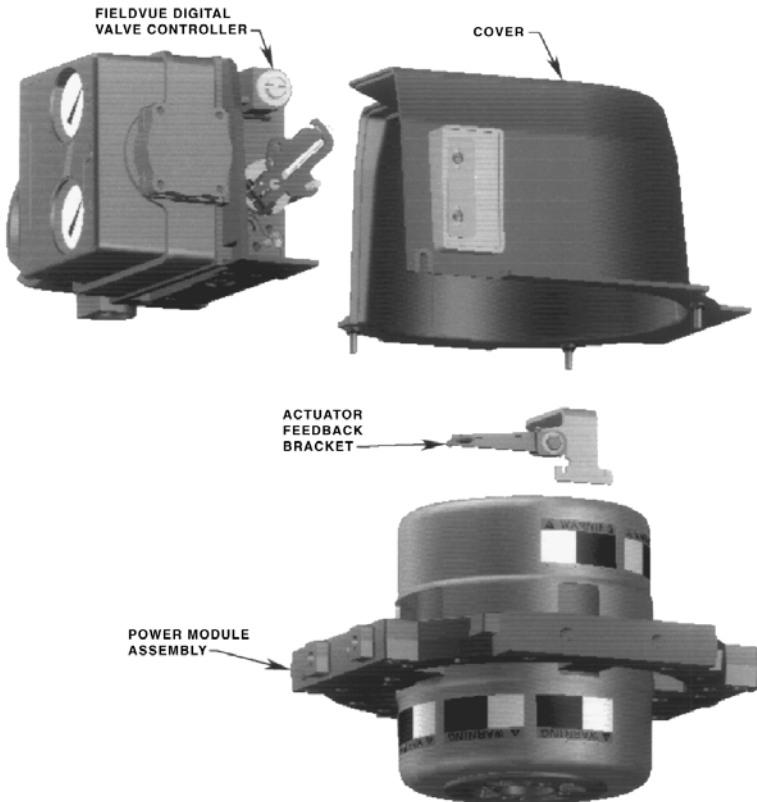


**Figure 5.20.** Piston cylinder actuator with canister assembly and integral positioner. (Courtesy of Fisher Controls International, Inc.)

canister assembly is held in place by the upper and lower casings. As the upper chamber moves, the integral positioner (which is encased in the upper casing) has a follower arm that can receive position feedback by the top of the chamber. Instead of tubing, special air chambers channel air to either the lower or upper chamber.

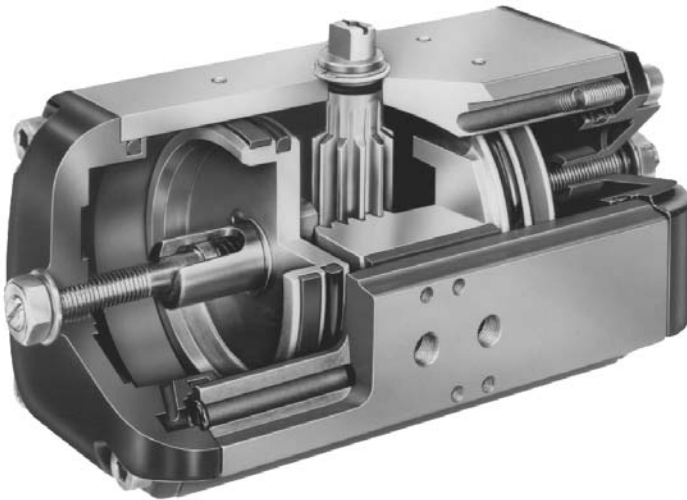
This design provides a low-profile, compact actuator without the problems associated with external linkage between the actuator and the positioner. With internal air passages, tubing is eliminated—reducing the possibility of damaged tubing or leaking connections. The only disadvantage of this design is that the canister assembly is not designed to be disassembled. The need for a spare part involves the entire assembly, which is far more costly than replacing typical soft goods.

Another commonly applied pneumatic actuator is the *rack-and-pinion actuator*, which is used to effectively transfer the linear motion of piston cylinder actuators to rotary action. Rack-and-pinion actuators are used extensively for actuating quarter-turn valves (ball, plug, and butterfly valves). As shown in Fig. 5.22, two pistons are placed on each end of a one-piece housing, typically extruded aluminum or stainless steel. Each



**5.21.** Internal view of piston cylinder actuator with canister assembly and integral positioner. (Courtesy of Fisher Controls International, Inc.)

piston is connected to a *rack*, a series linear teeth, that move in a linear motion with the piston. In most cases, the rack is an integral part of the piston itself. Sandwiched between the two racks is the *pinion*, which is a shaft equipped with linear teeth. The shaft is connected directly to the valve stem. With direct-acting rack-and-pinion actuators, as air is applied to the two outer pressure chambers, the pistons move toward the inner chamber, exhausted to atmosphere. As shown in Fig. 5.23, when the two pistons move toward each other, the attached racks move in opposite directions, allowing the rack teeth to drive the teeth of the pinion in a counterclockwise rotational manner. As shown in Fig. 5.24, when increasing air pressure is directed to the inner chamber and the outer chambers are exhausted, the pistons move away from each other and the pinion is driven in a clockwise direction.



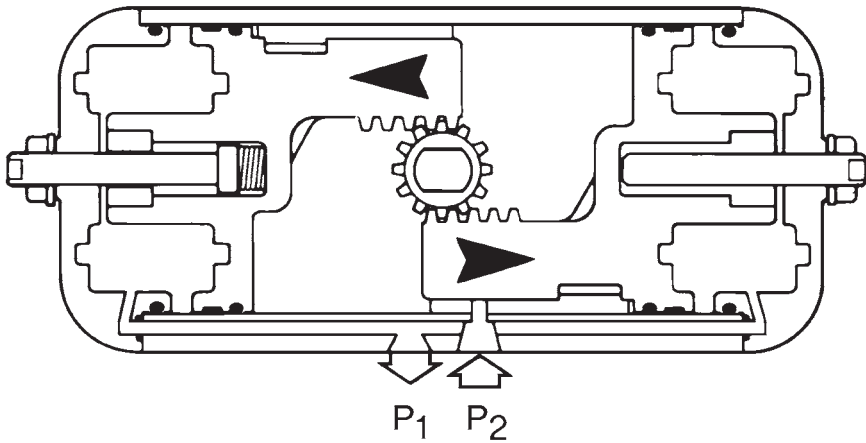
**Figure 5.22.** Double-acting rack-and-pinion rotary actuator.  
(Courtesy of Automax, Inc.)

Rack-and-pinion actuators can be equipped with internal springs to allow the actuator to achieve a failure mode (fail-clockwise, fail-counter-clockwise) when the air supply or signal is lost. They are also field-reversible by removing the end caps and rotating the pistons 180°. Rack-and-pinion actuators can also be provided with travel stops to allow for precise adjustment of the open and closed positions of the valve.

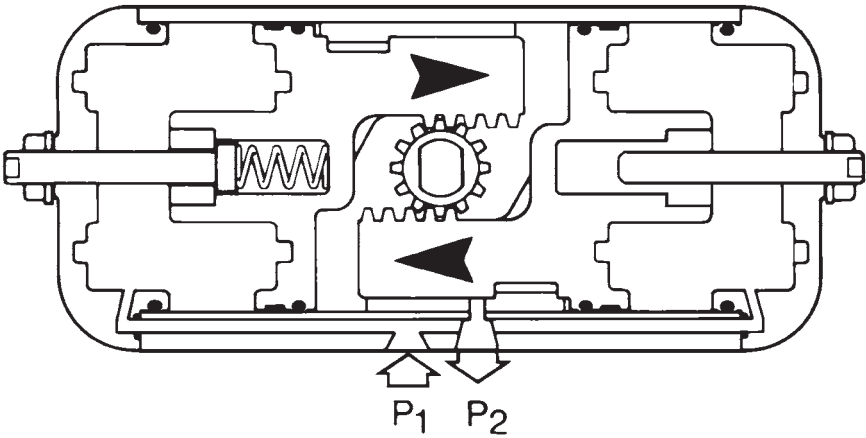
Overall, rack-and-pinion actuators are ideal for automating manually operated rotary valves: They are compact, allow for field reversibility, provide adequate torque for most standard operations, and are easy to maintain and to understand.

Another common, inexpensive double-acting actuator is the *vane actuator*, which uses a pie-shaped pressure-retaining housing and a rectangular piston, called the *vane*, to seal between the two pressure chambers (Fig. 5.25). As with rack-and-pinion actuators, vane actuators are commonly used with quarter-turn valve applications.

The housing is divided into two halves and is pie-shaped to allow the vane to move the 90° required for quarter-turn operation. The vane is pinned to the actuator shaft, avoiding excessive hysteresis and dead band. The vane seals the two pressure chambers with an O-ring. Generally the design does not permit the inclusion of a spring. Instead, a pneumatic fail-safe system is often used in place of the spring. The



**Figure 5.23.** Counterclockwise action of rack-and-pinion actuator.  $P_1$  = upstream pressure;  $P_2$  = downstream pressure. (Courtesy of Automax, Inc.)



**Figure 5.24.** Clockwise action of rack-and-pinion actuator.  $P_1$  = upstream pressure;  $P_2$  = downstream pressure. (Courtesy of Automax, Inc.)

double-acting design requires the use of a positioner for throttling applications; each pressure chamber has an air connection for increasing or exhausting air pressure.

The operation of the vane actuator can be reversed by simply removing the actuator from the valve and installing it upside down (since both ends of the actuator have universal mounting). Limit-stops can be included on both ends of the housing to limit the motion of the vane.





**Figure 5.25.** Vane rotary actuator. (Courtesy of Xomox/Fisher Controls International, Inc.)

The advantages of the vane actuator are its simple design with few moving parts, no hysteresis, low cost, minimal weight, and compact size. The chief disadvantage of the vane actuator is that it only generates relatively low torque values when compared to other designs; therefore, vane actuators are commonly applied to low-pressure applications. In addition, the two-piece housing with a joint down the middle provides a possible leak path between air chambers.

## **5.4 Nonpneumatic Actuators**

### **5.4.1 Electric Actuators**

Electric motors installed on process valves were one of the first types of actuators used in the process industry. Such electric actuators have been used since the 1920s, although the designs have improved dramatically since those early days, especially in terms of performance, reliability, and size. In basic terms, the electric actuator consists of a reversible electric motor, control box, gearbox, limit switches, and other controls (such as a potentiometer to show valve position).

The chief applications for electric actuators are in the power and nuclear power industries, where high-pressure water systems require smooth, stable, and slow valve stroking.

The main advantages of electric actuators are the high degree of stability and constant thrust available to the user. In general, the thrust capability of the electric actuator is dependent on the size of the electric motor and the gearing involved. The largest electric actuators are capable of producing torque values as high as 500,000 lb (225,000 kgf) of linear thrust. The only other comparable actuator with such thrust capabilities is the electrohydraulic actuator, although the electric actuator is much less costly.

