Monitoring for Negative and Transient Pressures in Distribution Mains

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Abstract

Negative pressures and transient pressures may affect water quality and structural integrity of distribution mains. A change in the flow rate in a full distribution main will cause a change in the pressure within that distribution main – either positive or negative. Positive transient pressures exceeding the structural strength of the distribution main will cause damage in the form of rupture or, as is more frequently the case, in the form of latent damage that results in failure at a later date. Negative pressures may cause damage in the form of structural collapse of flexible distribution main materials, and waterhammer; and may lead to the intrusion of contaminated groundwater into the water main. Engineers are pretty good at modeling distribution main hydraulics, and at designing to prevent damaging events. On the other hand, it has been difficult to actually measure these pressures after the distribution main is constructed, to determine if the internal transient and negative pressures are consistent with the design. Advances in digital data processing systems have significantly improved our ability to continuously monitor and record negative pressures and even the very-short waterhammer event. These improvements have facilitated monitoring for transient pressures under a wide variety of circumstances. Early detection of damaging transient pressure events is now more practicable, thus permitting the reduction of damage to distribution mains resulting from these events. This paper will briefly describe the causes of transient pressures and improvements in tools available to detect transient pressures. It will conclude with suggestions to civil engineers and distribution main owners regarding what we can do to reduce damages from transient pressures.

Background

Pipeline and distribution main failures are occasionally traced directly to the occurrence of transient pressures that have caused damage. Among the more familiar ruptures in this category are the failures in Dallas, TX; San Juan, Puerto Rico; Metropolitan Water District of Southern California; Houston, TX, Oigawa Penstock, Japan; and Bartlett Dam, AZ. The last mentioned caused catastrophic rupture at the outlet of the hydro generator, with fatal injuries to the operator. Countless other failures are believed to have resulted from transient pressures, but the evidence is not conclusive. In many cases the transient pressure events occurred repeatedly without detection prior to the failure.

Figure 1 – Transient-caused failure, Superaqueduct of Puerto Rico

A transient pressure in a pipeline is a generic term for a wave phenomenon that accompanies a sudden change of the velocity of the fluid in the pipeline. Authors variously use the term "surge" pressure to denote a transient pressure that has no detrimental effect, whereas the term "waterhammer" may be used to denote a transient pressure that will have serious consequences if not properly addressed and mitigated. Pressure transients can be positive or negative. The magnitude of these surges is independent of the operating pressure, and can be many times normal operating pressure.

Any event that causes a sudden change in the velocity of fluid in a distribution main will generate a transient pressure. The most common sources of transient pressures are

- Pump operational on/off cycles
- Sudden power failure at pumping plants
- Control valve operation
- Sudden changes in demand
- Air release valve operation
- Pressure reducing valve operation
- Pressure relief valve operation
- Pipeline rupture
- Filter flushing operations

Negative Pressure and Transient Pressure Measurement

An excellent report and discussion of traditional methods to record transient and negative pressures in presented in the November 2004 AWWA Journal by Richard Gullick and several co-authors. (Gullick et al, 2004) Mechanical pen-and-chart recorders have been in use for decades, and offer a good solution to many pressure-recording needs. They are relatively inexpensive, easy to use and continuously monitor all pressures. The disadvantages of the mechanical recorders are that they need to be manually reviewed and the charts need to be changed every day or every few days, are not typically designed for negative pressures, and they are not capable of providing detailed information on the duration of a transient since the width of the line drawn by the pen may cover up to 60 seconds of time.

