fixed bolt; on the other side is a lever that is used to lift and rotate the gate about the fixed bolt on the other side.

Flap Valves

Flap valves (see Figure 5-11) for pump discharge are substitutes for check and isolation valves and are an economical, reliable method of preventing backflow through out-of-service pumps. With this type of device, no isolating valve is installed. Rather, the flap valve is installed on the individual pump discharge piping at the point of discharge to the receiving sewer, channel, or discharge structure. A prudent engineer makes some provision (slide gate or bulkhead slots) for isolating the flap valve for maintenance purposes, but no expensive, heavy-duty isolating valves are required. Be sure to provide a vent just upstream from the flap valve to drain the pump discharge and prevent slam. Use flap valves with a cushion design specifically intended for pump discharge service.

Stop Plates

A stop plate is a thin, vertical, rectangular plate used to form a temporary dam in open channel flow. It is sometimes used in the wet wells of pumping stations to block flow to part of the wet well so that a pump and its suction piping can be dewatered for maintenance. The plate may have its own actuator or may be lifted by hand. Large plates can be lifted with a crane or hoist and stored on a rack or in a pit when not in service.

The plate is usually aluminum, but wood, fiberglass, stainless steel, and other materials are sometimes used. A local fabricating shop can make stop plates if supplied with detailed design information. Alternatively, a somewhat more sophisticated plate can be obtained from manufacturers, which means the engineer need not design such details as reinforcing.

Except for very small units, stop plates cannot be moved up or down when there is a substantial difference (more than about 0.2 m or 6 in.) in water level across the gate. If it is necessary to move the plate under such conditions, (1) a sluice gate may be used instead, or (2) a valve (typically a 100- to 200-mm [4- to 8-in.] gate or butterfly) or small stop plate can be mounted in a larger plate to allow equalization of water levels before the larger plate is moved. Stop plates are inexpensive, simple, suitable for local fabrication, and take up little of the valuable space in a wet well, but moving them is awkward and the leakage is high.

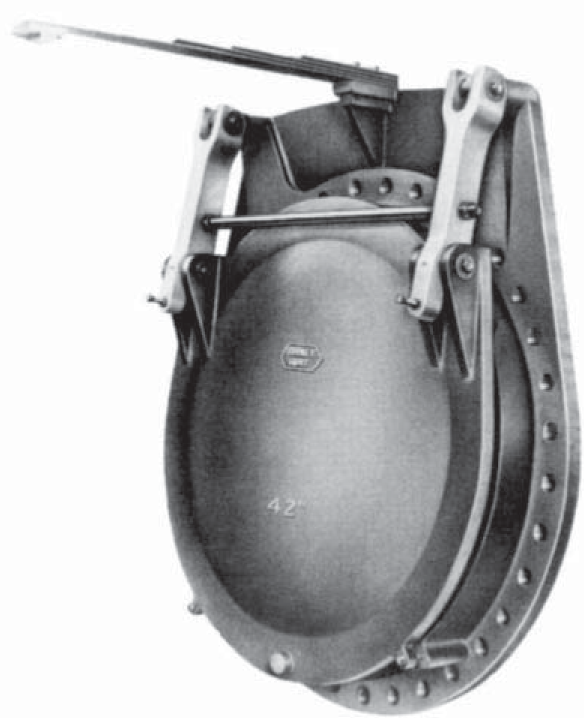

Figure 5-11. Flap valve designed for use with pump discharge. Courtesy of Rodney Hunt Co.

5-4. Check Valves

A check valve is usually (but not always) required to (1) prevent reverse flow and prevent runaway reverse pump speeds when the pump is shut off; (2) keep the pipeline full of water to prevent the entrance of air; and (3) minimize water hammer and surges for pump start-up and shut-down.