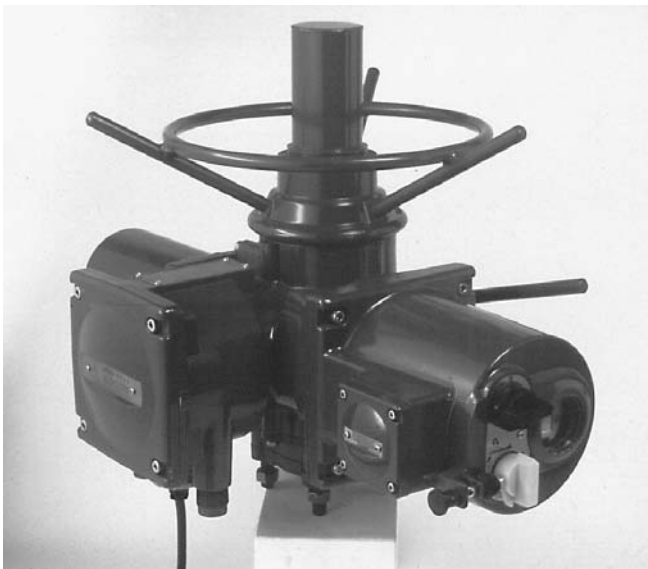
Stiffness is far better with electric actuators, because no compressibility of air is involved with the electric actuator. One additional benefit of an electric actuator is that it always fails in place upon loss of electrical power, whereas a pneumatic actuator requires a complex fail-in-place system. Since fluids (such as air or hydraulics) are not required to power the actuator, leaks and tubing costs are not factors.

The disadvantage of electric actuators is their relative expensive cost when compared to the more commonly applied pneumatic actuators. Also, they are much more complex—involving an electric motor, electrical controls, and a gearbox—therefore much more can go wrong. An electric motor is not conducive to flammable atmospheres unless stringent explosion-proof requirements are met. When high amounts of torque or thrust are required for a particular valve application, an electric actuator can be quite large and heavy, making it more difficult to remove from the valve. Depending upon the gear ratios involved and the pressures involved with the process, an electric actuator can be quite slow, when compared to electrohydraulic actuators or even pneumatic actuators. It can also generate heat, which may be an issue in enclosed spaces. If the torque or limit switches are not set correctly, the force of the actuator can easily destroy the regulating element of the valve.

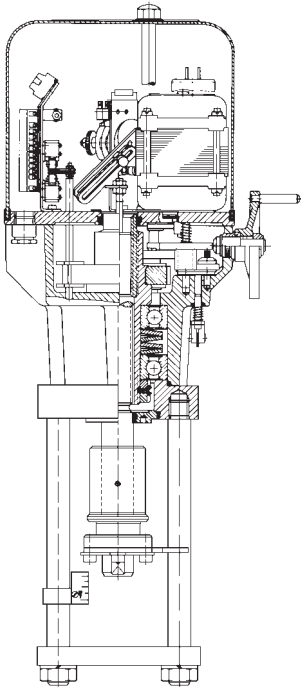
Based on the thrust requirements, electric actuators are available in compact, self-contained packages (Fig. 5.26), as well as larger units with direct-drive handwheels (Fig. 5.27). As shown in Figs. 5.28 and 5.29, the basic design of the electric actuator consists of the electric motor, the gearbox or gearing, the electrical controls, limit or torque switches, and the positioning device. By design, electric motors are more efficient at their maximum speed; therefore, most electric actuators use some type of mechanical device, such as a hammer blow yoke nut, to engage the load after the motor has achieved its full speed. This is especially important since the largest amount of thrust or torque is



**Figure 5.26.** Compact electric actuator.  
(Courtesy of Kammer Valves)



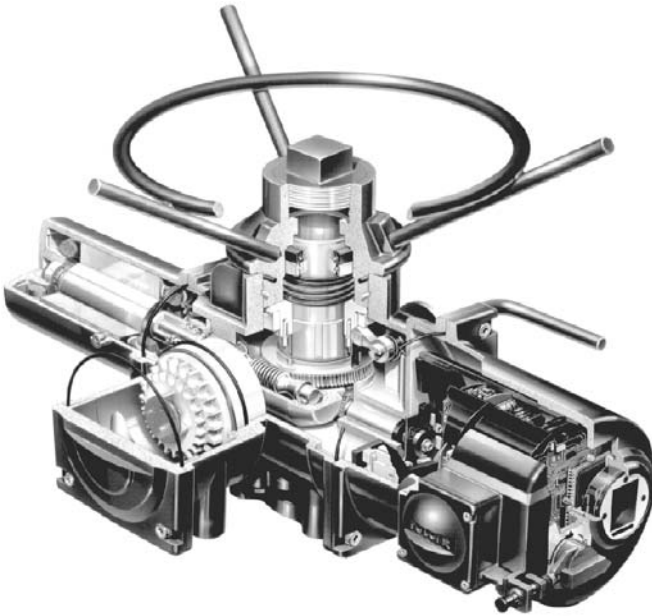
**Figure 5.27.** Electric actuator with direct-drive handwheel.  
(Courtesy of Rotork Controls Inc.)



**Figure 5.28.** Internal view of compact electric actuator. (Courtesy of Kammer Valves)

required at the opening or closing of the valve. For the actuator to operate in both directions, the motor must be reversible to open and close the valve. For efficiency reasons, electric motors operate best at high revolutions per minute (1000 to 3600 r/min). Therefore, gearing is used to reduce the stroking speed for use with valves. The gearbox uses worm gearing to make the reduction and is totally encased in an oil bath for maximum life of the gears.

Because of the exceptional stiffness and torque associated with electric actuators, the valve can overstroke if the actuator is not adjusted correctly—and possibly damage or destroy the regulating element or limit the stroke of the valve. To avoid overtravel, limit switches are used to shut off the motor when the open or closed position is reached. Torque switches can also be used to shut off the motor when the torque resistance increases as the closed or open positions are reached. The added benefit of the torque switch is that if an object is caught in the regulating element or if the valve is binding, the actuator will shut off rather than apply thrust to reach the closed position and further damage the valve.



**Figure 5.29.** Internal view of electric actuator with direct-drive handwheel. (Courtesy of Rotork Controls Inc.)

Ideally, torque switches are best used with valves that have floating seats (such as ball or wedge gate valves), while limit switches are best used with valves with fixed seats (such as globe or butterfly valves).

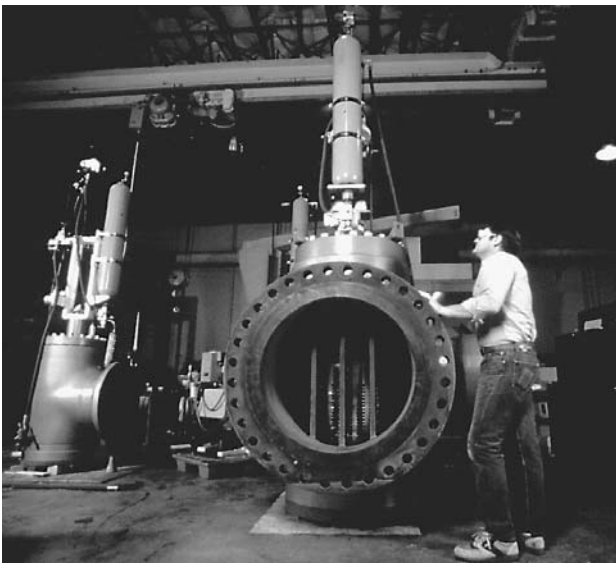
The electrical controls can be accessed on the valve itself or controlled at a remote location using extended electrical lines. Either handlevers or buttons are provided to operate the electric motor. With the handlever, turning the lever clockwise extends the actuator stem, while counterclockwise retracts the stem. Placing the handlever in the middle position shuts off the motor and maintains that particular valve position. With button controls, three buttons are used in the normal configuration: one to extend the actuator stem, one to retract, and another to stop the motor. Red and green lights are used to show the user if the valve is in the open position (usually green) or closed position (usually red). When the motor is in operation, both lights are on.

Electric actuators, in smaller sizes, operate using 110 to 120 V ac, 60-Hz, single-phase power, drawing anywhere between 3 and 30 A. Larger electric actuators use 220 to 240 V, three-phase, 50- or 60-Hz power supply—or 125 or 250 V dc. This may require drawing up to 300 A. Exceptionally large actuators may require even greater voltage (up to 480 V ac).

When manual operation or manual override is needed, most electric actuators allow for the electric motor to be disengaged. A declutchable handwheel can then be used to position the valve manually. Because of the complex electrical and mechanical nature of electric actuators, most calibration adjustments and recommended servicing are made at the manufacturer's factory or an authorized service center.

#### 5.4.2 Hydraulic and Electrohydraulic Actuators

When exceptional stiffness and high thrust are required—as well as fast stroking speeds—hydraulic and electrohydraulic actuators are specified. *Hydraulic actuators* use hydraulic fluid above and below a piston to position the valve. Hydraulic pressure can be supplied by an external plant hydraulic system (Fig. 5.30). Its design is similar to a cylinder actuator, with a cylinder and a piston acting as a divider between the two chambers. Hydraulic actuators do not have a failure spring, so providing a failure action requires a series of tripping systems, which are very complex and require special engineering. On the other hand, an *electrohydraulic actuator* uses a hydraulic actuator—rather than use an external hydraulic system, it has a self-contained



**Figure 5.30.** Hydraulic actuator mounted on a severe service valve. (Courtesy of Valtek International)

hydraulic source that is a physical part of the actuator. An electrical signal feeds to an internal pump, which uses hydraulic fluid from a reservoir to feed hydraulic fluid above or below the piston.

The advantage of using hydraulic and electrohydraulic actuators is that they are exceptionally stiff because of the incompressibility of liquids. This is important with those throttling applications that can be unstable when the regulating element is close to the seat. In some cases, these actuators are used in valves with traditionally poor rangeability, such as butterfly valves. When specially engineered, they can be designed to have exceptionally fast stroking speeds, sometimes closing long strokes in under a second—which makes them ideal for safety management systems. The chief disadvantages of hydraulic and electrohydraulic actuators are that they are expensive, large and bulky, highly complex, and require special engineering.

## 5.5 Actuator Performance

### 5.5.1 Performance Nomenclature

A number of technical terms are used to describe the performance capabilities of an actuator.

*Hysteresis* is a common term used to describe the amount of position error that occurs when the same position is approached from opposite directions. *Repeatability* is similar to hysteresis, although it records the maximum variation of position when the same position is approached from the same direction. Typically hysteresis and repeatability readings can be anywhere between 0.25 and 2.00 percent of the full stroke of the actuator. *Response level* is the maximum amount of input change required to create a change in valve-stem position (in one direction only). Typically response levels can be anywhere between 0.1 to 1.0 percent of full stroke. *Dead band* is a term used to describe the maximum amount of input that is required to create a reversal in the movement of the actuator stem. Typical dead-band measurements can fall between 0.1 and 1.0 percent of the full stroke. *Resolution* describes the smallest change possible in a valve-stem position. Typical resolution is between 0.1 and 1.0 percent full stroke.