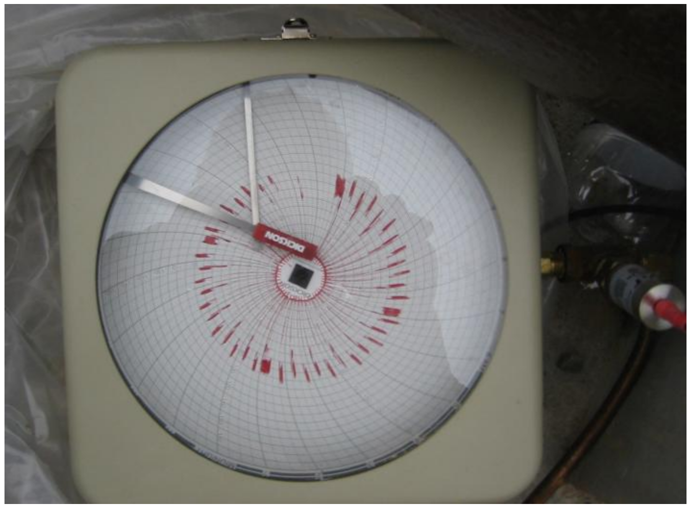

Figure 2 – Circular graph recorder, with no negative pressure capability

Several portable high-speed electronic data loggers are available. These do record negative pressures, and if set to record frequently enough can record the details of a specific surge event over a period of seconds to minutes. So if you know when the transient will occur and can set the data-recording rate accordingly, and can upload the data from storage immediately after the event, these devices may fulfill the need. Data recording intervals of 0.05 seconds (20 Hz) are available.

Figure 3 – Digital data logger for pressure measurement

On the other hand, if there is a need to monitor over longer periods of time, the data interval will have to be set at a longer interval to stay within the memory capacity of the device. An interval of once per minute might be selected, which would provide 1440 pressure readings per day. Surely this would convince a distribution main owner that the pressure is rigorously and carefully monitored. But is this sufficient? Not necessarily, because many of the most damaging transients may last only a fraction of a second, and would not be detected at all. It has been difficult to detect and measure an unexpected transient that may last a fraction of a second, and that may be 100 times the operating pressure or more. Not only are these events difficult to detect, they may be the most damaging of all and may go unnoticed for long periods of time. Digital systems engineers will recognize this as the Nyquist principle.

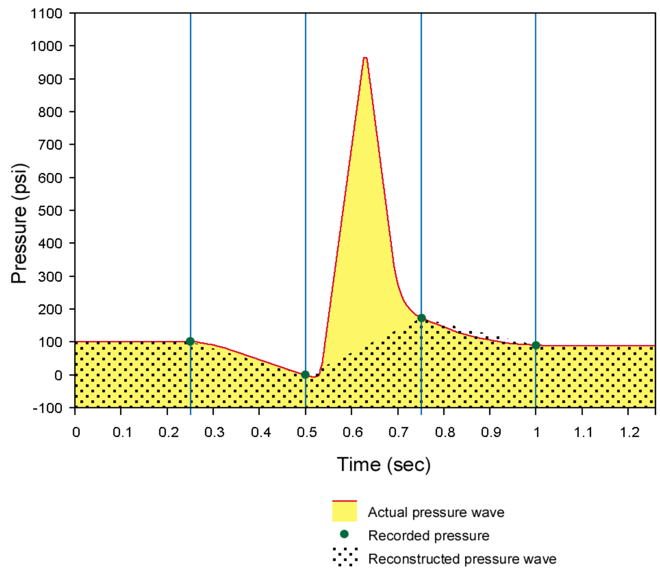

Figure 4 – Digital data collection with insufficient sample rate

A New Method of Pressure Measurement

Within the last year, a system has been devised that overcomes several of the limitations of previous systems. It is capable of monitoring over extended period of time in a "snoozing" mode, recording background pressure at a user-set interval between once per second and once per day. Although the system appears to be snoozing, in reality it is very busy. It continuously samples the pressure 1000 times per second and computes a running average. Effectively the system algorithm has a built-in alarm clock that goes off when a pressure is detected that differs significantly from the average – in other words when a transient is detected. When this occurs, the system "wakes up" and records all data at another user-set rate up to 100 Hz. This continues until the transient has passed, at which time the system goes back to the "snoozing" mode. The scheme is shown graphically in the figure below.

