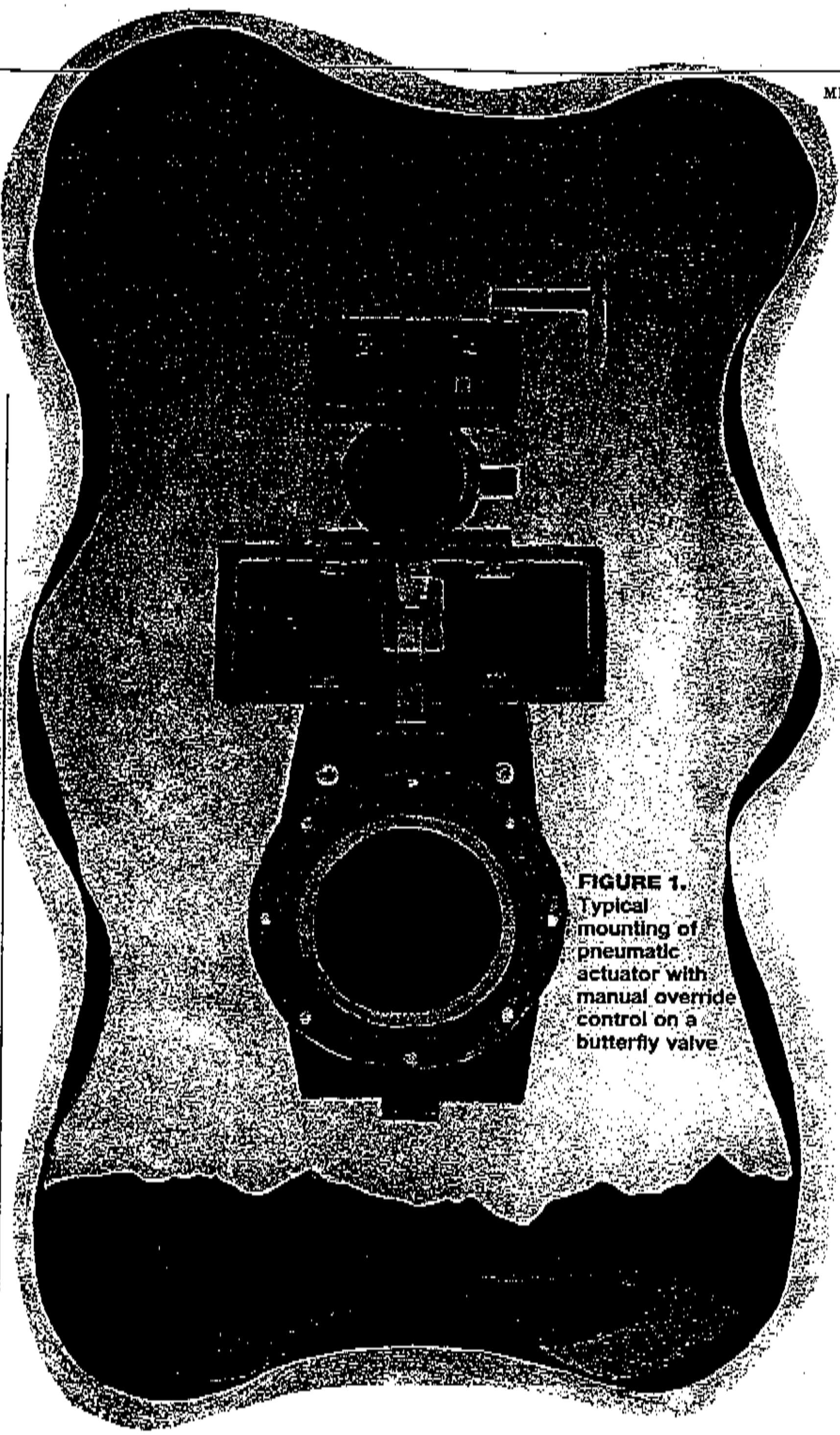

MEGAN REID

FIGURE 1. Typical mounting of pneumatic actuator with manual override control on a butterfly valve

# ACTUATOR

## There are at least a dozen points to consider

**Vinod C. Bhasin**
Westinghouse Electric Corp.

As modern process control demands high-precision regulated flow, proper choice of the actuator becomes critical. Given the importance of precise control in the safe and efficient operation of a plant, it is imperative that the user have an adequate knowledge of actuators, control valves and their characteristics. When specifying an automatic control-valve package, the engineer needs to consider a number of factors besides the pipe size and a particular valve, although these two items do provide a good starting point.