*Steady-state air consumption* applies to actuators with positioners in which the positioner consumes a certain amount of air pressure to maintain a required position. Depending on the positioner design, typical steady-state air consumption can vary anywhere between 0.2 and 0.4 SCFM (standard cubic feet per minute) (between 1.6 and 3.2 cm<sup>3</sup>/min) at 60 psi (4.1 bar). *Supply-pressure effect* describes the change

of the actuator stem's position for a 10-psi (0.7-bar) pressure change in the supply [for example, if a 50-psi (3.5-bar) supply is increased suddenly to a 60-psi (4.1-bar) supply]. Typical supply-pressure effects can vary anywhere between 0.05 and 0.1 percent of the full stroke of the actuator. *Open-loop gain* is the ratio of the imbalance that occurs when an instrument signal change is made and the actuator stem is locked up. Typical open-loop gains can be anywhere between 550:1 to 300:1 at 60-psi (4.1-bar) supply. *Stroking speed* is defined as the amount of time, in seconds, that an actuator requires to move from the fully retracted to the fully extended position. Stroking speed depends on the length of the stroke, the volume of the pressure chambers, the air supply, and internal resistance of the actuator itself.

*Frequency response* is a response to a system or device to a constant-amplitude sinusoidal input signal. In other words, it is a measurement of how fast a system can keep up with a changing input signal. When frequency response is calculated, the output amplitude and phase shifts are recorded at a number of frequencies. They are then recorded as a function of input signal frequency. *Independent linearity* is the maximum amount that an actuator stem will deviate from a true straight linear line. Typical linearity can vary anywhere between  $\pm 1.0$  and  $\pm 2.0$  percent.

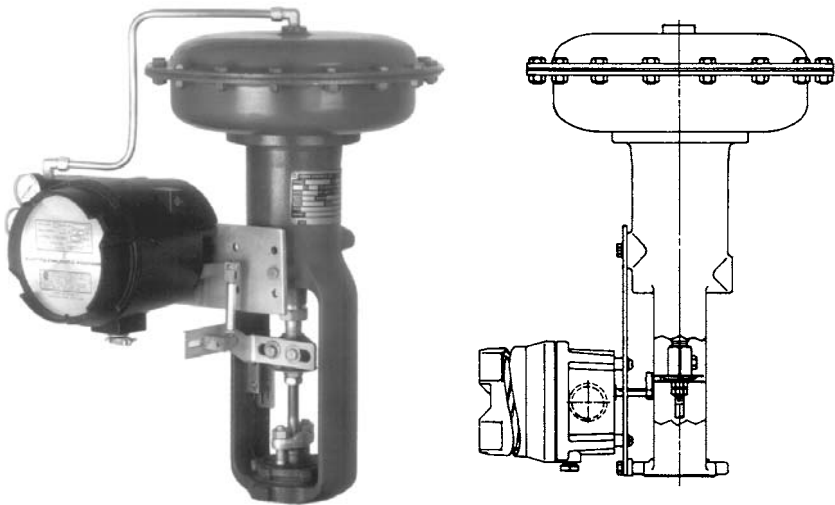
*Maximum flow capacity* is the volume of air pressure that can flow into an actuator during a particular time period. This is recorded in standard cubic feet per minute (SCFM) or in cubic centimeters per minute.

## 5.6 Positioners

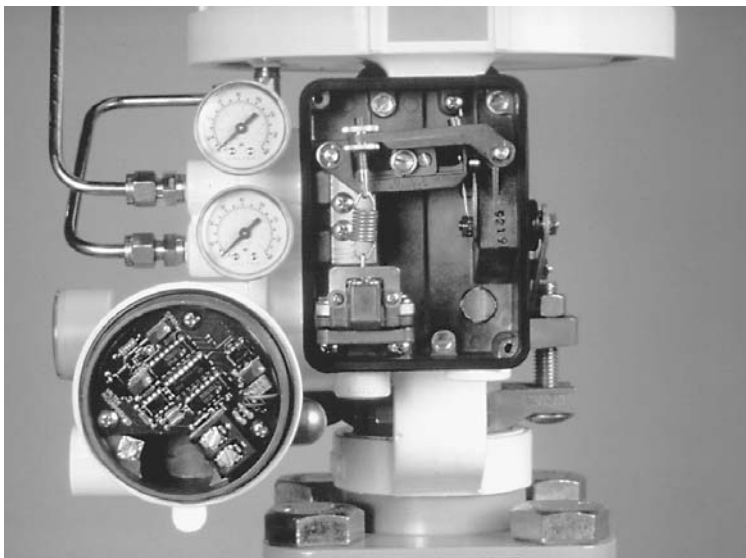
### 5.6.1 Introduction to Positioners

By definition, a *positioner* is a device attached to an actuator that receives an electronic or pneumatic signal from a controller and compares that signal to the actuator's position. If the signal and the actuator position differ, the positioner sends the necessary power—usually through compressed air—to move the actuator until the correct position is reached. Positioners are found in one of two designs. *Three-way positioners* (Fig. 5.31) send and exhaust air to only one side of a single-acting actuator that is opposed by a range spring. *Four-way positioners* (Fig. 5.32) send and exhaust air to both sides of the an actuator, which is required for double-acting actuators. A four-way positioner can be used as a three-way positioner by plugging one of the positioner-to-actuator air-supply lines on the positioner itself.





**Figure 5.31.** Three-way electropneumatic positioner mounted on a diaphragm actuator. (Courtesy of Fisher Controls International, Inc.)



**Figure 5.32.** Four-way electropneumatic positioner mounted on a piston cylinder actuator (without covers). (Courtesy of Valtek International)

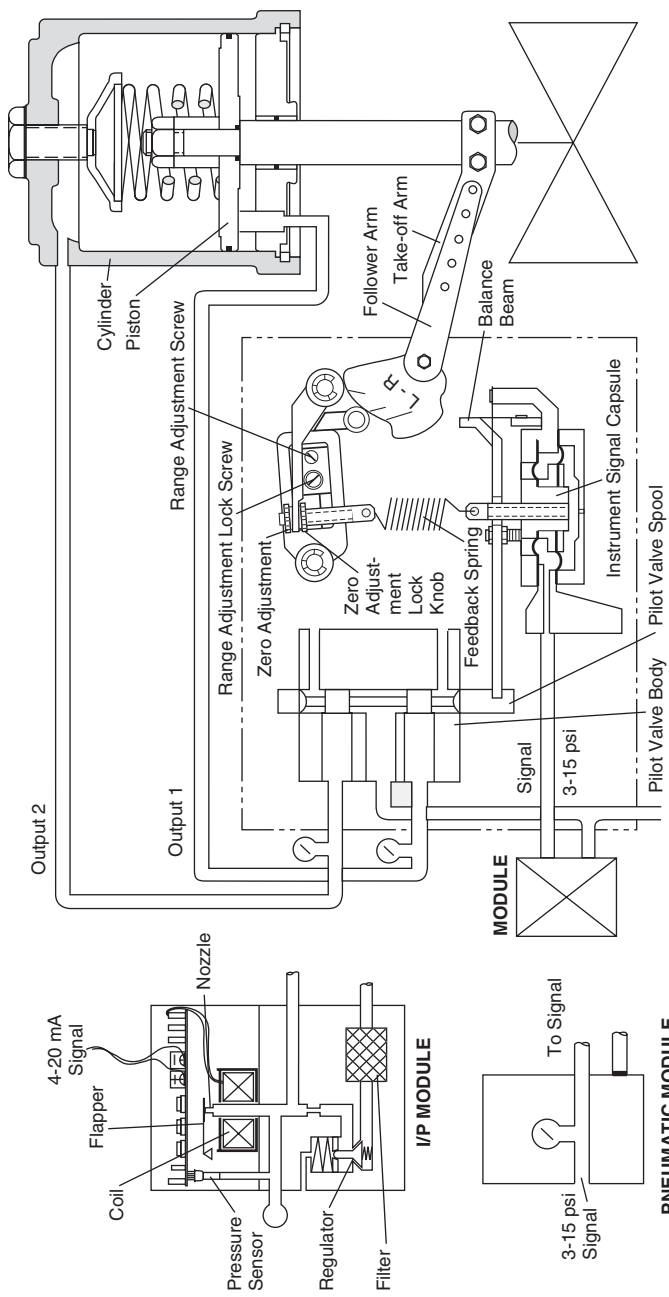
When a position signal is sent from a controller, positioners can receive either electronic signals with ranges of 4 to 20 mA and 10 to 50 mA or pneumatic signals with ranges of 3 to 15 psi (0.2 to 1.0 bar) or 6 to 30 psi (0.4 to 2.1 bar). The term *range* is used to show the region between the lower and upper signal limits. A *span* is defined as the difference between the lower and upper limits of the signal. For example, for a range of 3 to 15 psi (0.2 to 1.0 bar), the span is 12 psi (0.8 bar). Internal feedback springs (sometimes called *range springs*) are used inside the positioner to help determine the correct span. *Split range* is the term used to indicate a partial use of a range, such as a 3- to 9-psi (0.2- to 0.6-bar) signal or a 12- to 20-mA signal. In some designs, a split range can be achieved by adjusting a zero or range adjustment on the positioner, while in others a new range spring is required.

As the use of distributive control systems has increased in the past decade, so has the need for electropneumatic (I/P) positioners to handle the milliampere-current control signals. I/P positioners are capable of converting the milliampere signal to an equivalent pneumatic signal, which can then operate the pilot valve of the positioner.

### 5.6.2 Positioner Operation

Positioning is based on balancing the force between the incoming signal from the controller and the actuator positioner. In other words, the positioner works to balance two forces: first, the force proportional to the incoming instrument signal, and second, the force proportional to the actuator's stem position. As shown in Fig. 5.33, an incoming instrument signal is received by the positioner. If this signal is a milliampere signal, a conversion to a pneumatic signal must take place through the use of a *transducer*. The transducer consists of a feedback loop of a pressure sensor, electromagnetic pressure modulator, and necessary electronics. The pressure modulator consists of a flapper that can open or close an air nozzle. The flapper itself moves when attracted by an electromagnet. As the signal moves the electromagnet, the flapper moves accordingly, creating a proportional air signal to the positioner. The transducer can also include a small air regulator to assist in providing the proper air pressure for the pneumatic signal. If the positioner accepts a pneumatic signal, that signal is sent directly to the positioner.

As the pneumatic signal changes, the air pressure inside the instrument signal capsule also changes, causing a repositioning of the pilot valve. As the pilot valve opens, air is supplied or exhausted to one side of the actuator (three- and four-way positioners). In four-way



**Figure 5.33.** Positioner schematic for linear actuator (air-to-retract). (Courtesy of Valtek International)

positioners working with double-acting actuators, the opposite action occurs on the opposing side. If air is increased on one side, the other side must exhaust.

