Application of Laser-Generated Ultrasound for Evaluation of Wall-thinning in Carbon Steel Elbow

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Abstract

The objective of this research is to estimate location and size using laser ultrasound guided wave for wall thinning evaluation of elbow. Wall thinning of carbon steel pipe is one of the most serious problems in Nuclear Power Plant especially wall thinning of carbon steel elbow caused by FAC (Flow-Accelerated Corrosion). Therefore non-destructive inspection method of elbow is essential for safe operation of nuclear power plants. Specimens used in this study were carbon steel elbows as the main elements of real nuclear power plants, and shape of wall thinning was an oval with 120mm-width, 80mm-length and 5mm-depth. The L(0,1) and L(0,2) modes variation of ultrasound guided wave from the response obtained by the laser generation/air-coupled detection ultrasonic hybrid system represent characteristics of the defect. The trends of these characteristics and signal processing used to estimate the size and location of wall thinning.

Keywords : Ultrasound guided wave, Wall-thinning, Carbon Steel Elbow, Air-coupled, Flow-accelerated corrosion

1. Introduction

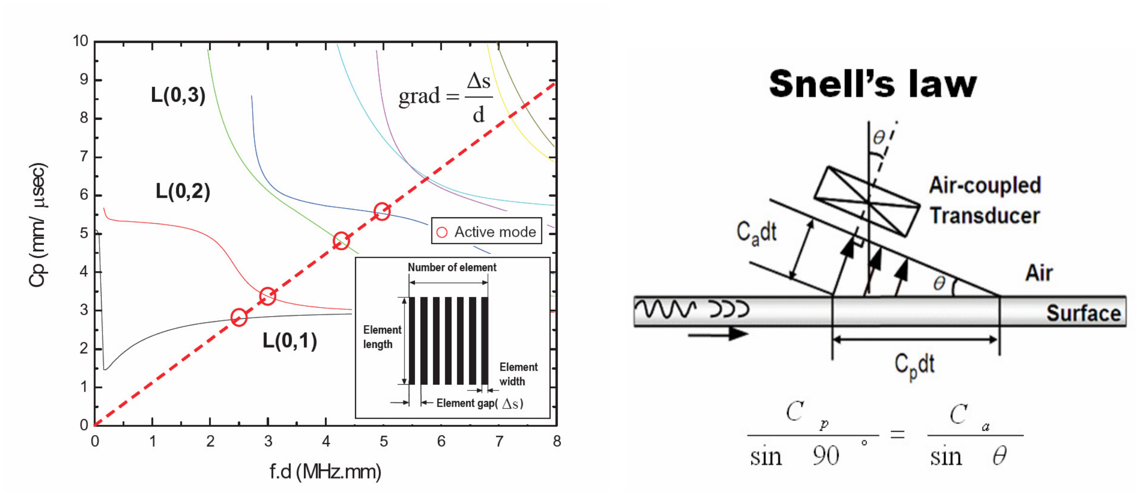
Carbon steel is one of the principal structural materials in power plants. Since local wall thinning caused by FAC occurs inside the elbows by flowing high temperature and high pressure water with high velocity, it can make a big disaster if this defect is growing unknowingly. Therefore structural evaluation of elbows with local wall thinning becomes more important in order to maintain the integrity of coolant piping systems[1, 2].

Most inspections were carried out using point by point examination. This method is inefficient and also takes a lot of time to inspect a large area structures. In these situations, the developed method for solving the drawbacks compare to conventional technique is the inspection using guided waves.

An ultrasonic guided wave technique is one of powerful tools to detect the reduction and has lots of benefit over conventional ultrasonic methods due to such features as lower cost, ease of operation, and testing speed. Moreover, broad-band, multi-mode guided waves, such as those generated by a laser system, have the potential for detecting flaws in various sizes [3-5]. For the purpose of this study, the characteristic of the guided wave will be shown, when it passed through the elliptical defect of elbow, a laser generation/ air-coupled transducer ultrasonic hybrid systems were employed as a way of detecting the defect of elbow by using guided wave. In addition, linear slit array were used for the directivity of laser-generated guided wave and the determination of wavelength. Air-coupled transducer as guided waves detector was controlled to detect specific mode among guided waves by adjusting its receiving angle to a leak direction of selected mode.

