Pipeline Safety Research Announcement #5 (693JK3191RA01), Increase Computational Pipeline Modeling (CPM) Performance with Liquid Leaks.

CRACK PREVENTION USING HIGH FREQUENCY PRESSURE TRANSDUCERS

Robert A. Leishear, Ph.D., P.E., ASME Fellow
Leishear Engineering, LLC
205 Longleaf Court, Aiken, S.C., 29803
Website: leishearengineeringllc.com, Email: leishear@aol.com,
Phone: 803-641-6753, Fax: 803-641-6753
DUNS: 080865312
EIN: 81-1066441

ABSTRACT

Representing a step change to the understanding of pipeline cracks and failures, high frequency pressure measurements can be used to assess and prevent pipeline cracks. Such transducers can be readily purchased and installed above ground where access is available. Transducer application is based on pipe fracture theory published by the American Society of Mechanical Engineers (ASME) and the American Water Works Association (AWWA). In particular, ASME Press published an engineering textbook titled, "Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design", by Robert A. Leishear, where this book was based on 20 of Dr. Leishear's 75+ piping, fluid flow, and dynamics publications. The theory that he invented for this book proved that hoop stresses in piping are dynamically affected due to the sudden application of pressures to the pipe walls. These dynamic stresses, or Leishear Stresses, effectively multiply the expected static stress by a factor less than four. Also, AWWA published papers which proved that this theory applies to a billion dollars a year in North American water main failures - 250,000 failures per year ("Stop Costly Water Main Breaks before They Happen", Leishear, Opflow Magazine, AWWA). This theory is also applicable to oil and gas pipelines where slam valves create stresses to damage seam welds and provide the motive forces to induce environmentally assisted cracking, i.e., stress corrosion cracking, stress oriented hydrogen induced cracking, and sulfide stress cracking. In other words, decades of pipeline failures have been misunderstood. By completing further research for this theory, the application of pressure transducers can be used to measure pressure anomalies in pipelines, minimize the pressure surges through valve control, re-measure the pressure transients following corrective actions, and then compare failure rates before and after corrective actions.

INTRODUCTION AND BACKGROUND RESEARCH

Environmental cracking is a well-known problem in the pipeline industry, but the cause was not, and is not presently, well known prior to this research. Stresses are frequently cited as the causes of cracking, but statements stop short of identifying where these stresses come from – residual stresses or indeterminate bending stresses are frequently cited without any detailed explanation to explain specific failures. The Leishear Stress Theory has resolved this problem, where stresses are the primary failure cause rather than corrosion.

Previously, fluid transient calculations have been performed to analyze pressure transients in pipelines. A phenomenon known as line pack has been evaluated by others, where the pressure slowly increases in the wake of a pressure wave that travels at near sonic velocity along the bore of a pipe. The effect of line pack on hoop stresses has a dynamic load factor DLF equals 1. However, the dynamic load factor, the DLF, approaches 4 at the steep fronted pressure wave. Prior to this research, a DLF = 1 would have been used in all cases to incorrectly evaluate stresses at the steep fronted wave. In other words, incorrect calculation methods were previously used to evaluate pipeline failures. Although hundreds of calculations have been completed to date, the present theory requires additional research with respect to pipeline failures.

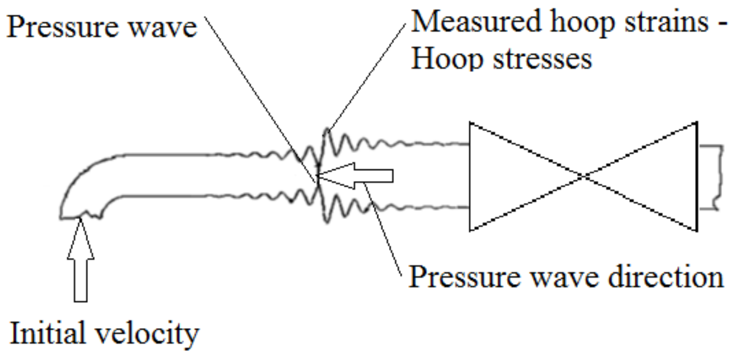

Figure 1: Pressure transient due to a suddenly closed valve and resultant hoop strains that cause hoop stresses

