

NONCONTACT AIR-COUPLED GUIDED WAVE MODE IDENTIFICATION USING WAVELET TRANSFORM

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Abstract: For efficient NDE of pipes, essential components of power facilities, ultrasonic guided waves were generated and received applying air-coupled transducers and comb ones as non-contact tech. Mode generation and selection were predicted based on theoretical dispersive curve and the element gap of comb transducers. In addition, a receiving angle of the air-born transducers was determined to acquire the predicted modes by theoretical phase velocity of each mode. Theoretical dispersive curve was compared with the results of the time-frequency analysis based on the wavelet transformation and 2D-FFT to identify the characteristics of the received mode. The received modes show a good agreement with the predicted ones.

Introduction: There have been many attempts to detect defect existed in plates and shells due to the advantage of guided waves to inspect long range at a fixed position[1-3]. However, a conventional guided wave technology has limitations for field application and automation because of the usage of contact transducers. Hence, the development of a better and faster technology has been demanded. Therefore, recently non-contact based technologies have been of a great concern. They involve EMAT, laser based technology and air-coupled technology[4-9].

Table 1 represents the features of guided wave generation and reception. The Piezo based technology is the most popular one with highest S/N ratio but it has the disadvantage to need for contact between transducer and specimen. This is why a non-contact technique is required. The EMAT, one of non-contact type guided wave techniques has advantage to easily control wavelength, although it has to be placed closed transducer has lack of sensitivity for generation and reception due to high acoustic impedance mismatch between solid specimen and air. Laser based ultrasonic one also has limit in generating and receiving signal over long distance[10]. Consequently, for convenience in automation and enhancement of stability in wave excitation and reception, it is crucial to select an appropriate scheme for wave excitation and reception depending on the material property of specimen and inspection environment.

In this study, the feasibility of using the comb transducer combined with air-coupled one is explored. The comb transducer is used to generate a guided wave mode while the air-coupled transducer is employed for reception. The wavelet transformation and the 2D-FFT are also conducted for mode identification, compared to theoretical dispersion curves.

Table 1 Type of the generator and detector for of guided wave

Guided wave Generator				
Type	PZT	EMAT	Air-couple transducer	Laser (with line array slit)
Variables	frequency angle	wavelength	angle	wavelength
Contact or not	contact	closely non-contact	non-contact	non-contact
Guided wave Detector				
Type	PZT	EMAT	Air-couple transducer	Laser Interferometer
Variables	frequency angle	wavelength	angle	displacement

Contact or not	contact	closely non-contact	non-contact	non-contact
Mode selection or not	selectable	unselectable	selectable	unselectable
S/N ratio	good	good	good	bad

Guided Wave Excitation and Reception:[comb transducer] The mode selection and its efficiency rely on the number of PZT elements, the element gap, the element width, frequency and the pressure distribution over each element. Figure 1 and Photo 1 show a schematic diagram of the comb transducer and the picture of the used one, respectively, In Figure 1, the transducer element gap was fixed as 12 mm. The number of elements are five and the center frequency is 1.5MHz.

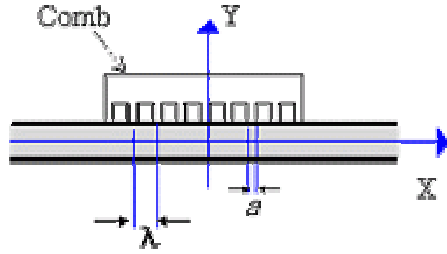


Fig. 1 Parameters of the comb transducer



Photo. 1 A comb transducer

Figure 2 is the dispersion curves obtained from the material properties of Table 1. With the wave length, possible guided wave modes are generated at each cross point on the corresponding diagonal line as shown in Figure 2. Varying frequency and element gap, further mode selection is also possible.

$$C_p = \Delta S \cdot f = \lambda \cdot f \tag{1}$$

Table 1 Material properties and dimensions of the sample tube

Materials	Outer Diameter	Thickness	Longitudinal velocity	Transverse velocity
Stainless steel	114mm	2mm	6,024m/sec	3,250m/sec