2. Selective generation and reception of guided wave mode

The problem in laser based guided wave testing is the difficulty to generate a desired mode due to the dispersive nature of Lamb waves [6]. While the excitation of a particular mode is made by a laser pulse, the different components of the wave will travel with different speeds and at least two modes are present even at low frequency range. This could make the evaluation of defect difficult due to interpretation of received signal. In this study, the selective generation and reception of guided wave modes are achieved by the technique that used the relation of dispersion curves and linear slit array [7]. Figures 1(a) show the process of selective generation using this linear slit array. The elements gap (Δs) in Figure 1(a) is equal to the wavelength of generated modes and illustrated as the diagonal line with a slope of Δs/d in Figure 1(a).



(a) Phase velocity of selected mode in Dispersion curve

(b) Determination of receipt angle for specific mode

Figure 1. Optional receipt of guided wave mode.

The active modes lie on at the intersection points between the line and the phase velocity of dispersion curves, and therefore it is possible to generate specific modes selectively by adjust the elements gap. The method to receive the modes generated by the above-mentioned technique is to rotate the air-coupled transducer by the angle based on Snell's law for the propagation velocity in air (C_{air}) and the phase velocity of the specific mode (C_p) as shown in Figure 1(b). In this study, the velocity of wave in air is 340 m/s and the phase velocity of modes is obtained in Figure 1.

This study adopted the modes of L(0.1) and L(0.2) as the suitable modes for experiments due to readily excited, received experimentally at low frequency-thickness and only slightly dispersive [8]. Table 1 shows frequencies, phase velocities, reception angles of L(0.1) and L(0.2) modes at 8mm slit spacing. In the process of this calculation, the velocity of wave in air was 340 m/s and the phase velocity of modes was obtained from the dispersion curves in Figure 1.

Wavelength [mm]	Mode	Frequency [kHz]	Phase velocity [mm/μsec]	Receiving angle [θ˚]
8mm	L (0,1)	305	3.2	6.09
	L (0,2)	382	3.6	5.4

Table 1 Theoretical values of L(0,1) and L(0,2) modes at 8mm wavelength on each defect

3. Specimen and Experimental Setup

The specimen used in the test was 8.5mm thick carbon steel elbow. To evaluate the guided wave interaction with defect in elbow, through compared with defect region and defect-free region. An elliptical defect with a constant width 120 mm and depth 5 mm was machined on the inner surface of 8.5 mm thick elbow having diameter of 218 mm. Figure 2 shows the shape of the side and front mentioned defect on carbon steel elbow.