Vertical pipelines are poor locations for check valves if the water contains grit or solids. For vertically placed valves in clean water service, special springs or counterweights may be needed. Manufacturers that state that a check valve can be placed in a vertical pipeline are referring only to the springs or counterweights and ignoring the danger of deposited grit and solids, which can (and will) jam the valve.

The designer's responsibility is the selection of a valve that will give good service in keeping with the pump selection, hydraulics, and size of the system. The first decision is whether a check valve will serve, or whether a more sophisticated pump-control valve is necessary to limit surges. Some insights for this decision are contained in Chapters 6, 7, and 26 as well as in Parmakian [13], but only a sophisticated mathematical model of the system solved by means of a computer can provide a rational analysis. Unfortunately, such modeling is time-consuming and expensive.

Valve Slam

Check valves can be divided into two broad classifications: (1) those that are closed by the static pressure of water above the valve (mechanical checks), and (2) those held shut by an external actuator (pump control or controlled check valves). The latter do not slam, but swing checks do if, before the valve is fully closed, any substantial reverse velocity catches the valve disc and accelerates it until it strikes the body seat abruptly. The sudden stop of disc, lever, and counterweight (if there is one) plus the violent impact of the disc on the body seat (especially if the contact is metal to metal) causes an explosive noise and vibrations that shake the pipe and may shake the whole building. The real problem is the water hammer that results if the water column is flowing backward at a significant velocity when the valve closes. However, valve slam can occur without water hammer and vice versa.

At worst, valve slam can rupture water lines and pump casings. At best, it is annoying. In between, it pounds the system, can overstress pipes and joints, and may well result in eventual leaks and greatly increased maintenance. It is difficult to give advice on the best kinds of valves to specify because valve slam depends on many interrelated factors in addition to valve design. Other factors that are just as important include static head, friction head, the inertia and spin-down characteristics of the impeller and motor, size of pipe, and velocity of flow. Generally, valve slam is caused or aggravated in the following ways:

Low flywheel effect. The principal cause of valve slam is quick deceleration of the pump due to low angular momentum of the impeller, the driver, and the water within the casing. With enough inertia, valve slam can be prevented, but the necessary flywheels may be large and costly.

High proportion of static head. If the headloss is 70% static and 30% dynamic (due to friction), valves slam worse than if the headloss is 50% static and 50% dynamic. A simple vertical lift (e.g., into an adjacent elevated tank) is especially prone to valve slam.

Frequency of valve slam. Valve slam may stress material beyond yield strengths and cause permanent deformations. A few deformations of a given intensity may be acceptable, but numerous deformations eventually cause leakage or rupture. Even a single slam, if severe, is dangerous.

Large pipe diameter. As valve size increases, the resulting time to close it increases, the disc velocity increases, and the energy in the system increases.

Parallel pumps. If two pumps are connected to a header and pump 1 shuts off while pump 2 is operating, pump 2 may cause the short water column between the two pumps to reverse very quickly and, thus, cause the check valve of pump 1 to slam.

Column separation. Water column separation can cause valve slam in two different ways: (1) rapid reversal of flow through the check valve, even though flow in most of the pipeline reverses slowly, and (2) a fast-rising positive pressure surge due to the collapse of a vapor cavity if the surge arrives at the valve when it is not closed fully (see Chapter 6).

Air chambers and surge tanks. These units can prevent column separation, but at the same time they can cause rapid flow reversal at the valve and thus aggravate valve slam (see Chapter 7).

Insufficient closing force. If the closing force due to the disc weight and spring or counterweight is low, the valve operates too slowly. But the closing force should not be so high that the valve does not open fully under steady-state pumping conditions. If the valve is not fully open, the headloss increases and debris is more likely to hang up in the valve. Also, excessive closing force can cause the disc to bounce off the seat so that valve slam recurs, sometimes two or three times.