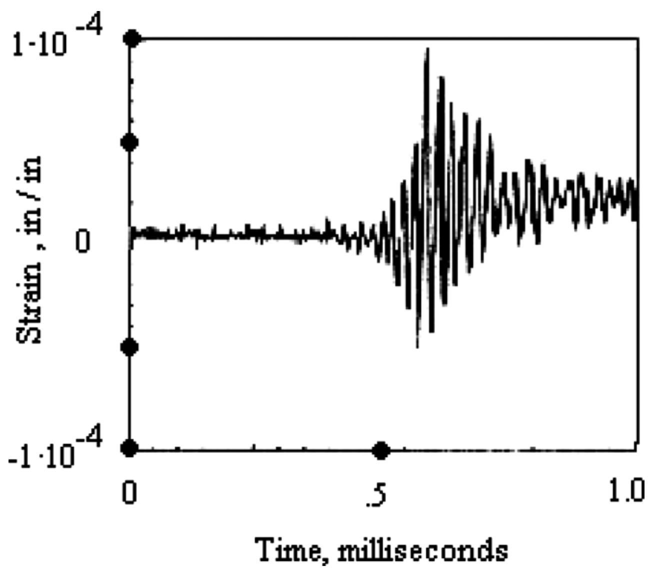

Figure 2: Experimentally measured hoop strains

First, consider some research completed to date. For the first time ever, Leishear solved fourth order differential equations to describe the dynamic stresses that occur due to fluid transients in pipelines. The basic problem is described in Fig. 1, where a pressure wave expands the pipe wall. Again, dynamic stresses were not considered prior to his research. In support of his theory, Dr. Leishear performed experimental validation using a three inch, diameter, Schedule 40 stainless steel pipeline. As shown in Figs. 2 and 3 experimental results were consistent with calculated results. For a suddenly closed valve, the magnitude of the pressure surge equals

$$\Delta P = \rho \cdot a \cdot V$$

where ΔP is the pressure change, σ is the fluid density, a is the subsonic wave speed in the pipe, and V is the initial velocity. The hoop stress then equals

$$\Delta\sigma = DLF \cdot \rho \cdot a \cdot V < 4 \cdot \rho \cdot a \cdot V$$

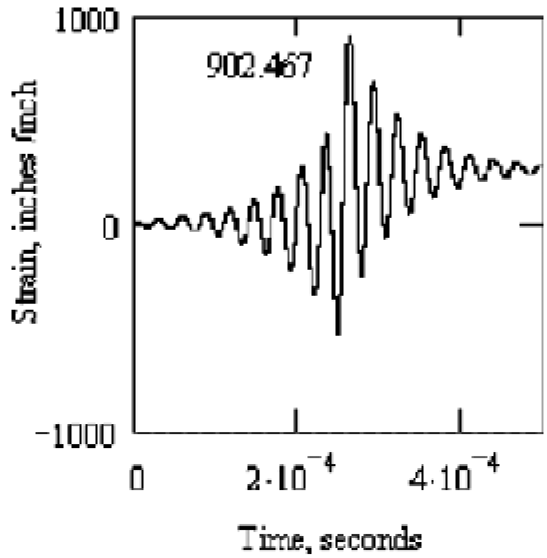

Figure 3: Calculated hoop strains

RESEARCH SCOPE

The technology to install pressure transducers is readily available, but the interpretation of transducer results requires research. To do so, the following research is recommended.

1) Perform Fluent calculations for different diameter pipes and liquids to determine the variance in frequency response to steep fronted pressure surges, considering both damped and undamped responses.
2) Perform AFT Impulse models to compare the effects of line pack in the wake of a pressure wave as compared to the effects of pressure surges at the wave front.
3) Perform Fluent models to evaluate fluid structure interactions for pipeline fatigue cracking, using AFT results as inputs, where fatigue is the mechanism that causes pipeline cracks and catastrophic failures.
4) Perform Fluent models to evaluate transients in gas pipelines.

Together, these studies will reach several conclusions. First, the maximum DLF of 4 will be confirmed for various pipe diameters and pipe lengths, and supporting pipeline frequencies can be established for different wall thickness pipelines. Second, the effects of damping will be further investigated to demonstrate that the DLF's decrease as the hoop stresses converge to the elastic limit of materials. Third, a DLF < 5 will be proved near the dead ends of elastic pipelines, where fluid transient pressures are doubled due to wave reflections. Fourth, the effects of plasticity will be investigated, where the DLF approaches one throughout the pipeline, but the

DLF approaches 2 near dead ends due to wave reflections. Fifth and finally, the direct relationship between stresses and valve closure times will be investigated. All in all, these findings will be directly related to measured pressures in pipelines.

With these results in hand, calculations can be used to assess pressure measurements for the purpose of predicting pipeline damages. Using these predictions coupled with valve closure time effects, pipeline damages can be prevented. Pressure measurements and re-calculations can then be performed on operating systems to demonstrate that the pressure cause of cracks has been eliminated. The principles of API 579 can then be used to establish lower limits for crack growth using fracture mechanics calculations, even though API 579 will not be extensively used during this research.

