Feasibility for Health Monitoring of Nuclear Power Plant Pipes by Ultrasonic Guided Waves

Won Deok Oh,a Younho Cho,b and Joon Hyun Lee,c
a Research Institute of Mechanical Technology, Pusan National University, San 30, Jangjeon-dong, Keumjeong-gu, Busan, 609-735, Korea, wondeokoh@pusan.ac.kr
b School of Mechanical Engineering, Pusan National University, San 30, Jangjeon-dong, Keumjeong-gu, Busan, 609-735, Korea, mechcyh@pusan.ac.kr
c School of Mechanical Engineering, Pusan National University, San 30, Jangjeon-dong, Keumjeong-gu, Busan, 609-735, Korea, johlee@pusan.ac.kr

1. Introduction

In carbon steel pipes of nuclear power plants, local wall thinning resulted from erosion-corrosion or FAC(Flow Accelerated Corrosion) damage is an important issue in nondestructive evaluation for the integrity of nuclear power plants. Thus, periodic in service monitoring of those pipes is very essential for maintenance and safety issue. The use of conventional point-by-point monitoring technique such as ultrasonic bulk wave technique and local thickness gauging requires lots of inspection time to cover entire piping structure [1,2].

Ultrasonic guided wave technique provides us with decent initial screening tool in much more faster and efficient manner. However, such advantage can be obtained only through a proper mode selection and tuning scheme. For the more, the mode conversion analysis becomes inevitably necessary for a quantitative interpretation of scattering data [3,4,5]. Although there has been an attempt to investigate the guided wave mode conversion in plates [6,7], the mode conversion data for a tube is relatively rare. In this study, after selecting a mode from theoretical dispersion curves of a pipe, the mode conversion from edge and scattering pattern around artificial hole and wall thinning are studied experimentally using comb transducer and laser.

2. Methods and Results

2.1 Experimental Setup

A high power pulser / receiver was used to generate guided wave modes and identify mode conversion in 2mm thickness stainless steel pipes. Two types of scattered signals are collected to study the mode conversion in pipes. One is from pipe end and the other is from artificial wall thinning. To identify mode conversion from the edge of pipe, a comb type transducer generates the guided wave toward the pipe end.

Also, laser-generated ultrasound technique was employed to evaluate local wall thinning due to corrosion. Guided waves were generated in the thermo elastic regime using a Q-switched pulsed Nd:YAG laser with an linear array slit. Time-frequency analysis of ultrasonic waveforms using FFT(Fast Fourier Transform) allowed the identification of generated guided wave modes by comparison with the theoretical dispersion curves.

This study shows some experimental results about mode conversion in pipe, optimization of generating laser ultrasound using various linear array slits and new method for detecting wall thinning region.

2.2 Mode Conversion in Pipe

If guided wave scattering is caused by a thickness variation or any geometric change in a waveguide, mode shifting will occur in scattered fields because of the thickness change. In this case, reflected modes are usually different from transmitted modes, which show different characteristics such as phase and group velocity, penetration ability, amplitude variation of mode packets, and sensitivity based on different wave modal fields. The converted modes from an incident mode through a guided wave scattering caused by scattering factor are associated with different phase velocities in the phase velocity dispersion curve as shown in Fig. 1, which can be found in a new fd value. Theoretically, each of those modes can be received as a single mode by adjusting the angle of the receiver to a suitable one for the mode to be received based on the Snell’s law. However, the converted modes that exist within a phase velocity spectrum because of a source influence can be simultaneously received as multimode signal at the same angle with different receiving efficiency [6]. In this study, the reflected L(0,2) mode from pipe end is not significantly converted to any other mode at any receiver angle as shown in Fig. 1. However, the mode L(0,3) experiences mode conversion to L(0,2) mode at receiver angle 50°. When the receiver angle is 32°, the mode L(0,2) is presented as well as L(0,3) mode. The mode L(0,5) shows the remarkable mode conversion to L(0,4) mode when the receiver angle is 30°. This results tell us that the mode conversion characteristic is different each other.

When the modes pass through defect, the waveform will change by each mode characteristics. Figure 2 illustrates scattering and mode conversion to artificial wall thinning along distance. Even though the scattering pattern of each mode is changed, it is difficult to

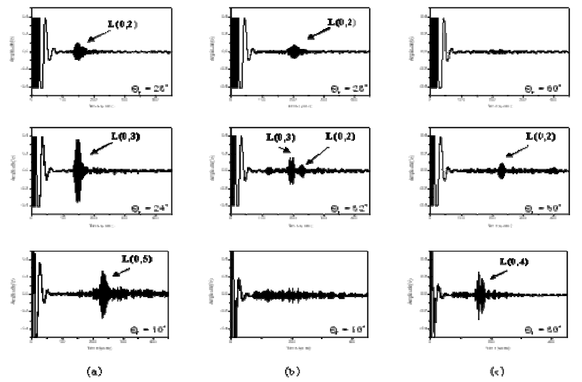
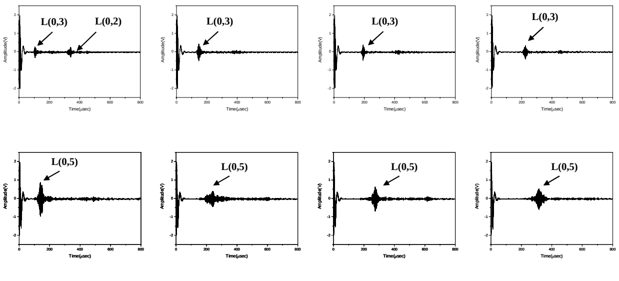