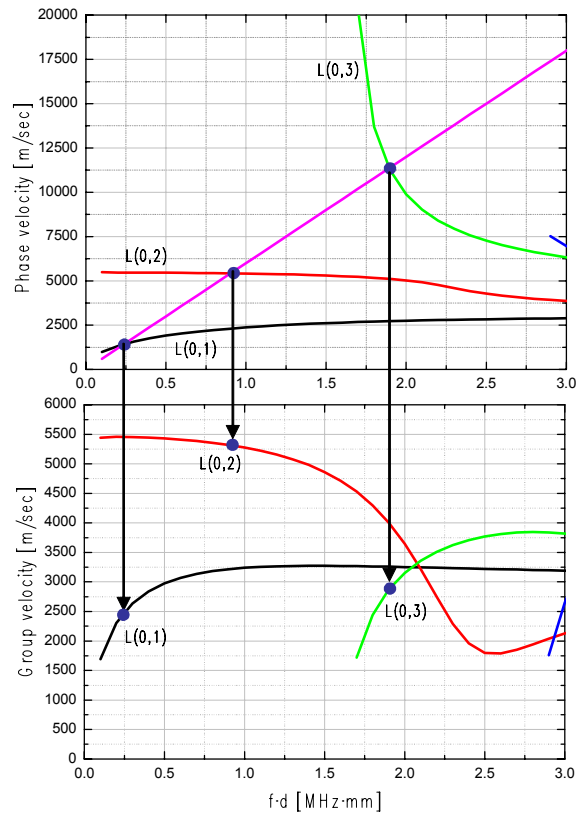


Fig. 2 The relationship between the wavelength and sound velocities

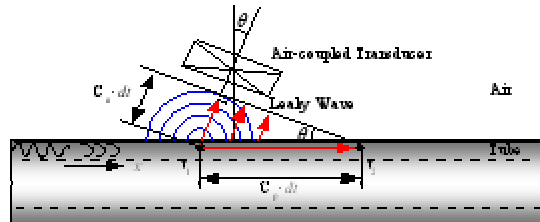


Fig. 3 Consideration of leaky guided wave and oblique angle of air-coupled transducer

[Air-Coupled Transducer] The receiving angle of air-coupled is determined in terms of the phase velocity of a desired mode and the wave velocity of the air, based on the following Snell's law.

$$\theta = \sin^{-1} \left(\frac{C_a}{C_p} \right) \tag{2}$$

C_a is the wave velocity of the air and C_p is the phase velocity of the generated mode.

Table 2 show the calculated receiving angle and the corresponding phase velocity at the cross points of Figure 2 for wavelength. The wave velocity of the air is 340 m/sec at 23° room temperature. The frequency bandwidth of the air-coupled transducer is 0.2~2.25MHz.



Photo. 2 A scene of experimental setup and the adjusting zig.

Table 2 Selected modes and oblique angles of leaky guided waves into air

Wavelength Mode	12mm	
	C_p [m/sec]	θ [°]
L(0,1)	2,166	9
L(0,2)	5,200	3.7
L(0,3)	7,400	2.6

