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Long-Range Piping Inspection by Ultrasonic Guided Waves

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1. Introduction

The ultrasonic guided waves are very promising for the long-range inspection of large structures because they can propagate a long distance along the structures such as plates, shells and pipes [1]. The guided wave inspection could be utilized for an on-line monitoring technique when the transmitting and receiving transducers are positioned at a remote point on the structure. The received signal has the information about the integrity of the monitoring area between the transmitting and receiving transducers. On-line monitoring of a pipe line using an ultrasonic guided wave can detect flaws such as corrosion, erosion and fatigue cracking at an early stage and collect useful information on the flaws. However the guided wave inspection is complicated by the dispersive characteristics for guided waves. The phase and group velocities are a function of the frequency-thickness product. Therefore, the different frequency components of the guided waves will travel at different speeds and the shape of the received signal will changed as it propagates along the pipe. In this study, we analyze the propagation characteristics of guided wave modes in a small diameter pipe of nuclear power plant and select the suitable mode for a long-range inspection. And experiments will be carried out for the practical application of a long-range inspection in a 26m long pipe by using a high-power ultrasonic inspection system.

2. Ultrasonic guided wave modes in a pipe

The stress wave propagation in an elastic hollow cylinder was first studied by Gazis [2] and the guided wave modes of a cylindrical structure have been extensively studied for the last two decades [3,4]. The guided wave of a pipe has three different mode types: longitudinal L(0,n), torsional T(0,n), and flexural modes F(m,n) where the circumferential order is m=1,2,3…. and the mode is m=1,2,3…. The longitudinal modes and the torsional modes are axisymmetric modes, but the flexural modes are non-axisymmetric modes. The theoretical calculation results of the guided wave modes can be represented by the phase velocity and group velocity dispersion curves. Fig. 1 shows the dispersion curves of the phase velocity and group velocity for a stainless steel pipe.

In a long-range inspection, it is important to select the suitable mode among the various modes. The non-dispersive mode and frequency range should be selected and optimized from the group velocity dispersion curves. For the generation of the selected mode, the incidence angle of the ultrasonic sensor should be adjusted from the phase velocity dispersion curve.

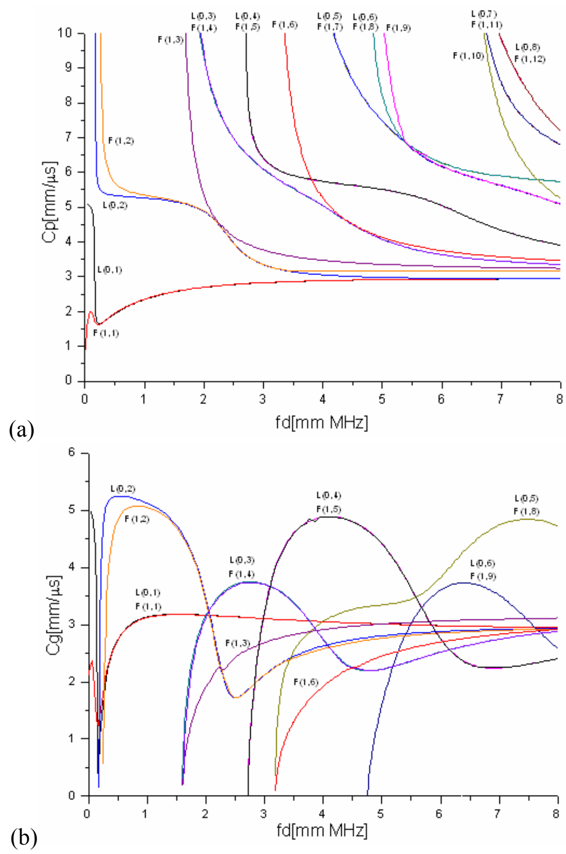

Figure 1. Dispersion curves of (a) phase velocity and (b) group velocity for a stainless steel pipe