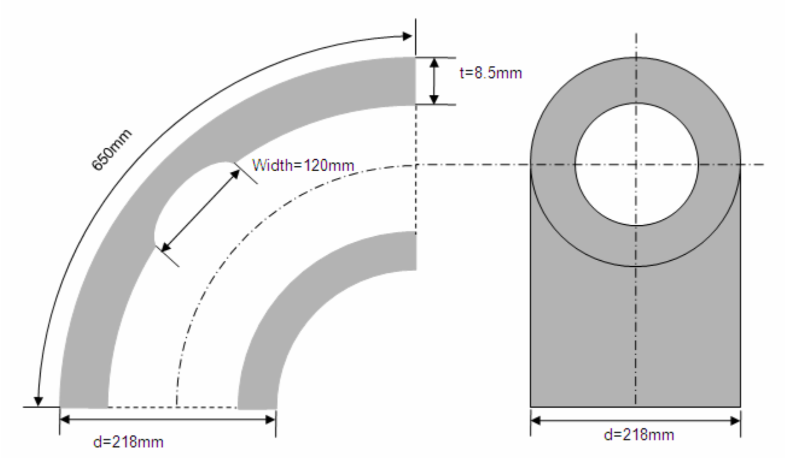


Figure 2. Shape of defects in 8.5mm thick elbows

A schematic diagram of the apparatus used to perform experiment is shown in Figure 3. As shown in this figure, the laser and air-coupled transducer were positioned on the same side of the test elbows and act as the generator and detector of the guided wave signal scanning at 20mm steps along the longitudinal direction. A wavelength of fiberized Nd:YAG pulse laser system was used to generate ultrasonic waves is 532 nm and this pulse laser system emited energy of 32 mJ at one pulse. The beam of this laser illuminated a linear array slit and transmitted beam act as line source on the elbow. The guided wave generated by this source propagated separation distance start at 160mm to end at 380mm between the source to the receiver, perpendicular to the surface of the elbow, and was subsequently detected using the air coupled transducer with a standoff from 5 mm the outer surface of elbow. In addition, the received signals from the air-coupled transducer were magnified by the amplifier and displayed through the signal averaging scheme with 1000 sampling data on the screen of oscilloscope. Here, the interval between slits, the width and the number of slits were fabricated 8 mm, 4 mm and 7 respectively.

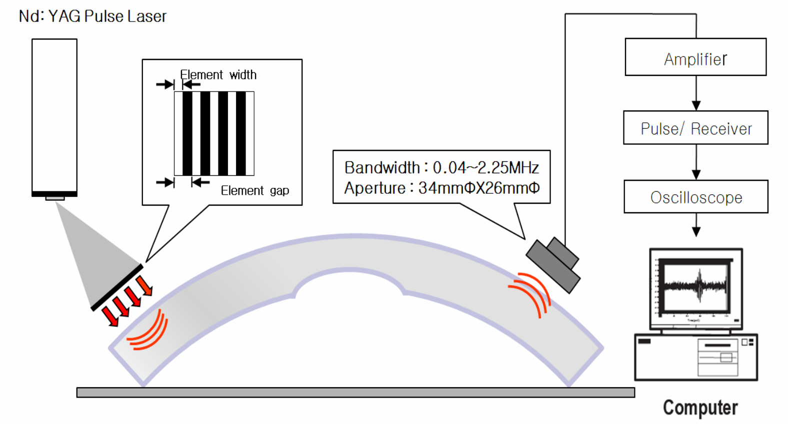


Figure 3. Schematic diagram of experimental setup

4. Experimental Results

4.1 Characteristic of L(0.1), L(0.2) modes in defect region of elbow

Figure 4 shows the variation of amplitude in defect region. In this Figure, it is possible to evaluate defect by the variation of L(0.1) and L(0.2) modes. Comparing to defect-free region, amplitude of L(0.2) mode is decreased clearly in defect region. This result indicates that the signal on defect region and passed by defect region is affected by defect.

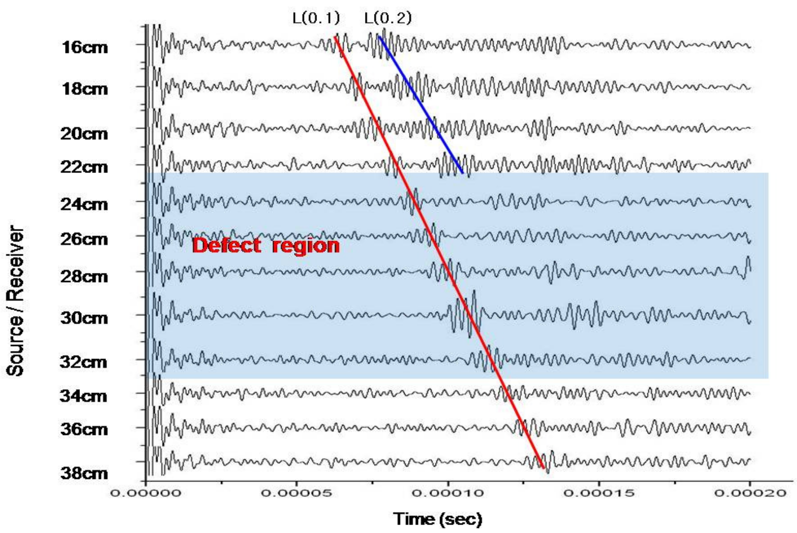
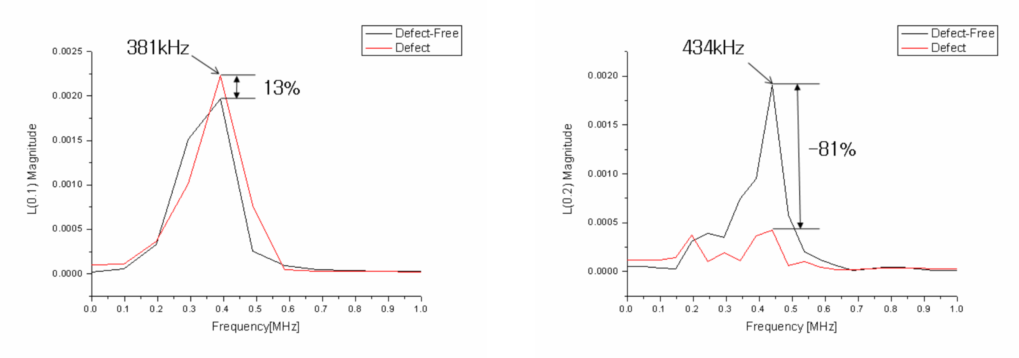