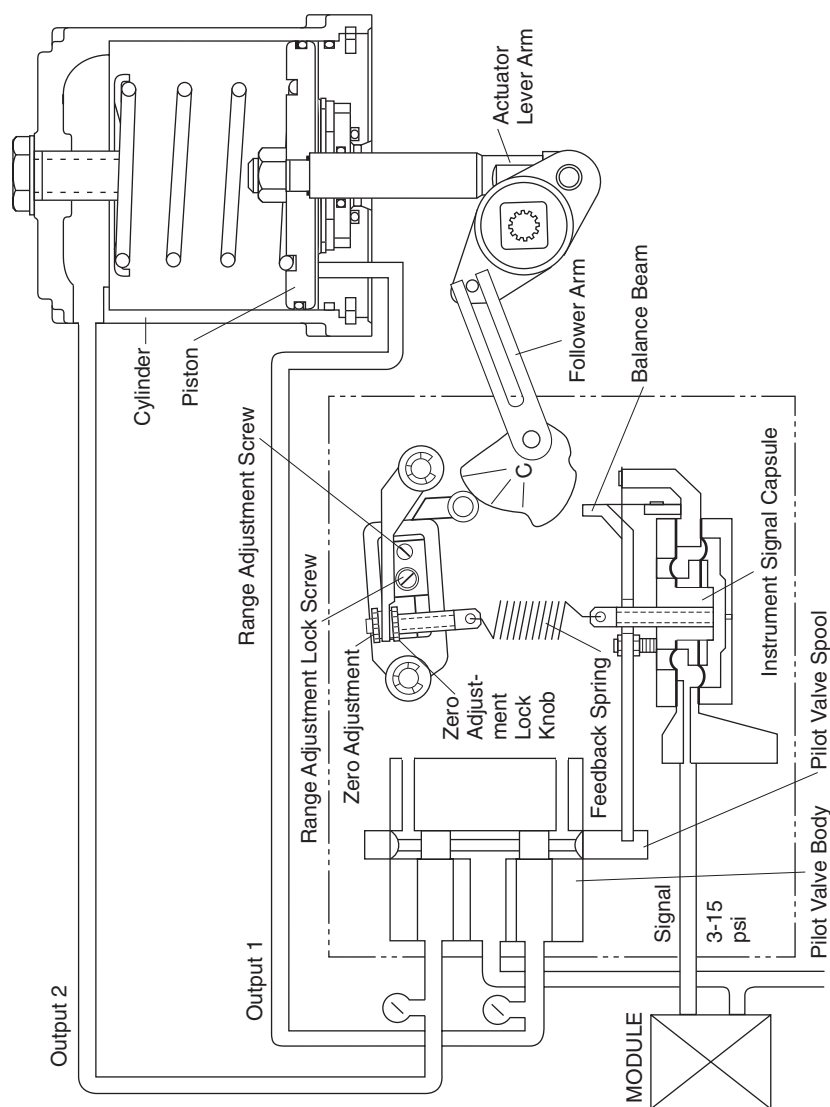
The change in air pressures to the upper and lower chambers of the actuator causes the actuator stem to move either upward or downward. The motion of the actuator stem is transmitted to the positioner through some type of internal or external linkage or lever. As this feedback motion is received by the positioner, the stretch and force of the feedback spring are increased or decreased, which changes the counterforce to the instrument signal capsule. At this point, when the correct actuator position is achieved, the instrument signal capsule and pilot valve return to their state of equilibrium and the air flow to the actuator discontinues.

With valves that only have inherent flow characteristics, such as a butterfly valve, a characterizable cam (Fig. 5.34) can be used with the positioner to provide a modified flow characteristic.

### 5.6.3 Positioner Calibration

Positioners normally come from the factory calibrated to the requirements of the actuator and valve application; however, shipping and handling may cause the calibration to shift. Prior to service, the positioner should be connected to the signal and supply lines and should then be operated. If significant inaccuracy occurs, the positioner calibration should be examined. The two most common adjustments with positioners are the zero and the span. The zero adjustment is used to vary the point where the actuator begins its stroke, normally 3 psi (0.2 bar) or 4 mA for most common applications. After the zero has been calibrated, the span adjustment is used to increase or decrease the span from the zero point, normally 12 psi (0.8 bar) for a 3- to 15-psi (0.2- to 1.0-bar) pneumatic signal or 16 mA for a 4- to 20-mA electronic signal. Some span adjustments allow for certain split ranges without changing the feedback spring. For example, a 3- to 15-psi (0.2- to 1.0-bar) feedback spring may allow the span to be adjusted to a 3- to 9-psi (0.2- to 0.6-bar) or a 9- to 15-psi (0.6- to 1.0-bar) split range. After the span adjustment has been made, the user should return to the zero point to ensure that it stayed true during the span adjustment. Locking nuts or other locking devices are installed to prevent the calibration from shifting during service.

The zero and span adjustments, as well as a number of split ranges available, depend on the type of the feedback spring being used. Significant range changes, such as changing from a 3- to 15-psi (0.2- to



**Figure 5.34.** Positioner schematic for rotary actuator (air-to-retract). (Courtesy of Valtek International)

1.0-bar) range to a 6- to 30-psi (0.4- to 2.1-bar) range would require a new feedback spring.

## 5.7 Auxiliary Handwheels

### 5.7.1 Introduction to Auxiliary Handwheels

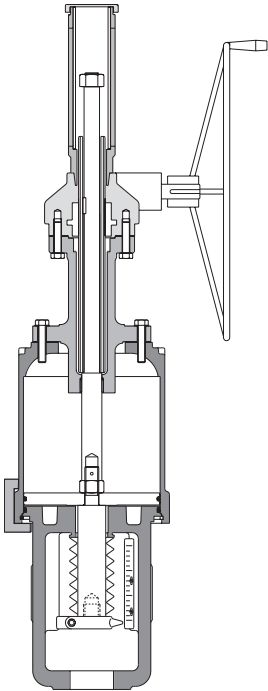
Occasionally manual operation of an actuated valve is preferred or required; therefore, an *auxiliary handwheel* is attached to the actuator to allow for manual operation of the actuated valve in case of an emergency or when a major power interruption or failure occurs. Not only do auxiliary handwheels allow for manual operations, but some designs can be set in a position so that the handwheel acts as a stop to limit the stroke of the valve.

If an auxiliary handwheel is used while the actuator is still under signal, a three-way bypass valve is installed before the actuator or positioner to shut off the air supply and bleed or neutralize the pressure chamber(s). To prevent accidental or intentional manual operation, some manufacturers provide a locking bar that can be placed around a leg of the handwheel and locked. If this feature is not provided, a simple chain and lock can prevent movement of the handwheel.

### 5.7.2 Auxiliary-Handwheel Designs

Designs of auxiliary handwheels vary widely. Designs are sometimes based upon the linear or rotary motion of the actuator and/or valve. Some are an integral part of the actuator, while others are an addition to the existing actuator design, following minor modification for attachment. Auxiliary handwheels can be mounted above the actuator (called *top-mounted handwheels*) or on the side of the actuator (called *side-mounted handwheels*).

The most common auxiliary-handwheel design for linear actuators is the *continuously connected handwheel*, which is an assembly attached to the actuator stem with a neutral range that accommodates the full stroke of the actuator without interference from the handwheel. When the handwheel is turned, the handwheel nut (or similar device) moves out of a neutral range and engages either an upper or lower stop. As the handwheel continues to turn, the handwheel nut pushes against the stop, causing the actuator stem to move in that direction. The advantage of the continuously connected design is that it does not require a declutching mechanism to engage or disengage the handwheel in order to operate

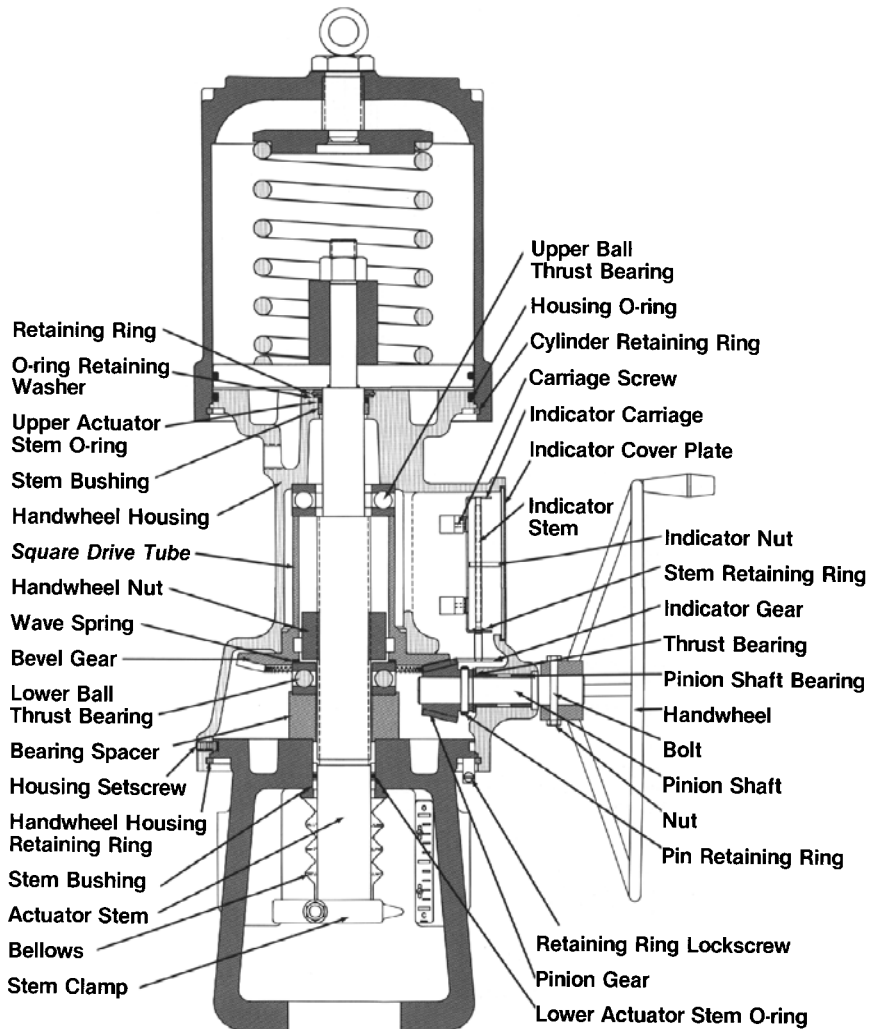


**Figure 5.35.** Top-mounted continuously connected handwheel mounted on a linear actuator. (Courtesy of Valtek International)

the actuator. In addition, when the handwheel is left in a non-neutral position, it can act as a limit-stop for that direction. Continuously connected handwheels that are integral to the actuator can be either top- or side-mounted designs (Figs. 5.35 and 5.36).

Side-mounted continuously connected handwheels can also be designed as a separate unit, which is then added to an existing actuator with slight modifications (Figs. 5.37 and 5.38), such as a special yoke. The attachment of the handwheel to the actuator stem is made external to the cylinder or diaphragm case. Therefore, the chief advantage of this design is that the handwheel can be used to lock the stem position, allowing for disassembly of the cylinder or diaphragm casing for maintenance while the valve remains in operation.