Constant-speed pumps. Constant-speed pumps have two features that aggravate valve slam: (1) they must be turned on and off at full capacity (unlike variable-speed pumps), and (2) as they are turned off, their speed cannot be ramped down gradually. With variable-speed pumps, the speed can be ramped down during normal shutdown (although not when the power fails). Soft starters equipped with soft deceleration features can be adjusted to mitigate valve slam.

Friction in the hinge pin bearings. Friction is increased by dirt and corrosion. If the disc hesitates before moving, valve slam is almost certain to occur—mostly significant with tilting disc check valves.

Body shape. Details of check-valve design influence the closure operation. Because the disc must open wider in a valve with a straight body than in a valve with a bulbous body (Figure 5-12), the movement upon closing is correspondingly greater and the valve slam may be greater.

Inertia. Closing time increases with inertia of moving parts. A counterweight in a valve without a dashpot may therefore cause valve slam, and replacing such a counterweight with a spring sometimes min-

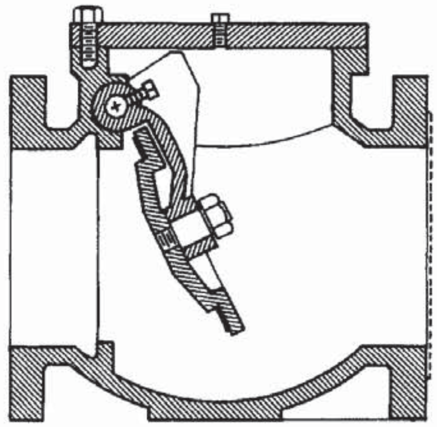

Figure 5-12. A swing check valve at full flow. After GA Industries, Inc.

imizes slam if the pumps have no significant spin-down time.

Preventing Valve Slam

Valve slam can be prevented, or at least kept within bounds, by

- using a valve that closes quickly—before the flow can reverse by adding a heavy counterweight or a stiff spring to the external lever;
- adding a dashpot or buffer to make the disc seat gently; or
- closing the valve with an external actuator so that the water column is gradually brought to rest without a significant increase in pressure.

The first two methods may prevent valve slam but do not necessarily prevent pressure surges.

Small Valves

For small valves, either confine swing checks to pipe less than, say, 250 mm (10 in.) in diameter or precede the valve with a reducer and follow it with an expander. Ordinary swing check valves are manufactured in large sizes, but there is a potential problem in using them in a low friction head system because they cannot close quickly enough.

Spring-Loaded Levers

Many engineers advocate the use of springs instead of counterweights to reduce the inertia of moving parts and thus speed the closure. However, as the valve closes, the spring tension relaxes and the torque on the disc shaft may decrease enough to be insufficient to prevent valve slam, so choose a design in which the combination of spring tension and the lever arm between the spring and shaft creates high torque at closure. A resilient seat aids in minimizing contact noise. These are the least expensive check valves.

Counterweight and Dashpot

A counterweight has the advantage of providing maximum torque on the disc shaft at closure, but it does not close the valve as quickly as a spring because of the inertia of moving parts. Some professionals (especially manufacturers) think the valve should be equipped with either (1) a side-mounted or top-mounted oil-filled dashpot to cushion the movement of the lever at shut-off, or (2) a bottom-mounted, piston-type shock absorber that engages the disc before it closes. Air-filled dashpots are difficult—occasionally impossible—to adjust to prevent valve slam. The required massiveness of construction needed to resist the high force of water against the disc and the dashpot mechanism makes this valve more expensive, but it is the recommended style when the spring-loaded lever type is inadequate. But note, however, that a heavy counterweight or a stiff spring, properly adjusted, is cushioned by the water in the valve.

Pressure-Regulated Bypass Dump

A spring-loaded, pressure-actuated surge relief valve (Chapter 7, Figure 7-8) with a pipeline returning the wasted water to the wet well can reduce the surge to an acceptable, preset level, but it does nothing to mitigate valve slam.