Selecting the right type of actuator is as important as choosing an appropriate valve type for a given application. Undersizing an actuator will make the valve operation unreliable, whereas oversizing will increase cost and add unnecessary weight. Unfortunately, too little attention is given to the selection and sizing of actuators. This is evident from the fact that numerous industry-standards on valves have been written, yet there is none dedicated to actuators.

The engineer who specifies the control valves often selects an actuator at random, or is left at the mercy of distributors who typically stock an assortment of not-necessarily-related valves and actuators. To make matters worse,

# SELECTION

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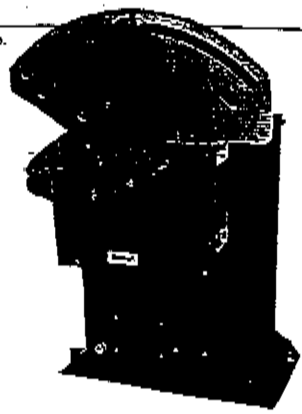
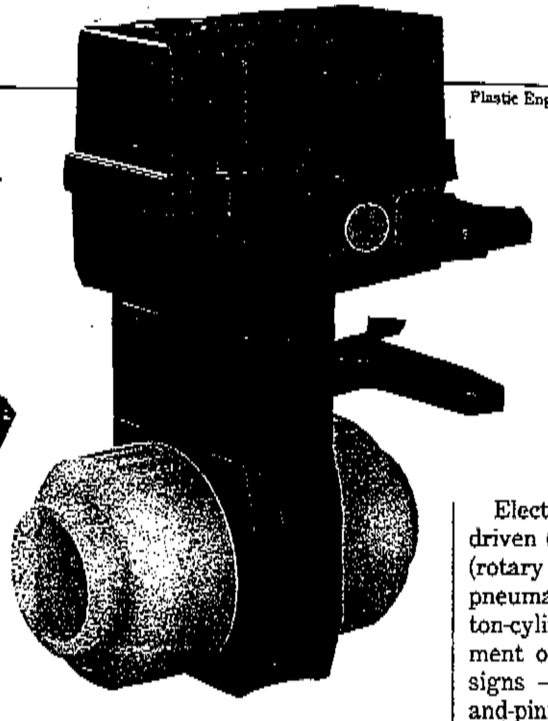




Plastic Engineered Products Inc.

the distributors are often not well-qualified to provide technical guidance.

Depending on the type of valve, an actuator may be required to provide either torque output for rotary motion, or a force output for linear motion. The actuator power source must be able to match the torque or force requirements of the valve with the torque or force output of the actuator. For some applications, such as throttling of a flow, a detailed analysis of the torque or force output needs to be evaluated. Most actuators, however, will perform satisfactorily if the starting torque output exceeds the valve break-away torque. Here the break-away torque is defined to be the amount of torque required to crack open a valve from the fully closed position.

Furthermore, service environments and operating conditions can change the torque or force requirements of the valve rather significantly. It is, therefore, important to recognize these situations. Special assemblies of valves and actuators are often necessary. The following provides a basic familiarity with the types of actuators, and some important variables that affect their selection.

## Types of actuators

Control valves and actuators (see Figure 1) make up the "final control element" in a process-control system, because they effect the control action. The torque output of an actuator is required to deliver the rotary motion to quarter-turn valves, such as ball, butterfly, and plug valves, while a force output is needed to achieve the linear motion of rising stem valves, such as diaphragm, globe or gate valves.

The actuator may be asked to provide either on-off motions (e.g., fully open to fully closed valve-positions), or stroke motions, such as those required to keep the valve partially open (for throttling applications, for example). The actuator may also be required to provide a combination of the above motions for on-off and throttling modes.

The torque or force output of the actuator is usually increased via gear reduction, and can vary with the span of the stroke. Generally, the starting torque delivered by an actuator may not be the same as the torque at some intermediate position of its travel. This characteristic is generally called the torque versus stroke (travel) plot of the actuator output. Figure 2 depicts some of the plots covering the torque output versus stroke (stem travel) for typical actuators.

