BY JOHN V. BALLUN

A methodology for predicting check valve slam

USING A METHODOLOGY DEVELOPED BY EXTENSIVE TESTING, DESIGNERS CAN MATCH THE DYNAMICS OF A PUMPING SYSTEM WITH THE NONSLAMMING CHARACTERISTICS OF MANY COMMON CHECK VALVES.

Although check valve slam is a common problem associated with check valves, little information has been published about how to predict and prevent its occurrence. Transient analysis software programs are often used to prevent surges in pipelines, but few, if any, can predict the occurrence of check valve slam.

The term "basic" refers to a check valve without oil dashpots and other devices that significantly slow down the closure of the valve and intentionally allow reverse flow to pass through it. The closing characteristics of basic check valves have been extensively studied in Europe for many years (Thorley, 1989; Provoost, 1983). Only recently, however, have US check valve manufacturers tested the closing characteristics of water system check valves and made these data available to design professionals. This article describes a program that was used to perform extensive testing on several types of check valves and details a methodology that can be used by engineers to help ensure that the check valves they select will not be subject to slamming and associated water hammer. This methodology, when combined with field experience, should significantly benefit the water supply community.

FUNDAMENTALS OF CHECK VALVE SLAM REVIEWED

Mechanics of check valve slam offer insight into cause and prevention. Check valve slam occurs after pump stoppage when the forward flow reverses and flows back toward the pump before the check valve is fully closed. The reverse flow is stopped almost instantaneously by the closing valve, causing a sometimes loud water hammer in the pipe. The noise associated with the slam is not the impact of the disc into the seat but rather the rapid stretching of the

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A tilted-disc check valve often provides slam-free operation without dashpots because of its short stroke and balanced disc.

pipe caused by the water hammer. Even a resilient-seated check valve makes the same metallic slam sound as a metal-seated valve because the sound emanates not from the valve seat but from the stretching of the pipe. In severe pumping applications, almost all basic check valves will slam, and in extremely mild applications, hardly any check valves will slam. It is the uncertainty of the middle ground between these extremes that makes the task of predicting check valve slam difficult.

To prevent check valve slam, a check valve must close either very rapidly before appreciable reverse flow occurs or very slowly once reverse flow has developed (Landon, 1993). Thorley (1991) has suggested that in order for the check valve to close rapidly

- the disc should have low inertia and friction,
- the travel of the disc should be short, or
- the motion should be assisted with springs.

To close slowly, a check valve needs to be equipped with external devices such as oil dashpots, and the pump must be capable of withstanding reverse flow and backspin. Oil dashpot devices have proven effective at providing slow closure, but they add significantly to valve cost and may cause valve clogging in wastewater applications. The methodology described in this article focuses on basic check valves without oil dashpots. If slamming is predicted, oil dashpots can be added or a different valve can be selected.

> The best check valve is not necessarily the one with the least potential to slam, but the one that meets all of the relevant selection criteria.

Check valve slam can be predicted and prevented. The solution to preventing check valve slam is not to find the fastest-closing check valve and make it the "standard" but to match the nonslam characteristics of the check valve to the pumping system. To select a nonslam check valve, the designer must first analyze the pumping system and calculate the deceleration of the liquid column after pump stoppage. In other words, if the flow rate is 12 fps (3.66 m/s) and calculations or measurements show that the flow will stop in 2 s,

FIGURE 1 Dynamic characteristics of dual-disc check valves

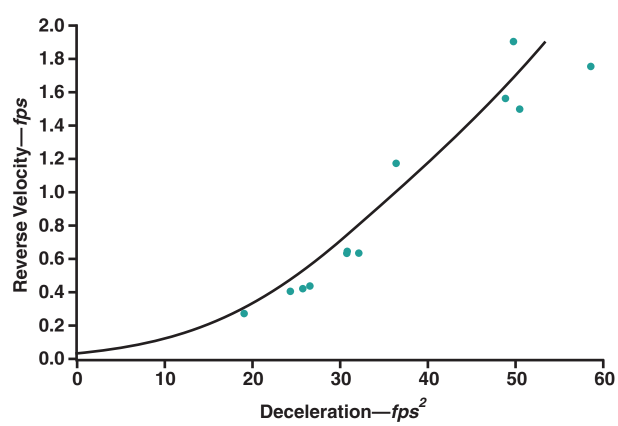

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FIGURE 2 Check valve test loop