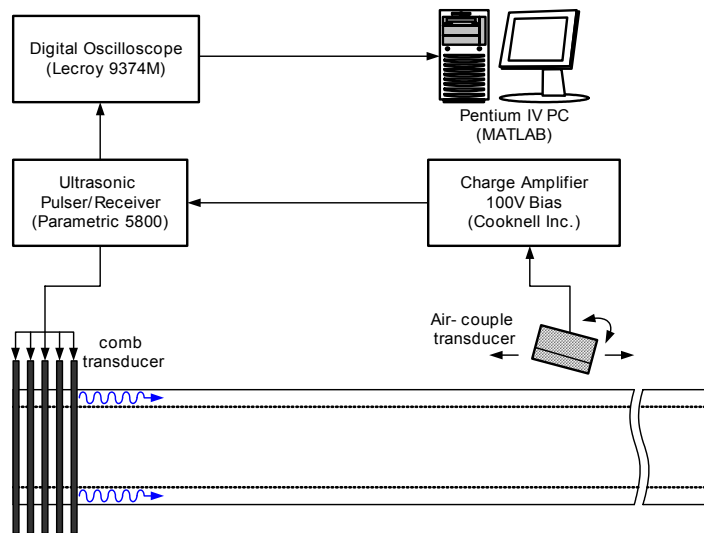


Fig. 4 The setup of experimental system

Experimental Details: Figure 4 represents a schematic diagram of experimental setup. The ultrasonic pulse/receiver is equipped with the comb transducer to generate guided wave mode in 2 mm thickness stainless pipe. The distance from the middle point of the comb transducer to air-coupled one is set as 1000 mm and the air-coupled receiver was placed with the gap of 30 mm from the outer surface of the pipe. The amplitude change of the air-coupled receiver was negligible with increase of the gap between transducer and specimen up to 50 mm and it

remarkably decayed beyond this point. However, it was possible to receive the signal of guided wave modes leaked through the air even at the gap of 100 mm. The scanning system for the air-coupled transducer was built up to selectively receive a guided wave mode. The received signal from the air-coupled transducer was magnified by the charge amplifier of 100 V bias. High and Low pass filters were set as 100 kHz and 5 MHz respectively to remove mechanical and acoustic noise. The received guided wave signal was installed through the signal averaging scheme with 1000 sampling data and the averaged signal is used for the time-frequency analysis. It is necessary to acquire enough number of data at a different position moving the air-coupled transducer with uniform increment in the longitudinal direction of pipe to obtain a reasonable resolution in 2D-FFT image. The 100 data set was collected every 1 mm increment in the scanning path from 500 mm to 599 mm span between the comb transducer and the air-coupled receiver. The gap between the specimen and air-coupled transducer is maintained as 70 mm.

