Dynamic Testing of Check Valves

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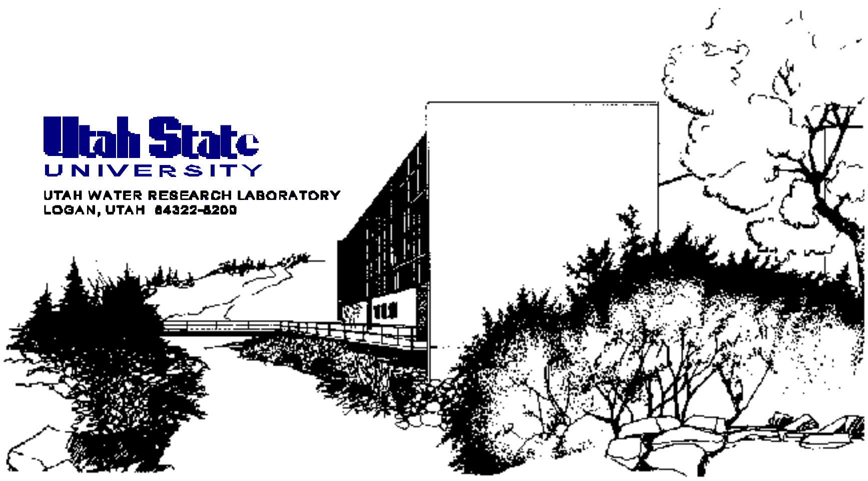

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DYNAMIC FLOW TESTING OF CHECK VALVES

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INTRODUCTION

The two objectives of this paper are: (1) to present a test method by which check valves can be dynamically tested for sudden closure due to reverse flow; and (2) to discuss the valve and pipe characteristics which affect the reverse velocities and pressure surges at the check valves . The information developed from the test method can then be used to predict the resulting upstream and downstream transients or pressure surges caused by a check valve closure for a given piping system and flow deceleration. It should be possible to apply the following test method for the field testing of check valves that are already in use.

Flow deceleration is calculated from the piping system and flow change due to pump shutdown or closure of a control valve. The test method of this paper produces a relationship between the flow deceleration and the reverse velocity at which the check valve closes. The reverse velocity is then used to calculate the pressure surge from transient equations and methods found in publications such as Hydraulics of Pipelines by J. Paul Tullis and Fluid Transients by Wylie and Streeter. The test method can be used for most types of check valves, as long as they are un-dampened and in a full open position when the flow deceleration begins.

The method and results presented in this paper are from the 10-inch and 12-inch swing check valves, bifold valves, and center-guided valves that were tested in vertical and horizontal piping. Observations are also included from the testing of larger check valves in pipelines with varying degrees of upward and downward slope. Tests were conducted at different initial forward flows with varying rates of flow reversal. The results were compared and verified with test data of similar valves tested by Delft Laboratories in the Netherlands. This paper would not be possible without the cooperation from Stockham Valves and Flomatic Valves.

Background

In a piping system, the shut down of a pump or the closure of a control valve, can cause the flow in the system to reverse. Check valves are used to prevent flow reversal, but due to the inertia and friction of the check valve components, limited flow reversal will still occur. Regardless of the initial velocity of the flow (as long as the check valve is fully open) the reverse velocity at which the valve closes is dependent only upon the valve geometry, mass of the valve, and the deceleration of the flow. Figure 1 shows that reverse velocity decreases with a decrease in deceleration. At a constant rate of change of velocity, or deceleration, the reverse velocity is independent of the initial velocity as long as the initial velocity is greater than the minimum velocity at which the valve is fully open.

The sudden closure of the check valve at a reverse velocity can cause large pressure surges downstream of the check valve and negative pressures upstream of the check valve. However, the magnitude and duration of the pressure surges are as much a result of the piping configuration as the check valve. The resulting upstream and downstream transients are typically calculated with a set of complicated equations or with a transient computer program (Tullis 1989). The calculations require information in the form of the relationship between the deceleration of flow and the reverse velocity at which the check valve closes.

The test method presented in this paper is based on the measurement of the flow deceleration (change in velocity with time) and the resulting pressure surge. The reverse velocity is calculated from the measured pressure surge. The test method is not unique, a similar method for testing reverse flows was discussed in a 1983 publication by Valibouse and Verry.

Test Setup

The test valves were installed in either horizontal or vertical test lines with standard schedule, carbon steel pipe. Figure 2 shows a sketch of the test setup and piping used for the horizontal setup. The vertical installation required air release valves to purge the downstream pipe of trapped air. A pressure transducer and pressure tap were located at the equivalent distance of one pipe diameter downstream of the test valves. The transient pressure or pressure surge was measured with a differential pressure transducer that had the negative port opened to atmospheric pressure. The output of the transducer was amplified and sent to a recording analyzer that produced a hard copy of the pressure surges with time. The transducer was zeroed and checked against a known pressure before each series of tests.

