TECH BRIEF

Pipelines

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Vibrations in Pipeline Systems

Vibration and transient forces can occur in pipelines and pipeline facilities that can generate elevated stresses, fatigue, and other unacceptable conditions. Vibration issues can often be difficult to diagnose and correct. Stress Engineering Services can provide analysis and testing assistance to solve vibration issues in pipelines and associated equipment. Some of the more common vibration issues observed in piping systems are discussed in this Tech Brief.

Equipment Driven Pulsations

A common cause of vibrations in piping systems is periodic forcing from equipment such as pumps and compressors. All equipment used to make fluids move operates in a periodic manor, whether through rotating impellors or reciprocating pistons. This periodic motion will cause fluctuations in the flow rate and pressure (pulsations). If the frequencies of the pulsations coincide with acoustic and/or structural resonances of the piping system, large amplitude motions and excessive vibrations can result. These vibrations can cause high noise levels and lead to fatigue damage and piping failure.

Vibrations caused by pulsations from mechanical equipment will typically appear at discrete frequencies that can be traced to a harmonic of the equipment's rotational speed. Existing problems are typically addressed by collecting pressure and vibration data in the field using specialized measurement devices. This data is then used to calibrate hydraulic and structural models of the system.

These models are used to identify acoustic and mechanical resonances, to identify potential fatigue issues, and to develop approaches to solve the vibration problem. Solutions often involve the addition of pulsation dampening bottles and filters, modifications to the piping layout, modification of supports, adding orifice plates at flanges, and/or modification of operating conditions. Simulations can also be used during the design phase to reduce the likelihood of encountering problems in a new system.

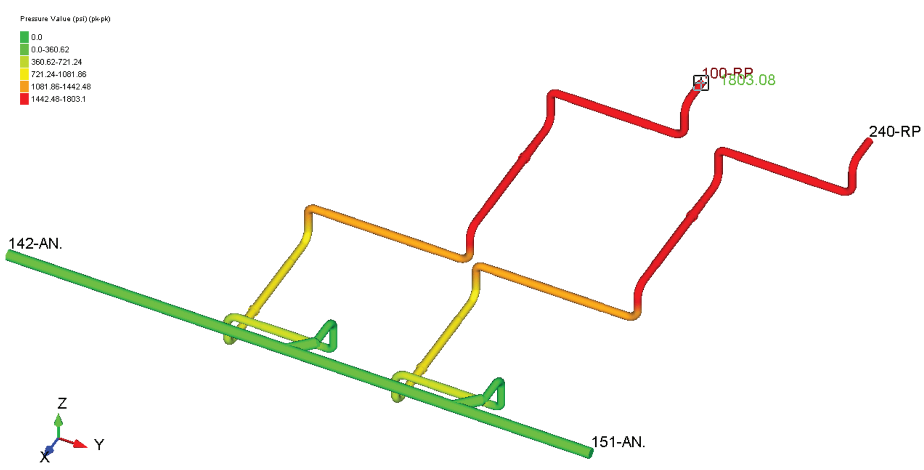

Figure 1: Pulsation simulation of a high pressure pump manifold showing high amplitude oscillations at the pumps and an acoustic standing wave between them.