Figure 1. Reflected L(0,2), L(0,3) and L(0,5) modes from pipe end (a) reference input signal (b) reflected signal (c) mode conversion monitoring with respect to receiver angle tuning.

perceive wall thinning when the generated mode is only one. However, it is seen in Fig. 2 that the mode L(0,2) is disappeared after passing through wall thinning and it is easy to find defect of pipe when the multi modes are generated into pipe than a single mode.



(a) (b) (c) (d)

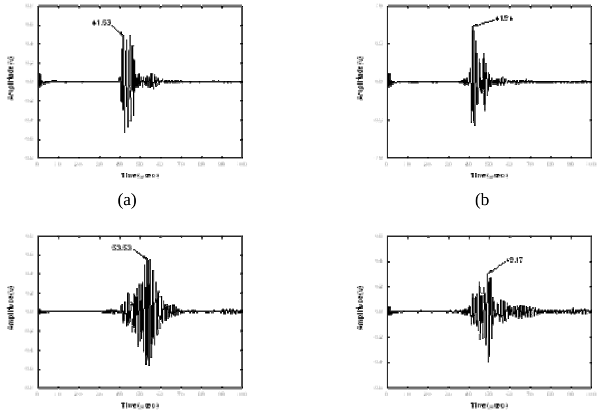
Figure 2. Scattering and mode conversion monitoring to the corrosion-simulated artificial defect along distance: (a) 100mm in front of wall-thinning (b) 100mm through wall-thinning (c) 200mm through wall-thinning (d) 300mm through wall-thinning

2.2 Laser Ultrasonic Guided Wave

Figure 3 represents the waveforms of guided wave passing through wall thinning region in pipe using laser ultrasonic guided wave technique. The selected modes in dispersion curve diagram were L(0,1), L(0,2), L(0,3) and L(0,4). However, only L(0,1) and L(0,2) modes are generated with optimized single mode. After passing through thinning defect area, the group velocity of L(0,1) mode is not changed. However, the mode L(0,2) is changed significantly. Thus, the mode L(0,2) will be useful in detecting wall thinning defect region in pipes.

3. Conclusion

As sample cases of guided wave scattering, scattering pattern around wall thinning region and reflection from pipe end were studied. Predicted modes could be successfully generated by controlling frequency and receiver angle at a fixed wavelength. The axisymmetric guided waves from comb transducer are generated and the reflected pattern from pipe end is symmetric. However, the fields through defect show asymmetrical pattern. L(0,2) mode shows sensitive reaction to scattering factors than L(0,3) mode. When the mode L(0,2) is generated into pipe end, the mode conversion is negligible. However the mode L(0,3) is converted to L(0,2) mode at the receiver angle of theoretically predicted point on the dispersion curves when is generated toward pipe end. The mode L(0,5) shows significant mode conversion. In case of using laser ultrasonic, the L(0,2) mode was selected the most useful mode for detecting wall thinning defect. Experimental feasibility study on the guided waves was presented to explore scattering pattern and mode conversion for data calibration of a long range pipe monitoring. Also, new method to find defect in pipe using multi-mode input was exhibited.



(a) (b (c) (d)

Figure 3. Experimental results with L(0,1) and L(0,2) modes (a) L(0,1) waveform for a defect free (b) L(0,1) waveform for a 30% thinning defect (c) L(0,2) waveform for a defect free (d) L(0,2) waveform for a 30% thinning defect

REFERENCES

[1]A.Demma, P. Cawley, M.Lowe, A.G. Roosenbrand and B.Pavlakovic : NDT& E International Vol. 37, p. 167~ 180, 2004

[2]J.L.Rose, S.P. Pelts and M.J. Quarry : Ultrasonics, Vol. 36, p. 163 ~ 169, 1998

[3]M.H.S.Siqueira, C.E.N. Gatts, R.R. da Silva and J.M.A. Rebello : Ultrasonics, Vol. 41, p. 785 ~ 797, 2004

[4]Takahiro Hayashi, Won-Joon Song and J.L.Rose : Ultrasonics Vol. 41, p. 175 ~ 183,2003

[5]S.P.Pelts, D. Jiao and J.L.Rose : IEEE Ultrasonic Symposium, p. 857 ~ 860, 1996

[6]Younho Cho : IEEE Trans. Ultrason., Ferroelect., Freq. Contr., Vol. 47 (3), p. 592~599, 2000

[7]Younho Cho, Won Deok Oh and Joon Hyun Lee : Asian Pacific Conference for Fracture and Strenth ‘04, p. 155, 2004