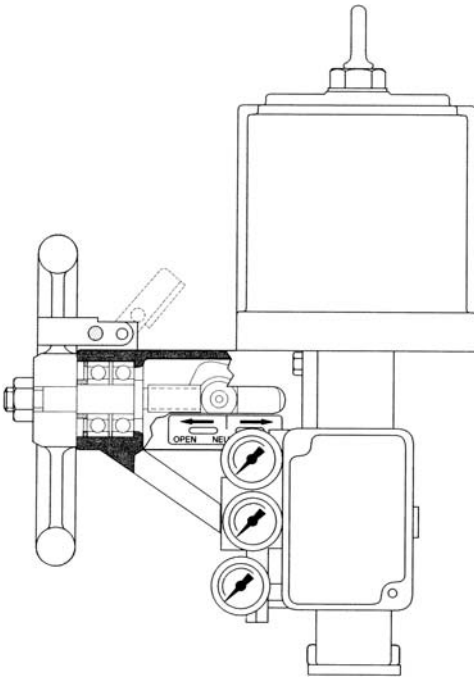
Another common auxiliary-handwheel design for linear actuators is the *push-only handwheel*, which is commonly seen with both diaphragm and piston cylinder actuators (Figs. 5.39 and 5.40). This design is top-



**Figure 5.36.** Side-mounted continuously connected handwheel mounted on a linear actuator. (Courtesy of Valtek International)

mounted and very simple in concept. When the handwheel is turned, the handwheel stem—which is threaded to the top of the actuator—lowers until the handwheel stem makes contact with the piston or diaphragm plate and pushes it until the valve is closed or reaches a midstroke point. The push-only design requires a spring on the opposite

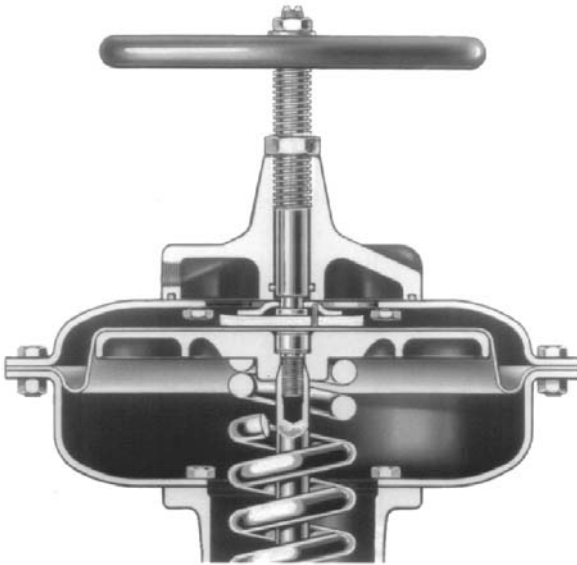




**Figure 5.37.** Internal view of auxiliary side-mounted handwheel mounted on a piston cylinder actuator. (Courtesy of Valtek International)



**Figure 5.38.** Auxiliary side-mounted handwheel mounted on a diaphragm actuator. (Courtesy of Fisher Controls International, Inc.)



**Figure 5.39.** Top-mounted handwheel mounted on a direct-acting diaphragm actuator. (Courtesy of Fisher Controls International, Inc.)

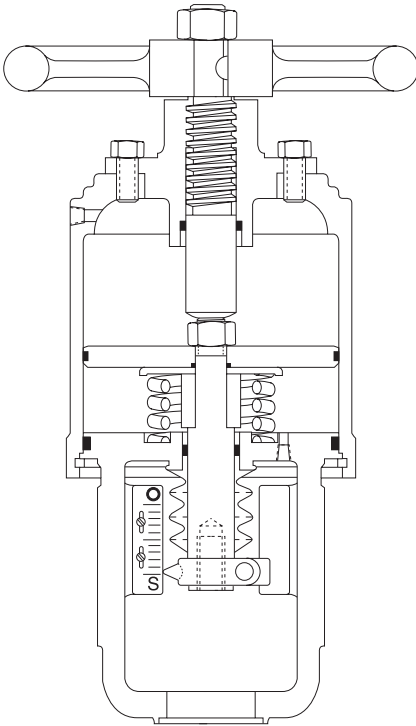
side of the piston or diaphragm to ensure a counterforce. Not only can the handwheel be used to close or throttle the valve, but it can also be used as an upper limit-stop. A modified design is available for reverse-acting diaphragm actuators (Fig. 5.41).

Rotary-motion valves can also be equipped with auxiliary handwheels (Fig. 5.42), although the rotation of the shaft does not normally permit the continuously connected design. Instead, a declutchable handwheel is used that allows the user to engage or disengage the handwheel from making a positive connection with the shaft. The main problem with the declutchable handwheel is that forces on the handwheel during operation make it difficult to disengage. Also, the user must be careful to disengage the auxiliary handwheel after use, since automatic operation of the actuator and valve will turn the handwheel, creating potential safety and eventual maintenance problems.

## 5.8 External Failure Systems

### 5.8.1 Introduction to External Failure Systems

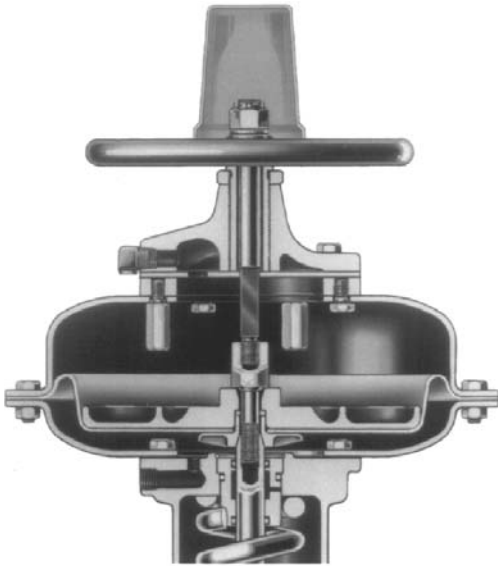
In some situations, the conditions of a service are greater than the capability of an actuator's fail-safe spring. In other applications, an



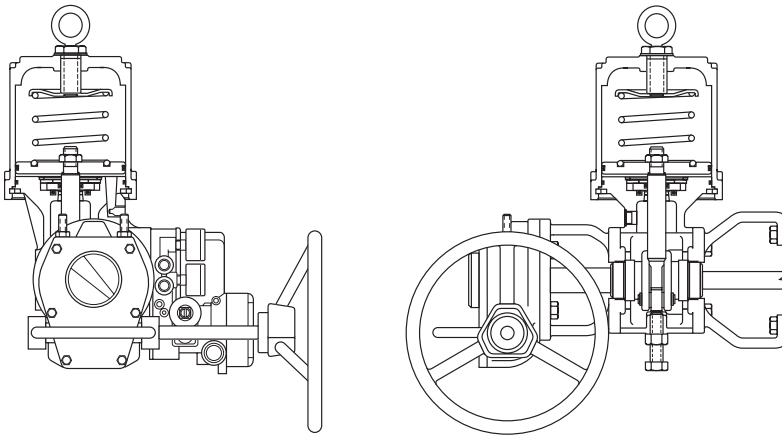
**Figure 5.40.** Top-mounted push-only hand-wheel mounted on a piston cylinder actuator. (Courtesy of Valtek International)

actuator with a heavy-duty spring may not be practical, either mechanically or economically. In these cases, an external failure system (called an *air spring*) may be added to a pneumatic actuator. An air spring is a self-contained, pressurized system that has enough pneumatic power to force the closure element to move to a particular position when the actuator's power supply is interrupted. In most cases, this failure action is to close the valve, although some applications exist that require a fail-open action. The volume of air required for this action can sometimes be provided by the actuator, or in other cases, by an external volume tank.

Occasionally the design of the valve will permit a smaller air spring. For example, with globe valves, a flow-over-the-plug design allows the plug to remain in the seated position because of the process forces; therefore the air spring needs to generate only enough force to move



**Figure 5.41.** Top-mounted handwheel mounted on a reverse-acting diaphragm actuator. (Courtesy of Fisher Controls International, Inc.)



**Figure 5.42.** Auxiliary rotary declutchable handwheel mounted on a rotary actuator (two views). (Courtesy of Valtek International)

the plug to the seated position. If the valve is a flow-under-the-plug design, the air spring must not only have the capability of seating the valve, but also maintaining that position, which may require a larger volume of air and larger external volume tanks. Obviously, if the air spring is designed to open the valve upon failure, a flow-under-the-plug design would help that situation. The point to remember is that sometimes modifying the design of the valve itself can sometimes overcome the need for a huge external failure system.

Occasionally, the application will require that the valve remain in its last position upon loss of power, which requires a different failure system configuration. In that case, the design of the valve has no bearing on the size of the failure system, because the system must be able to handle any throttling position between full-open and full-closed.

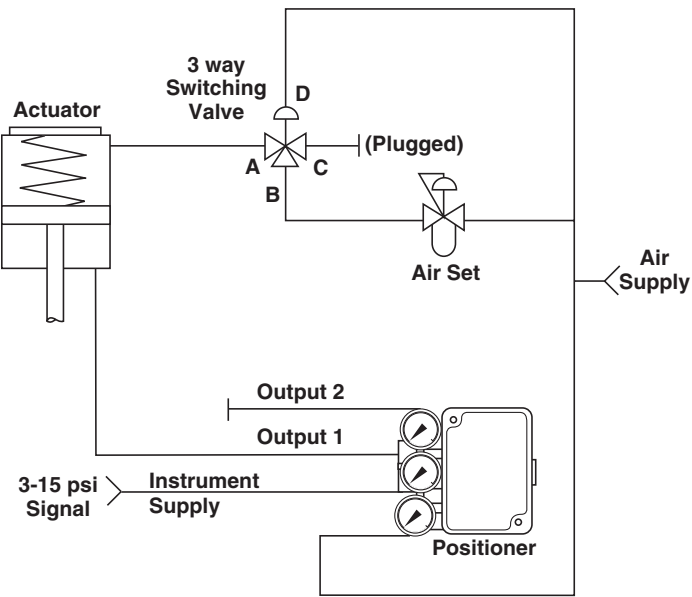
### 5.8.2 Air Springs Using Cylinder Volume

For applications where the service conditions are moderate in nature, yet the failure spring cannot overcome the process, an air spring can be applied, using the air volume from the actuator. This system (air spring using cylinder volume) requires the use of a positioner. As shown in the two schematics for fail-closed and fail-open in Figs. 5.43 and 5.44, the air spring uses a three-way switching valve and an airset. The positioner acts as a three-way positioner, providing air to only one side of the actuator. The airset is used to supply a constant air pressure on the opposite side of the actuator. It is preset at the factory to provide the necessary pressure to overcome the unbalanced forces for that particular application while still allowing the actuator to stroke normally. The three-way switching valve is used to monitor the air supply and is preset at a level close to the expected air supply—yet low enough to avoid problems with normal swings of the supply pressure. When the air supply fails or decreases below a certain preset point, the constant-pressure side of the actuator drives the actuator to its failure position. When the air supply is restored to normal levels, the three-way switching valve opens to allow normal operation of the actuator.