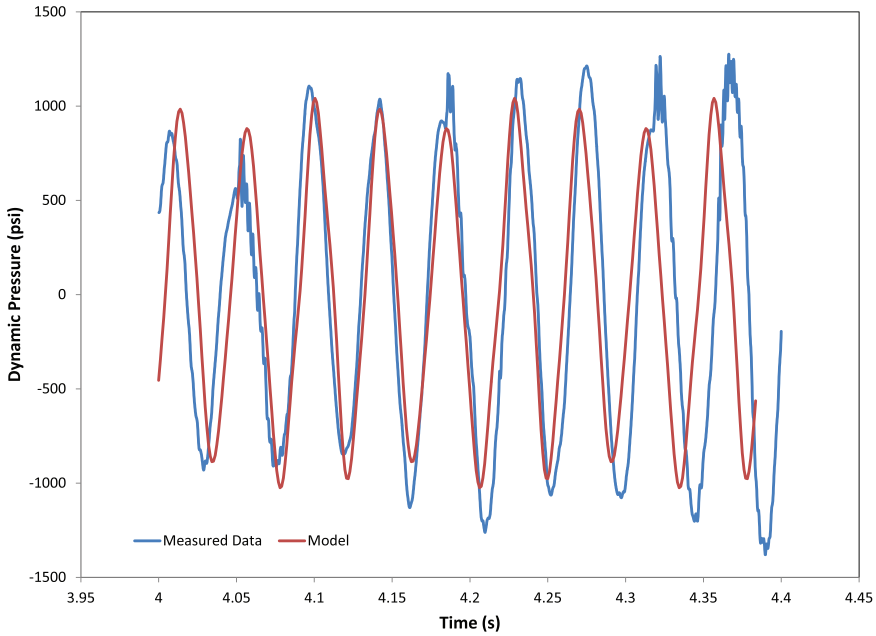

Figure 2: Measured and simulated acoustic pressures at the discharge of a high pressure pump experiencing flow pulsations.

Resonant Acoustic / Fluid Dynamic Coupling

Discreet frequency vibrations that occur throughout a large section of piping at a frequency that does not coincide with mechanical equipment like pumps and compressors can indicate that a fluid mechanical process is coupling with an acoustic resonance of the piping. Like mechanically driven vibrations, this type of vibration can often reach large amplitudes, especially if the acoustic resonance occurs at a frequency similar to a structural natural frequency. Large vibration amplitudes can lead to rapid fatigue issues. The fluid dynamic forcing is often due to:

- Flow restrictions and valves
- Dead legs and branches
- Instruments protruding into the flow
- Heat exchanger tubes

While adding structural support may reduce the amplitude of the vibrations, the preferred solution is to eliminate the acoustic forcing. In order to determine the cause of the forcing, measured data and piping drawings are reviewed to identify potential vibration sources. These are then analyzed to identify their typical natural frequencies which are compared to measured vibration data. A model of the relevant piping can be constructed to identify resonant behavior around the measured oscillation frequency and to assist in comparing solution approaches. Reduction or elimination of the vibrations can often be achieved through relatively small changes in instrumentation or piping or through the use of acoustic damping techniques.

Turbulence Induced Vibration

Flow turbulence can generate fluctuating pressures that lead to flow induced vibration (FIV). The pressure fluctuations generated by turbulence do not occur at discreet frequencies, but are distributed over some range of frequencies due to their chaotic or random nature. These vibrations are usually analyzed using probabilistic methods. Often, experimental data from pressure or vibration measurements are used to establish forcing functions in the form of power spectral density (PSD) distributions. Probabilistic structural dynamics methods are then used to calculate the structural response to the turbulent forcing, which can then be used to estimate cyclic stress ranges and fatigue life.

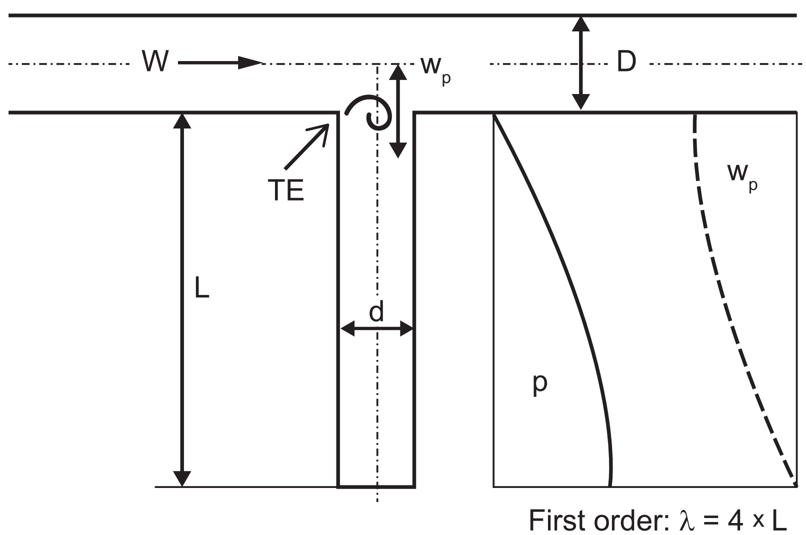

Figure 3: Schematic showing acoustic coupling in a dead leg that can cause piping vibrations.

