An Experiment on Long-Range Ultrasonic Guided Wave Inspection of Pipes for On-Line Monitoring in NPP

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1. Introduction

On-line monitoring (OLM) approach for the structural integrity of the components can detect flaws in the early stage and collect useful information on the flaws during the operation of a Nuclear Power Plant (NPP), so that an ISI could be efficiently performed based on the information obtained by the OLM. On the other hand, the extended refueling interval of the next generation NPPs raises new maintenance challenges. The inspection and maintenance regulations imposed on the current plants have been developed based on the current refueling schedule, which is typically 1 to 1.5 years. Therefore, to take advantage of the next generation NPP's extended refueling interval, new approaches are required to keep the maintenance from interrupting the operation. From this point of view, a promising method is to replace the current outage-based inspections with an on-line inspection and monitoring, to ensure the maintenance of the current level of safe operation [1].

The final object of our research is to develop a practical and effective on-line inspection and monitoring system using the ultrasonic guided waves. The ultrasonic guided waves has been known as one of promising techniques that could be utilized for on-line monitoring, because it enables us to do long-range inspection of the structures such as plates and pipes [2]. In the present work, we developed a high-power ultrasonic guided wave inspection system, and carried out a series of experiments with the developed system to detect flaws at a distance of about 20M from the sensors.

2. Development of a high-power, ultrasonic guided wave inspection system

The developed system is composed of a) 32-channel ultrasonic pulser to excite ultrasonic signals, b) 8-channel receiver to capture the reflected ultrasonic signals c) a function generator and a ring counter circuit to drive the pulser with proper time delays, and d) an array transducer consist of 40 elements of piezoelectric composite.

Generation of a specific mode is the key technique in the inspection using the ultrasonic guided wave [3]. In order to tune a specific mode of the ultrasonic 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.

The transmitter part of the array transducer is composed of 32 elements of piezoelectric composite and the receiver part of the array transducer is composed of 8 elements of piezoelectric composite. A 32-channel pulser module was fabricated in order to excite the elements of the array transducer individually. Each channel can be sequentially fired with same time delay. In order to trigger the multi-channel pulser a sequential triggering circuit was developed. Fig. 1 is 32-channel pulser, 8-channel receiver, and the sequential triggering circuit. Fig.2 is the array transducer consists of 40 elements of piezoelectric composite.

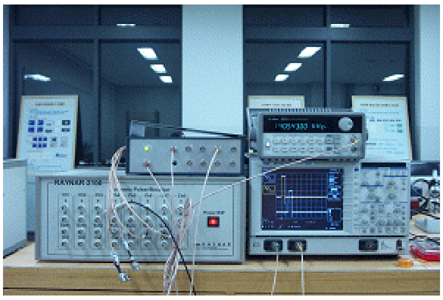

Figure 1. 32-channel pulser, 8-channel receiver and sequential triggering unit

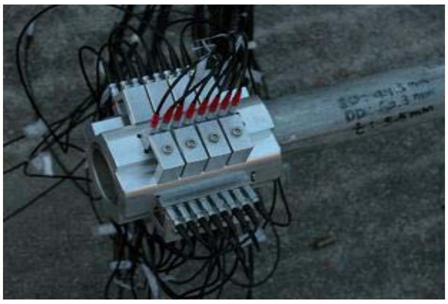

Figure 2. An array transducer

3. Results and discussion

The test pipe (Fig. 3) was a seamless stainless steel pipe of which outer diameter, thickness, and length were 60.3 mm, 5.54 mm, and 26M, respectively. Its material is SUS 304 and SCH-80. It has four welds and two artificial flaws. In Fig. 3 WP1, WP2, WP3, and WP4 are welds. S1 and S2 are flaws. A series of experiments were carried out in order to verify the feasibility of long-range inspection with the developed system and our flaw detection method.

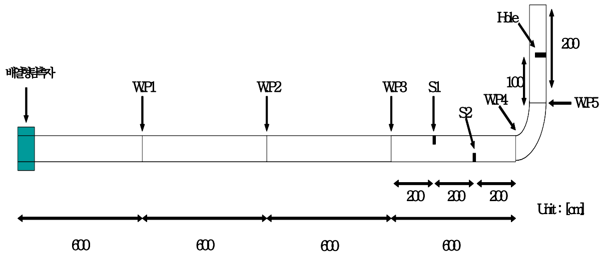

Figure 3. 26 M stainless steel test pipe, its welds and flaws

As shown in Fig. 2, the array transducer of 40 elements was attached at the end of the test pipe. Synthetic phase tuning method was used to generate the pertinent mode of ultrasonic guided waves by delaying the time of triggering the adjacent element. 32 elements were used as a transmitter and 8 transducers were used as a receiver. 8 signals from the receiver were post-processed by low-pass and high-pass filtering. Then the 8 signals were summed after the consideration of time delay as same as that in transmitter. The final processed signals are shown in Fig. 4.

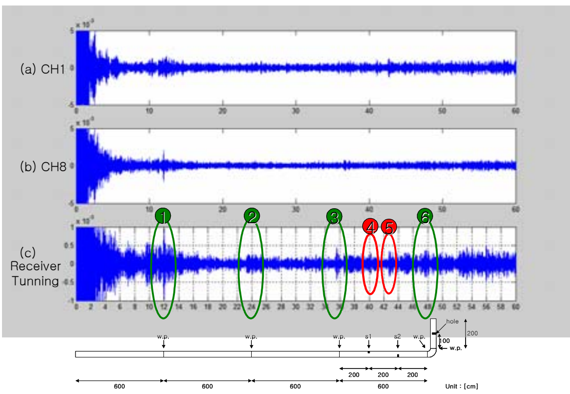

Figure 4. Signals captured by pulse-echo method

Fig. 4 (a) is a filtered signal received at the channel #1 and Fig. 4 (b) is a filtered signal received at the channel #2. As shown in Fig. 4 (a) and (b) it is hard to find the sign of flaws in the signals. Then Fig. 4 (c) is filtered, compensated (time delay), and summated (8 channels) signal. The oval-marked ①, ②, ③, and ⑥ in Fig. 4 (c) are the signals of the welds (WP1…WP4 in Fig. 3) and ④ and ⑤ are the signals of the flaws (S1 and S2 in Fig. 3).

4. Conclusions

On-line monitoring approach for the structural integrity of the important components such as the pipes in NPPs is an emerging technology to complement ISI in the current operating NPPs and to solve the maintenance challenges in the next generation NPPs. To meet such a situation we developed a prototype high-power ultrasonic guided wave inspection system and experimentally investigated the feasibility of the ultrasonic guided wave in long-range inspection of a pipe for on-line monitoring in NPPs. The results of the experiments showed the possibility of the developed system and our method. Also it showed the need of additional research on the quantification of the flaws.

Acknowledgements

This research was supported by "The Mod– and Long Term Nuclear R&D Program" of Ministry of Science and Technology, Korea.

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