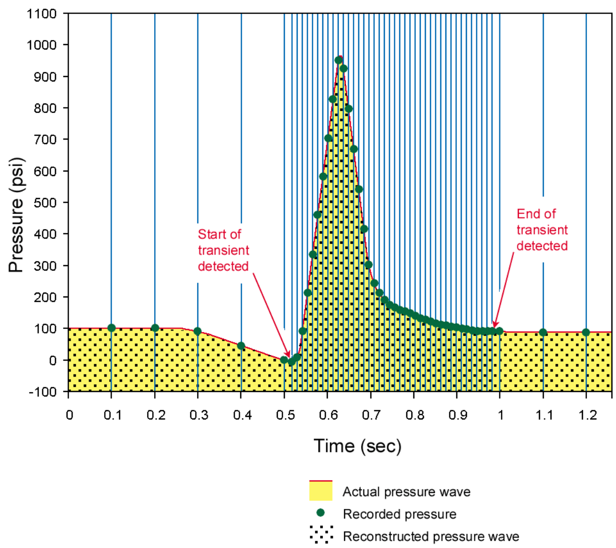

Figure 5 – The TP1 Transient Pressure Monitoring System algorithm

The so-called TP-1 Transient Pressure Monitoring System is comprised of

- A pressure transducer with an effective range fitted to the pipe being tested. For example, the range selected might be minus 14.7 to plus 500 psi for typical water transmission mains.
- A system controller, which processes all of the input signals, and performs all of the logic in the system. It also stores all of the historical data until it is retrieved using the PDA.
- A means of communication, such as a wireless-capable PDA or laptop. SCADA integration and internet have also been used.
- Data analysis software to facilitate data interpretation.

Figure 6 – TP1 Transient Pressure Monitoring System components

The TP-1 has been under development for nearly 2 years, undergoing extensive bench testing and modification. One of the early examples of data recorded with the TP-1 include the acceptance testing of a new Wastewater Treatment by the City of Glendale, AZ. They had experienced the rupture of several 8" (20.3 cm) ductile iron pipes in the course of testing, and had attempted to diagnose the problem with a chart recorder. The test data from the chart was not very revealing.

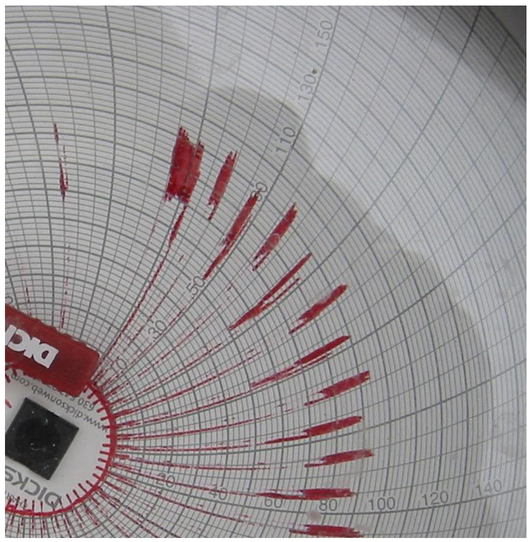

Figure 7 – Circular graph of sewage lift station discharge pressure

They installed a demonstration model of the TP-1 to see if it could detect the transients at the discharge line of the lift pump station.

