Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 25-26, 2007

Focusing of Ultrasonic Guided Waves by using an Array of Transducers

Heung-Seop Eom,a Jin-Ho Park,a Hak-Joon Kim,b Sung-Jin Song,b
a Advanced Condition Monitoring Lab., Korea Atomic Energy Research Institute, Dukjin-dong 150, Yusong-gu, Daejeon 305-353, Korea, ehs@kaeri.re.kr
b School of Mechanical Engineering, Sungkyunkwan University, Suwon 440-746, Korea

1. Introduction

Pipe inspection by an ultrasonic guided wave is faster and more effective than a conventional ultrasonic inspection which has been widely used for an In-Service Inspection (ISI) of nuclear power plants, because it can detect flaws in a pipe at a long distance without moving the ultrasonic sensors [1,2]. However, when we use the ultrasonic guided wave for a pipe inspection, one of the unsolved problems is its poor signal-to-noise (S/N) ratio. This paper describes one method that can enhance the probability of a detection of flaws in a pipe by using an array of transducers, and the development of an ultrasonic guided wave system that can implement this method.

2. Time reversal Technique

The time reversal technique has been claimed to be a sound method for a phase tuning and/or focusing of guided waves onto a flaw [3]. Currently, two types of time reversal techniques have been proposed: (1) the time reversal mirror (TRM) technique and (2) the D.O.R.T. (French acronym for Decomposition of the Time Reversal Operator) method [4]. These methods are motivated by claims that they provide robust solutions to determine the proper time delays on a flaw for a system using an array of transducers. However, the TRM technique generally requires special hardware including programmable generators, a storage memory in each channel, etc. Contrary to the TRM technique, the D.O.R.T. method does not require programmable generators, and it allows for a simultaneous detection and separation of several defects based on a mathematical analysis of the iterative time reversal process. Thus we adopted D.O.R.T. method for focusing of guided waves by using an array of transducers..

3. Developed Array-type Transducer System

The developed ultrasonic guided wave system is composed of four major components: (1) a 8-channel ultrasonic pulser and receiver to excite and receive the ultrasonic signals, (2) a program for a calculation of the time delays by the D.O.R.T method, (3) a non-linear time delay controller to drive the pulser with the proper time delays obtained by the time reversal program, and (4) an array of transducers consisting of 4 elements of a piezoelectric crystal.

Figure 1 shows a schematic diagram of the developed ultrasonic guided wave system. First, the time reversal program calculates the proper time delays. Proper time delays are necessary to focus ultrasonic guided waves onto target flaws, and they can be determined from the fired inter-element signals. Then a non-linear time delay controller controls the time delay of each channel in the multi-channel ultrasonic pulser and receiver.

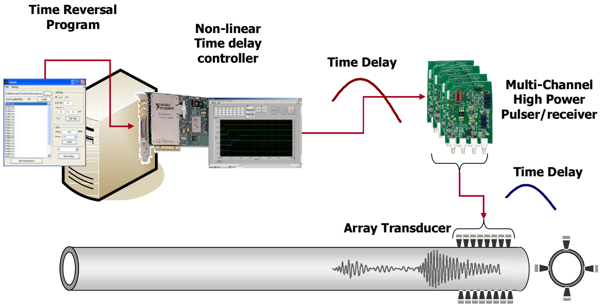


Figure 1. Schematic diagram of the ultrasonic guided wave system

3.1 Multi-channel Ultrasonic Pulse/receiver and Array of Transducers

Figure 2 shows a fabricated pulser/receiver module and an array of transducers. Each pulser module can generate a 300 voltage spike-pulse with a width of 30 ns. In the receiver side, the range of the low-path filter is 300 kHz to 5 MHz and the range of the high-path filter is 5 MHz to 30 MHz. The gain of the pulser/receiver is 80 dB with a 1 dB step. Each pulser/receive module is activated by an external trigger signal which is provided by a time delay controller

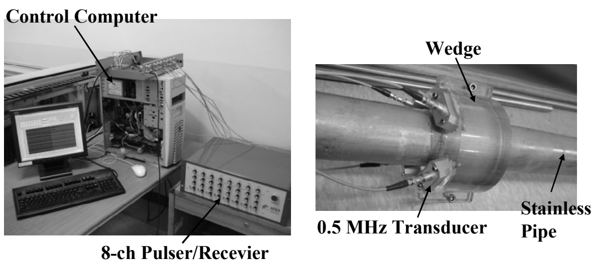
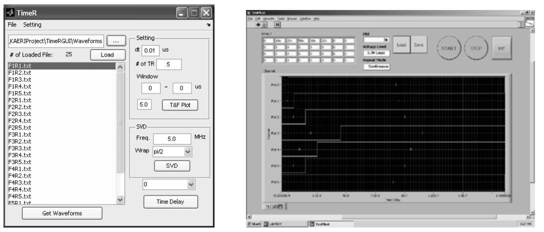


Figure 2. 8-channel pulser/receiver (left) and an array of transducers (right)

3.2 Time Delay Controller and Control Programs

The developed time delay controller consists of one triggering board that can generate an arbitrary type of time delays and two programs: a time reversal program to calculate the time delays from the fired inter-element signals and a control program to control the triggering board with a 10 ns accuracy as shown in Figure 3 (a) and (b), respectively.