The actuating devices come in many configurations. The power source to operate them can be electricity, hydraulic fluid pressure, pneumatic fluid pressure, or it can be simply a manual effort such as turning a hand wheel. There are several designs available for each of these power sources.

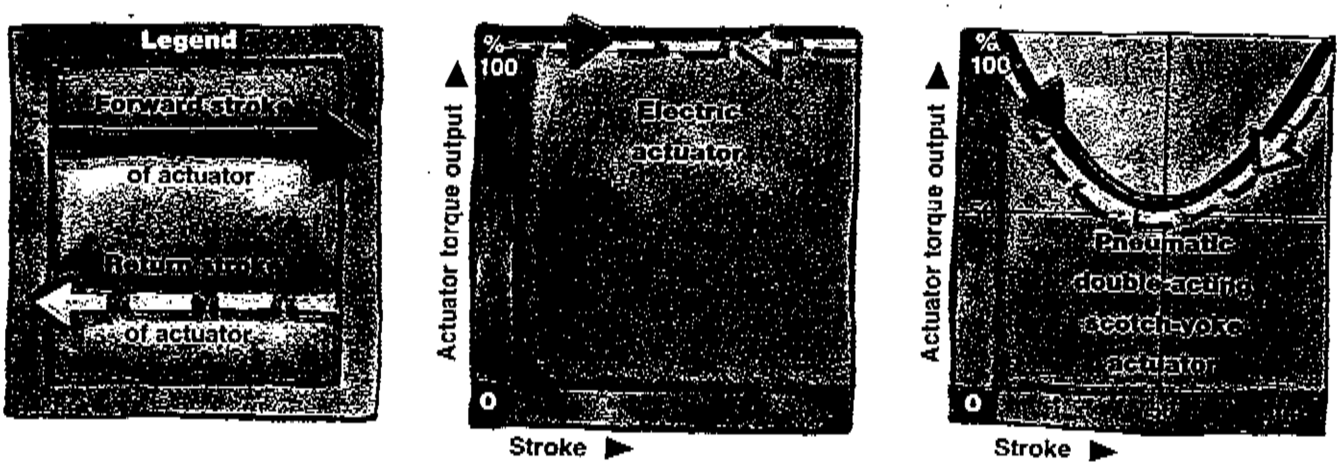
Electric actuators are either solenoid driven (linear motion) or motor driven (rotary and linear motion). Hydraulic or pneumatic actuators may utilize a piston-cylinder arrangement, or the movement of a diaphragm. Numerous designs — scotch yoke, cams, and rack-and-pinion mechanisms, for example — are utilized to convert the rotary motion into linear motion or vice versa.

Positioners are specified on control valves to maintain very precise control of the flow media. A pneumatic positioner is a device that places the moving part of a valve at a spot assigned in accordance with a pneumatic signal. Similarly, an electronic positioner controls the stem position of an electric actuator in response to a standard signal from a process controller.

## Power source

The type of available power source generally dictates the type of actuator that can be used for a given application. Electric actuators, which can be solenoid or motor-operated, are quite versatile, because a power source of 110V or 220V a.c. is usually readily available. The wiring and control instrumentation required are relatively simple, too.

Electric, solenoid-operated actuators are usually reserved for smaller force outputs and linear actuation. These devices are compact, lightweight, and inexpensive. They are mainly used for on-off service. However, electric motor-operated actuators, which are by far the largest in number in industrial use, tend to be bulky if very large torque




outputs are needed. The response time of an electric, motor-operated actuator is slow, especially when a large gear-reduction is used in the actuator housing to increase the torque output. The electric supply is also prone to failures under fire and power brownouts. Their main advantage is that the torque output is fairly constant throughout the stroke, and their response is linear.

Pneumatic actuators derive their power from air pressure. Air-supply pressure up to 80 psi is quite commonplace in industrial plants, and it is easy to tap air from existing pipelines. These pneumatic units respond quickly to a signal that may be coming from a small, pilot-operated pneumatic valve or a manual valve, and can produce very small to very large torque outputs. The units, usually of piston-cylinder design, are most suitable, given an air supply in the 60- to 120-psi pressure range. However, for low-pressure air between 30 to 60 psi, the diaphragm-operated designs provide an economical alternative.