Actuator-Controlled Plug or Ball Valve

An actuator can be programmed to both open and close the valve slowly enough to prevent water hammer (see Chapter 7, Figure 7-7). A stored energy system is needed to operate the valve when power failures occur.

Summary

Selecting a proper type of check valve and control mechanism is more art than science. Experience, not analytical theory, is a key consideration. Of course, a simple method to determine whether a conventional swing check valve can be used without excessive valve slam would be desirable, but unfortunately the complexity of the problem precludes a simple, accurate procedure. Complex computer programs can be used to predict with fair accuracy whether valve slam will occur. The cost of the analysis may be discouraging if the system is small, but large systems should always be so analyzed. If any general statement on check-valve selection can be made, it is probably this: use a swing check valve with an outside lever and spring. If that is inadequate, use a valve with a cushioned closure system such as a dashpot or bottom buffer. As a last resort, use a powered actuator. But note that even the experts disagree, and some prefer counterweights to springs.

Check Valves for Water Service

Check valves useful for water service include:

- Swing check valves
- Center-post guided (or silent) check valves
- Double leaf (or double door, double disc, or split disc) check valves
- Foot valves
- Ball lift valves
- Tilting (or slanting) disc check valves.

The several styles of swing check valves can be divided into those with and those without an outside lever. Outside levers can be equipped with either springs or counterweights, and the levers can be cushioned or noncushioned. Bottom buffers can be used instead of dashpots affixed to the outside lever.

Check Valves for Wastewater Service

Valves for wastewater service must be capable of passing large solids and, as with isolation valves, must have no obstructions to catch stringy material. Valves likely to be used for wastewater are essentially limited to:

- Swing check valves
- Flap valves, which might be used in special circumstances (for example, with combined sewers that contain storm water and wastewater)
- Ball lift valves, which are useful in positive displacement sludge pumps as the ball can be lifted completely out of the flow path.

The rubber clapper swing check valve has no outside lever, is not fully ported, and, hence, should not be used for raw wastewater or sludge.

Description of Check Valves

The following descriptions of check valves for water and wastewater offer some guidance and suggestions. A summary of recommendations for use is given in Table 5-3.

Ball Lift Check Valves

A ball lift check valve contains a ball in the flow path within the body. The body contains a short length or guide piece in which the ball moves away from the seat to allow the passage of fluid. Upon reverse fluid flow, the ball rests against an elastomeric seat.

Table 5-3. Recommendations for Use of Check Valves[a]

	Water		Wastewater		
Type of valve	Raw	Clean	Raw	Treated	Sludge
Ball	E	E	E	E	E
Ball lift	F–G	F–G	F–G	F–G	G
Center-post guided	P	F	X	X	X
Double door	X	G	X	X	X
Flap	—	—	G	—	—
Foot	F	G	—	—	—
Swing					
No outside lever	P	P	P	P	P
Outside lever and counterweight	F–G	F–G	F–G	F–G	G
Outside lever and spring	F–G	F–G	F–G	F–G	F
Outside lever and air cushioned	F	F	F	F	P
Outside lever and oil cushioned	G	G	G	G	G
Slanting disc	G	G	X	F	X

[a]E, excellent; G, good; F, fair; P, poor; X, do not use; —, use is unlikely.

These valves are often encountered in pumping stations in sizes of 50 to 150 mm (2 to 6 in.) or smaller for pump seal water or for wash water supply piping. They have also been successfully used by at least one major pump manufacturer for raw wastewater pump discharge piping up to 600 mm (24 in.). Except for small sizes, bodies are made of ductile iron. The ball is hollow with an external rubber coating resistant to grease and dilute concentrations of petroleum products, acids, and alkalies. The specific gravity of the balls can be adjusted to suit a wide range of operating conditions.

The valves are said to be self-cleaning, rugged, reliable, nonclogging, and to be able to withstand repeated cycling, because each time the ball is reseated, a different part of the surface rests on the seat. In larger sizes (100 mm [4 in.] or more) for sludge pumping service, ball lift checks are part of the mechanism in plunger (piston) sludge pumps.

