ABSTRACT

The reactor containment vessel of a pressurized water reactor (PWR) plant is an important structure. The lower part of the containment vessel embedded in concrete, however, cannot be accessed for visual inspection. If it is determined in the future that corrosion can occur in such an inaccessible area, then an inspection technique that can locate such defects and assess their severity will be needed. To inspect the reactor containment vessel plate embedded in concrete, a technique that can detect defects in a component from an accessible location at a distance of 20m or more is needed. We therefore chose a method that uses a transducer with piezoelectric elements, and developed a shear horizontal (SH) wave transducer with a large, low-frequency active element composed of three parallel-connected active elements with a refractive angle of 90 degrees. Combining three active elements made possible an active element transducer of large width, which could not be made with a single element. This transducer was capable of clearly detecting echoes from 19mm depth and 9.5mm depth hollows at a distance of about 1.5m.

To improve the capability of propagation over longer distances, we constructed a multi-element transducer with a multi-channel pulsar / receiver (P/R) and synthesis of received signals with each element.

Through synthesis of signals received from a five-element transducer excited by 5ch P/R individually, we could obtain an echo signal 3.9–4.6dB higher in amplitude, and thus evaluated the feasibility of use of the multi-element transducer with multi channel P/R and synthesis of echo signals.

INTRODUCTION

The reactor containment vessel of a pressurized water reactor (PWR) plant is an important structure that contains the reactor, cooling system, and other components, and functions to prevent the external release of fission products in the event of an accident. The integrity of the containment vessel as a pressure-retaining boundary is confirmed by the leak rate test on each periodic inspection. Visual inspection of the containment vessel must be performed for accessible surface areas [1]. The lower part of the containment vessel embedded in concrete, however, cannot be accessed for visual inspection. If it is determined in the future that corrosion can occur in such an inaccessible area, then an inspection technique that can locate such defects and assess their severity will be needed.

To inspect the reactor containment vessel plate embedded in concrete, a technique that can detect defects in a component from an accessible location at a distance of 20m or more is needed. We therefore chose a method that uses a transducer with piezoelectric elements, the most popular devices in practical use for ultrasonic testing, and developed a shear horizontal (SH) wave transducer with a large, low-frequency active element composed of three parallel-connected active elements with a refractive angle of 90 degrees for effective detection of surface thinning by corrosion and for minimization of dispersion of ultrasonic waves from steel plates to concrete [2, 3]. Combining three active elements made possible an active element transducer of large width, which could not be made with a single element. This transducer was capable of clearly detecting echoes from 19mm depth and 9.5mm depth hollows at a distance of about 1.5m as well as echoes from a 9mm diameter stud bolt at various distances between about 0.7 and 1.7m on the surface of a concrete-covered carbon steel plate. Furthermore, the capability of propagation of SH waves over a distance of about 12m with the newly made large transducer has been estimated by detecting multiple echoes between the front and back sidewalls of the concrete-covered steel plate 2m in length.

To improve the capability of propagation over longer distances, we constructed a multi-element transducer with a multi-channel pulsar / receiver (P/R).
TEST ASSEMBLY

Mock-up test assembly

Figure 1 shows the mock-up test assembly used for the experiment. Simulating the containment vessel plate, the carbon steel plate was 38mm in thickness, 2000mm in length and 1000mm in width. Two artificial hollows were made on its surface to simulate thinning by corrosion; one was 200mm in diameter and 19mm depth at the thinnest point (about 1/2 of the plate thickness), while the other was 100mm in diameter and 9.5mm depth at the thinnest point (about 1/4 of the plate thickness). As shown in Figure 1, the hollows were located at a distance of about 400mm along the longer side from one end. The steel plate was covered with a layer of concrete 200mm thick on both surfaces to simulate embedding in concrete; two edges on opposite sides were left uncovered to support the mounting of the transducers. Each artificial hollow was placed with a gap from the concrete, to simulate a gap that would appear in the case of natural thinning by corrosion. The surface of the hollow was made irregular rather than smooth. The steel plate embedded in concrete also had concrete fixing stud bolts (8mm in diameter) welded onto the surface.

Transducers were installed on both ends of the plate left uncovered, across the longer side, and the incidence of ultrasonic waves was measured.

Test equipment

To be able to detect surface corrosion of a concrete embedded steel plate remotely from a long distance, the ultrasonic transducer must have the following capabilities:

1. ability to detect reflected sources on surfaces such as hollows produced by corrosion;
2. ability to propagate ultrasonic waves over a long distance; and
3. little dispersion of ultrasonic waves into the concrete in contact with the steel plate.