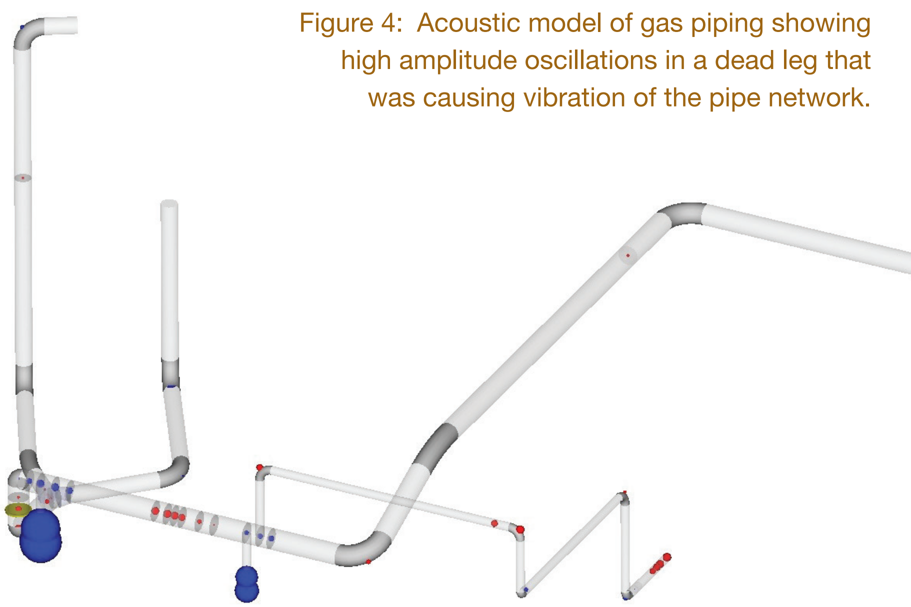

Figure 4: Acoustic model of gas piping showing high amplitude oscillations in a dead leg that was causing vibration of the pipe network.

Shock Loading Due To Fluid Transients

Changes in flow rates can generate high localized pressures in pipes. The magnitude of the pressure change is associated with fluid acceleration (or deceleration). The effects can be significant if a change in the flow velocity occurs “suddenly”, resulting in what is known as a hydraulic shock, or more commonly, water hammer. Whether or not a change is considered sudden is determined by comparing the time of, for example, closing a valve, to the time it takes a pressure wave to make a roundtrip in the pipe. In a diesel pipeline, for example, the wave propagation speed is approximately 3900 ft/s, so closing a valve in less than 5 minutes would be considered “sudden” in a 110 mile long section of pipeline. The effect of the pressure loading on the pipe and supporting structures is better described as shock rather than vibration, due to the typically short duration of the loading from the transient event. In anything other than the most simple pipe configurations, computer modeling is required to analyze the forces generated during a fluid transient event. Stress has the capabilities and experience to analyze local transient pressures and the forces on the piping that will result from hydraulic shock events.

While hydraulic shock problems involve fluid-structure interaction, the fluid tends to influence the structure much more strongly than the other way around, so the typical analysis approach is to decouple the fluid dynamics from the structural dynamics. First, a transient fluid flow model is created to estimate the forces generated on the piping during the hydraulic event. Then, the resulting force history can be applied to a finite element structural model to determine the mechanical response of the system. The models can be used to simulate approaches for preventing damaging forces from occurring.

Vortex Induced Vibrations

Vortex induced vibration (VIV) occurs due to an interaction between an exposed section of pipe and the flow of water or air around it. Over a wide range of conditions, the fluid will tend to flow faster on one side of the pipe and then the other, alternating in a periodic manor. The periodic vortices shed in the pipe wake result in oscillating forces on the pipe, both in