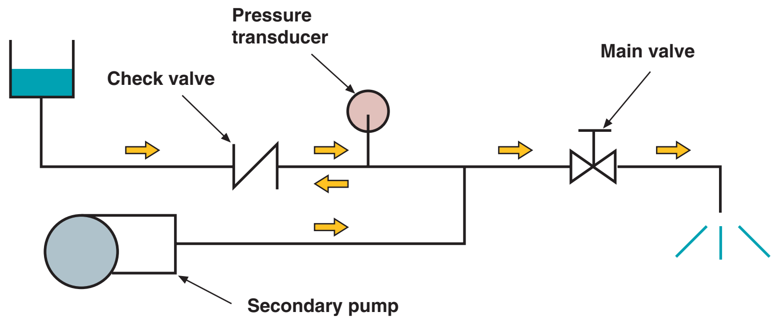

FIGURE 3 Sample pressure recording

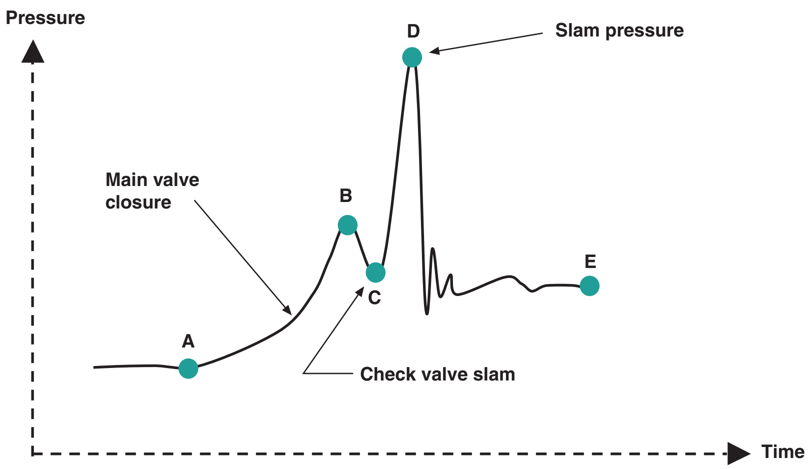

TABLE 1 Slam predictions* for a multiple-pump station with a calculated system deceleration of 20 fps^2 (6.1 m/s^2)

Valve Type	Reverse Velocity—*fps (m/s)*	Level of Slam
SCV	0.20 (0.06)	None
RHCV-S	0.30 (0.09)	None
DDCV	0.35 (0.11)	None
TDCV	0.30 (0.09)	None
RHCV	0.85 (0.26)	Mild
BCV	>2.0 (0.61)	Severe
SWCV	>2.0 (0.61)	Severe

BCV—ball check valve, DDCV—dual-disc check valve, RHCV—resilient hinge check valve, RHCV-S—resilient hinge check valve with spring, SCV—silent check valve, SWCV—swing check valve, TDCV—tilted-disc check valve

*Predictions are based on data shown in Figure 6.

then the average deceleration is 12 fps (3.66 m/s) divided by 2 s, or 6.0 fps^2 (1.83 m/s^2). Calculating the deceleration can be difficult because it is a function of many parameters such as pump inertia (provided by the pump manufacturer), length of the liquid column, friction losses in the piping system, and the static head or slope of the pipe. Engineers typically rely on a computer simulation of the system to compute deceleration.

It is the valve manufacturers' responsibility to provide the closing characteristics of their valves so that the engineer can predict the maximum reverse velocity that may occur. For each type of check valve, a response curve should be generated to show the relationship between the deceleration of the liquid column and the maximum reverse velocity through the check valve (Provoost, 1983). The deceleration is expressed in terms of dv/dt, or change in forward velocity, divided by change in time, or fps^2 (m/s^2). The reverse velocity is developed from testing and is expressed in velocity terms, or fps (m/s).

For example, Figure 1 shows dynamic test data for a dual-disc wafer check valve. The horizontal axis represents the deceleration of the piping system expressed in fps^2 (m/s^2). The vertical axis is the maximum reverse velocity through the check valve expressed in fps (m/s). A single-pump, low-head system will have a deceleration of <20 fps^2 (6.1 m/s^2). A high-head system of a multiple-pump system may have a deceleration as high as 40 fps^2 (12.2 m/s^2). For this higher deceleration, the dual-disc check valve of Figure 1 would allow a reverse velocity to develop equal to ~1.0 fps (0.3 m/s). The reverse velocity can be converted directly into water hammer pressure using the familiar Joukowski equation:

$$h = \frac{av}{g} \quad (1)$$

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in which h is the pressure rise is feet of water; a is the steel pipe wave velocity, fps ≈ 3,200 fps (975 m/s); v is the reverse velocity in fps (m/s); and g = 32.2 fps^2 (9.81 m/s^2).