Hydraulic actuators are based on the same piston-cylinder design, and are commonly used to deliver torque outputs smaller than those from the pneumatic ones. In most instances, a pneumatic actuator can be readily converted into a hydraulic unit simply by changing the material of the piston seals.

## Things to consider

An actuator should be selected such that its output torque exceeds the valve's operating torque throughout the entire valve stroke by an adequate safety margin. Under most situations, determining the required torque output of an actuator is an easy process when the maximum valve operating torque throughout the valve stroke is equal to the valve break-away torque. However, determining the required actuator torque can become a major task in situations where the valve operating torque exceeds the valve break-away torque.

The valve operating-torque must overcome the frictional forces generated during rubbing of the valve stem against bearings and packing, and the valve-closure member against its seat. Furthermore, it must overcome the torque associated with the unbalanced pressure-loading acting on the closure member in both flow and no-flow situations.

The valve operating torque is never constant, and varies at various opening positions. For example, the torque may start out with a peak torque (also known as the break-away torque) when the valve is fully closed, drop by almost 70% in the half-open position, and then rise rapidly during the last 10% of the travel. Figure 3 shows plots of typical valve operating-torque for various applications. The following factors will further define the torque characteristics of valves and actuators

- Valve type and size
- Pressure drop (ΔP)
- Service or operating conditions
- Seat material
- Flow medium
- Bidirectional sealing
- Fire-safe feature of the valve
- Fail-safe feature of the actuator
- Temperature
- Cycling rate of the actuator
- Cycle speed and its effects
- Stem orientation of the valve

### *1. Valve type and size*

The shapes of the plots for valve operating-torques (Figure 3) result from the inherent design of the basic valve type and its size. Butterfly valves will exhibit a curve that will be different from the globe-valve curve. The operating torque for rubber-seated butterfly valves is usually the lowest for a given valve size. High-performance butterfly valves with a double-stem offset have somewhat higher operating-torques due to the additional effort required to overcome the static imbalance of forces on the valve disk. Gate and globe valves need still larger operating-torques, and hence would require larger actuators.

### *2. Pressure drop* (ΔP)

Operating torque increases somewhat hyperbolically with an increase in pressure drop across the valve. A valve operating at full-rated pressure drop will require significantly more operating-torque than at low pressure-drop.

One should be careful in estimating the pressure drop across the valve. Depending upon the source of the pressure, the pressure drop may be constant, or it may vary throughout the entire stroke of the valve. For example, when the valve is installed at the bottom of a large storage tank, the pressure drop across the valve may stay almost steady during the time the valve is opened and closed. Another example of constant pressure drop is when the pressure source is a constant-displace-

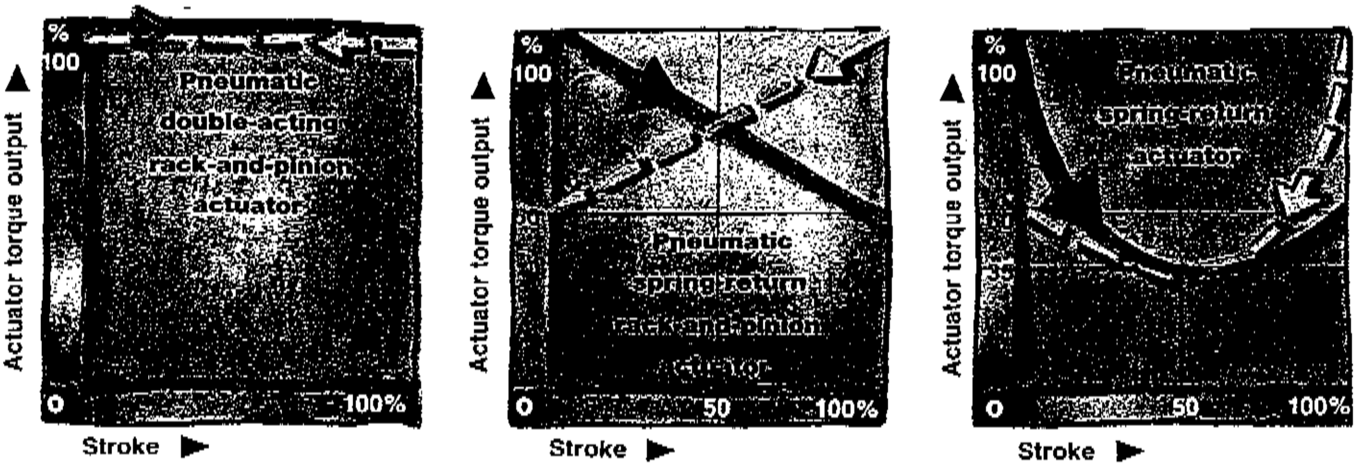



**FIGURE 2.** Typical torque outputs of actuators may vary with valve strokes

ment pump whose head does not vary with the rate of flow.