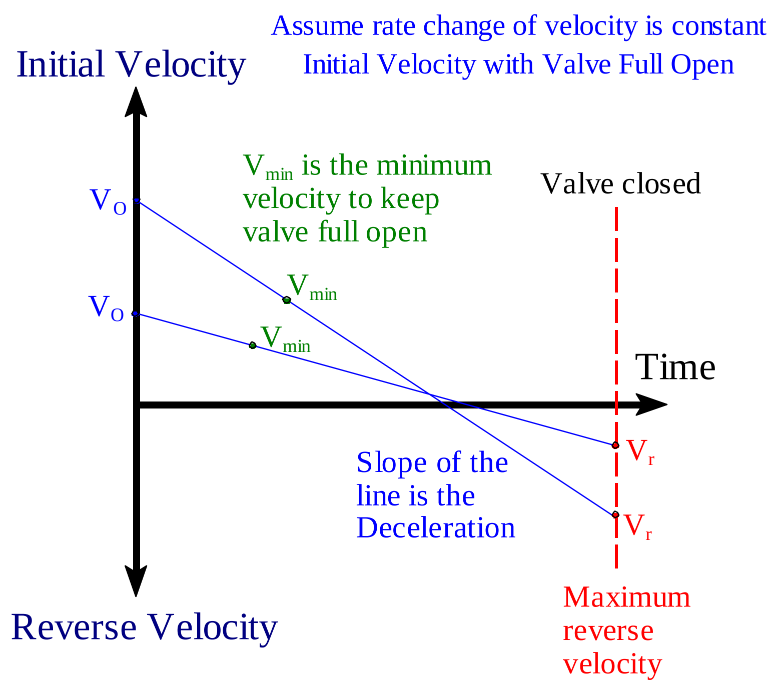

Figure 1 Reverse Velocity versus Deceleration

A precision dial gage was attached to another pressure tap at the same location to verify the measured hydrostatic pressure. An accelerometer was installed on the downstream flange of the test valve to indicate the sudden closure of the check valve. The output of the accelerometer was recorded simultaneously with the pressure on the same data analyzer. Samples plots from the data analyzer are included in this paper.

The piping downstream of the test valve expanded to a larger sized pipe with a 24" butterfly valve which served as the downstream control valve. A lever actuator was used with the butterfly valve, and the larger size of the butterfly valve was selected to insure that the control valve could be quickly closed without any time lag in the flow deceleration.

For the majority of the tests, flow was supplied to the test setup from a constant head reservoir. Flow was not re-circulated since the valve discharge was never returned to the pumps or reservoir. Re-circulated flow could introduce undissolved air into the test setup which would significantly dampen pressure surges. Flow was controlled with upstream and downstream remote control valves. Flow measurement was made with the weight collection systems of the lab.

A flow reversal, similar to a pump shut down, was produced by rapidly closing the downstream control valve. A secondary flow source, with limited discharge but high pressure, was supplied to the downstream pipe (Figure 2). The reverse flow supply allowed better control of the flow reversal and produced larger deceleration rates.

