Water Hammer & Pressure Surges in PVC Systems

by Larry Workman

Everyone is familiar with the phenomena of "Rattling Pipes" when turning on and off water systems within the house. Pressure surges in piping systems are common and many times can be destructive too. The typical cause of this rattling or “Water Hammer” and is caused by valve operation, entrapped air in the line and sometimes pumps operations. The effect of any one of these events can be effectively multiplied many times by the geometry of a piping system if the pressure wave is allowed to reflect, or bounce, back and forth within the system. Figure 1 shows that a single valve closure can generate multiple positive and negative pressure surges, for seconds afterwards.

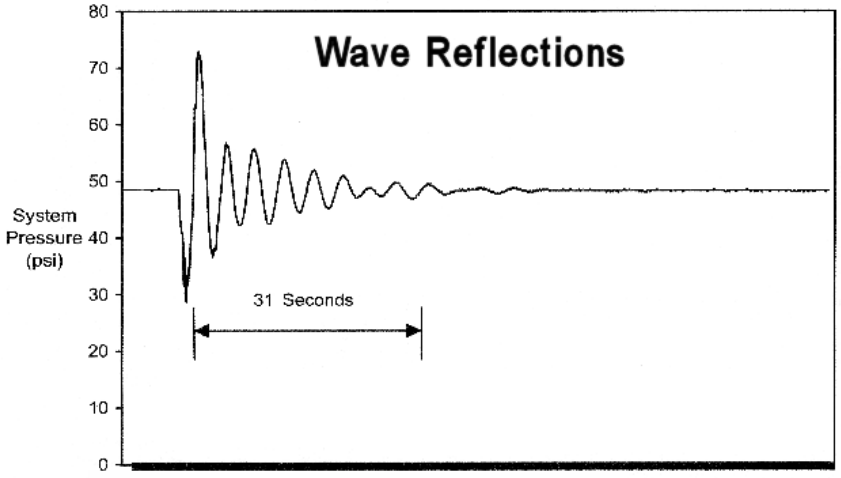

Figure 1: Water Hammer Profile[i]

Electric control valves used in irrigation systems are good examples of a part which can cause water hammer. Studies have shown that most solenoid control valves do not have a linear shut down of the water flow rate. About 85% of the flow rate will be controlled in the last 15% of close time. Therefore, it is best to consider that remote control valves are of the “quick close” category.[ii] Conversely, the majority of the flow rate through the valve must be expected in the early moments of the opening time. The combination of the high flow velocity within the valve and the instantaneous on-off action set the stage for large surges within a system.

Add to this the fact that an irrigation system which uses this type of valves is often used daily, sometimes more than once a day. So, the frequency of cycles is increased and adds to the problem. If a system will tolerate a million surges, an increase in the surges from 1 to 10 an hour will produce a failure rate in about 1/10 of the time. This proportional relationship will be evident in all systems.

The industry standards for pressure ratings of PVC pipe are based on static pressure, without regard for surge conditions which are known to take place in working systems. It is often found that the designer has not made allowance for the surge pressures in the system. This condition leads to working conditions which allow surges that exceed the stress rating of pipe, and can cause damage.

The ASTM pressure ratings were never meant to be a fool proof system by which all other cautions can be ignored. It is a known fact that frequent pressure surges or fluctuations in a piping system will cause a fatigue failure. By the proper placement of gauges, recorders and early design consideration, these conditions can be held to a minimum to prevent future failures.

Cutting both the number and peak of the pressure surges to extend the life of a system have been suggested by many including IPEX[iii] and D. B. Edwards[iv]. They consign an extra safety factor in the rating of thermoplastic pipe by recommending that the operational pressure not exceed 60% of the maximum rated pressure by ASTM. The Soil Conservation Services Engineering Standard 430-DD[v] recommends the working pressure be held to a maximum of 72% of the ASTM ratings and limits flow velocities to 5 feet a second. These measures increase the margin of safety but cannot guarantee that surges won't be generated and damage result.

The profile of a pressure wave form is the least investigated and understood variable in cyclic behavior of PVC piping. The shape or wave form describes how rapidly the pressure rises and falls and how long it stays at the higher and lower level. Various pressure forms such as a saw-tooth (steady rise/steady drop), spike (instant rise/immediate fall), square (rapid rise/hold/rapid fall), and many combinations have been examined. Poly-Vinyl Chloride, like most plastic, is a viscoelastic material. A classic example of this is the child's toy, "Silly Putty"®[vi].