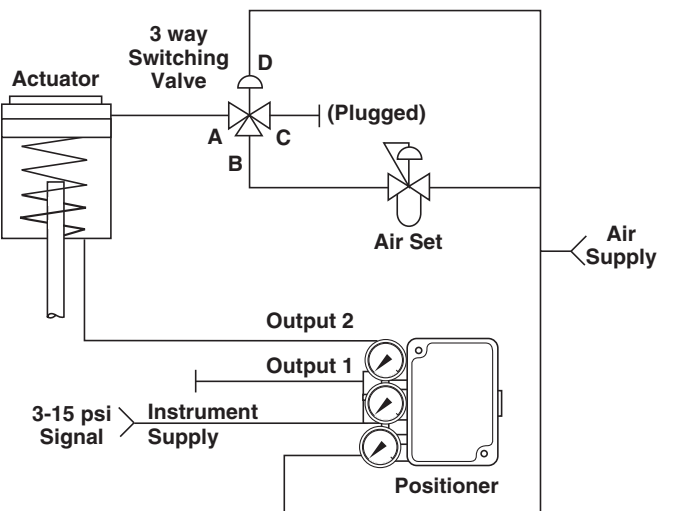
When air springs using cylinder volume are required, the set pressure must be calculated, using the following equation:

$$P_{A1}V_{C1} = P_{A2}V_{C2}$$

where  $P_{A1}$  = initial air pressure (absolute)  
 $P_{A2}$  = final air pressure (absolute)



**Figure 5.43.** Signal-to-open (fail-closed) air spring using cylinder volume schematic. (Courtesy of Valtek International)



**Figure 5.44.** Signal-to-close (fail-open) air spring using cylinder volume schematic. (Courtesy of Valtek International)

$V_{C1}$  = initial volume of the actuator's pressure chamber  
 $V_{C2}$  = final volume of the actuator's pressure chamber

The user must then evaluate the worst-case scenario for the required actuator force ( $F_A$ ) and the actuator's piston or diaphragm area ( $A$ ), which can be obtained from the manufacturer. After the force and the area are known, the following equation is used to determine the final air pressure required in the actuator ( $P_{A2}$ ) for the proper failure operation:

$$P_{A2} = \frac{F_A}{A} + 14.7$$

where  $F_A$  = required actuator force  
 $A$  = area of the piston or diaphragm (square inches)

To determine the switching valve setpoint (also known as the initial actuator pressure), the following equation should be used:

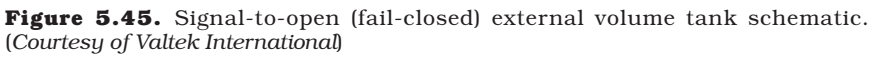
$$P_{SVS} = \frac{P_{A2}V_M}{V_M - AS} - 14.7$$

where  $P_{SVS}$  = switching valve setpoint (psig)  
 $V_M$  = maximum volume of the actuator side that requires air to move actuator to failed position (in<sup>3</sup>)  
 $S$  = length of valve stroke (inches)

If the switching valve setpoint ( $P_{SVS}$ ) exceeds 80 percent of the air supply pressure, then the air volume of the actuator is not capable of handling the failure mode and an external volume tank must be used.

### 5.8.3 Air Springs Using a Volume Tank

When the air volume inside an actuator is not large enough to drive the actuator to its failure position, an external volume tank is provided with the valve to supply the necessary air volume. The typical air spring using a volume tank system involves an external volume tank, a three-way switching valve, two pilot-operated three-way lock-up valves, and a check valve. A four-way positioner is necessary for this arrangement, which acts to supply air to both sides of the actuator. The purpose of the check valve is to maintain the air pressure inside the volume tank if the air supply should fail.





As shown in the two schematics for fail-closed and fail-open cases in Figs. 5.45 and 5.46, the three-way switching valve monitors the air supply and is preset to a level close to the expected air supply yet low enough to avoid problems with normal swings of the supply pressure. During normal operation, the lock-up valves allow air to flow normally between the positioner and the actuator. When the air supply decreases or falls below the preset value, the pressure from the pilot of the three-way switching valve causes the two lock-up valves to be released. One lock-up valve channels air from the volume tank to one side of the actuator, while the other lock-up valve exhausts the other side of the actuator to atmosphere. Air from the volume tank drives the actuator to its failure position. Unless air leakage is occurring through the tubing, connections, lock-up valve, or check valve between the volume tank and the actuator, the actuator should maintain its position indefinitely. The seal between the two sides of the actuator must also be leak-free.

If the tank volume must be calculated, the following equation should be used:

$$P_{A1} V_{T1} = P_{A2} V_{T2}$$

where  $V_{T1}$  = initial volume of the external volume tank  
 $V_{T2}$  = final volume of the external volume tank

The user must then evaluate the worst-case scenario for the required actuator force ( $F_A$ ), and the actuator's piston or diaphragm area ( $A$ ), which can be obtained from the manufacturer. After the force and the area are known, the following equation should be used to determine the final air pressure required in the actuator ( $P_{A2}$ ) for the proper failure operation:

$$P_{A2} = \frac{F_A}{A} + 14.7$$

To determine the switching valve setpoint (also known as the initial actuator pressure), the following equation should be used:

$$P_{SVS} = \frac{P_{A2} V_M}{V_M - AS} - 14.7$$

If the initial pressure exceeds 80 percent of the air supply pressure, an external volume tank must be used. The following calculations help determine the correct size of volume tank.

Fail-closed actuators:

$$V_T = \frac{P_{A2} V_M}{P_{SVS} + 14.7 - P_{A2}}$$

Fail-open actuators:

$$V_T = \frac{P_{A2} V_M A}{P_{SVS} + 14.7 - P_{A2}}$$

where  $V_T$  = volume of the external volume tank (cubic inches)

### 5.8.4 Lock-Up Systems

Some applications require that the valve remain in place on loss of power supply. In these situations, a *lock-up system* is used. As shown in Fig. 5.47, the typical lock-up system requires a three-way switching valve, two pilot-operated three-way lock-up valves, and a four-way positioner. The three-way switching valve monitors the air supply and is preset to a level close to the expected air supply yet low enough to avoid problems with normal swings of the supply pressure. During normal operation, the lock-up valves allow air to flow normally between the positioner and the actuator.

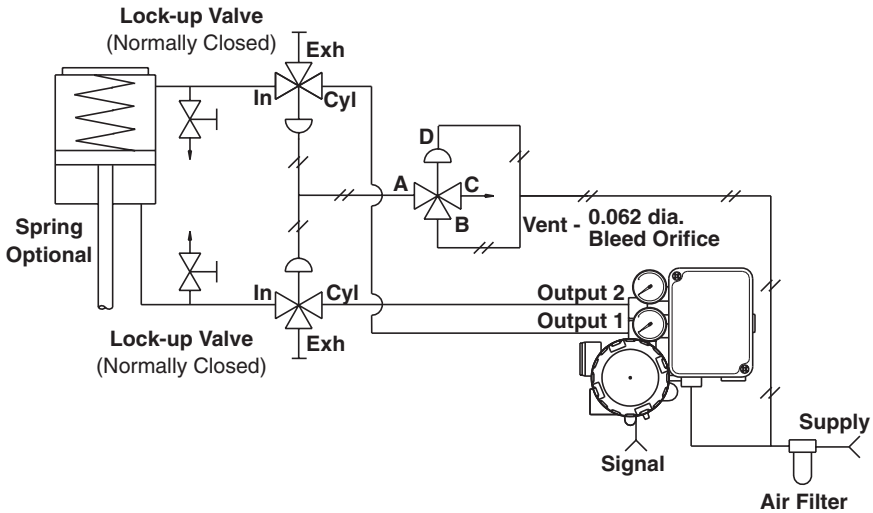
When the air supply decreases or falls below the preset value, the pilot pressure from the three-way switching valve to the lock-up valves is released, causing both lock-up valves to close. This traps the existing air pressure on both sides of the actuator. The exhaust ports of the two lock-up valves must be plugged; otherwise, the existing air to the actuator bleeds out, creating an unstable condition.

## 5.9 Common Accessories

### 5.9.1 Introduction to Accessories

Some special actuation systems or actuators require fast stroking speeds, signal conversions from one medium to another, position transmissions, etc. In these applications, *accessories* are included with the actuator to help perform these special functions. Ideally, accessories are mounted directly onto the valve to ensure that the user is aware of the location of the device—although sometimes the accessory is not mounted directly onto the valve and the user must determine the location of the device.

Accessories may be produced directly by the valve manufacturer; however, in most cases they are produced by a separate manufacturer and purchased by the valve manufacturer. Rather than recreate the

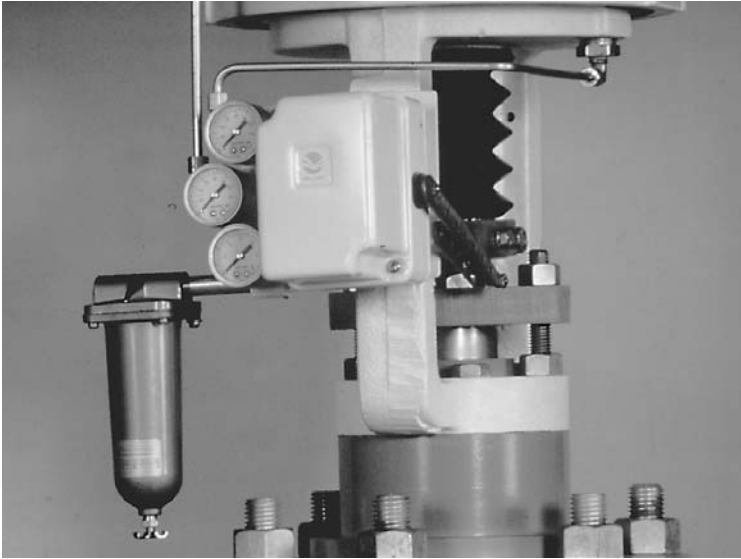


**Figure 5.47.** Signal-to-open, fail-in-place lock-up system schematic. (Courtesy of Valtek International)

original vendor instructions, valve manufacturers normally include them with the valve shipment. These instructions are either attached to the accessory or included with the valve's or actuator's instructions. Keeping this literature for both the valve or actuator and accessories is important, since it details installation and servicing instructions. If instructions about the accessory are not included in the shipment, the valve manufacturer should be contacted.

### 5.9.2 Filters

One of the most basic accessories for actuators, whether pneumatic or hydraulic, is the filter. The *filter* is designed to screen the power supply medium of impurities or other foreign fluids or objects that may contaminate an actuation system, positioner, or other accessory. As shown in Fig. 5.48, filters are installed between the source of the power supply and the actuator or positioner. Generally, the filter is mounted immediately upstream from the accessory to ensure that the fluid is screened just prior to entering the actuator or positioner. Most are nipple- or bracket-mounted to the actuator or positioner. Filters have either a filter cartridge that has minute openings or a series of screens (screen openings are typically 5  $\mu\text{m}$  in diameter). These filters or



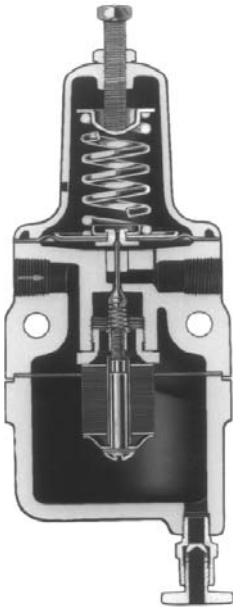
**Figure 5.48.** Air filter installed before a pneumatic positioner.  
(Courtesy of Valtek International)

screens trap any particles of a larger diameter that can clog the inside small passages of a positioner, foul a metal moving part (such as a piston), or damage an elastomer (such as an actuator stem O-ring).