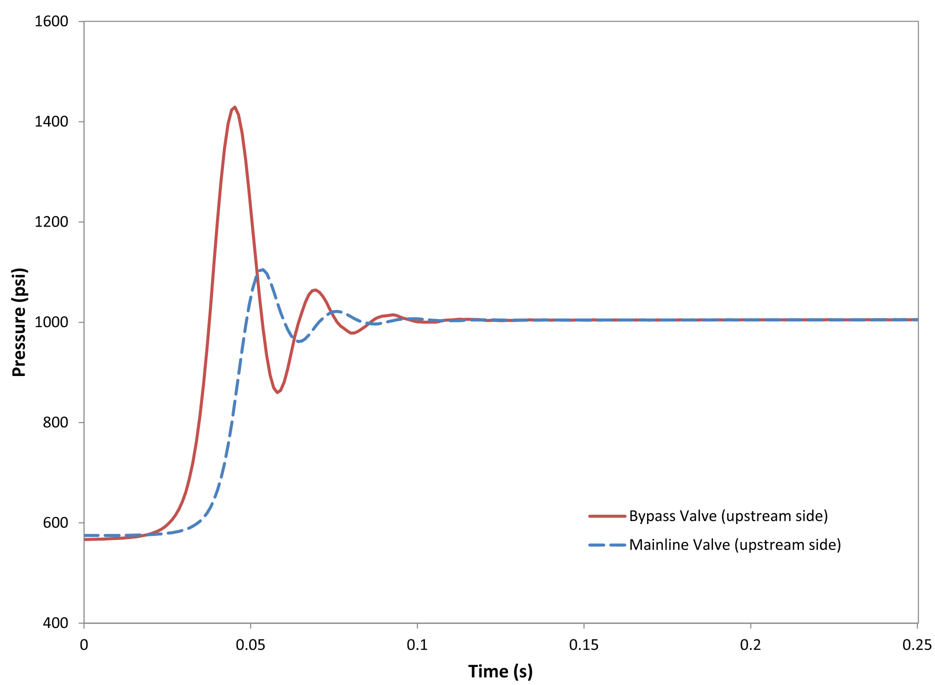

Figure 5: Simulated pressures due to rapid closing of a valve in a pipeline bypass loop

the direction of the flow and perpendicular to it. These periodic forces drive motion in the pipe. If the frequency of vortex shedding is near a natural vibration frequency of the pipe, the motion of the pipe can amplify the intensity of the vortex shedding, which then feeds back causing the amplitude of the pipe motion to increase. This feedback loop can result in a high amplitude limit cycle oscillation of the pipe. The cyclic stresses induced by this oscillation can result in rapid fatigue damage to the pipe and lead to failure.

Stress Engineering Services employs a combination of hydraulic and structural modeling, along with field data, if available, to analyze the potential for vortex induced vibrations and to predict the pipe vibration amplitudes and stresses. These models are used to predict fatigue lifetimes for exposed pipe sections.

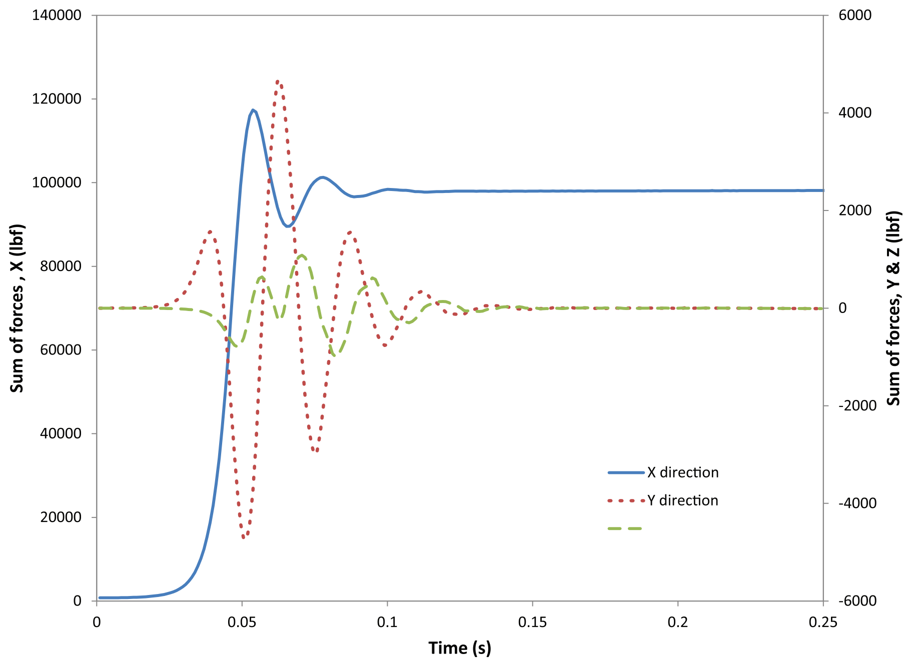

Figure 6: Forces generated on the pipes due to the rapid closing of a valve in a pipeline bypass loop

Figure 7: Test equipment mounted on a pipe span for field measurement of the damping factor

For more information on Vibrations In Pipeline Systems contact: Larry Matta, P.E. at larry.matta@stress.com