Dynamic Mode Tuning of Ultrasonic Guided Wave Using an Array Transducer For On-Line Monitoring of Pipes in Nuclear Power Plant

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1. Introduction

Ultrasonic guided waves have been widely used for long range inspections of the thin-walled structures such as plates, rods and pipes, and have a great advantage for the application to the on-line monitoring in nuclear power plant. In guided waves, however, numerous modes can be excited, and different modes of guided waves show different behavior of propagation and interaction with defects. Therefore, selective generation and detection of a specific mode among numerous modes of guided waves become important to an appropriate nondestructive evaluation application of ultrasonic guided waves [1].
Various methods for generation and detection of guided waves have been developed. Angle beam incidence method is the most convenient method to generate and to detect a tuned mode of ultrasonic guided wave [3], however it is hard to align the angle of incidence accurately. The array transducers including comb transducer and interdigital transducer have been used to generate guided waves with the flexible tuning of the wave modes [4]. The modes can be tuned by adjusting either the spacing between the array elements or the frequency of the exciting signals. A linear phased array transducer can facilitate the dynamic tuning of modes without repositioning or realigning the transducer. In the previous works, tuning of guided wave mode has been carried out by *synthetic* method in order to avoid requirement of the bulky ultrasonic instruments [5].

In the present work, tuning mode of ultrasonic guided wave using an array transducer was carried out not by synthetic method but by hardware implementation. The transducers, multi-channel ultrasonic pulser and sequential triggering circuit were developed, and a series of experiments were carried out.

2. Hardware Implementation

In order to tune a specific mode of the guided wave, elements of the array transducer should be individually excited with time delay. Multi-modal and dispersive wave is generated by an element. The adjacent element is exactly excited at the arrival of the desired wave mode, so that the desired wave mode is constructively interfered. Progressive repetition for all elements increases the amplitude of the desired wave mode. The time delay between adjacent elements is determined by the center-to-center spacing between adjacent elements of the array transducer and the phase velocity of the desired wave mode. Only a sequential excitation with variable time delay is required for the dynamic tuning of wave modes

Fig. 1 shows the schematic diagram of the dynamic tuning of guided wave modes. Nine of individual transducers were fabricated using piezoelectric composite. An array transmitter consisted of eight elements and receiver of a single element were employed in a pitch-catch setup. Eight channel ultrasonic pulser were fabricated in order to excite elements of array transducer individually. Each channel was sequentially fired with same time delay. In order to trigger the multi-channel pulser, sequential triggering circuit was developed. An eight bit ting counter to generate a sequential pulses with the time interval as same as the period of clock generated by a function generator, so that the time delay can be accurately controlled.

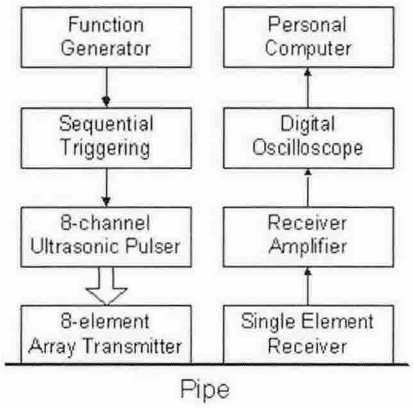

Fig.1 Schematic diagram of the phase tuning system.

3. Results and Discussion

The test pipe was a seamless stainless steel pipe of which outer diameter and thickness were 60.3 mm and 5.54 mm, respectively. A series of experiments were carried out in order to verify the feasibility and performance of the developed technique.
The mode can be selected by the changing the time delay. Mode tuning was occurred for the time delay of 2.08 μs and 4.17 μs. Mode tuning for the receiver was synthetically carried out. In order to simulate a array receiver, a receiver moved by the step as same as spacing of elements in an array transmitter. The detected signals were summed with the time delay as same as that in transmitter. The final tuned signals are shown in Fig. 2.

