Dual Ultrasonic Waveguide Sensor for the Detection of Surface Defects

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1. Introduction

In a sodium-cooled fast reactor (SFR), a conventional visual inspection can not be used for observing the in-vessel structures under a sodium level because liquid sodium is opaque to light. An ultrasonic inspection technique can be applied for observation of the in-vessel structures in a SFR [1, 2]. Recently an ultrasonic waveguide sensor has been developed for the under-sodium visual inspection of in-vessel structures of SFR [3, 4]. The ultrasonic waveguide sensor is to have an ultrasonic transducer over the reactor head and a transmission of the ultrasonic waves using some specific waveguides still in the hot sodium. In the previous feasibility test, the C-scanning performance of single waveguide sensor was successfully demonstrated [5]. But the waveguide sensor has a limitation of the detection of micro surface defects of less than 0.8 mm width. Further research and development of ultrasonic waveguide sensor technology are required to detect a micro surface defect with a higher precision. In this study, a new approach of dual waveguide sensor is suggested for a detection application of micro surface defects.

2. Dual Ultrasonic Waveguide Sensor

Dual waveguide sensor was developed for a detection of micro surface defects on the structure for the application to an under-sodium inspection of the in-vessel structures of SFR. Dual waveguide sensor consists of two thin strip plates (transmitting and receiving waveguides), wedges and ultrasonic sensors (transmitter and receiver). Figure 1 shows a schematic design of the dual waveguide sensor module. Variable angle liquid wedge is applied to produce A_0 mode Lamb wave in a low frequency range. To prevent an energy loss taking place due to a liquid contact, the waveguide strip plate is enclosed within an acoustical shielding tube. A_0 Lamb wave is generated in a transmitting plate by an excitation from the transmitter transducer where the compression wave is impinging at an angle within the wedge. The A_0 Lamb wave generated at the top of the transmitting plate propagates downwards towards the radiating surface side contacting a liquid. The transmitting wave creates a longitudinal wave within the liquid by a mode conversion. The longitudinal ultrasonic beam resulting from the mode conversion is emitted at an angle α to the waveguide normal, given as:

$$Sin\ \alpha = \frac{V_L}{C_p} \tag{1}$$

where V_L is the longitudinal wave velocity in a liquid and C_p is the phase velocity of the A_0 Lamb wave. Rayleigh wave (surface wave) can be generated on the surface by the longitudinal ultrasonic beam from the liquid side at the incident angle β, given as

$$Sin\ \beta = \frac{V_L}{C_R} \tag{2}$$

where C_R is the phase velocity of the Rayleigh wave.

For the generation of a Rayleigh wave, the angle of the radiating surface side of transmitting waveguide plate can be calculated by the equation $\gamma = 90 - \alpha - \beta$. Radiated longitudinal ultrasonic beam is geometrically reflected from the object in water. And the trailing leaky field is produced by the leaky Rayleigh wave that propagates along a surface. Leaky waves are received via the face of the receiving waveguide sensor plate surface by the reciprocal mode-conversion process. The surface crack causes a decrease in the amplitude of the received signal. C-scan image can be obtained by scanning the dual waveguide sensor.

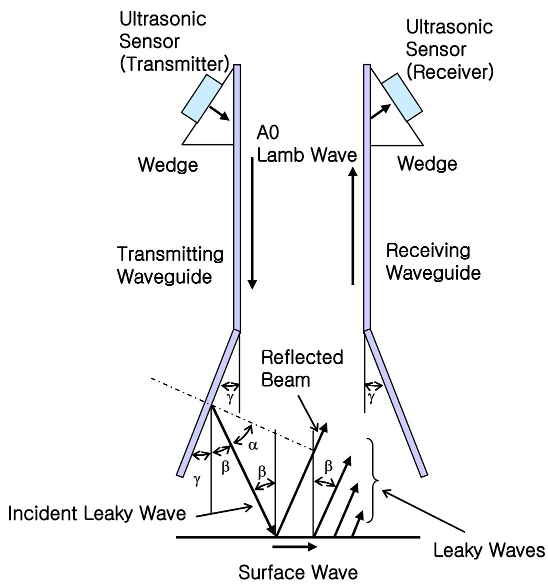


Figure 1. Schematic design of dual waveguide sensor

3. Experimental Verification

An experimental facility was set up to verify the detection ability of surface defects by the dual waveguide sensor, as shown in Fig. 2. It consists of a 2-axis scanner, a high power ultrasonic system (RITEC RAM-10000), a computer, a Lecroy oscilloscope and a dual waveguide sensor module. High power pulse generation is necessary to send the ultrasonic signal to the end plate of the waveguide sensor. The transducers use a commercial PZT sensor (0.5 inch diameter and 1 MHz). The Winspect^{TM} software was used for the C-scan imaging.

