ELIMINATION OF STRONG WATERHAMMER TRANSIENTS IN WATER DISTRIBUTION SYSTEMS

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Pressure transients resulting from water flow transients can cause substantial damage to piping, piping fittings and valves if not properly mitigated. These pressure transients are given the term of "waterhammer" because of the loud "bang" which accompanies these events. Typically this is due to the starting or stopping of water in long lines due to a rapid valve closure, the pump start, etc. This deceleration/acceleration of a water column can generate a pressure that is given by

$$\Delta P = \rho c \, \Delta U$$

where ρ is the density of water, c is the speed of sound in water and ΔU is the change in water column velocity. Substituting typical values into this expression of 62.4 lbm/ft^3 for the water density (1000 kg/m^3), 4500 ft/sec for the water sonic velocity (1370 m/sec) and 10 ft/sec (3.3 m/sec) for the initial water velocity, the calculated pressure increase is over 600 psi. It is easy to see why such events could cause substantial damage to the piping fittings and valves. In addition, for branch lines, which dead-end, the pressure wave would reflect at the end of the line, causing the pressure increase to be twice this value, i.e. approximately 1200 psi.

In a municipal water distribution system like that illustrated in Fig. 1, the fluid transients associated with starting and stopping of pumps, the opening and closing of

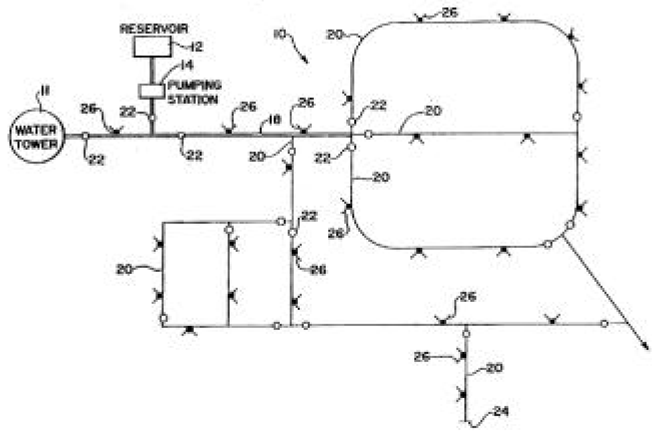

Figure 1: Typical Municipal Water Distribution System (Taken from Heil, 1993)

valves, as well as the column separation and rejoining that could occur with the combination of elevation changes and the starting and stopping of pumps, are complex due to the numerous flow paths. Furthermore, the lengths of these lines are miles long such that the acoustic transient time for distributing the influence of these events through the system is quite long. This acoustic transient time (τ) is defined by

$$\tau = \frac{L}{c}$$

where L is the effective length for the distribution system. Considering an effective length for a municipal distribution system to be 2 miles (10,560 ft), the acoustic transient time is 2.3 seconds. The larger the distribution system, the longer this interval and thus the more acute the problem. Furthermore, Wylie and Streeter (1978) have shown that if such transients are distributed over an interval of four acoustic intervals (9.4 seconds in the example given above) the results of such transients are minimal. This time is long compared to typical startup and shutdown times for pumping systems and may also be long compared to some valve closure transients. It is particularly long compared to transients resulting from column closure that could result from elevation changes in the piping system and intermittent loss of pumping power. (Note that column separation issues are specific to the elevation changes and the use of water towers to maintain the system pressure.)

Given this situation, the capabilities to mitigate such pressure transients (waterhammer events) within a large distribution system are best addressed by having a series of compressible volumes (gas surge volumes) distributed throughout the system. With these, the local fluid transients are diffused as a result of the flow into and out of these volumes. Figure 2 shows an example of a local volume that is designed and

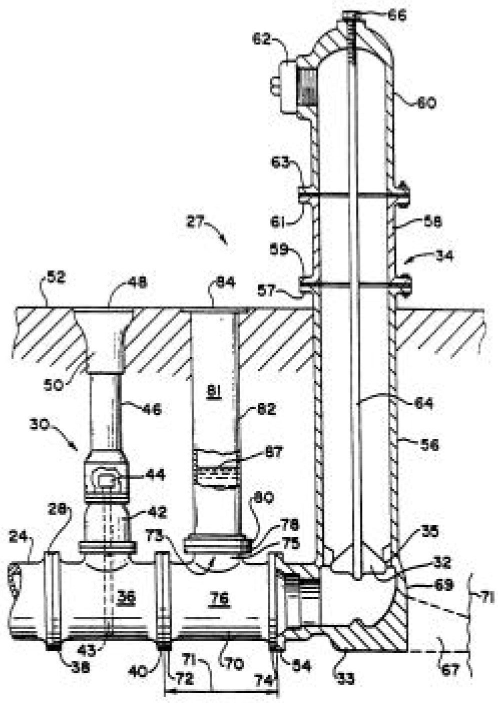

Figure 2: Fire Hydrant Installation With a Compressible Volume

(Taken from Heil, 1993)