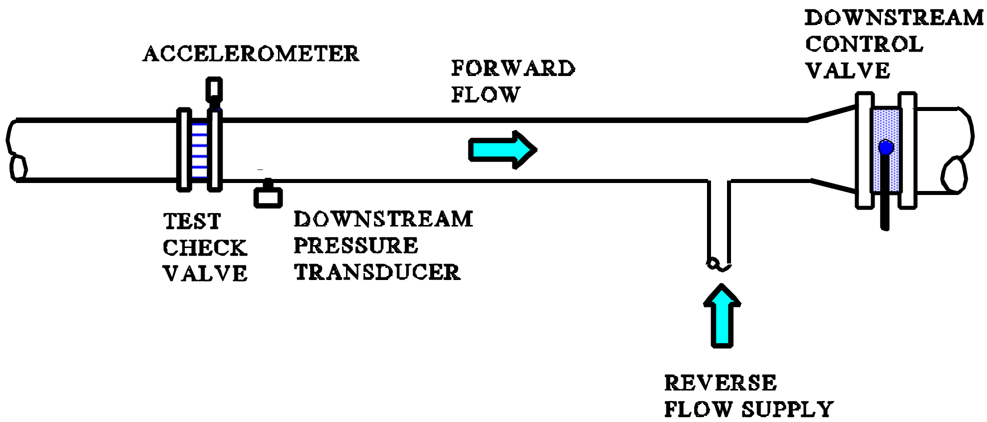

Figure 2 Horizontal Test Setup

The 12-inch check valves were installed and tested in horizontal piping. The test valves included center-guided or pivot valves, bifold checks, and swing checks. The bifold checks were tested with different maximum openings for the discs and with varying spring stiffness. The 10-inch check valves were tested in both horizontal and vertical test setups. The test valves also included center-guided or pivot valves, bifold checks, and swing checks. An additional type of 10-inch swing check was tested that had an external lever arm and weight to aid closing in vertical installations. Several types and models of swing checks, bifolds, and center-guided check valves were tested.

TEST METHOD

The reverse flow velocity at the check valve was not measured, it was calculated (Equation 2) from the measured pressure surge by use of the water hammer equation (Newton's 2nd law):

$$\Delta H = \frac{c \cdot \Delta V}{g} \qquad \textbf{(1)}$$

$$V_r = \frac{g \cdot \Delta H}{c} \qquad \textbf{(2)}$$

Where $V_r = \Delta V$ and is the reverse velocity in fps (m/s), ΔH is the transient pressure in feet (meters) of fluid, g is the gravitation constant 32.2 fps^2 (9.806 m/s^2), and c is the fluid celerity or speed of the transient wave in fps (m/s).

The speed of the transient wave is a function of a number of different variables such as air content, pipe material, pipe connections, etc. The wave speed can be calculated from Equation 3 where fluid and pipe properties are known, and the piping is void of undissolved air and gasses. The general equation (Tullis 1989) for wave speed is:

$$c = \frac{\sqrt{K/\rho}}{\sqrt{1 + \frac{C_P K d}{E e}}} \qquad \textbf{(3)}$$

where K is the fluid bulk modulus, E is the fluid modulus of elasticity, ρ is the fluid density, C_P is a correction for the pipe connections, e is the wall thickness of the pipe, and d is the inside diameter of the pipe.

Figure 3 shows a sample plot of the measured downstream pressure from the tests of a sudden closure of a check valve. After the closure of the valve, the pressure will oscillate as the downstream transient moves in the downstream piping. The period of the oscillation is equivalent to the value of 4L/c, where L is the length of the piping between the test check valve and the downstream control valve. It is possible to estimate the wave speed from the measured period of oscillation, 4L/c.

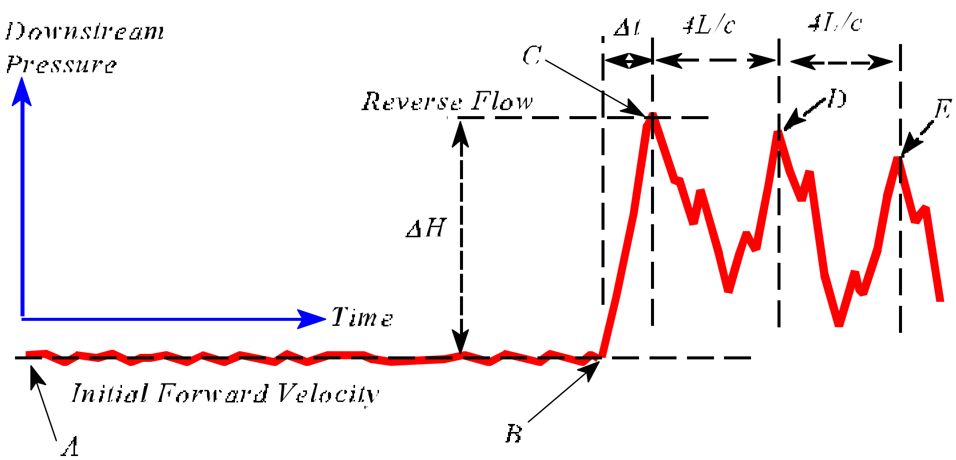

Figure 3 Sample Pressure Plot

The portion of the pressure plot (Figure 3) from point A to point B represents the steady state condition of forward flow with a measured initial velocity V_o. Point B corresponds to the closing of the downstream control valve, and is the start of the deceleration of the flow at the check valve. Point C represents the closure of the check valve after a time interval of Δt. The maximum reverse flow occurs just prior to point C, and the maximum rise of downstream pressure is ΔH. Points D and E represent the return or oscillation of the downstream transient with a time increment of 4L/c.