RESEARCH DATA PRESENTATION AND DATA MANAGEMENT

The end result of this research is the creation of a series of models and graphs that will describe a comprehensive relationship between measured transducer pressure signals and expected piping hoop stresses. To accomplish this task, a series of ASME formatted papers will be written as part of this research. Conference papers are planned to be titled, "Pipe Stresses in Oil Pipelines Due to Sudden Valve Closures", "Stress Induced Fatigue Failures and Damping Effects in Oil Pipelines", "Pipe Stresses and Fatigue Failures in Gas Pipelines", and "A Relationship Between Measured Pressures and Pipeline Failures". A summary ASME Journal publication is planned, which will be titled, "Pipeline Fatigue Failures Due to Fluid Transients". In short, approximately 50 pages of graphs and discussions are planned to be published through four ASME conference papers and one ASME journal paper.

APPLICABLE INDUSTRY / GOVERNMENT ORGANIZATIONS

Research results will be applicable to AWWA, API, and NACE standards. Additionally, these results will be the foundation for an in-process ASME Standard, "ASME B31D, Design of Piping Systems for Dynamic Loads From Fluid Transients", where Dr. Leishear serves as the ASME Project Manager responsible for the production of this Standard through the ASME Mechanical Design Committee for B31 Piping Design.

RESEARCH: QUALITY ASSURANCE AND STANDARDIZATION

Validation and standardization of calculation results will be performed by using initial Fluent models for comparison to already published pipe stress results (Figs. 1-3). Once validation is complete at this smaller scale, scale-up to larger pipes will be assured using AFT Impulse and Fluent, where AFT Impulse is NQA-1 certified and Fluent is approved for use in piping analysis by the US Nuclear Regulatory Commission and qualified to ISO 9001. This scale-up technique has been successfully applied to mixing experiments in million gallon nuclear waste storage tanks, where 1000 gallon test tank results were scaled-up at Savannah River National Laboratory (CFD and Safety Factors", 2013, Leishear, et al. ASME Mechanical Engineering Magazine).

PERFORMANCE METRICS

The extent of oil and gas pipeline failures in the U.S. can be reduced, where the extent is likely in terms of billions of dollars. Once a clear relationship is provided between measured pressures and resultant failure stresses, stress corrosion cracking and seam weld cracks can be eliminated. However, this technology needs to be refined with this research and then applied throughout the pipeline industry. This theory was first published in 2010, but has not yet been adapted by the pipeline industry, even though a few pipeline engineers have reported that they use this new theory in design. In short, this requested research will be the final step to hammer pipeline cracks into submission.

By implementing the results of this research into pipeline operations, CPM performance can vastly improve pipeline reliability through pipeline failure prevention. The installation of a minimal number of pressure transducers (temporary or permanent) at above ground locations are the key to evaluating and preventing the initiation and promulgation of pipeline cracks.

RESEARCHER CREDENTIALS FOR ROBERT A. LEISHEAR

To complete this research, Dr. Leishear has a comprehensive technical background, which includes the following accomplishments.

* BSME, Mechanical Engineering, Johns Hopkins University.
* MSME, Mechanical Engineering, University of South Carolina.
* PhD, Mechanical Engineering, University of South Carolina.
* PhD, Nuclear Engineering, University of South Carolina (All courses complete, Dissertation research in progress).
* Two years of full time study of piping, infrastructure, instrumentation, and processes in a nuclear facility.
* Fluent training: Fluent, Ansys Structural, and Autodyne.
* AFT Impulse training.
* Two ASME textbooks on piping design and failure analysis.
* More than 75 conference, journal, and magazine publications on piping failures, pump failures, vibration analysis, mass transfer, mixing, and fluid mechanics.
* Experience as a Research Engineer at Savannah River National Laboratory.
* Experience as a Calibrations (Metrology) Engineer at Savannah River National Laboratory.
* Experience as a Piping and Pump Engineer at Savannah River Site (SRS), a Department of Energy nuclear facility in South Carolina.
* Experience as a Shift Technical Engineer, overseeing operations and process safety for piping, compressors, pumps, electrical systems, and nuclear processes at Savannah River Site.
* A dozen SRS corporate awards for stopping pump and piping failures, which resulted in cost savings of over $50,000,000.
* The 2016, Mensa Award for Intellectual Creativity for analysis of piping explosions in nuclear power plants and oil pipelines.
* ASME Fellow appointment for “outstanding engineering accomplishments”.