Because compressed air, especially in humid environments, has a tendency to produce water condensation, air filters have a drip well and a drain valve to allow for draining of any water. Water can foul the passages in a positioner or cause bacterial growth that can lead to erratic performance. In single-acting valves without an air filter, the pressure chamber can fill with water, causing slow operation or eventually no actuation at all. Through the air pressure of the system itself, the drain can also be used to remove oil and large particulates, which may be present in the air line.

### 5.9.3 Pressure Regulators

A *pressure regulator* (also known as an *airset*) is used to regulate or limit the air supply to the actuator. A typical pressure regulator is shown in Fig. 5.49. While many plants provide air pressures between 60 and 80 psi, some actuators cannot operate at such pressures without an internal failure. As discussed in Sec. 5.3, single-acting actuators are limited to the lower range of air pressure (usually limited to 40 psi or 2.8 bar) and require the installation of pressure regulators.



**Figure 5.49.** Pressure regulator, including air filter and moisture trap. (Courtesy of Fisher Controls International, Inc.)

A common problem found in plants that use both single- and double-acting actuators is that some technicians, as a routine procedure, install pressure regulators on all valves regardless of the style—thereby limiting the pressure to all actuators. However, some actuators, such as piston cylinder actuators, actually operate better at higher pressures, providing greater thrust, faster stroking speeds, better stiffness, etc. In addition, placing a pressure regulator on an actuator unnecessarily can lead to possible misadjustments or add one more device that can possibly fail. Manufacturers commonly provide a sticker or tag on the actuator, notifying the user as to the pressure limits of the actuator. The general rule is to install pressure regulators only on those actuators that can only perform with lower air pressures.

#### 5.9.4 Limit Switches

When an electrical signal must be sent indicating an open, closed, or midstroke position of an actuator or valve, an electrical switching

device—called a *limit switch*—is used. Limit switches are normally used to sound alarms or operate signal lights, electric relays, or small solenoid valves. A typical signal-at-open and signal-at-closed limit-switch design is shown in Fig. 5.50, while a cammed limit switch is shown in Fig. 5.51. Limit switches are mounted directly to the actuator or rotary-transfer case and use energized arms to make a connection with the moving stem or shaft through a stop plate or similar device. Limit switches come in two basic styles: a single-pole–double-throw style that allows one signal to be sent to one receiver, and a double-pole–double-throw style that allows for two signals to be sent to two receivers. Cammed limit switches are capable of operating anywhere between two and six switches with one unit. Both ac and dc voltage models are available.

### 5.9.5 Proximity Switches

When a mechanical connection between the limit switch and the stem or shaft is not desirable, a proximity switch is used. A *proximity switch* is a limit switch that use a magnetic sensor instead of a mechanical arm. The switch's sensor is placed close to the stem or shaft, and a metal protrusion is used to trigger the switch when it approaches the sensor.



**Figure 5.50.** Signal-at-open and signal-at-closed limit switch schematic.  
(Courtesy of Valtek International)



**Figure 5.51.** Cammed limit switch. (Courtesy of Fisher Controls International, Inc.)

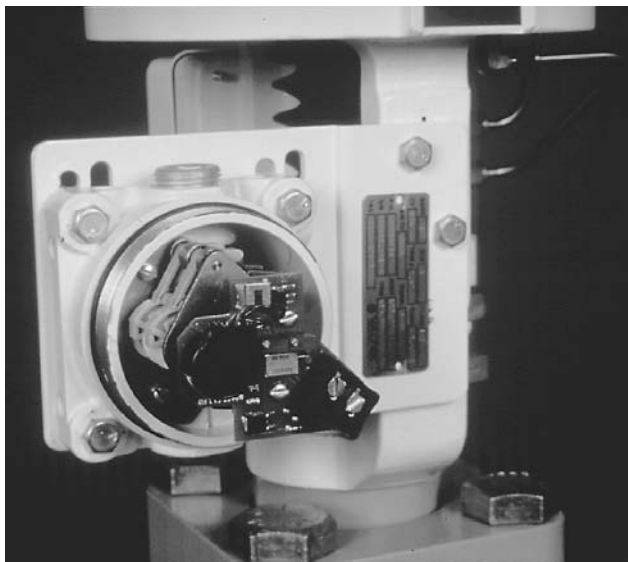
### 5.9.6 Position Transmitters

A *position transmitter* is a device that provides a continuous signal indicating the position of the valve or actuator, allowing for signal indication, monitoring actuator performance, logging data, or controlling associated instrumentation or equipment. A potentiometer inside the position transmitter is directly linked to the actuator stem or rotary linkage through an energized arm or linkage (Fig. 5.52). Separate zero and span adjustments are provided, allowing for special modifications, such as monitoring only a critical portion of an actuator stroke. Position transmitters can also be designed with up to four limit switches. Most position transmitters operate off of a two-wire loop, using a 4- to 20-mA dc power supply, and can be made explosion-proof with a special housing.

From a performance standpoint, position transmitters typically provide linearity and hysteresis of between  $\pm 1$  and  $\pm 2$  percent of full scale and repeatability between  $\pm 0.25$  and  $\pm 1$  percent of full scale.

### 5.9.7 Flow Boosters

*Flow boosters* are used to increase the stroking speed of larger pneumatic actuators. Because of their increased volumes, large actuators have difficulty making fast and immediate strokes. Overall, flow boosters respond quickly to sizable changes in the input signal while allowing



**Figure 5.52.** Position transmitter (without cover).  
(Courtesy of Valtek International)



**Figure 5.53.** Flow boosters mounted to double-acting actuator. (Courtesy of Valtek International)



for smooth response when the actuator receives small signal changes. A common flow-booster arrangement is shown in Fig. 5.53.

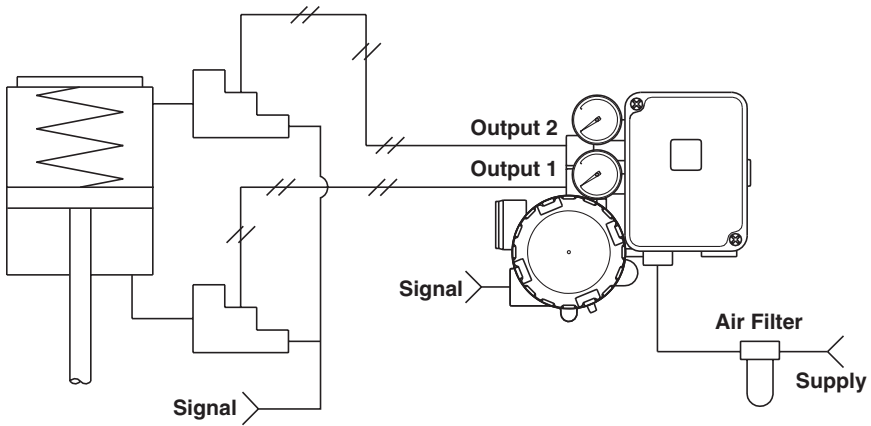
Flow boosters are typically used with positioners with the flow booster being mounted between the positioner and actuator. The flow booster is tubed to the air supply, allowing for the full air pressure to be used to stroke the actuator in the event a larger signal increase or decrease is given. The flow booster utilizes the full air supply only if a large signal is received; otherwise, the normal air flow from the positioner moves through the booster unaided. The air flow is preset using a bypass valve inside the booster. However, when a larger signal is received, the booster inlet or exhaust port opens. If the booster inlet opens, full air supply is sent unregulated to the desired air chamber. At the same time, another booster's exhaust port opens, allowing the opposite air chamber to vent. Both boosters remain in these positions until the pressure differential reaches the dead-band limits of the bypass valve in the booster. When the bypass valve opens, the supply inlet or exhaust ports close and the flow boosters return to normal operation.

To illustrate the advantage of using flow boosters, the following example is provided. A standard 50-in<sup>2</sup> (322-cm<sup>2</sup>) actuator requires nearly 4 s to stroke 3 in (7.6 cm), using 0.25-in (0.6-cm) tubing and a 80-psi (5.5-bar) air supply. With flow boosters, this same actuator can stroke in under 1 s. In larger actuators, the example is even more dramatic. A 300-in<sup>2</sup> (1935-cm<sup>2</sup>) actuator with a 4-in (10.2-cm) stroke, using 0.375-in (1-cm) tubing and a 80-psi (5.5-bar) air supply, requires over 30 s to stroke. However, with the aid of flow boosters, the stroking time is decreased to under 3 s.

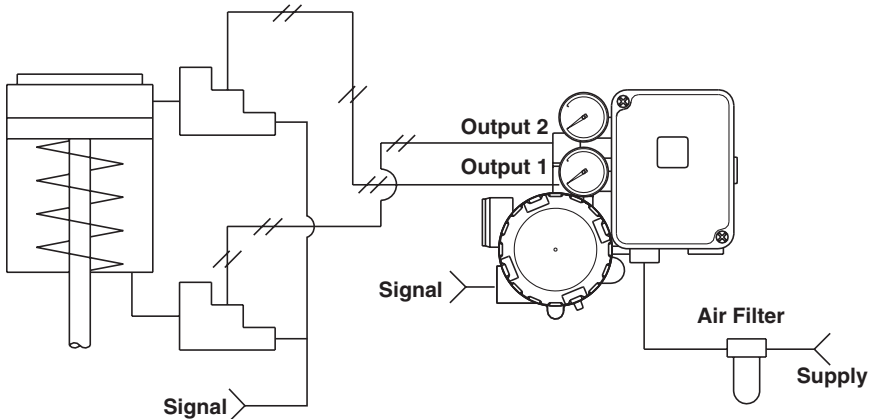
Figures 5.54 and 5.55 show flow-booster schematics for both signal-to-open and signal-to-close arrangements. For exceptional situations, two flow boosters can be installed on each side of the actuator—as long as both flow boosters are connected parallel to the cylinder port, positioner output tubing, and the air supply.

### 5.9.8 Solenoids

A *solenoid* is an electrical control device that receives an electrical signal (usually a 4- to 20-mA signal) and, in response, channels air supply directly to the actuator. Two types of solenoids, three-way and four-way, are commonly used with actuators and positioners. *Three-way solenoids* are sometimes used to operate single-acting actuators, such as diaphragm actuators, since they are designed to only send air to one air chamber in the actuator. With double-acting actuators, three-way solenoids are used to interrupt or override an instrument signal to a pneumatic positioner.