The equivalent reverse velocity is calculated from Equation 2. Where ΔH is the measured pressure rise in head or feet (meters), c is the wave speed in fps (m/s), and g is the gravitational constant 32.2 ft/s²(9.806 m/s²). The deceleration of flow is calculated from the plot and Equation 4, where V_o is the measured initial velocity in fps (m/s) and Δt is in seconds.

$$Deceleration = \frac{Vo + Vr}{\Delta t} = \frac{Vo}{\Delta t} + \frac{c\,\Delta H}{g\,\Delta t} \qquad \textbf{(4)}$$

RESULTS

Figures 4, 5, and 6 show sample pressure plots from a data analyzer and the tests of a swing check valve, a center-guided check valve, and a bifold check valve. Figure 6 also show the dual plot from both a pressure transducer and an accelerometer. The peak vibration occurred at the closure of the check valve. Figure 7 is a comparison plot of the tests of three different check valves tested at different initial velocities. Figure 7 demonstrates that the relationship between reverse velocity and flow deceleration is independent of initial velocity as long as the test valve is fully open at the initial velocity.

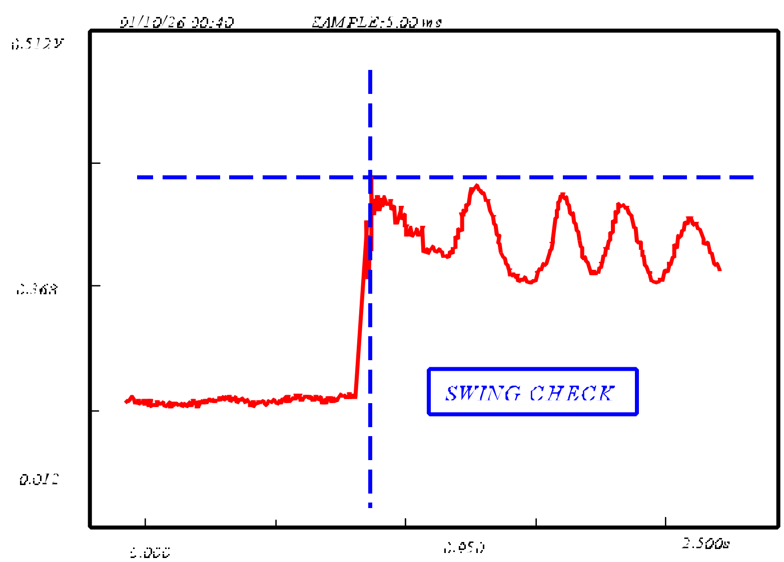

Figure 4 Sample Pressure Plot for A Swing Check Valve

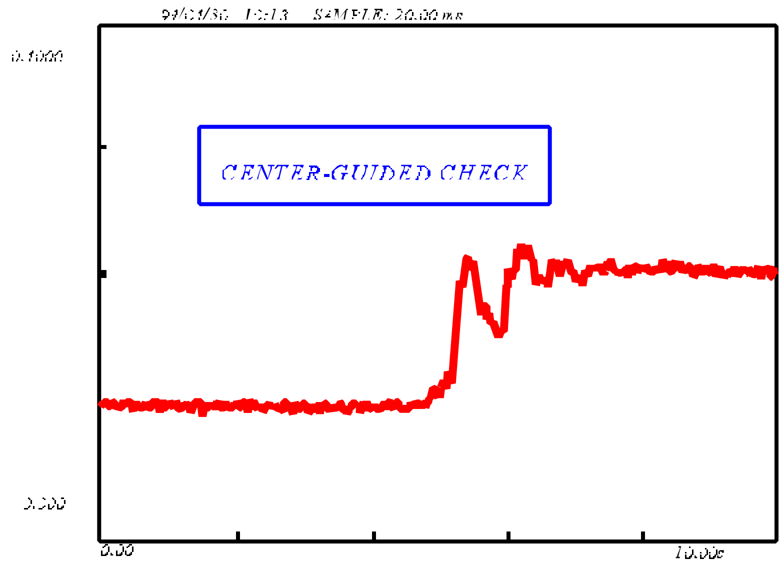

Figure 5 Sample Pressure Plot for A Center-guided Check Valve

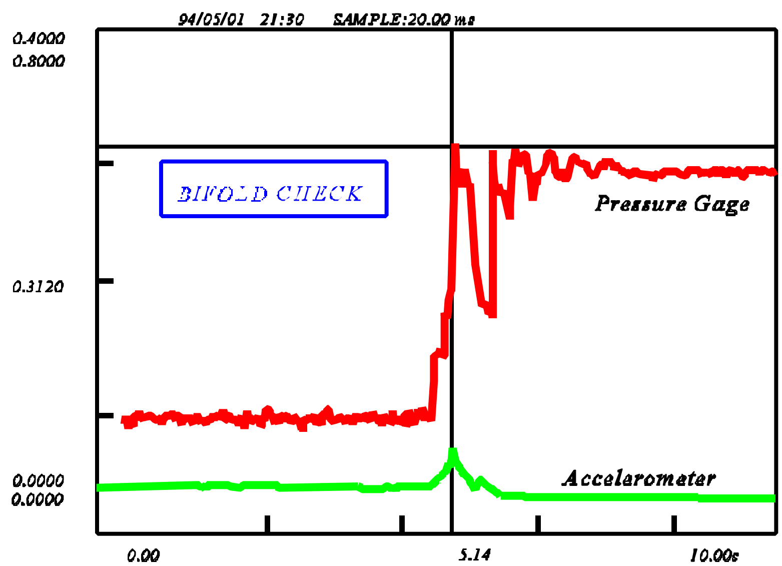

Figure 6 Sample Pressure Plot for A Bifold Check Valve

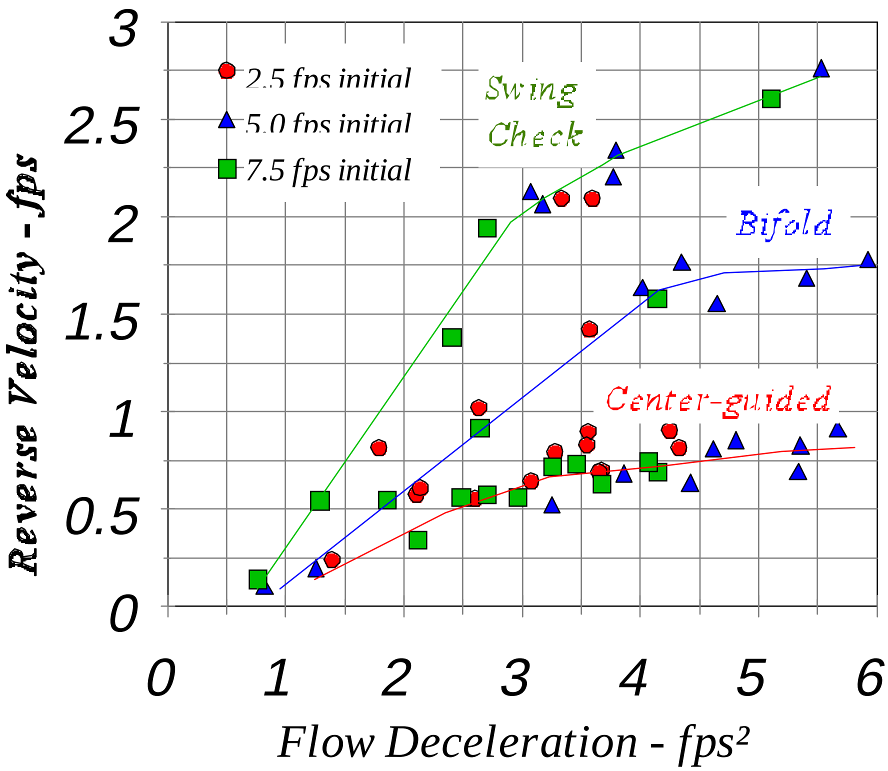

Figure 7 Comparison Plot

Conclusions

Previous studies at Delft Labs concluded that valve geometry affected the magnitude of pressure surges and reverse velocities. The conclusions were:

(1) Reverse velocities and pressure surges are greater for valves with a larger mass of valve components.
(2) Reverse velocities are greater for valves with larger strokes or travel of components to close.
(3) Reverse velocities are less for valves that were spring assisted to close.

These conclusions are justified because of the increased time necessary to accelerate and overcome the inertia of valve internals and the distance they must travel.

Tests of the 10-inch and 12-inch valves, and piping configuration tests of larger check valves have produced the additional conclusions:

(4) Reverse velocities will be greater for valve designs with larger flow coefficients.
(5) Reverse velocities will be greater for valves with increased friction in the valve shafts, guides, and internal components.
(6) The slope or orientation of the pipeline has a significant effect on reverse velocities. An upward slope will usually cause a decrease in reverse velocity, and a downward slope will increase the reverse velocity.
(7) The wear of flow components can also have a significant effect on reverse velocity. Wear can cause additional friction or can effect the alignment and position of valve components.

To overcome the mass or inertia of the valve internals, the reverse flow must develop sufficient flow forces (pressure drops) to close the valve. Valves with larger flow coefficients require larger reverse flows to produce the same pressure drops or flow.

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