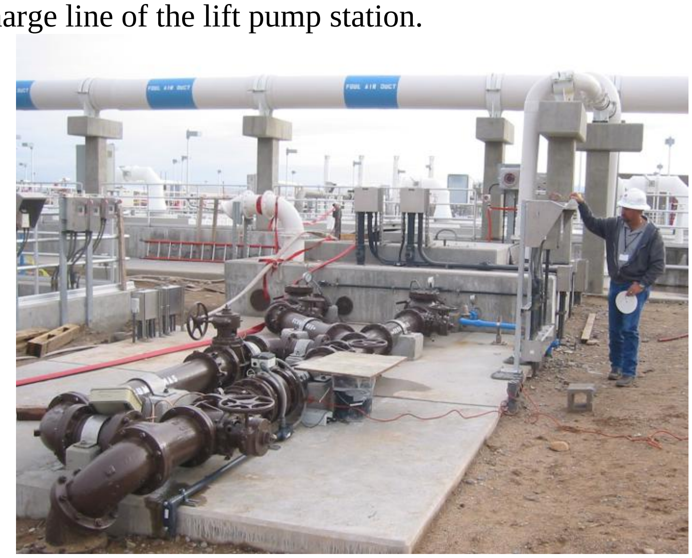

Figure 8 – TP1 installed at sewage lift station

The results were such that when the City Engineer visited during the TP1 demonstration, his remark to the author was that this TP-1 is installed on a City facility, and had at that moment been appropriated by the City; he would not allow it to be removed.

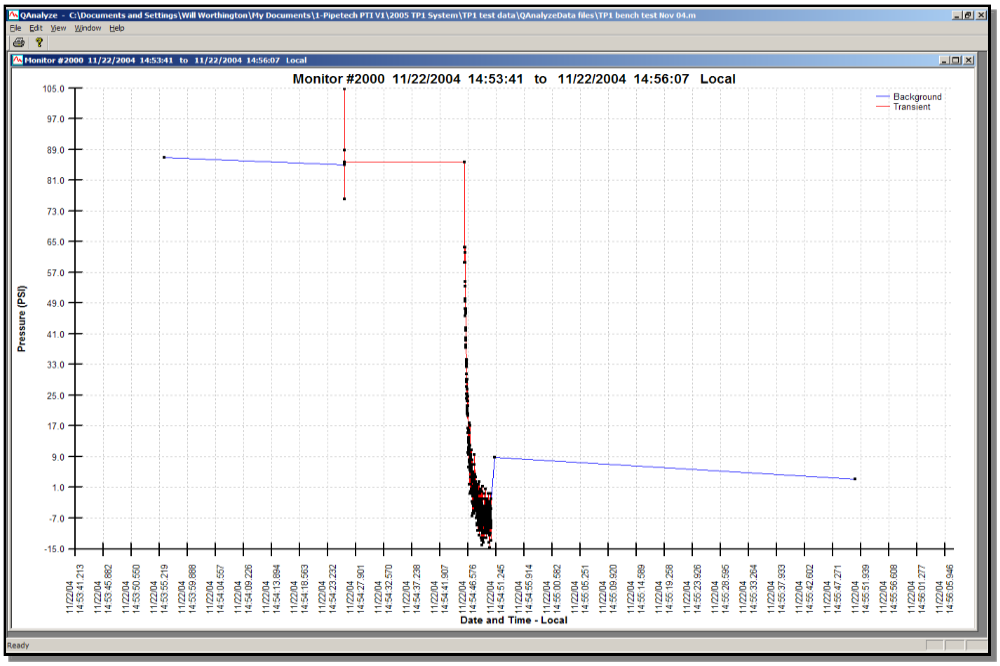

Figure 9 – TP1 graphic depiction of the lift station pump shutdown sequence pressure (Note negative pressures to -14.5 psi)

The data collected at the sewage lift station showed negative pressures approaching the cavitation range during the pump shutdown sequence. Remediation measures were installed to prevent damaging waterhammer events. The system allowed the careful evaluation of surge reduction measures, and continued to monitor the dynamic pressures at this $30 million facility during its early months of operational testing.

A Hydrodynamic Pressure Test for New Distribution mains

The availability of this new technology should open the door to new testing and improved asset management. For instance, some specifications for a new distribution main typically include a hydrostatic test to be performed by the general contractor to prove system integrity prior to final acceptance by the owner. This test may be slightly above the working pressure to demonstrate the structural capacity of the distribution main to withstand internal loads, while the makeup water volume is measured to demonstrate water-tightness. (AWWA Manual M9) It is typically accomplished under controlled conditions, with the pass/fail criteria being makeup water rate and absence of any indication of structural failure. This test is all well and good, but it misses the problem caused by transients in normal operation.

