Long range ultrasonic guided wave focusing in pipe with application to defect sizing

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Abstract: Guided waves have been used commercially to screen long lengths of pipe for corrosion from a single test position since the late 1990's. The technology has recently been advanced by the idea of focusing the energy into one region of the pipe. This potentially enhances the inspection by concentrating the energy on the defect so that there is more potential for determining information about size, shape and circumferential position. Finite element modelling and theoretical calculations have been used to derive a general analytical algorithm for focusing energy into regions of the pipe. This algorithm takes into account the dispersive characteristics of the wave modes, which means the method can work over a wide frequency range and on both small and large pipe diameters. Laboratory trials have been conducted to demonstrate the method. The experiments have shown that the circumferential position can be clearly determined and that there is potential for determining through wall extent. The method is generally applicable to all pipe sizes and testing frequencies and could revolutionise long range pipe inspection.

Key words: Guided waves, long range, ultrasonic, inspection, defect sizing, focusing, dispersion.

A. Introduction

The state of the art technology in guided waves is volumetric screening of tens of metres of pipe from a single axial position. The signal received gives the user an indication of the loss of cross section but cannot distinguish between a relatively low risk defect like a uniform circumferential thinning or a severe patch of localised corrosion at one circumferential position. Focusing is a new technique, which if successful will tell the user the circumferential extent of the defect and potentially the defect depth and axial extent. This is valuable information as it could mean the difference between no further action required or excavating the pipe for further inspection.

Current focusing methods [1]-[9] work relatively well at high frequency but can be problematic at lower frequency, in small diameter pipes and over long distances. This is because the dispersive characteristics of the wave modes have not been taken into account.

A novel focusing method, called AD focusing (analytical dispersion focusing) has been independently developed by TWI. AD focusing takes into account the dispersive characteristics of the wave modes. This means that it is generally applicable for a range of frequencies, pipe diameters and axial focus distances.

B. Finite element modelling and experimentation

B.1. Focusing techniques

The concept of focusing guided waves in pipes is a new idea and as a result there is currently not a great deal of information in the public domain. The earliest publication was in 2001. The focusing concept was first implemented using a tuning method [1], [2]. The method was then improved to a novel approach called TD focusing (time delay focusing) with support from Plant Integrity Ltd [3-8] and successfully employed by TWI [10] using Teletest®, see Fig. 1.

Focusing is the concentration of ultrasonic energy at once particular position in a structure. This is achieved in pipes by taking advantage of the nature of the possible wave modes that can be excited. For example, groups of wave modes, with a sinusoidal variation of energy around the circumference travel at approximately the same velocities. An example of this is shown in Fig.2 for a 6inch schedule 40 steel pipe at around 65kHz. The wave modes shown have similar velocities. The completely non-dispersive wave mode is the first torsional wave mode, the others are flexural wave modes. It is therefore possible to excite a combination of these wave modes such that they superimpose to form a focus at one particular circumferential location, and knowing the velocities, at a designated axial location.

Focusing involves the individual excitation of quadrants (or octants). For TD focusing, the excitation is a modulated pulse containing a discrete number of cycles. In order to focus the energy, varying amplitudes and time delays are applied to each quadrant or octant [9].

In addition to the TD focusing approach time reversal techniques for focusing in pipeline have been investigated and compared to TD focusing [11].

For the new AD focusing technique, a non-standard pulse is excited. This signal is the superposition of each wave mode, taking into account the dispersive nature. This ensures that all the wave modes superimpose at the desired focal location, maximising the energy at that point and avoiding any spurious signals. This technique is particularly effective for situations where the wave...
modes are dispersive, such as for small diameter pipes, low frequencies or for axial locations remote from the defect.

B.2. Finite element modelling

Finite element models were used to simulate AD focusing. The models were 3-dimesional and transient so that the sound field is predicted over the total time range and at every location in the structure. The models were set up, analysed and post processed using ABAQUS [12]. It was ensured that the element sizes were small enough such that the smallest wavelength possible in the bandwidth of excited frequencies was sufficiently simulated [13], [14].

Initially a model was run without a defect being simulated. The excitation was at 65kHz in a 6inch schedule 40 steel pipe. The AD focusing inputs were applied to eight circumferential locations and the focal distance was 1m. A polar plot of the focus spot is shown in Fig.2. It can be seen that the amplitude is concentrated at 0 degrees and there is minimal amplitude elsewhere around the circumference. This indicates that circumferential location will be determined correctly.

In order to test the AD focusing method at a longer axial distance a model was run at 65kHz, simulating a focus 3.5m from the excitation. A contour plot of the focus spot is shown in Fig.3.

B.3. Experimental trials

Experiments using mark II Teletest® kit with torsional only modules were carried out on a 6inch schedule 40 steel pipe (OD=168.3mm, wall thickness=7.11mm). There were 24 modules in total. The tooling was controlled by octants (3 modules per octant). The pipe contained a ~3% cross sectional area loss transverse saw cut, 1.5m from one end at 0 degrees (top dead centre). This is currently below the detection limit (~9%) of the state of the art axisymmetric testing system. The pipe was 6.2m long.

An experiment at 40kHz and 1.6m from the defect was conducted. The resulting reflection amplitude versus circumferential location is shown in Fig.5. It can be seen that the only indication is at 0 degrees, where the defect is positioned and that the defect can be clearly seen since the signal to noise ratio is significant. These tests suggest that the AD focusing method has the potential to reliably tell the circumferential location of the defect.

Further experiments were carried out on a 6inch pipe (OD=168.3mm, wall thickness=8mm). A transverse saw cut was introduced into the pipe. The size of the saw cut was gradually increased and AD focusing tests were repeated for each defect size. Inspections were carried out on defects of cross sectional area loss of 0, 1.5%, 3.0%, 4.5%, 6.0%, 7.5% and 9%. Fig.6 shows the resulting amplitude of reflection against defect loss of cross sectional area. There is a clear trend. This indicates that the AD focusing method has the potential for determining the through wall extent of the defect as well as the circumferential position.
D. Acknowledgements

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E. Literature


[12] ABAQUS User’s manual version 6.5, ABAQUS Inc. Rising Sun Mills, 166 Valley Street, Providence, RI 02909-2499


C. Conclusion

A combination of finite element analysis and experimentation has been used to demonstrate that the AD focusing method works for different frequencies and axial distances. The potential for using the technique to determine circumferential and through wall extent of defects has been demonstrated.