The reverse flow of 1.0 fps (0.3 m/s) corresponds to a water hammer of 100 ft (30.5 m). Field experience shows that water hammer in the range of 50–100 ft (15–30.5 m) or reverse velocity of 0.5–1.0 fps (0.15–0.30 m/s) represents a mild slam and can be tolerated. Conversely, water hammer greater than 100 ft (30.5 m) or reverse velocity <1.0 fps (0.3 m/s) is extremely loud and should be avoided by either selecting a different check valve or modifying the check valve with heavier springs or hydraulic dashpots.

The Joukowski equation also provides insight into why the same check valve may create different effects in various systems. Because the pressure rise (h) is directly proportional to the wave velocity (a), the pipe characteristics that affect the wave velocity should be evaluated. Pipe material has a major influence on wave velocity; for example, steel pipe can have a wave velocity of 3,200 fps (975 m/s), whereas the same size polyvinyl chloride pipe has a wave velocity of 800 fps (245 m/s). Therefore, the same slam in a steel pipe can produce a four-times greater pressure rise than in a polyvinyl chloride pipe.

TEST METHODOLOGY CAPTURES CHECK VALVE SLAM DATA

Test methods described. To develop dynamic characteristics for various check valves, a series of valve flow tests were conducted at the Utah Water Research Laboratory in Logan. Several types of 8-in. check valves were flow-tested with water under various dynamic conditions.

