REVERSE VELOCITY PARAMETER OF VALVES

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Abstract: The main objective of this paper is to discuss the valve and pipe characteristics which affect the reverse velocities and pressure surges at the check valves. It is presented a test method by which check valves can be dynamically tested for sudden closure due to reverse flow. It is point out the influence of valve design, flow coefficient, and friction of the reverse velocity. 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. The test method of this paper produces a relationship between the flow deceleration and the reverse velocity at which the check valve closes.

Keywords: pressure surge, reverse velocity, dinamical test, flow deceleration.

1. INTRODUCTION

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 show 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. We note with Vmin the minimum velocity to keep the valve full 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 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 and the resulting pressure surge. The reverse velocity is calculated from the measured pressure surge.

2. MEASURED INSTALLATION

Figure 2 shows a plan 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 can be 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, amplified, is sent to a recording analyzer that produces a hard copy of the pressure surges with time.

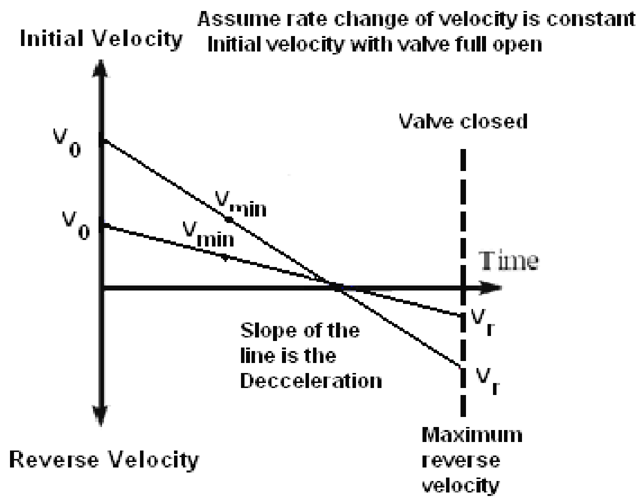

Fig.1. Reverse velocity versus deceleration

An accelerometer installed on the downstream flange of the test valve is necessary to indicate the sudden closure of the check valve. The output of the accelerometer is recorded simultaneously with the pressure on the same data analyzer. Samples plots from the data analyzer are included in this paper. A lever actuator is used with the butterfly valve, and the larger size of the butterfly valve is selected to insure that the control valve could be quickly closed without any time lag in the flow deceleration.

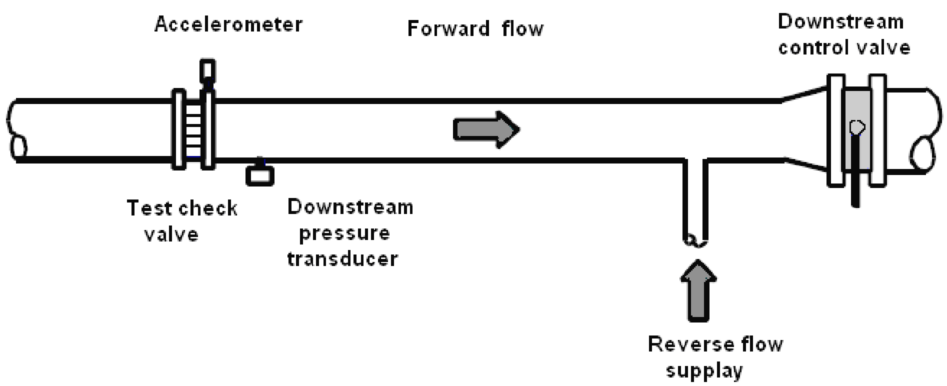

Fig. 2. Horizontal test setup

The 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. 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.

3. TEST METHOD

The reverse flow velocity at the check valve was not measured; it was calculated using equation 2, from the measured pressure surge by use of the water hammer equation.

$$\Delta H = \frac{c \cdot \Delta V}{g} \tag{1}$$

$$V_r = \frac{g \cdot \Delta H}{c} \tag{2}$$

Where $V_r = \Delta V$ and is the reverse velocity in (m/s), ΔH is the transient pressure (meters) of fluid, g is the gravitation constant, and c is the fluid celerity or speed of the transient wave in (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 equation for wave speed is:

$$c = \frac{\sqrt{K/\rho}}{\sqrt{1 + \frac{C_p K d}{E e}}} \tag{3}$$

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.