The author suggests that the time has come for us to include a "Hydrodynamic Pressure Test" in the specification for new transmission pain construction. This proposed test would not be in lieu of the traditional hydrostatic test, but in addition to it. To capture the capability of new technology to protect the interests of all parties, it is suggested that a paragraph in the specification for a new transmission main might read:

- *Hydrodynamic Pressure Test - The CONTRACTOR shall engage the services of a THIRD-PARTY ENGINEERING FIRM to conduct pressure monitoring of the distribution main at the points designated below. The pressure monitoring shall be continuous during the initial filling of the distribution main, and throughout the acceptance test, and for period of 30 days following substantial completion of the project. All pressures, both positive and negative, shall be recorded not less frequently than once every minute throughout this period, except that any transient pressures shall be recorded not less than 50 times per second. A transient shall be defined as any sudden departure of more than 10 psi from the running 5-second average pressure. The THIRD-PARTY ENGINEERING FIRM shall submit interim reports following initial filling, and following the simulated power failure of the XYZ pumping plant; and a final report of all recorded pressures in graphic and tabular form. The graphic presentation shall depict a separate graph for each recorded transient in sufficient detail to observe each data point. The report shall compare the recorded pressures to the design pressures specified by the ENGINEER. The final report shall include calibration curves for the pressure transducers used in the test before the initiation of testing and upon completion of testing, and a certification that the equipment used is capable of meeting the requirements of this paragraph, and shall be sealed by a registered engineer. One copy of the final report shall be submitted to each the CONTRACTOR, the OWNER, and the ENGINEER. Points to be tested are: (to be determined by the design engineer, and should include locations vulnerable to transient and negative pressures e.g. pumping plant discharge lines, air valves, butterfly valves, pressure reducing valves, and pressure relief valves)*

The photo at the beginning of this paper might illustrate the point. As the Superaqueduct project in Puerto Rico neared completion, it was a textbook success story – a tribute to the advantages of the design-build delivery system. It was an elegant water development project meeting an urgent need for the people of San Juan - ahead of schedule and under budget – until the water main rupture of 9/11/99. This pipeline rupture was caused primarily by a butterfly valve that closed too quickly. The project had been properly designed and the proper control valves and valve actuators had been specified. The concrete pressure pipe had been properly manufactured. The general contractor had done an excellent job, except for one small detail. When the electricians wired the valve actuator, they eliminated a $5 closure-delay device, which caused the valve to close in 5 minutes instead of the 30 minutes specified by the designer. During operational testing, that valve was closed about fifteen times causing excessive and damaging pressures to the water main. The final closure on 9/11 was the straw that broke the transmission main's back, causing it to rupture in two locations. In the litigation that followed the rupture, damage estimates approaching $30 million were described. If the Hydrodynamic Pressure Test had been required, that problem associated with the improperly wired valve actuator would have been recognized the first time it was closed. Clearly all parties to the construction would have benefited: the engineer, contractor, valve manufacturer, and facility owner.

This new transient monitoring technology can be used to advantage at other junctures in the life of a water main, for instance:

- Upon substantial modification to the facility, such as the addition of a booster station
- Upon completion of any maintenance activities involving valves or pumps
- Upon addition of any delivery point or customer
- During periods of freezing weather, when air valves and siphon-prevention valves may become frozen and dysfunctional
- Periodically, as a matter of active distribution main management

In Conclusion

Advances in digital technology and equipment have opened the door to improved monitoring of negative and transient pressures. Owners, engineers, contractors, and operators are able to continuously monitor, detect and record these events that may be causing structural damage to distribution mains or contamination of water supplies. The greatest benefit of this capability may be through the implementation of a hydrodynamic pressure test, in addition to the standard hydrostatic pressure test, as part of the acceptance testing for new distribution main facilities.

References

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