FIGURE 4 Typical ball and swing check valves

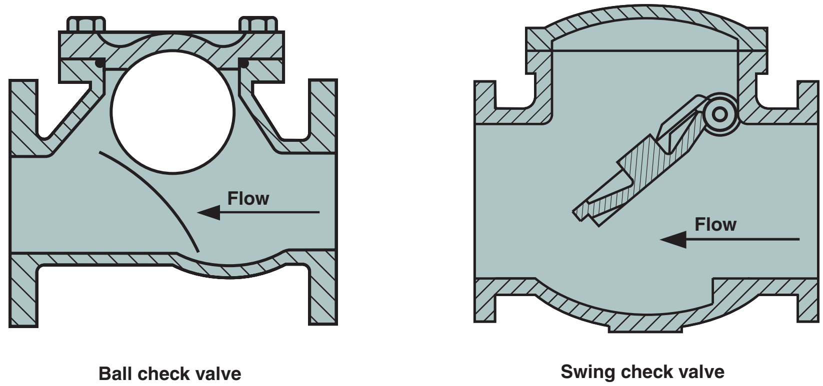

FIGURE 5 Check valves tested at Utah Water Research Laboratory

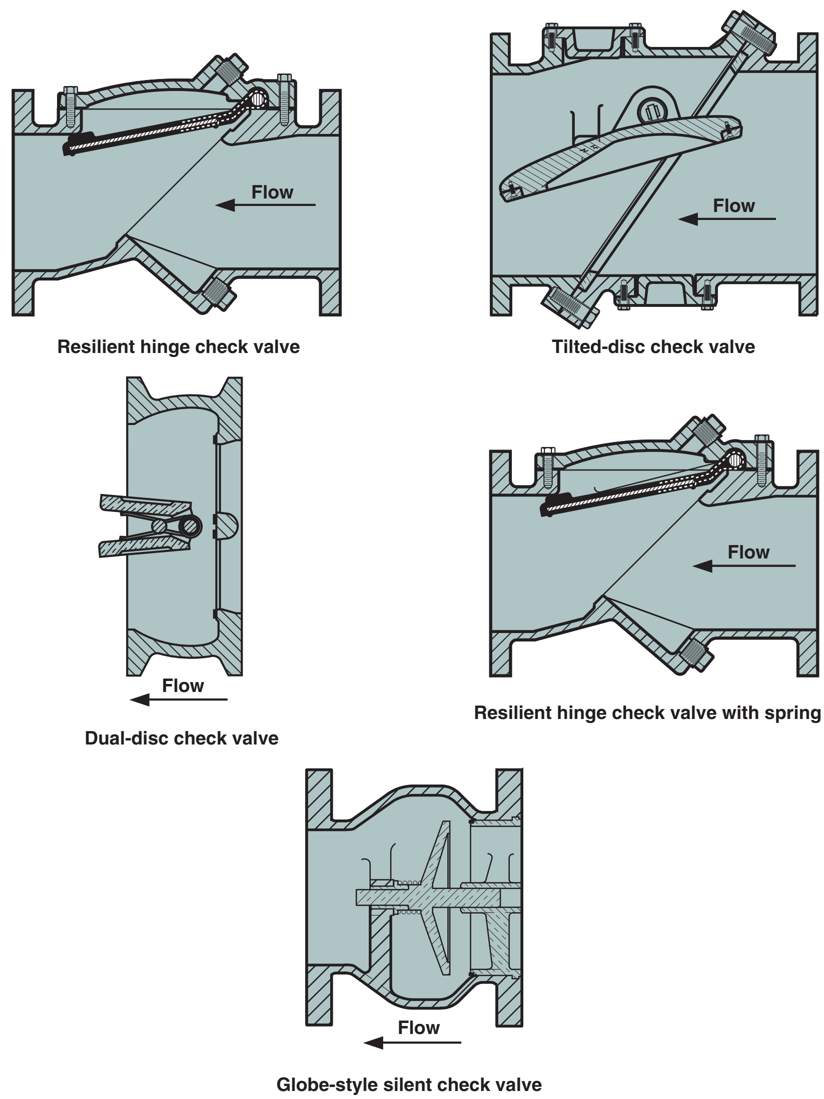

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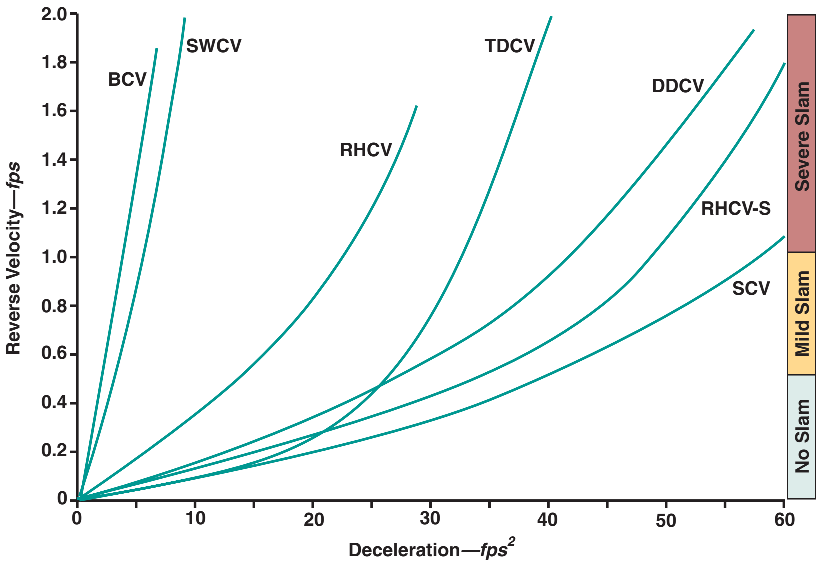
FIGURE 6 Dynamic characteristics of various check valves



BCV—ball check valve, DDCV—dual-disc check valve, RHCV—resilient hinge check valve, RHCV-S—resilient hinge check valve with spring, SCV—silent check valve, SWCV—swing check valve, TDCV—tilted-disc check valve

The check valves were installed in a horizontal test piping run and subjected to different initial forward flows and varying rates of flow reversals. The test line was supplied with a natural supply of mountain runoff water from a reservoir through a 48-in. (1,219-mm) pipeline so that velocities in the range of 4–20 fps (1.2–6.1 m/s) were easily attained. Valve head loss was read by manometers, and dynamic pressures were recorded using transducers and a high-speed data recorder.

Forward flow from the reservoir was established by opening the main valve shown in Figure 2. The supply flow at ~5 psig (34 kPa) from the reservoir automatically opened the check valve fully, and flow rates and head loss data were recorded. Next, a secondary pump was started to supply additional flow at a higher pressure of ~20 psig (138 kPa). Both flows merged downstream of the check valve and exited through the main valve.