(a) (b)

Figure 3. (a) time reversal program and (b) time delay control program

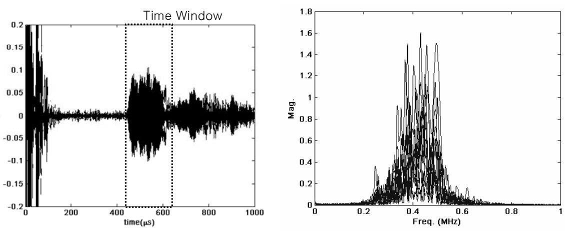
4. Experiments

4.1 Experimental Setup

The stainless steel pipe used in this experiment has a through-wall hole with 4 mm of diameter, located at 1.2 m from the center of the transducer. The total length, outer diameter and thickness of the stainless steel pipe are 6 m, 60.5 mm and 5.4 mm respectively. The array of ultrasonic transducers is composed of four rectangular transducers mounted at the end of the pipe. The size and center frequency of each rectangular transducer were 12.5 mm × 25.4 mm and 0.5 MHz respectively. The array of transducers was mounted on a ring-type wedge with a 70° incline angle for a tight coupling onto the curved surface of the pipe and an efficient generation of ultrasonic guided waves.

4.2 Focusing the Ultrasonic Guided Waves

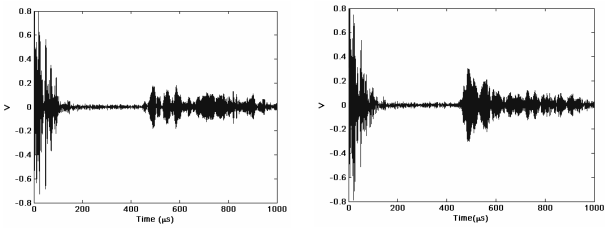
An experiment of focusing ultrasonic guided waves onto a through-wall hole was carried out with an array of transducers and the time delays obtained from the D.O.R.T method. To determine a proper time delay by the D.O.R.T method for the given experimental setup, a time reversal operator is needed. Thus, inter-element responses from the through-wall hole are acquired by the array of transducers circumferentially mounted onto the pipe. A time window was placed as shown in Figure 4 (a) to isolate these signals from the initial signals. In addition, Figure 4 (b) shows the frequency spectrums of the windowed inter-element signals.



(a) (b)

Figure 4. (a) inter-element fired signals scattered from the through-wall hole and (b) its frequency spectrum

Using the calculated time delays, we re-generated the ultrasonic guided waves without changing the experimental setup for focusing them onto the through-wall hole. Figure 5 shows the ultrasonic guided waves reflected from the through-wall without and with time delays respectively. As shown in Figure 5 the amplitude of the first group of received signals with a time delay is greater than the amplitude of that without a time delay.



(a) (b)

Figure 5. Guided waves reflected from the through-wall hole: (a) without time delay and (b) with time delay calculated by the D.O.R.T method

5. Summary

For a long range inspection of pipes in nuclear power plants, we have developed an ultrasonic guided wave system using an array of transducers including a multi-channel pulser/receiver, a non-linear time delay controller and a program that can use the D.O.R.T method. Using the developed system, a focusing of ultrasonic guided waves onto a through-wall hole in a stainless steel pipe was performed to investigate the performance of the developed system and the D.O.R.T method. From the experiments, the amplitude of received ultrasonic guided waves with a time delay was approximately 70% bigger than the one without a time delay. And the D.O.R.T method proved its usefulness in focusing ultrasonic guided waves generated by an array of transducers onto a flaw in a pipe.

Acknowledgements

This work has been supported by the Ministry of commerce, Industry and Energy.

REFERENCES

[1] P. Cawley, (2003), "Predictical Long Range Guided wave inspection – Managing Complexity", in Review of Progress in Quantitative NDE, eds. D. O .Thompson and D. E. Chimenti, AIP, New York, pp. 22-37

[2] J. L. Rose (1999), Ultrasonic Waves in Solid Media, Cambridge University Press, Cambridge, UK

[3] M. Fink, (1992), Time reversal of ultrasonic field-Part I: Basic principles, IEEE Trans. Ultrason. Ferroelectr. Freq. Control, Vol. 39, pp. 555-566

[4] C. Parada, J. Thomas and M. Fink (1995), "the iterative time reversal process: Analysis of the convergence", Journal of Acoust. Soc. Am., Vol. 97, pp. 62-71