Based on these requirements, we used SH waves, which are shear waves with direction of oscillation parallel to the surface of the test assembly. We chose a refractive angle of 90 degrees to allow waves to propagate close to the surface of the test assembly. We assumed that a sharp ultrasonic beam with concentrated ultrasonic wave energy would be effective for propagation of ultrasonic waves over a long distance. We therefore elected to use a larger active element. However, since the maximum width of an element for SH waves that could be manufactured was 40mm in the direction of oscillation, we used several 40mm wide active elements in parallel. Considering the need to excite the active elements simultaneously and ease of handling of the transducer, we used three active elements. Specifically, we arranged three 40mm depth x 40mm wide active elements in a row, each facing the direction of incidence. These were contained in a single housing to compose a single transducer unit with a total active element size of 40mm depth x 120mm width. Three elements are connected to a detector with single P/R and excited at the same time. Figure 2 shows the large three-active-element transducer.
Figure 1 - A mock-up for the experiments, (a) The plate covered with concrete, (b) details of artificial hollows

Figure 2 - Views of the SH transducer developed with three elements, (a) Top view, (b) bottom view

Figure 3 - Five separated transducers assembled in a frame

Figure 4 - Configuration of test assembly
To improve the capability of propagation over longer distances we attempted to use a larger element transducer. However, it is difficult to maintain acoustic contact to permit transmission of ultrasonic energy between the transducer and the surface of the work piece, as an SH transducer requires a highly viscous couplant. Furthermore, some of the trial transducers with three elements were found to be inferior to the exciting of two elements in receiving ultrasonic waves. It appeared that differences in the properties and geometric arrangement of each active element caused differences in phases and directions among waves transmitted from elements.

To deal with these problems, we have adopted five active elements and separated them into five transducers. Each transducer was connected to a 5ch. P/R individually. Figure 3 shows five separated transducers assembled in a frame for fixation to the surface of the mock-up.

Furthermore, the echo signals received by the five separated transducers were digitized and synthesized on PC. Figure 4 shows the configuration of the test assembly. Each transducer is connected to an individual P/R. The 5ch P/R can control the time of excitement of each transducer individually. We can control the time of reception for each signal individually and synthesize signals on a notebook computer connected to the 5ch P/R.

**Test Procedure**

We installed the transducer at a position not covered with concrete on a side far from the hollows in the concrete-embedded mock-up shown in figure 1. With the incidence of ultrasonic waves parallel to the longer side of the steel plate, we examined echoes from the small hollows at a distance of about 1.5m and the back side wall of the steel plate at a distance of about 1.9m.

**SYNTHESIS OF RECEIVED WAVES WITH A MULTI-ELEMENT TRANSDUCER**

Figure 5 shows the principle of synthesis of waves received with three-element transducer. Figure 5 (a) shows that the paths from each element to the reflector differ. The paths from No.1 and No.2 to the reflector are different, and the path from No.3 is also different from the others due to misalignment. Echo signals, simulated by sine waves, are shown as examples in figure 5 (b). Echo signals received by the three-element transducer with single pulser/receiver were summed without accounting for time delay. The purple curve in figure 5 (c) shows the summed signal. Synthesis of the received signals, performed by adjusting the time period to account for the delay in the signal reception, yields a higher amplitude signal, as indicated by the red curve in figure 5 (c).

**TEST RESULTS AND DISCUSSION**

Figure 6 shows the results for the backside wall of the plate embedded in concrete. The transducers were installed at a position not covered with concrete on a side far from the hollows of the concrete-embedded mock-up shown in figure 6 (a). The distance from each transducer to the backside wall is
the same. Figure 6 (b) shows wave signals from each transducer. The signals summed without adjusting for time delay are shown in figure 6 (c). Receiving time on each element differ slightly from each other, despite each being at equal distance to the backside wall. By synthesis accounting for time delay, as shown in figure 6 (d), we obtained a signal that is about 4.6dB higher than (c). The time delay was -200 ~ 800ns in comparison to the No.3 transducer.

It is impossible to eliminate the difference in path length among elements by arrangement of the transducer. However, with synthesis of received signals by accounting for time delay, we can eliminate the differences in time among received signals and obtain a synthesized signal of higher amplitude.

Figure 6 - Waves signals from the backside wall of the plate, (a) installation of transducers, (b) signals received by each transducer, (c) sum without accounting for time delay, (d) synthesis accounting for time delay.

Figure 7 shows the result for the small hollow on the plate embedded in concrete. We obtained a signal that is about 3.9dB higher than the signal obtained though summing alone, without adjusting for time delay. The time delay was 200~1400ns. However, as shown in figure 7(b), the signals received by No.1 and No.5, which are set on the two sides of the array of transducers, did not perform well. Perpendicular lines to these transducers were far from the small hollow. It appeared that these transducers could not receive the echo from the small hollow, and that it is possible to improve reception of higher signal by installation of these transducers, which face the reflector.
CONCLUSION

Through synthesis of signals received from a five-element transducer excited by 5ch P/R individually, we could obtain an echo signal 3.9–4.6dB higher in amplitude, and thus evaluated the feasibility of use of the multi-element transducer with multi channel P/R and synthesis of echo signals.

REFERENCES