To trigger a check valve slam, the main valve was closed suddenly, stopping the forward flow, and the secondary pump rapidly produced reverse flow and valve slam. Different rates of deceleration were achieved by closing the main valve at different rates.

The pressure downstream of the valve was recorded and used to calculate the deceleration of the flow and the reverse velocity through the valve. Figure 3 shows a sample computer trace. Point A represents reservoir pressure. Between points A and B the main valve is closed (stopping forward flow), and the check valve starts to close. At point B, the flow is stopped, and the check valve continues to close. From points B to C, reverse flow builds, until at C the valve disc strikes the seat, causing slam and water hammer. Point D represents water hammer pressure resulting from sudden reverse flow stoppage, and E represents secondary pump pressure. Average decelerations were calculated by dividing the initial velocity by the time interval between points A and B. Reverse flow velocity was calculated on the basis of the surge pressure measured between points C and D and the Joukowski equation.

Methodology can be used to assess check valves' propensity for slam. This test methodology has been applied by different researchers to many types of check valves. For example, Thorley (1991) tested and reported results for the common ball check valve and swing check valve shown in Figure 4. The test methodology was applied at the Utah laboratory on the five basic check valves shown in Figure 5 (Rahmeyer, 1998). Figure 6 shows test results for these five valves together with similar data for the ball check valve and swing check valve tested by Thorley (1991).

Results indicated that the best nonslam check valves were the dual-disc check valve, resilient hinge check valve with spring, and silent check valve, all of which featured spring-assisted closure. The next best nonslam check valves were the resilient hinge check valve and tilted-disc check valve, which featured an

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angled seat and short stroke. The valves with long strokes and no spring assist, i.e., the ball check and swing check, had the greatest potential for slamming.

The graph shown in Figure 6 was divided into three ranges: no slam, mild slam, and severe slam. These divisions were based on numerous field observations of valve slams and acceptable levels of noise and disturbance to the valve and pumping system. The Joukowski equation can be used to convert the given reverse velocity to a quantitative surge pressure to provide a separate determination of system impact.

A system designer can assess possible check valves by finding the system deceleration on the horizontal axis in Figure 6 and then reading the reverse velocity for the various types of check valves. For example, given a multiple-pump station with a calculated system deceleration of 20 fps^2 (6.1 m/s^2), data provided in Figure 6 can be used to predict the slam levels of various types of valves (Table 1). The designer can go on to calculate an estimated water hammer pressure on the basis that there is ~100 ft (30.5 m) of water hammer for every 1 fps (0.3 m/s) of reverse velocity. In the example shown in Table 1, the resilient hinge check valve with spring (RHCV-S) would produce a slam pressure of ~30 ft (9.1 m) pressure surge, which would sound like a dull thud at closure.

However, the designer may still consider using a valve in the mild or severe slam ranges by possibly changing to a speed-controlled pump or modifying the valve to include a stronger spring or an oil dashpot. At first glance, such an approach may seem impractical, but a specific characteristic of these valves (such as the low head loss of a tilted-disc check valve) could be essential for a particular application, and an oil dashpot could be economically justified.

The solution to preventing check valve slam is not to find the fastest-closing check valve and make it the "standard" but to match the nonslam characteristics of the check valve to the pumping system.

Although the dynamic characteristic data shown in Figure 6 can be valuable in valve selection, their use may be limited. First, the test data reflect installation in a horizontal pipeline. Some valves (e.g., the swing, tilted-disc, and resilient hinge check valves) rely on gravity to accelerate disc closure and, when installed in a vertical pipe, may have a greater tendency to slam. Conversely, other valves (e.g., the dual-disc and silent check valves) close faster in a vertical line because of gravity effects on their discs and have less tendency to slam. Furthermore, the dynamic characteristics of the valve are dependent on valve size, but no data are available at this time to predict the exact effect of size. Larger valves have heavier discs and longer strokes and will likely produce higher reverse velocities than those predicted by Figure 6. The valve manufacturer should be consulted for the potential effects of orientation and size on the performance of the selected valve.

CONCLUSION

The closing characteristic data for check valves offer a way to evaluate the nonslam characteristics of various check valves. This information, combined with other readily available valve characteristics such as head loss, laying length, waterway design for fluids containing solids, and cost, will enable system designers to make informed check valve decisions. Every check valve has inherent advantages such as reduced cost, low head loss, or special flow characteristics. The best check valve is not necessarily the one with the least potential to slam, but the one that meets all of the relevant selection criteria.

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