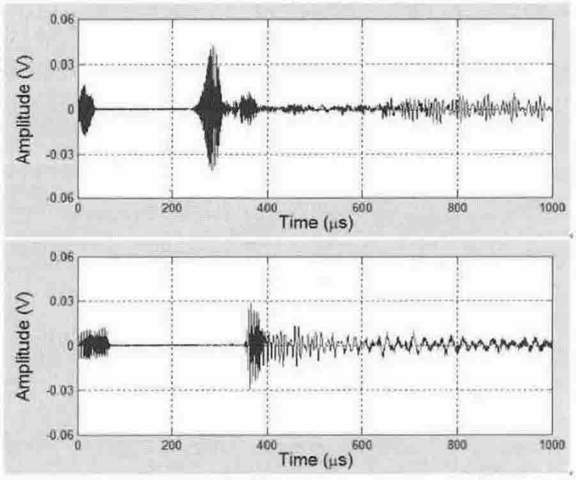

Fig. 2 Tuned waveform for time delay of (a) 2.08 μs and (b) 4.17 μs.

Group velocity measurement is essential to identify the modes of the guided wave. In order to compensate time delay in system, the time of flights were measured as the receiver transducer moved. The group velocities can be determined from the slop of the fitting line in the relationships between time of flight and the distance between transmitter and receiver. Measured group velocities are 4.32 mm/μs and 3.31 mm/μs for the time delay of 2.08 and 4.12 μs, respectively.

Fig. 3 shows detail procedure of the mode analysis used in the present work. Systematic combination of waveform, phase velocity dispersion curves, frequency spectrum, STFT result and group velocity dispersion curves (from top in counterclockwise direction) offers convenient tool for identification of wave mode. A vertical line indicates the phase velocity value, 4.8 mm/μs, determined by the delay time, 2.08 μs, and the horizontal line indicates the peak frequency obtained from the frequency spectrum. The dot at which the vertical and horizontal lines crosses indicates phase tuning conditions, and it is on the phase velocity dispersion curves of L(0,2)~F(m,3). The group velocity was also determined from the dots at which horizontal lines and the group velocity dispersion curves of corresponding modes cross. The group velocities determined by this manner showed a good agreement with the measured group velocity 4.32 mm/μs. Therefore, the mode of the transmitted and received guide wave was identified as L(0,2) or F(m,3). Similarly, the mode of the transmitted and detected guide wave was identified as L(0,1)~F(m,1) for the time delay of 4.17 μs.

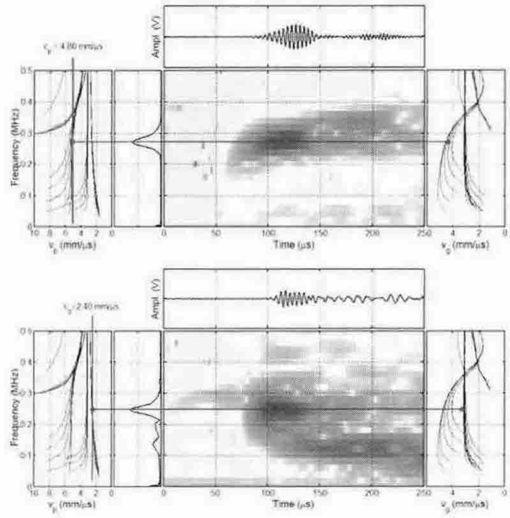

Fig. 3 Tuned waveform for the time delay of (a) 2.08 μs and (b) 4.17 μs.

4. Conclusions

Dynamic mode tuning of ultrasonic guided waves using an array transducer has been demonstrated by hardware implementation. Ultrasonic transducers, multi-channel ultrasonic pulser and sequential triggering circuit was fabricated. Time delay between adjacent elements in an array transducer can be precisely controlled by a function generator. Two distinct modes were generated for different time delay. In order to identify the modes, group velocities were measured by moving receiver transducer. Modes generated by array transducer were figured out as L(0,2)~F(m,3) modes and L(0,1)~F(m,1) modes by measured group velocity and STFT analysis. Pulse-echo setup and array receiver will be implemented in further works.

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