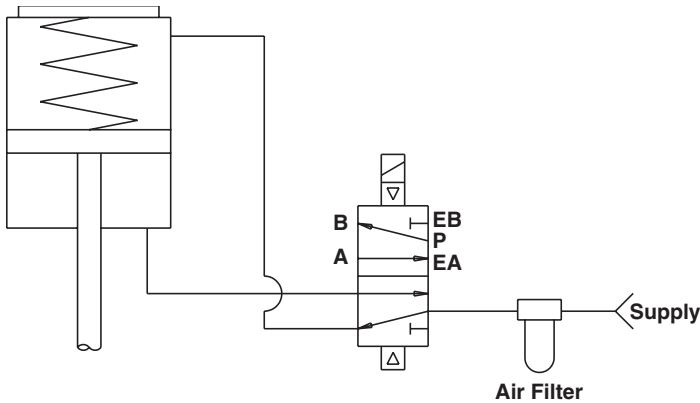


**Figure 5.54.** Signal-to-open, fail-closed flow-booster schematic. (Courtesy of Valtek International)

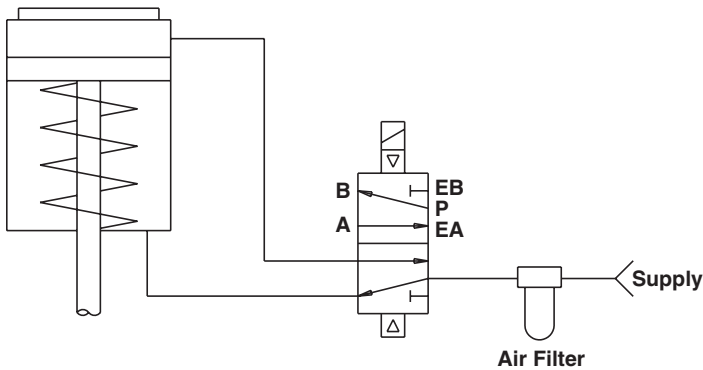


**Figure 5.55.** Signal-to-close, fail-open flow-booster schematic. (Courtesy of Valtek International)

*Four-way solenoids* are used in lieu of positioners to provide on-off operation of double-acting actuators, providing a positive two-direction action. As shown in Figs. 5.56 and 5.57 (showing both closed and open actions), upon deenergization the four-way solenoids send full air supply to one side of the actuator, while exhausting the other side to atmosphere.



**Figure 5.56.** Deenergized-to-close, fail-closed four-way solenoid schematic. (Courtesy of Valtek International)



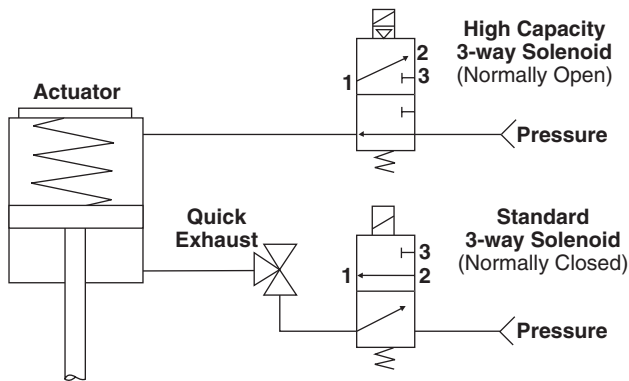
**Figure 5.57.** Deenergized-to-open, fail-open four-way solenoid schematic. (Courtesy of Valtek International)

### 5.9.9 Quick Exhaust Valves

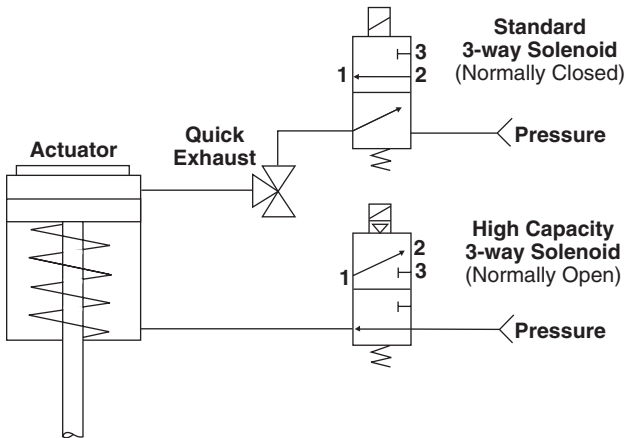
*Quick exhaust valves* are pressure-sensitive venting devices that are used with double-acting actuators in on-off applications where positioners are not required. When triggered, quick exhaust valves almost instantaneously vent one side of the double-acting actuator to atmosphere, allowing the valve to move to the full-closed or full-open position. Quick exhaust valves are installed between the air supply and the actuator. As long as a normal air supply is provided to the actuator, normal operation continues. However, when the air supply fails or is interrupted, the quick exhaust valve reacts to the significant differential pressure. An internal

diaphragm diverts the exhaust flow coming from the actuator through an enlarged orifice, allowing the internal pressure of the actuator to vent much more quickly. A needle valve must be installed parallel to the quick exhaust valve so that the trip point of the quick exhaust valve can be adjusted, allowing it to react only to large signal demands.

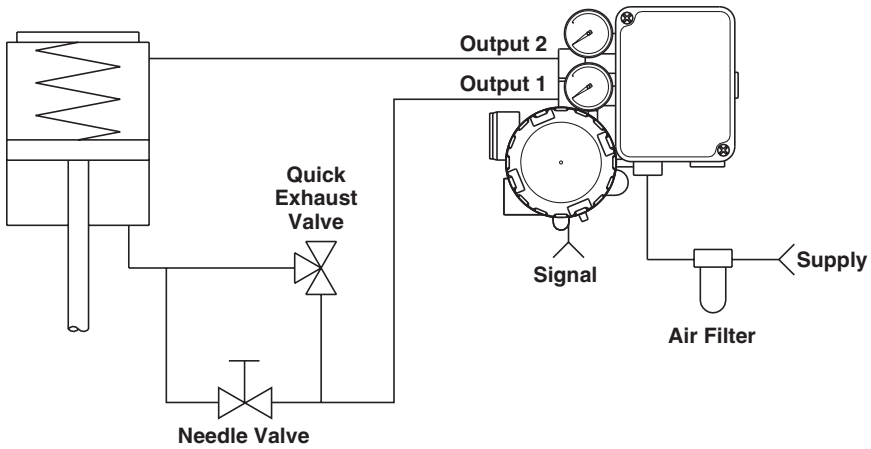
Quick exhaust valves are especially helpful with on-off applications, where exceptional stroking speeds are required in both directions (see Figs. 5.58 and 5.59). Another common application for quick exhaust valves is when a double-acting actuator with a positioner must provide a fast stroke in one direction (as shown in Figs. 5.60 and 5.61).



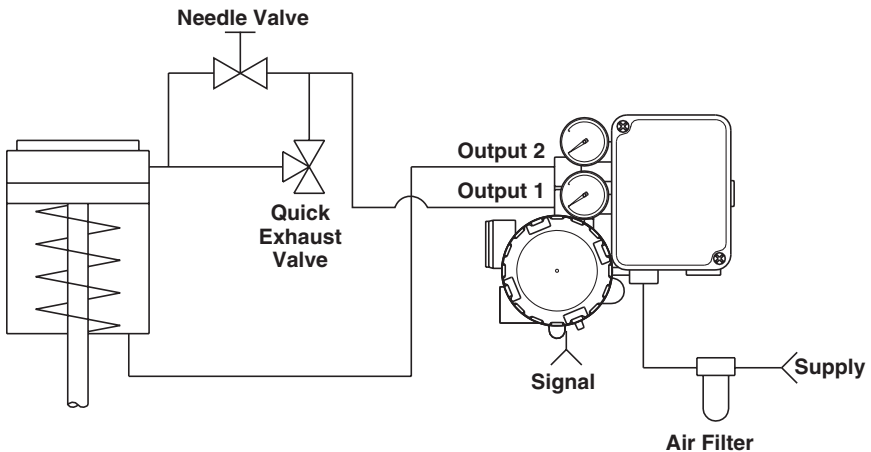
**Figure 5.58.** Fast-closing, fail-closed on-off system with quick exhaust schematic. (Courtesy of Valtek International)



**Figure 5.59.** Fast-opening, fail-open on-off system with quick exhaust schematic. (Courtesy of Valtek International)



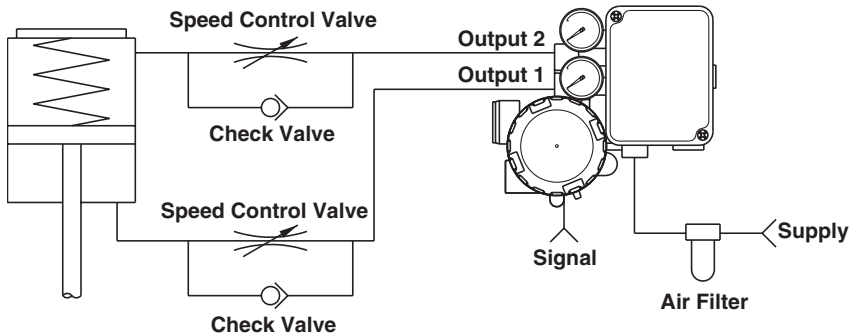
**Figure 5.60.** Signal-to-open, fail-closed positioner with quick exhaust schematic. (Courtesy of Valtek International)



**Figure 5.61.** Signal-to-close, fail-open positioner with quick exhaust schematic. (Courtesy of Valtek International)

### 5.9.10 Speed Control Valves

*Speed control valves* are used to limit the stroking speed of an actuator by restricting the amount of air flow to or from the actuator. These small valves can be mounted between the tubing and the actuator and are available in sizes that match common tubing sizes. They can only be used in one direction; therefore, if stroking speeds must be controlled in



**Figure 5.62.** Signal-to-open, fail-closed speed control system schematic. (Courtesy of Valtek International)

both directions, two speed control valves must be used (one in each direction). A typical application using speed control valves is found in Fig. 5.62.

### 5.9.11 Safety Relief Valves

When volume tanks are used or if high-pressure actuators must be used to handle the service conditions, some local codes require the installation of safety relief valves on these high-pressure vessels as protection against overpressurization. By definition, *safety relief valves* are designed to open to atmosphere when a particular pressure is exceeded. Because of the differing codes for local governing bodies, valve manufacturers normally defer to the user to install safety relief valves.

### 5.9.12 Transducers

*Transducers* are devices that convert an electrical signal to a pneumatic signal, which may be required to operate a positioner with a pneumatic actuator. Transducers have become more commonplace as the popularity of I/P signals has increased with newer control systems, and existing positioners must be converted from pneumatic to electrical signals. The most common transducer is one that converts a 4- to 20-mA signal to a 3- to 15-psi (0.2- to 1.0-bar) pneumatic signal. The pneumatic output signal coming from the transducer normally follows a linear characteristic. Transducers can be mounted directly on the actuator or installed separately, if vibration is a problem (Fig. 5.63).