As check valves for wastewater pump discharge piping, the valves have these advantages: (1) the headloss is lower than it is for other types; (2) there are no external penetrations and no leakage to the outside (although good swing check valves properly set up do not leak either); and (3) stringy materials have nothing to wrap around and do not foul the valve. On the other hand, the standard valve (unlike swing check valves) gives no indication of whether water is flowing—a serious disadvantage. Ball lift check valves are, however, available with ball position indicator-proximity switches.

Decisions to use a ball lift check valve instead of, say, the faster-closing swing check valve with a spring-loaded lever should be based on a computer-aided dynamic hydraulic analysis of the system.

Center-Post Guided Check Valves

Center-post guided check valves are low-cost and are called "silent check valves" by some manufacturers. They close more rapidly than any other check valve. As shown in Figure 5-13, the disc is held closed by a spring until the pump is started. The spring selection is very critical; it is the differential pressure across the valve (difference between static head and TDH) that must be specified and not the safety pressure rating of the system. An incorrect specification results in valve slam.

Three disadvantages of this valve type are that (1) the operating mechanism is enclosed so the valve must be removed for servicing; (2) there is no external indicator of the position of the disc; and (3) the headloss is high.

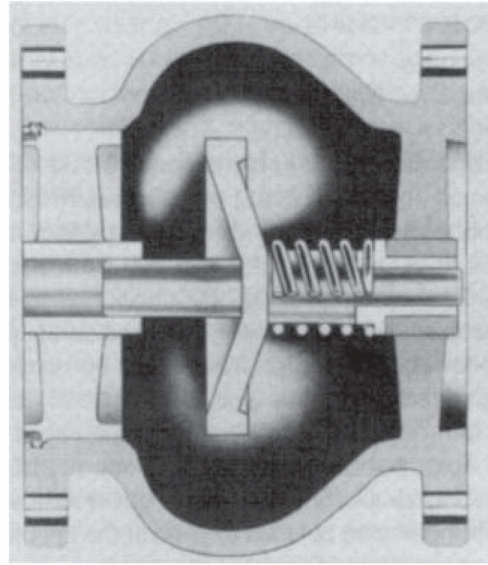

Figure 5-13. Center-post guided "silent" check valve. Courtesy of APCO Valve & Primer Corp.

Double Leaf Check Valves

Double leaf (also double door, double disc, or split disc) check valves contain two hinged half-discs in a short body. The two half-discs are hinged in the middle and contain a spring that forces them closed. This type of valve has no connecting flanges of its own. Instead, it is inserted between two adjacent pipe flanges. It can be installed in either the horizontal or vertical position.

These valves should never be used in wastewater or sludge service or in abrasive conditions because the hinge and discs can catch solids and the seat and discs would wear in abrasive service. Double leaf check valves are small, light, and inexpensive and have a short laying length. They close very quickly but they cannot be adjusted from the outside, nor can they be cushioned, so a sudden flow reversal can cause slam and water hammer. Shut-off is not leak proof. Other disadvantages are (1) the valve must be removed to service the mechanism; (2) there is no external indication of whether the valve is open or closed; and (3) they are subject to a fluttering motion caused by vortex shedding as the fluid moves past the valve plates. If the fluid velocity is less than 3.4 m/s (11 ft/s) and the valve is at least eight pipe diameters downstream from any source of flow disturbance such as a pump or a fitting, the problem is reduced [14].

Foot Valves

A foot valve is a special design of a lift check valve. It is used in the suction line of a sump pump to prevent loss of prime. It is designed for upflow and is attached to the bottom of a pump suction pipe.

Foot valves are prone to leakage, especially when used in fluids containing abrasives and solids, and they are difficult to service. Foot valves decrease the net positive suction head available ($NPSH_A$, see Section 10-4). In a raw wastewater pumping station, a better choice would be to use a self-priming pump if a conventional wet well–dry well pumping station cannot be used or is not feasible.