Under most situations, the pressure drop would vary through the stroke. A case in point is when the pressure source is a centrifugal pump whose supply pressure drops with an increase in flow. It is important to understand how fluid flow relates to the supply pressure, and hence the corresponding valve pressure-drop versus the stroke relationship. This can have a special significance when selecting an actuator whose torque output needs to be carefully matched with the torque requirements of the valve throughout the valve stroke.

**With time, the operating torque requirements of the valve may rise substantially — up to twice that of a new valve**

*3. Service or operating conditions*
Most control valves need to open and close partially (throttling flow), depending upon varying flow requirements. Actuators for valves requiring only on-off regulation may simply be selected based upon the valve breakaway torque because the torque required to crack open a valve from the fully closed position would be the highest value during its entire stroke.

For quarter-turn ball and butterfly valves requiring throttling operation, the selection is more complicated, since additional torque is needed to counterbalance the momentum of the flow media. For example, unbalanced forces are generated on the closure member, resulting in additional torque, known as the "hydrodynamic torque." The magnitude of the hydrodynamic torque depends on the valve type, pressure drop, percent valve opening, and the direction of fluid flow. Evaluation of this additional torque may require plotting a valve operating torque versus stroke curve comprising several data points, and then plotting the actuator output torque at the corresponding valve openings.

Keep in mind that the pressure drop across the valve may vary throughout the valve stroke. Therefore, the actuator-torque-output curve must lie well above the operating-torque curve for the valve to ensure smooth actuator operation.

*4. Seat material*
Most valves incorporate a metal-closure member to seal against a soft seat made of elastomers. Because of higher coefficients of friction, metal-seated valves may require operating torques of up to 1.5 times the operating torques for soft-seated valves.

*5. Flow medium*
The operating torque for a control valve is also a function of the type of flow medium. Fluids, such as dry air or gas, provide little or no lubrication, adding to frictional forces. Water and oily media, on the other hand, often act as excellent lubricators, and therefore require much less operating torque. Furthermore, fluids carrying solids and slurries tend to clog clearances between the stem and bearing, and erode smooth sealing surfaces.

With time, the operating torque requirements of the valve may rise substantially — up to twice the requirements of a new valve. Actuator output torque also deteriorates from usual wear and tear. The published operating torques of valves are typically based on using new valves for clean water service. An adequate safety margin must be established to ensure continued and reliable operation of the specified actuator.

*6. Bidirectional sealing*
Some valve designs exhibit widely differing operating-torque requirements when the direction of flow is reversed. Butterfly valves, in general, require almost 30 to 50% more operating torque when the valve is installed with the seat

retainer facing the downstream side of the flow.

Similarly, globe valves will require a lower lifting force when the fluid flows from under the disk. If bidirectional sealing is not required, one may be able to specify smaller-sized actuators by taking advantage of the preferred direction, which requires lower operating torque.

### *7. Fire-safety of the valve*

Fire-safe valves generally incorporate a dual seating arrangement. In addition to the primary soft (elastomeric) seating, a secondary metal seat is incorporated so that if the primary soft-seat is destroyed by fire, the secondary metal-seat maintains the seal with tolerably small leakage. Such fire-safe valves, however, can require 50 to 100% more operating-torque compared to standard valves.

### *8. Fail-safe actuator*

Valve applications specifying fail-safe actuation need significantly larger-size actuators. Fail-safe actuation is intended to close (or open) a valve automatically in the event of a loss of power to the actuating device. The automatic fail-safe operation demands that the actuator store the extra energy in a compressed spring during its normal operation. This, however, results in an actuatorunit of larger size.

### *9. Temperature*

Valve operating-torque requirements are generally the lowest at room temperature. High-temperature service valves are usually equipped with all-metallic bearings, seats and packing that can withstand elevated temperatures, requiring much higher operating-torques due to the higher coefficients of friction. Valves used at cryogenic temperatures also require higher operating-torques because their plastic seating, bearing, and packing materials lose much of their resiliency and lubricity at colder temperatures.