When stretched slowly it reacts as if it were warm taffy. But, if the material were to be "jerked", stretched rapidly, it snaps apart. Rising slowly allows time for plastic to reorient or adjust to the load level. When the pressure surges rapidly the plastic may not be able to respond fast enough and ruptures.

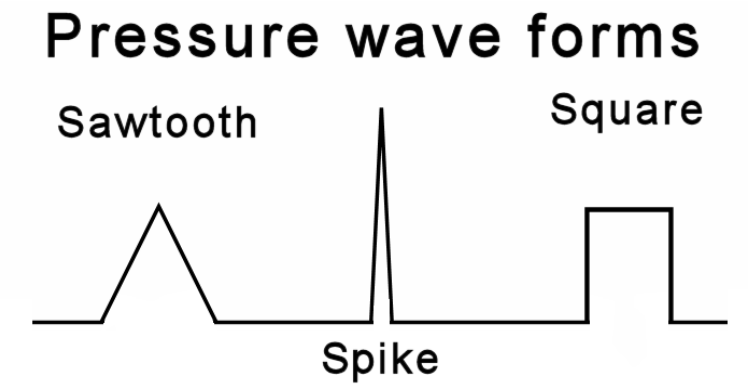

Figure 2: Surge Profiles

The surge profile of water hammer from quick acting valves is most similar to the spike profile and can be very damaging to viscoelastic materials.

It is often thought a pressure regulator can control, or dampen, water hammer surges. Sadly, this is not true! The water hammer, pressure wave, travels through the system between 1,000 and 1,400 feet a second. This means it passes the mechanism of pressure regulator in about 50 microseconds, or millionths of a second. This is too quick for the regulation mechanism to overcome its own inertia and react.

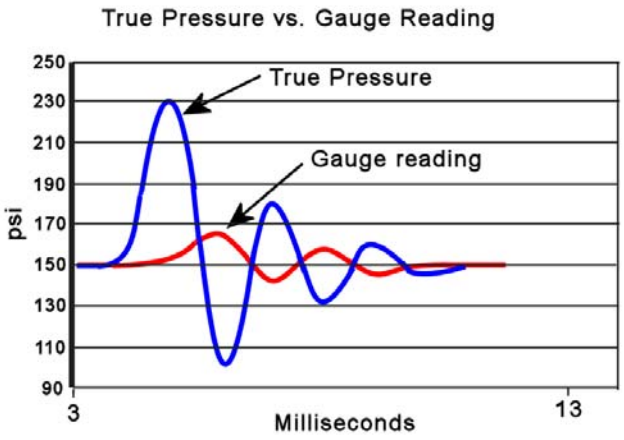

Figure 3: Surge wave pressure readings

This lag time is also evident in pressure gauges, pressure recorders and air relief valves. In each case the pressure spike passes the mechanism before it has sufficient time to react fully. Testing has shown that these mechanisms only react or reflect about 20 percent of the peak pressure of a surge wave.

When surges continue and a fatigue failure occurs, there are certain characteristic features that can be seen in the failure. A short split will be noticed in the exterior wall of a fitting. The area next to the split may be eroded away by the "Slurry" of water and soil that is churned up during the normal operation of the system. It is important to note that a cyclic failure starts from the interior surface of the fitting. The failure starts with a small tear near the crotch or inter-corner of Tee's and Elbows; over time with additional surges works its way to the external surface and a leak is evident.

Figure 4: Typical cyclic fatigue in a fitting

Occasionally the split and the erosion will continue to lengthen into a larger split or adjacent pockets on the wall. With high surge pressures that are typical of water hammer failure, the pipe and/or fitting may shatter and leave a fracture pattern that points toward the origin of the failure. If the pipe is colored, a V-shaped,

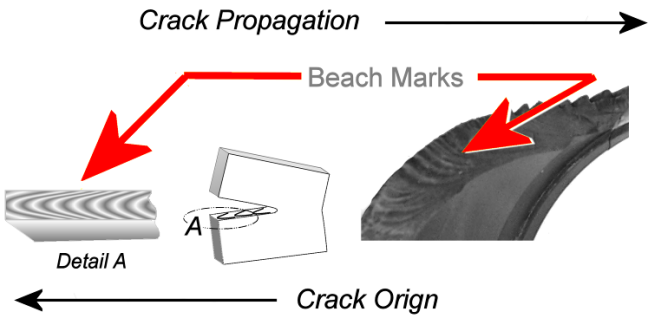

Figure 5: "Beach" or Clamshell" marks

whitened area will be visible at the ends of the original split.