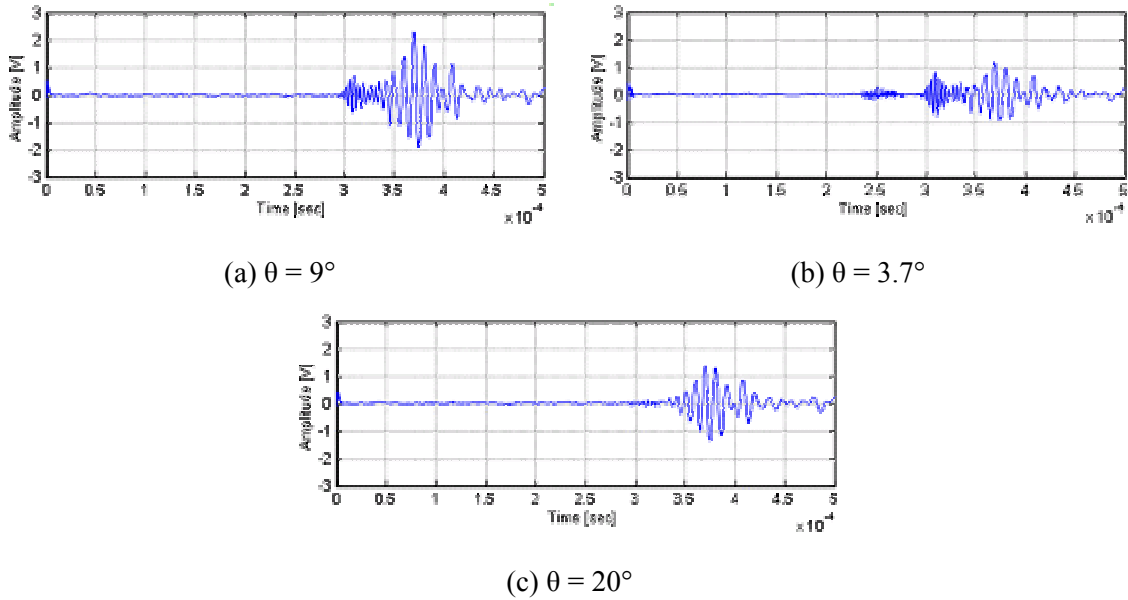


Fig. 5 Waveform of predicted L(0,1) and L(0,2) mode with $\lambda=12\text{mm}$

Results: Figure 5 is the waveform received by air-coupled transducer. Each waveform was obtained depending on the corresponding receiving angle calculated for the mode of Table 2. Figure 5(a) is the result for the receiving angle of 9 degree, which is associated with L(0,1) mode. As shown in the figure, the single L(0,1) mode dominantly appears and it is observed from the waveform that the mode is very dispersive. In addition, the group velocity of the mode increases with frequency. The time-frequency analysis can help to enhance the accuracy of predicting guided wave mode variation on dispersion curves. Figure 6(a) shows the result of the time-frequency analysis by wavelet transformation of Figure 5(a). As predicted, Figure 5(a) turns out to be L(0,1) mode. The profile of the L(0,1) time-frequency analysis appears broadly on the group velocity dispersion curve over the frequency range of air-coupled transducer, 0.2~2.25 MHz. Figure 5(b) is the waveform of L(0,2) received at 3.7 degree. It was observed that a new mode occurs at 250 μsec and the mode is corresponding to L(0,2) mode from the group velocity dispersion curves. The L(0,1) mode was consistently received when receiving angle was change. Figure 5(c) is the waveform of L(0,1) mode at 20 degree receiving angle. Increasing receiving angle, the mode with faster group velocity disappears and the other mode with slower group velocity becomes dominant. This results in the shrink of the time-frequency analysis image for L(0,1) from Figure 6(a) to Figure 6(c).