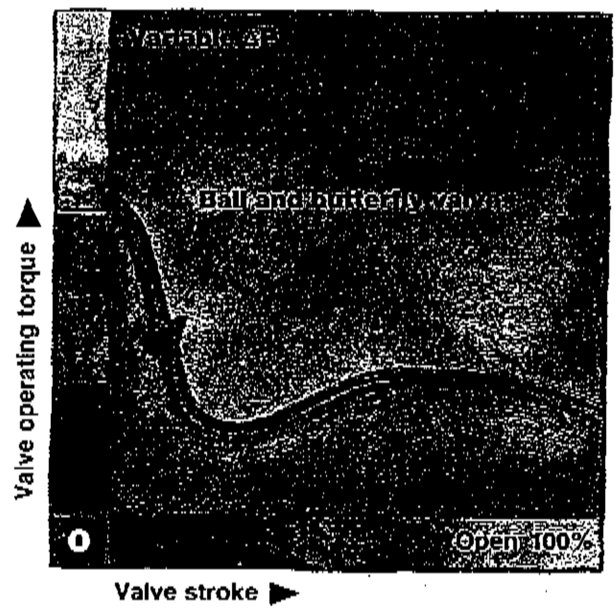
Line temperatures above 300°F may require a special actuator assembly. Special mounting, bracketing and shielding, and even stem extension, may be needed, depending on the degree of temperature elevation.

One should be aware of conditions other than the temperature of the pipeline. For example, the line temperature may be 250°F, but the valve and actuator could be located over a high-temperature heat exchanger where the "ambient" temperature is 310°F. Similarly, electric actuators in outdoor installations may have to be shielded from direct heating by sunlight. Thus the actuator should be prepared for use at the highest temperature to which it is exposed.

### *10. Cycling rate*

Applications requiring high cycle-rate will require special considerations. Pneumatic and hydraulic actuators cycling continuously in excess of 30 cycles an hour are considered to be operating at "high cycling rates." And the same applies to their electric counterparts cycling in excess of 10% duty cycle. An electric actuator with a 10% duty cycle operates for one cycle and rests for the equivalent of 9 cycles. For good performance, such electric units would need an extended-duty motor. At the same time, the motor's size would have to be increased to maintain the required torque output.

**FIGURE 3. Operating torque or force vs. stroke curves for typical valves and pressure conditions**




### *11. Cycle speed*

Fast cycle speeds (actuator operating at less than 50% of the standard actuator cycle time) require careful selection of both the valve and the actuator. The sudden physical shocks associated with fast cycling speeds can damage the valve and actuator components, especially when combined with high cycle rates.

Pneumatic actuators would require larger-size actuating devices, special solenoids, piping and quick-exhaust valves to handle high cycle-speeds. Cycle speed of these pneumatic devices can be reduced without affecting the output torque by using speed-control valves in the air piping.

The cycle speeds of electric actuators cannot be increased. They can only be reduced by specifying either special cycle times (using a different gearing arrangement, which may increase the torque output) or an electronic speed control (without affecting the torque output).

### *12. Stem orientation*

The vertical, horizontal or somewhere-in-between orientation of the valve stem is yet another important factor to consider. Actuator mountings with the valve stem in other than the vertical position are prone to stem-seal leakage and galling of the stem. The galling is due to side thrusts induced by the overhung load of the actuator. Use heavy-duty mounting brackets, along with double-universal spider couplings, to minimize these problems.

Low-temperature services requiring cryogenic valves with extended bonnets and stems generally have the valve stems installed in the vertical position, or limited to 30-deg incline. Such extended bonnets, coupled with the inclined stems, may require heavy-duty actuator-to-valve mountings.

**Standardization issues**

An actuator is seldom mounted directly on a valve. As illustrated in Figure 1, a bracket and a coupling are usually needed to connect the actuator stem to the valve stem. Because there exists no industry standard on valve actuators, there is no uniformity in the actuator-to-valve interface design, and every actuator is mounted as a custom fit for the valve selected. In addition, the valves do not have standardized actuator mounting-flanges; the bolt-circle diameters and the bolt diameters for the valve-actuator flanges differ widely among valve manufacturers.