Lift Check Valves

The body of a lift check valve is similar to that of a globe valve. A plug or stem moving within a guide lifts upward and allows fluid to pass through the valve. The plug seats when the flow reverses.

A lift check valve does not provide a tight shutoff. It cannot be used in fluids containing solids or abrasives, and gum-forming fluids can cause the stem to stick. Sudden flow reversal can cause water hammer.

This type of valve is normally encountered in pumping stations only in sizes 50 mm (2 in.) and smaller and in services such as utility water and compressed air.

Swing Check Valves

A swing check valve (Figure 5-12) contains a hinged clapper or disc that rests on a seat and prevents fluid from flowing backward through the body. A disadvantage of metal-to-metal design is the lack of a tight seal when the disc is seated, so a rubber seat is better. The disc is usually affixed to a hinge pin by means of an arm. The pin and arm allow the disc to move up and out of the flow path in the direction of fluid flow.

Swing check valves can be installed in both horizontal and vertical positions. In a horizontal position, the valve bonnet must be upright. In a vertical pipe, the valve must be installed so that fluid flow is in the upward direction, but never install swing check valves in vertical pipes in wastewater, sludge, or slurry service because rags, debris, and grit would settle against the disc and eventually prevent functioning. Clearing the valve in this position is a messy, disagreeable task.

Slamming when a pump stops and the fluid reverses direction is a significant problem when using swing check valves of some designs. In general, swing check valves larger than 150 mm (6 in.) should have an outside lever and spring to close the disc quickly before the fluid can reverse direction. Note, however, that a commonly used check valve standard, AWWA C508, does not cover the outside lever and spring design. A disadvantage of this type of valve is that the outside lever and spring or counterweight can prevent the disc from opening fully, especially at low flow velocities—less than about 3 m/s (10 ft/s)—with a consequent increase of headloss. The swing check valve in Figure 5-12 is fully ported when open 20 degrees, but most designs require a swing of 60 degrees to open fully. Headloss through the valve at low velocities is generally higher than the manufacturer's data, which are usually based on a fully open valve disc. If the valve is properly chosen for the specific application and the spring tension or the counterweight properly adjusted, however, the headloss should agree with the manufacturer's data. Headloss increase is often caused by increasing spring tension or the weight on the lever arm to reduce slam—a direct result of improperly selecting the valve. Swing check valves in pipes larger than 400 or 450 mm (16 or 18 in.) should be specified with caution, especially if the head exceeds about 15 m (50 ft), because the force on the disc is enormous.

Cushioned Swing Check Valves

Some check valve manufacturers offer pneumatic and/or hydraulic dashpots attached to the valve to regulate the speed of closure of the disc upon water column reversal. The cushioning system consists of:

- a weighted lever arm attached to the disc pin or axle
- a piston mounted outside of the valve body and contained in a cylinder (dashpot) attached to the weighted arm.

As the fluid velocity decreases, the weighted lever arm forces the disc to close, and the piston moves downward in the cylinder. The piston compresses the air (in a pneumatic system) or displaces oil through an orifice (in a hydraulic system). Adjusting the valves on the pneumatic or oil lines (or the orifices in the dashpot) controls the rate of closure.

The hydraulic system offers better control than the pneumatic system, which often does very little to reduce the slam. Sturdy valves can be closed quickly or slowly and can even be closed in two or three stages, such as quick closure to 50%, moderate speed of closure to 95%, and slow closure to shut-off.

Be very careful in selecting applications for these valves; close coordination with the manufacturer is necessary. In addition, field adjustment after installation is needed to set the closing controls properly. These valves are vulnerable to tampering.

