ABSTRACT

Localised pin-hole type corrosion defects affecting the structural stability of pipes is a serious challenge faced by the oil and gas industry. The problem is even more severe at support locations where the pipe is held. To mitigate the corrosion wall loss a sacrificial plate is welded between the pipe and support. This critical region now becomes inaccessible for future ultrasonic inspection using conventional methods. An alternate NDE method for live monitoring of hidden regions using Higher Order Mode Cluster (HOMC) is proposed. This high frequency and high resolution HOMC technique combined with a portable semi-automated scanning system is developed and tested to ensure high speeds of inspection in line with industry standards.

Keywords: Guide waves, Inspection of hidden pipes and support structures, Corrosion monitoring

INTRODUCTION

Pipelines are extensively utilized in the oil and gas industry. They are used to transport petroleum fuels and gases from one place to another. Since they are exposed to highly corrosive environments, chances of failure are far greater, which can prove fatal. These pipelines run several kilometres at a stretch and are supported at intermediate distances by pipe supports. Degradation of pipe material at support locations is more likely to occur due to the presence of moisture, minerals and stresses due to loading. Corrosion actually extends both circumferentially and axially along the length of the pipe. In most cases the corrosion defect at the support locations is localized in nature with small pitting corrosion. In order to minimise such occurrences, the industry resorts to adding a sacrificial pad between the pipe and support. This pad is tack welded to the outside of the pipe at the boundaries. Presence of a sacrificial pad only minimises occurrence of corrosion defect, not eliminate it altogether. Now, the downside to this scenario is that, the critical region is hidden from view and is no longer available for conventional ultrasonic inspection. Also the pipes have to be lifted out of the supports, which involves complete shutdown of the flow lines and run the risk of stressing a pipe that would have already been weakened by corrosion. This calls for an alternate method of NDE inspection to monitor corrosion wall loss in inaccessible regions of pipe without disturbing its structural arrangement. As opposed to conventional method of ultrasonic inspection, circumferential guided waves can be employed to inspect inaccessible pipe regions. Using this short range ultrasonic inspection technique, a collection of Higher Order Mode Clusters (HOMC) is formed in the accessible portion of the pipe. Once generated, it propagates the entire circumferential distance of the pipe. Small pitting type defects and other features including from hidden regions are detected. Imaging of defects and its circumferential location can be evaluated using this technique. Other commercially available guide wave inspection techniques operate in the low frequency regime. But this requires the size of the defect to be relatively large, in order for the technique to detect flaws. Also unlike HOMC inspection technique, the computer resources for advanced signal processing of low frequency guided wave systems are enormous. Some of the advantageous features of the HOMC include the high frequencies, minimal displacement at the pipe surfaces, signal less attenuating due to its non-dispersive nature and detection of wall loss associated with pitting and corrosion from a fairly long distance. Most of these pipes have a coating on the surface for protection. There is no need to remove this coating at the time of inspection using HOMC technique.

HOMC GUIDED WAVES

Guided waves require a boundary for propagation and are formed due to reflection and mode conversion of bulk waves at the boundaries within a structure. They superimpose with areas of constructive and destructive interference leading to the formation of guided waves. A principal advantage of guided waves is their inspection potential over long distances from a
single ultrasonic transducer. To design an efficient inspection system, it is necessary to understand the modes of propagation that exists in the pipe and also be able to transmit and receive these modes independently. In many instances, these waves travel long distances, depending on the frequency and mode characteristics of the wave, and follow the contour of the structure in which they are propagating. Usually, these waves not only propagate along the length of the structure but also cover the entire thickness and circumference (in the case of cylinders and rods). Dispersion curves show the kinds of HOMC guide wave modes that could actually propagate in the pipe. Application to corrosion monitoring, pipe wall thinning, and weld defect detection are well known using guide waves. One key parameter associated with how good a particular point might be on the dispersion curve is to selectively generate only non-dispersive mode cluster. The particular point on the dispersion curve was chosen away from the dispersive region, which allows the mode cluster to propagate long distances along the circumference of the pipe with minimum losses. Angle beam longitudinal waves offer accurate and efficient method for selectively generation of HOMC modes. In pipes, and other structures that can be approximated to be one, the dispersion relationships show that the frequency of the wave and the thickness of the plate are always coupled into a single variable and cannot be decoupled. Figure 1 shows the phase velocity curves for various modes as a function of frequency-thickness (MHz-mm) product. While the non-dispersive regions are indicated by horizontal (zero slope w.r.t. the x-axis) portions, the highly dispersive regions of the modes are indicated by steeper slopes. In our experiment, HOMC wave modes are generated by sending longitudinal waves, by exciting a piezoceramic element on the specifically designed angle wedge which is attached firmly to the pipe. The wedge is made of Plexiglass material whose bulk properties are \( v_L = 2692 \, \text{m/s}, \rho = 1180 \, \text{kg/m}^3 \). The wedge angle for each pipe is determined using Snell’s law.

\[
\frac{\sin \theta_L}{\nu_L} = \frac{\sin \theta_H}{\nu_PH}
\]

Where \( v_L \) is the longitudinal wave velocity in Plexiglass and \( v_{PH} \) is the phase velocity of HOMC mode generated in the pipe. The piezoceramic element material is Lead Zirconate Titanate (PZT) of diameter 20 mm and frequency 2 MHz. Non-dispersive modes are more useful in many practical NDE applications. Figure 2 shows the incident Plexiglass wedge angles to generate these modes.

The Higher Order Modes Cluster (HOMC) of guided wave regime is the basis of our pipe support inspection technique. The individual modes in this regime are found to have small differences between their group velocities and consequently similar associated angles of excitation using oblique incidence. It was observed that these waves were not dispersive and possessed several other advantages over previously reported guided wave regions especially for inspecting corrosion under supports and detecting small voluminar defects such as pitting.

**EQUIPMENT DETAILS**

A typical HOMC testing equipment setup is shown in Figure 3. It consists of the following:

1. Portable battery operated Ultrasonic Pulser-Receiver with digitizer.
2. Laptop Computer with software for data processing and displaying A and B-scans, loading calibration data to facilitate data analysis.
3. Software tools for data collection, data replay/analysis and reporting to present findings in a user friendly manner.
4. Suitable customized wedges with in-built transducers for each diameter thickness combination.

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Fig. 1 : Phase velocity curves of various modes in a pipe
Fig. 2: Incident wedge angles in Plexiglass to generate these modes

Fig. 3: Typical experimental setup for HOMC inspection of pipes
signals from the defects. A and B-scan images were used to visualise and quantify the defect size and location. From the collected B-scan image it was concluded that, HOMC technique consistently detected single, in-line and buried defects on the pipe. The presence of sacrificial pad did not hinder the detection of flaws. It was also noticed that there was no significant difference in the amplitude of flaw echo buried inside the weld pad. This proved there was not much leakage of propagating HOMC waves into the weld pad. A typical B-scan image after pipe inspection was completed is shown in Figure 6 and Figure 7.

CONCLUSIONS

Experiments have shown that using cluster of modes at high frequency provide higher sensitivity to small defects. These modes also possess high resolution capability which explains detection of in-line defects. Tasks involving defect sizing are well within the capability of this technique. This is live NDE inspection technique especially useful to monitor hidden of the pipe. Finally, the entire experimental setup is compact, portable and user friendly.

REFERENCES