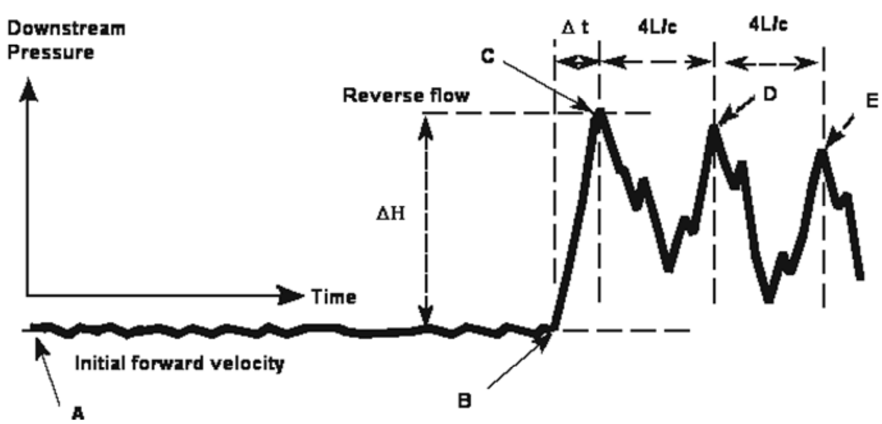

Fig. 3. Sample pressure plot

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 Vo. 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 represents 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, c is the wave speed and g is the gravitational constant. The deceleration of flow is calculated from the plot and equation 4, where V is the measured initial velocity.

$$Deceleration = \frac{V_0 + V_r}{\Delta t} = \frac{V_o}{\Delta t} + \frac{c\,\Delta H}{g\,\Delta t} \tag{4}$$

4. ANALYZE OF RESULTS

Figures 4, 5, and 6 show sample of pressure plots from a data analyzer and the tests for 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 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.