Rubber Flapper Check Valves

The rubber flapper swing check valve is a swing check that is entirely enclosed. The seat is on a 45-degree angle and the steel-reinforced flapper need travel only about 35 degrees to reach the fully open position. The short stroke and light weight of the flapper make it capable of very fast shut-off, which, combined with the resilient seat, reduces slam. The construction of the valve is simple, as is maintenance. There is no outside lever, no way of adjusting the closing force, and no way of determining whether the valve is open or closed. This type of valve should not be used in raw wastewater service because debris can pack above the disc and prevent the disc from opening.

Slanting Disc Check Valves

A slanting disc check valve contains a disc balanced on a pivot. Instead of being perpendicular to the longitudinal axis as in conventional swing check valves, the seat is at an angle of 50 to 60 degrees from the valve longitudinal axis. Slanting disc check valves should only be used in water service; rags and solids present in raw wastewater and sludge would hang up on the disc.

The advantages of this type of valve are (1) headloss is low (although not as low as in a swing check valve) in the open position because the vane or flapper is designed as an air foil; (2) various pneumatic and oil-filled dashpots can be used to control the opening and closing speeds; and (3) the performance of these controls can be adjusted in the field. The disadvantages are (1) velocities less than 1.5 m/s (5 ft/s) do not fully open the vane; (2) the disc oscillates in the flow and the bearings wear on the bottom, so the valves begin to leak; and (3) the valve is not fully ported.

The two controls most frequently encountered are bottom buffers and top-mounted dashpots. These two systems are sometimes mounted together on one valve.

The bottom buffer consists of an oil-filled cylinder in which a piston is moved by the closing disc or vane. The disc moves freely for the first 90% of its closure, then strikes the buffer piston, which can be adjusted in the field to control the last 10% of disc travel.

The top-mounted oil dashpot system allows both the opening and closing speeds of the disc to be adjusted over the full range it travels. This adjustment can be especially valuable with pump start-up because the opening speed can be regulated to open the valve slowly, which greatly reduces hydraulic transient effects caused by pump start-up. A disadvantage is the high load exerted on the mechanical linkage when the pump reaches shut-off head. However, no electrical interconnections between the pump motor control center and check valve are needed.

5-5. Control Valves

Control valves are used to modulate flow or pressure by operating in a partly open position, thus creating a high headloss or pressure differential between upstream and downstream locations. Such operations may create cavitation and noise. If there is a large pressure differential and the limits of operation are approached or exceeded, the discs tend to flutter and bearings may wear quickly. Valve seats are especially vulnerable to wear because, if the pressure differential is high across the seat, small channels may be cut (called "wire drawing"), which prevents a tight seal, aggravates the wire drawing, and makes frequent replacement necessary.

To minimize wasting energy and to increase the life of the valve, it is desirable to minimize the time of operation at partly open positions. If the valve must throttle flow for extended periods, choose a style well adapted for the purpose and select hard materials for those parts that wear quickly.

Some control valves may be manually operated (for example, needle valves used to control the flow of a fluid in a valve actuator). Most control valves, however, are power-operated by programmed controllers. These valves are used for a variety of purposes: pump control, check valve control, control or anticipation of surges, or control of pressure or flow. The power source can be (1) hydraulic (usually oil), (2) pneumatic, (3) a combination of pneumatic and oil, (4) electric, or even (5) the pressure of the pumped water. All control methods feature some kind of adjustable-speed actuator, sometimes with three electric speeds that depend on the position of the valve mechanism. Whatever the power source, a backup is needed for power outages. The backup can be a pressure tank for pneumatic or hydraulic actuators or trickle-charged batteries for electric actuators (see Section 5-6).

Control valves are selected on the basis of the requirements of the hydraulic system and the characteristics of the pump. A major decision is whether to use a check valve that is controlled by the flow or a more sophisticated valve that itself controls the flow. The characteristics of the type—and even the brand—of pump-control or check valves are important. Every type of valve used as a check valve suffers some of the effects of cavitation, noise, and vibration while opening and closing, and some types are more