Developments in Ultrasonic Guided Wave Inspection

Ultrasonic Guided Waves for Gas Entrapment Detection in Pipelines
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ABSTRACT

Gas Entrapment in pipelines is often detrimental to a pump startup where extreme damage could occur with plant shutdown potential. Use of an ultrasonic normal beam sensor is difficult to use because of heights, elbows, insulation, and time to do the tests. As a consequence, an ultrasonic guided wave technique has been developed to estimate gas entrapment volumes in a pipeline. Selection of a proper mode and frequency along with appropriate feature selection can lead to an attractive solution to this problem. Both theoretical and experimental results will be discussed.

INTRODUCTION

A prototype guided wave gas entrapment system has been developed. The system is based on ultrasonic energy transfer through a liquid loaded pipe. The amount of energy transferred is dependent upon the amount of energy that is absorbed by the liquid. If a pipe’s wall surface is in total contact with the liquid a minimum amount of energy will be transferred from a transmitter to a receiver. If some portion of the pipe wall does not have contact with the liquid (e.g. an air void) then more energy will be transferred to a receiver.

Prototype gas entrapment detection system

Figure 1 shows the overall configuration of the gas entrapment detection system. Figure 2 illustrates the principle of ultrasonic energy leakage into the pipe liquid. In Figure 1, a selected mode is generated that has both an in-plane component and an out-of-plane or “leaky” component. When an air gap is encountered, the amount of leaked energy is reduced and more energy is transmitted by the in-plane component.

Mode selection is based on wave structures (displacement pattern) obtained from the dispersion curves of the pipe making up the piping system. The mode is implemented by using an angle beam transducer with a specified angle and excited at at specified frequency. See Figures 3 and 4.

An energy “feature” was created to measure the received energy. This feature is described in Figure 5.
Figure 1 - Overall arrangement for use of the entrapped gas detection system

Figure 2 - Illustration of displacements that can occur when guided waves are used. The guided wave mode determines the displacement direction. a. Propagating sound energy is absorbed by the liquid when out-of-plane displacements are present. b. Example of an air gap position.
Figure 3 - Phase velocity dispersion curves for a 4” Schedule 40 carbon steel pipe. A sample coordinate, (470 kHz, 3800 m/sec), is shown for illustrative purposes. If the wave structure of this coordinate is desired and an angle beam transducer is used, the required incident angle, $\theta$, can be calculated using Snell’s law.

\[
\theta = \sin^{-1} \left( \frac{c_{\text{Plexiglas}}}{c_{\text{Phase}}} \right) = \sin^{-1} \left( \frac{2670 \text{ km/sec}}{3800 \text{ km/sec}} \right) = \sin^{-1} [0.703] = 44.6^\circ
\]

Figure 4 - The use of Snell’s law for determining the incidence angle.
EXPERIMENTAL RESULTS

Three mock-up systems were built to investigate the validity of the approach. Figure 6 shows the experiment arrangement for a large inverted “U” mock-up. The pipe was 2” Schedule 10 [0.109”] carbon steel. Using the dispersion curves for this pipe and the wave structure of the L [0, 2] mode at 170 kHz and at 470 kHz, the calculated incident angle was 26º. Five transducer shoes were designed and fabricated for experiments on the mock-ups. Each transducer was cut to match the curvature of the 2” pipe and to have a 26º incident angle.

Four transducers were placed 90 º apart around the bottom left hand side of the mock-up to act as the transmitter, and one transducer placed at the bottom right hand side to act as a receiver. The mock-up initially completely filled with water. Data was collected in increments of 20 in³ water removal (1.6% of the total volume of the pipe interior.)

The results for 170 kHz excitation are shown in Figure 7. Similar results were also obtained for the 470 kHz case. Figure 7 shows a very high coefficient of determination, $R^2 = 0.974$, for the least squares curve fit. The initial steps from no air to 1.6% air, 3.2% air, etc. show that the system resolution is on the of 1.6% or 20 in³ of air volume for this experiment.

CONCLUSIONS

It has been shown that the use of guided waves and the virtually infinite number of wave structures that they can support can be effectively applied to the gas entrapment detection problem. The key concept is the propagation of both in-plane and out-of-plane [Leaky] modes. The in-plane component for long range energy transport [penetration] and the out-of-plane component for energy absorption by the liquid contain within a pipe.
Volume = 1,268 in$^3$

Figure 6 - Test specimen arrangement and components used to evaluate the energy feature concept
Figure 7 - Results from an experiment performed on an inverted “U” mock-up. These are very good results showing resolution ~ 1.6% volume change and a monotonic trend as volume versa the energy feature

\[ y = 0.004x - 0.211 \]

\[ R^2 = 0.9739 \]

170 kHz excitation