Figure 4. Guided wave signals of L(0.1), L(0.2) mode in elbow with defect region

Figure 5 shows the characteristics of the frequency spectra of L(0.1) mode with the frequency of 381kHz (Theoretical value is 376kHz) and L(0.2) mode with 434kHz (Theoretical value is 423kHz) distinctly. The plots in Figures 5 (a)-(b) are frequency spectra of these modes in the 0~2MHz range. As shown Figure 4, the signal without defect includes both of L(0.1), L(0.2) modes. However amplitude of L(0.2) mode is decreased dramatically in defect region.



(a) Frequency spectrum of L(0.1) (b) Frequency spectrum of L(0.2)

Figure 5. Signal characteristics of L(0.1) and L(0.2) mode on frequency spectrum

Analysis of the frequency spectra were obtained by performing a Fast-Fourier Transform (FFT) of the time-domain waveforms, the magnitude of L(0.1) mode with the center frequency of 381kHz in the defected region is increased by 13%. However, the L(0.2) mode of waves propagating in the defected region suffers a dramatic attenuation. The maximum decrease in center peak magnitude of the signal with frequency of 434kHz is 81%

4.2 Defect localization along the longitudinal direction

The guided waves are received with a constant source/receiver separation along the longitudinal direction. The air-coupled transducer is passed by the center of defect for obtaining clear characteristics of defect. Figures 6 shows the results of line scan using pitch-catch method in defect region. The maximum magnitude of the frequency spectrum in L(0.1) and L(0.2) modes were plotted as a function of the scan position by scanning at 20mm steps along the longitudinal direction respectively.

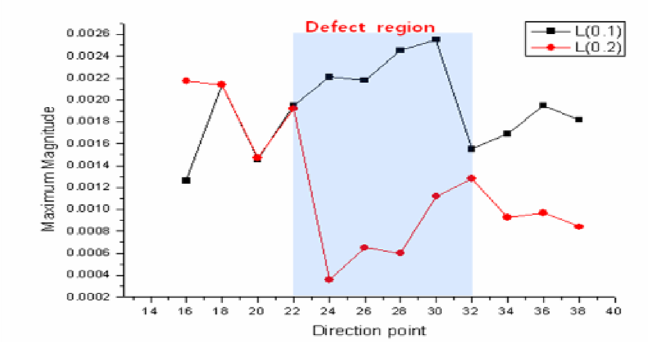


Figure 6. Maximum Magnitude using line scan technique on defect region.

The L(0.1) mode has the relation between depth of defect and variation of signal. As a depth of elliptical defect is increased, amplitude of signal received is increased. L(0.2) mode using the maximum magnitude of frequency spectrum is the factor to distinguish defect region.

5. Conclusions

The possibility for measuring thickness reduction using the group velocity of guided wave was applied to the elbow. To evaluate the thickness reduction using the group velocity, mode identification was conducted by time-frequency analysis. In the elbow, L(0.1) and L(0.2) modes were appeared in defect-free region, but amplitude of L(0.2) mode were decreased in wall-thinning and characteristic the maximum magnitude of frequency spectrum of L(0.2) mode is varied in the defect region. So we could know that it is possible to evaluate wall-thinning of elbow by using the ratio of L(0.2) to L(0.1) for the magnitude quantitatively

6. Acknowledgement

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