Even if such an actuator standard did exist, diameters of the output stem-shaft would not be consistent with the valve stem-diameters. Part of this discrepancy is attributable to the fact that the valve manufacturers design their stem diameters based upon the torque requirements of the valve and the allowable stress of the valve-stem material. A 'lower allowable stress' stem material, such as Type 316 stainless steel, will require a larger stem diameter than a 'higher allowable stress' stem material, such as Type 17-4PH stainless steel.

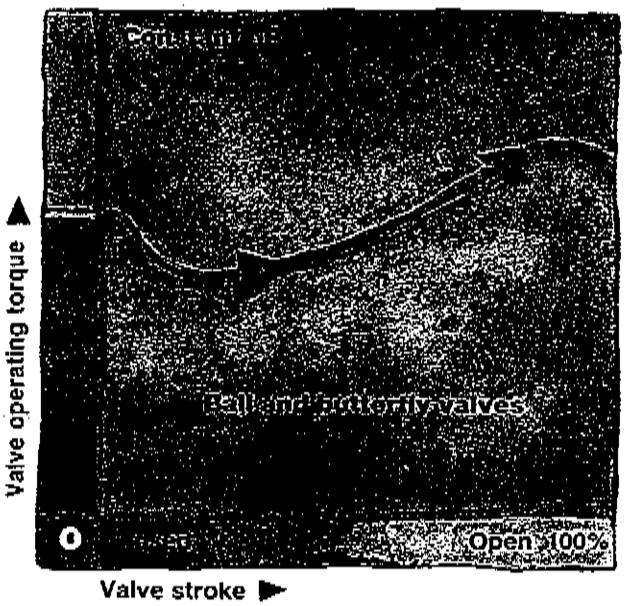
The stem materials selected are based on cost, their commercial compatibility with the fluid media, and the service temperature. Furthermore, the torque requirements for fire-safe valves would necessitate larger operating-torques, and hence larger stem-diameters.

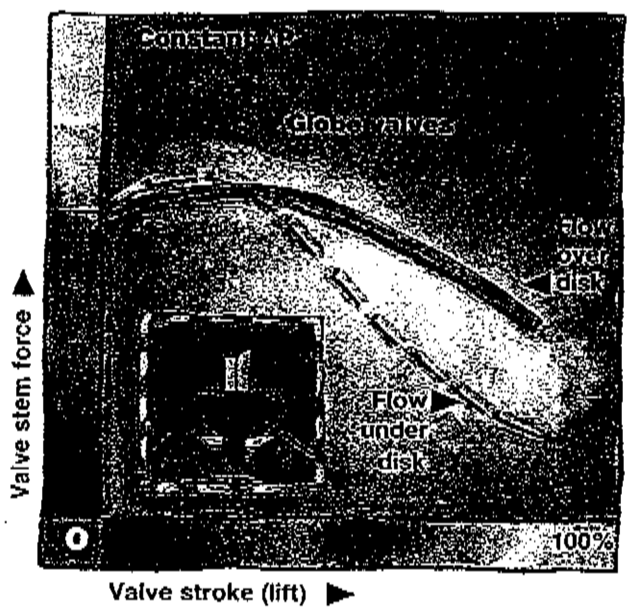
**Use custom supply**

As mentioned earlier, it is quite common for an end user to purchase the valve and actuator from two different sources, and mount the actuator on his or her own. Under most circumstances, this should be no problem.

But when the actuator assembly fails to work properly, it becomes difficult to determine if the problem lies with the valve, the actuator or both. To avoid such ambiguities, it is prudent that the valve user procure the valve and the actuator as a single assembly from a reputable valve manufacturer. Then, the responsibility for selecting, mounting and testing an optimum valve-actuator assembly would rest with the valve manufacturer, who is generally aware of the valve torque requirements, or what the actuator can deliver. Since the actuator and the valve would have already been tested as a complete unit by the supplier, this would reduce the expensive, and often very time-consuming fine tuning of the actuator adjustments in the field.

It should, however, be understood that to implement precise control, it's the user who must be aware of the factors pertinent to the actuator selection process, and provide the device supplier with all the necessary information. And the supplier should not hesitate to ask for additional information, if needed. Failure to do so may lead to improper control action with undesirable consequences on product quality and process safety.




*Edited by Gulam Samdani*

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