Various factors influence the life of a system working under cyclic conditions, such as:

- Maximum surge pressure
- Variation between maximum/minimum pressure
- Working temperature
- Frequency and duration of surges
- Chemicals within the system

The extreme stress within the interior wall during a surge is the largest single factor controlling the time to failure of a system. If the surge is large enough, failure will occur in one cycle (i.e., a quick burst). If the pressures, cycle profile, frequency and peak are held constant, it could be possible to determine a stress versus cycle failure relationship. Yet, past studies only provide a guide to real world performance and cannot faithfully predict the cyclic life in real use. The most damaging situation takes place with wide fluctuations of pressure. The range between maximum and minimum pressure is important. The greater the range between the surge peak and working pressure, the more damaging the effects suffered by the piping.

Surge resistance of PVC is also affected by the temperature. Since PVC is a thermoplastic it is softer when it is heated or being used above 73°F, both the static and surge resistance is lowered along with the stiffness. In municipal and turf water systems this is normally not a consideration. Still, it may become important in warm climate irrigation or surface irrigation where the water can be heated by atmospheric conditions or solar radiation. Not enough data is available to prove if the static pressure de-rating factors are suitable corrections for water hammer conditions.

The design stage is the ideal time to focus on and resolve the factors that produce surges, such as high flow rate and rapid valve operations. Yet, there is no single resolution that is applicable to every situation. Consideration must be given to the design of the pump, its operation, the operation of the valves and regulators. This may involve choosing an alternate pump, control system, valves, pipe lengths and/or a surge tank.

PVC pipe can tolerate occasional surges well above its pressure rating. Still, when repetitive surges are expected, they must be restricted to a level below the pipe pressure rating. Bliesner[vii] in addition to the earlier, FHA and the Soil Conservation Services recommend a working pressure of fittings to be held at 60% to 72% of the static pressure rating of the pipe as a useful guide for PVC piping design.

The obvious question is how many surges a system can tolerate? An exact answer is without a solution, and we can make only an estimate. Tests of PVC pipe have shown that a peak pressure (saw-tooth wave form) that creates about 2500 psi stress, or 125% of pipe pressure rating, will fail at about 140,000 surges. At a peak

stress of 1500 psi. (75% of pressure rating), fatigue occurs at 2.2 million surges. The cycle rate, or frequency, also has a direct effect on decline a of system life.

What does 2 million surges correspond in real world conditions? Remember, most surge conditions contain multiple positive and negative cycles. Although each of these reflective surges is less damaging, some may be strong enough to be considered.

In a controlled system, with medium profile saw-tooth profile surges, and limited to 10 cycles a day, then expect 548 years of service. Yet, in a less controlled system with 10 cycles, plus 5 additional reflective surges, an **hour** only 15 years of service could be expected. With a peak stress of 2,500 psi the expected life of the PVC piping may be one year or less. As a rule, municipal water systems are reasonably controlled and long service life is expected. Some problems have been noticed in uncontrolled golf course and turf installations where surges exceed the pressure rating of the pipe, occurred many times daily. In this situation, the service life of the golf course was be reduced drastically.

Pressure surges damage all components of a piping system: pumps, valves, fittings, and pipe. A PVC system can run satisfactorily for many years, if pressure surges must be controlled. Control begins with good design and continues with operation and upkeep. Proper equipment choice, including the use of piping with proper pressure rating, is the good starting point for a successful installation.

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[i] PVC Fitting Failures on Golf Course Irrigation Systems, M. Harrington, 1995
[ii] Turf Irrigation Manual, James A Watkins, 1977
[iii] Industrial Technical Manual Series, IPEX Inc, 2009
[iv] Fatigue Testing of PVC Fittings, D. B. Edwards, 1992
[v] Irrigation Water Conveyance High-Pressure, Underground, Plastic Pipeline, NRCS, 2002
[vi] Silly Putty is a trademark of Crayola LLC, Forks Township, Northampton County, Pennsylvania.
[vii] Designing, Operating & Maintaining Piping Systems Using PVC Fittings, R.D. Bliesner, 1987