installed to protect a fire hydrant as discussed in the United States patent by Heil (1993). If several of these volumes are distributed throughout the water distribution system such that the inflows and outflows to these local volumes causes the total distribution of a fluid transient to occur over an interval comparable for acoustic time constants, then these will accomplish the desired mitigation of the localized fluid transient. In particular, they damped the system sufficiently that the local fluid transients are not those directly associated with the fluid transient resulting from restarting of the distribution pumps or the rapid closure of a valve.

Practically speaking, these distributed volumes work in a combination of series and parallel responses. Considering a pump start transient, the volume nearest the pump location would absorb some of the original fluid associated with the pump restart and will also permit some pressurization of the fluid in the piping line. As the water moves through the first part of the piping system and pressurizes increasing lengths of piping, some of the water is distributed into the next compressible volume which then acts in parallel with the first volume that is still absorbing some of the water and continuing to compress. As the influence of the pump start is transmitted through the entire distribution system the other volumes will pressurize sequentially and thereby reduce the initial fluid velocity in the piping system that is associated with the pump restart. The meaning of the acoustic transmission interval is that pressure waves propagating through the water-piping network are the mechanism for eventually adjusting the system to the steady-state distribution pressure, flow, etc. associated with the pump, which was started.

As discussed above, the installation of the compressible volumes identified by Heil (1993) for a number of fire hydrants throughout the system provides the necessary distribution of the compressible volumes and also provides direct protection for the fire hydrant itself. Since the hydrant can be located on a branch from the main line, it may also be at the end of this branch. Consequently, without such a compressible volume to absorb the fluid transient, this location can be subject to not only the waterhammer event but twice this pressurization since the pressure wave is reflected at the end of a branch line and the magnitude is doubled. By including such compressible volumes near fire hydrants, the potential for such waterhammer events impacting on valves is eliminated.

By far the most important aspect of such systems is field experience. These types of mitigation systems have been installed in a number of municipal water systems and have been demonstrated to essentially eliminate the strong hydraulic transients that damage fire hydrants. Furthermore, they have also successfully prevented the rupture of the underground pipes themselves since the fluid transients are mild and the strong waterhammer events associated with a system that is completely filled with water are eliminated.

In summary, there is a sound technical basis for why such distributed volumes virtually eliminate the strong fluid transients that can damage municipal water distribution systems. This understanding is consistent with the state-of-the-art for assessing fluid transients and these have also proven their worth in the field. The implementation of such a distributed compressible volume system as presented in the patent by Heil can greatly extend the life of current distribution systems and correspondingly reduce the maintenance cost.

References

Heil, H. W., 1993, "Method and Apparatus for Water Surge Protection and Protection of Fire Hydrant Systems," United States Patent 5,218,987.

Wylie, B. E. and Streeter, V. L., 1978, Fluid Transients, McGraw-Hill International Book Company, New York.

About the Author

Dr. Robert E. Henry holds a Doctorate degree in Mechanical Engineering from the University of Notre Dame and is the senior vice-president of Fauske & Associates, Inc. Dr. Henry is known worldwide for his work in heat transfer, water hammer and two-phase flow.

About Fauske & Associates, Inc.

Fauske & Associates, Inc., a professional engineering firm located in Burr Ridge, Illinois (western suburb of Chicago), has been successfully servicing chemical, process industry and electrical generation organizations for over 20 years. The FAI staff is recognized worldwide as experts in the areas of problem-solving involving heat and mass transfer, multi-phase flow, thermodynamics and structural mechanics. Advanced training and research in physics, chemical engineering, mechanical engineering, nuclear engineering and other fields facilitate an effective team approach to apply basic scientific principles to complex problems and obtain straightforward solutions. To complement the information presented in the paper, FAI has performed scaled and full-sized waterhammer experiments along with analytical calculations to form the technical basis for measuring, mitigating and eliminating waterhammer events. In addition, FAI has won EPA, OSHA and other governmental organization endorsements of "Good Engineering Practices" for work that has been completed in the past.