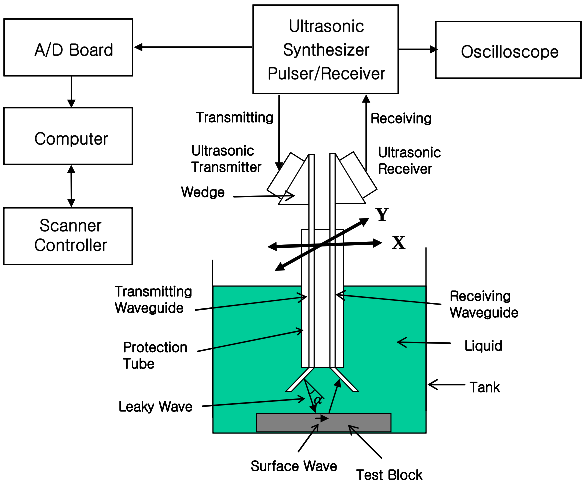
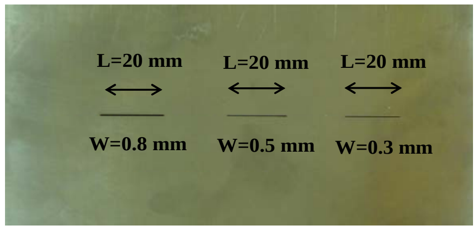


Figure 2. Experimental setup

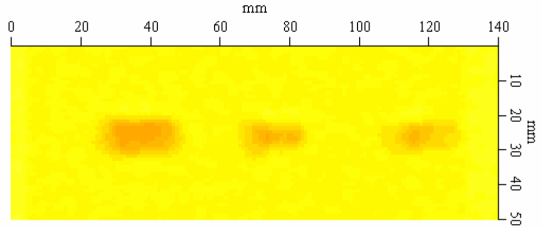
The possibility for the detection of micro surface cracks using a dual waveguide sensor is evaluated by a C-scan imaging test with a test target with surface defects. A single waveguide sensor module and a dual waveguide sensor module were prepared for a comparison of the detection performance of the surface cracks. The transmitting waveguide sensor generates the Rayleigh surface wave on the surface of the structures and the receiving waveguide sensor receives the leaky wave from the surface by the pitch and catch technique. The surface defects can be detected by the amplitude measurement of the leaky surface wave. The test target was a rectangular plate with three slits of different widths (0.8 mm, 0.5 mm and 0.3 mm). The surface defects were manufactured by EDM (electro discharge machining). Figure 3 shows the C-scanning test results of both the single and double waveguide sensors. In the C-scanning image by a single waveguide sensor, the surface cracks were partially identified. But in the C-scanning image by a double waveguide sensor, the surface cracks were clearly resolved in the image. It was verified that a spatial precision ability of the surface crack detection of double waveguide sensor was less than 0.3 mm.

4. Conclusion

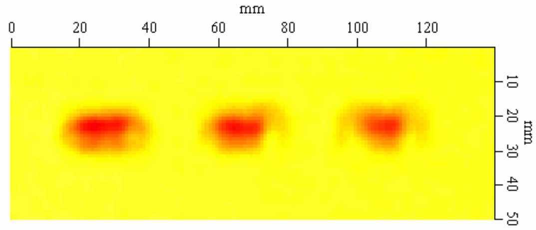
A dual ultrasonic waveguide sensor has been developed for the detection of micro surface defects in an under-sodium visualization of the in-vessel structures of a sodium-cooled fast reactor. The possibility of the dual ultrasonic waveguide sensor for the detection of surface defects has been verified by C-scanning experiments in water. It was confirmed that the surface defects could be visualized clearly with less than a 0.3 mm precision. This new technique to detect micro surface flaws by using dual ultrasonic waveguide sensor is suggested for an improvement of the detection capability of surface defects on structures.



(a) Test target with surface defects



(b) C-Scan image by single waveguide sensor



(c) C-scan image by dual waveguide sensor

Figure 3. Visualization image of test target using single and dual waveguide sensor

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