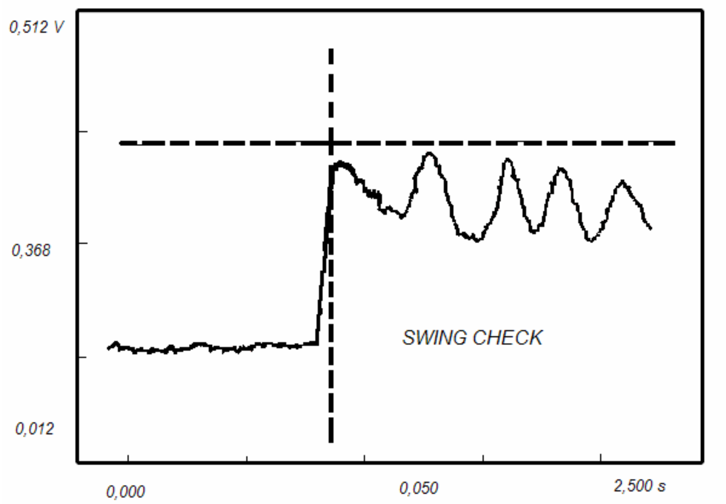

Fig. 4. Sample pressure plot for a swing check valve

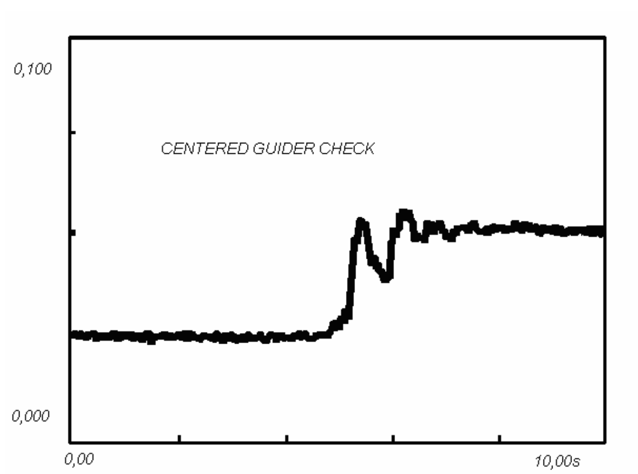

Fig. 5. Sample pressure plot for a center-guided check valve

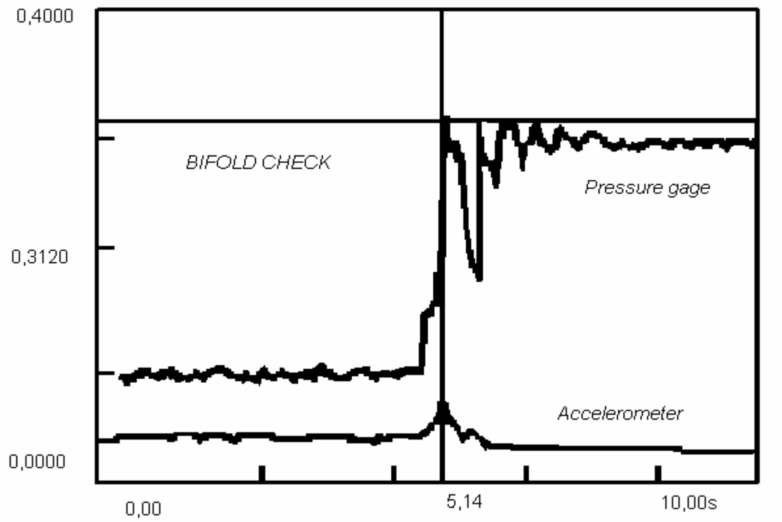

Fig. 6. Sample pressure plot for a bifold check valve

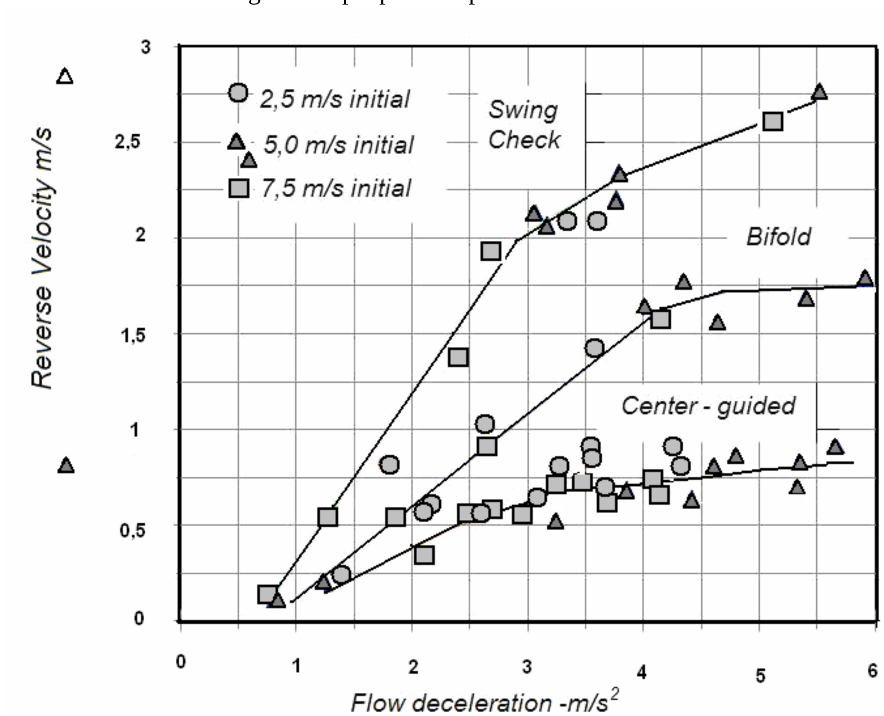

Fig. 7. Comparison plot

5. CONCLUSIONS

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

- Reverse velocities and pressure surges are greater for valves with a larger mass of valve components.
- Reverse velocities are greater for valves with larger strokes or travel of components to close.
- 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 two types of valves have produced the additional conclusions:

- Reverse velocities will be greater for valve designs with larger flow coefficients.
- Reverse velocities will be greater for valves with increased friction in the valve shafts, guides, and internal components.
- 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.
- 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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