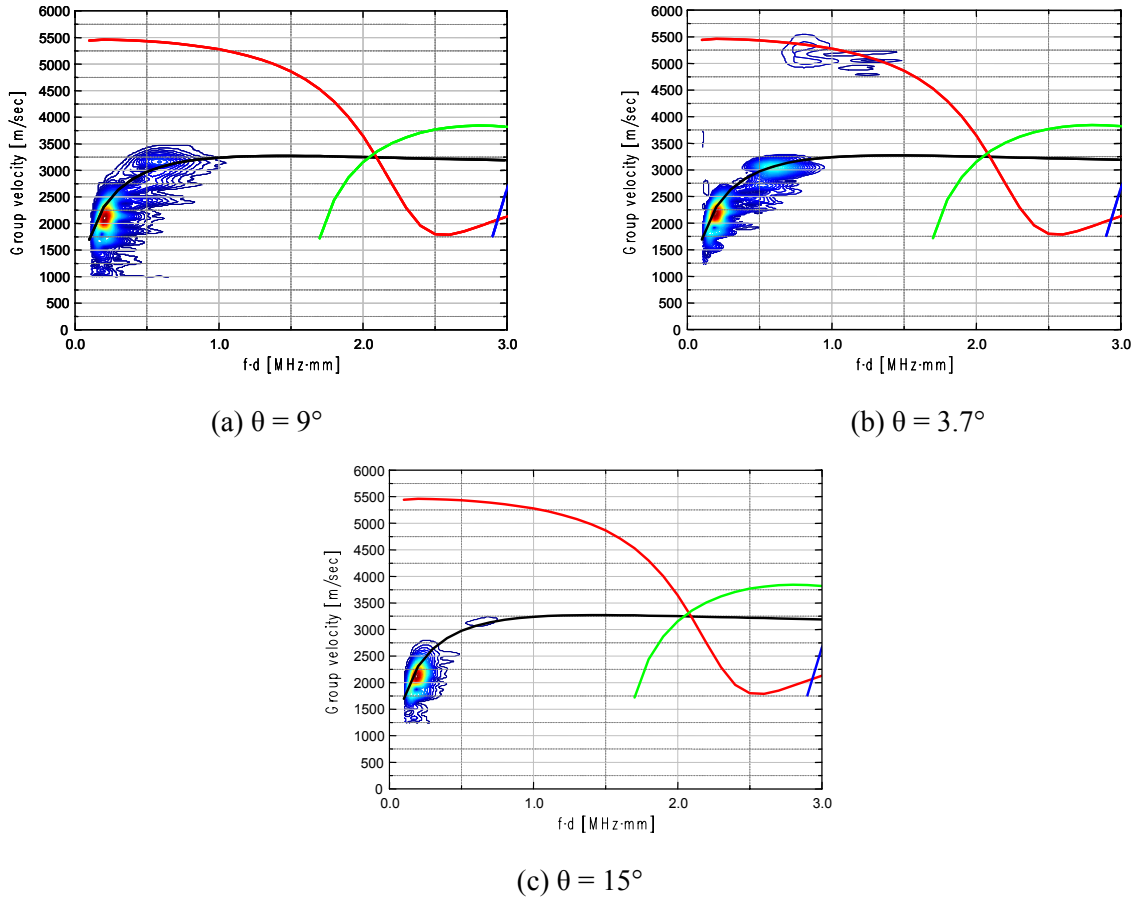


Fig. 6 The Group velocity dispersion curve and time-frequency contour plot by wavelet transform

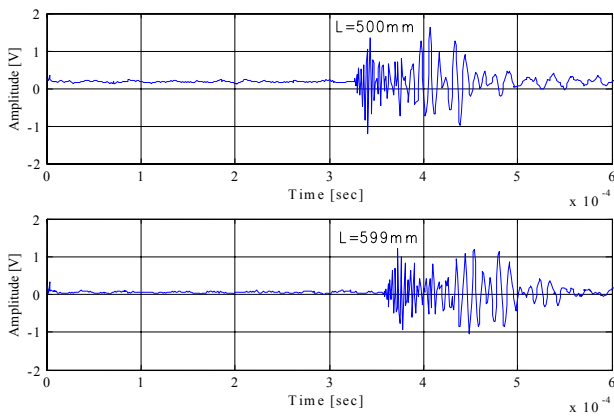


Fig. 7 The waveform at regularly spaced points

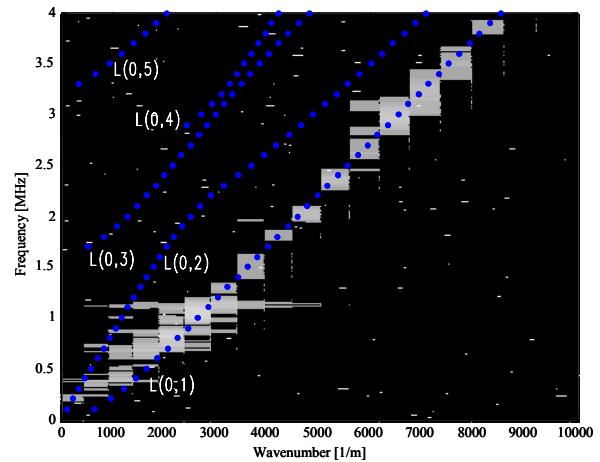


Fig. 8 k-f image by 2D-FFT

Figure 7 represents the guided wave signals collected for 2D-FFT. Figure 7(a) is a schematic diagram showing the scanning process with air-coupled transducer. Figure 7(b) shows the RF waveform at 500 mm and 599 mm propagation distance, respectively. Figure 8 is the comparison of the wave number versus frequency image between theoretical data and 2D-FFT one. Those two data show a good agreement with each other and the waveform of Figure 7(a) is proven to be L(0,1).

Conclusion: The combination of comb transducer with air-coupled one was employed to propose an efficient generation/reception mechanism for guided wave. It was possible to selectively receive a mode generated from the comb transducer by the air-coupled transducer. The results of wavelet transform and 2D-FFT are consistent with theoretical data representing a promising feasibility to identify a guided wave mode in further applications.

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