3. Experiments and Results

A seamless stainless steel pipe (SCH-80) with the outer diameter of 60.3 mm, the wall thickness of 5.54 mm and the length of 26m was used. The pipe has four welds and two artificial flaws. The guided waves were generated and detected from the end of the test pipe by using the RITEC RAM-10000 high power pulser receiver. The tone burst signals was used for the excitation pulse of the ultrasonic transducer. The time domain signals were displayed and stored on the LeCroy digital oscilloscope. The short time Fourier transformation (STFT) was performed for the reflection signal from the end of the pipe. The modes can be identified by a comparison between the group velocity dispersion curves of each mode and the processed STFT results. The 0.5MHz ultrasonic transducer with a variable angle wedge was attached at the end of the test pipe. The mode of a guided wave can be selected by an adjustment of the incident angle in the wedge. Fig. 2 (a) shows the time signal and STFT result when the incident angle of the wedge is 45 degree. The time signal is very widely spread due to the dispersive characteristics of the L(0,2), F(m,2) and F(m,3) modes. Fig. 2 (b) shows the time signal and STFT result when the incident angle of the wedge is 75 degree. L(0,1) and F(m,1) modes were generated with a non-dispersive signal pattern. Fig. 3 shows the acquired reflection signal from the four welds and circumferential flaws #1 and #2 by using the L(0,1) and F(m,1) modes. The reflection signals from the flaws can be clearly detected in a 24m long distance. So, the longitudinal L(0,1) and flexural F(m,1) modes are better for a long-range piping inspection.

4. Conclusions

Ultrasonic guided wave inspection can be very attractive as a long-range inspection and on-line monitoring for the structural integrity of a pipe and large structures. It is important to make an appropriate choice of the guided wave modes and frequency-thickness range. An experiment was carried out in order to verify the propagation characteristics of the guided wave modes for long-range inspection of a small-diameter nuclear piping. The longitudinal L(0,1) and F(m,1) modes are suitable for the long-range inspection of a small-diameter nuclear piping at a frequency of 0.5MHz.

Acknowledgements

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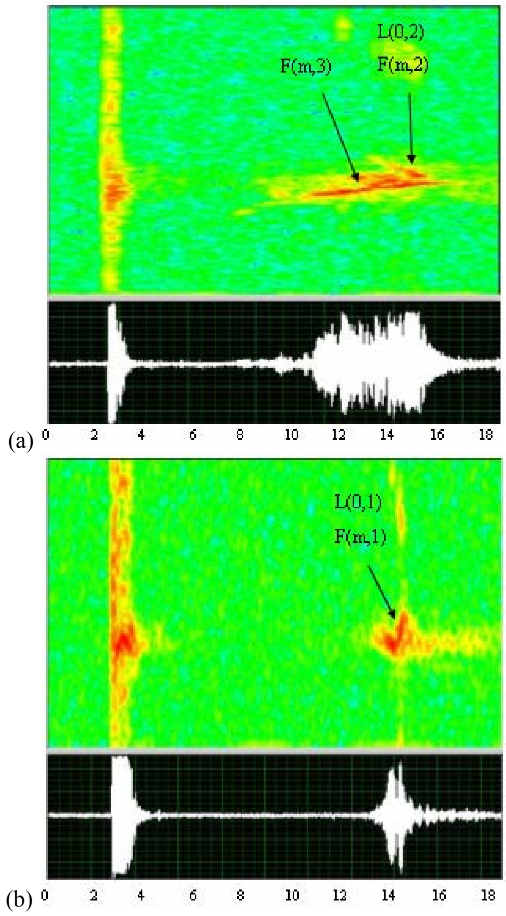

Figure 2. Time signals and STFT spectra from the end of pipe for incident wedge angle of (a) 45 degree and (b) 75 degree.

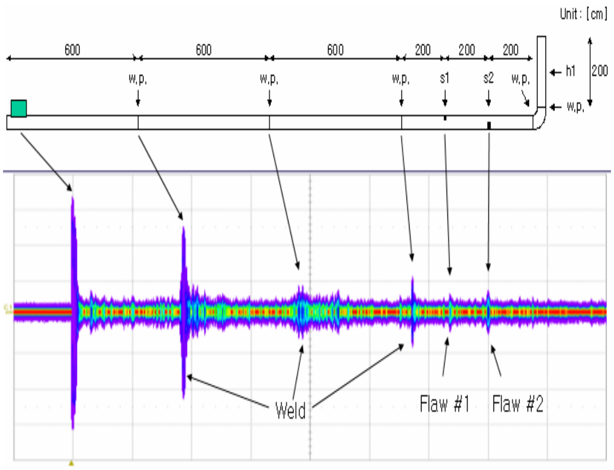

Figure 3. (a) Schematic diagram of 26m stainless steel test pipe with welds and flaws and (b) time domain signal of guided wave by the generation of L(0,1) mode