Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

Application of a Waveguide Sensor for a Volumetric Inspection of SFR Reactor Internals

Sa-Hoe Lim, Young-Sang Joo, Jae-Han Lee
Korea Atomic Energy Research Institute, P.O.Box 105, Yuseong, Daejeon, Korea, 305-353, sahoe@kaeri.re.kr

1. Introduction

In a sodium-cooled fast reactor (SFR), an in-service inspection (ISI) is necessary to examine the integrity of its safety related structures. ASME Section XI Division 3 provides rules and guidelines for an in-service inspection of the components of a SFR [1]. For the ISI of reactor internals, a visual examination and continuous monitoring are adopted for the major inspection techniques. For the dissimilar metal welds and the high stress components such as a reactor support structure, a volumetric examination using an ultrasonic test should be applied. As liquid sodium is opaque to the light, a conventional visual examination can not be used under a sodium condition. An under-sodium viewing (USV) technique using an ultrasonic wave should be applied for the visual examination of the reactor internals [2-4]. Recently a new plate-type waveguide sensor has been developed for USV applications. An under-sodium visualization of an ultrasonic waveguide sensor was successfully demonstrated in previous research works [5]. In this study, the possibility of a volumetric examination by using a waveguide sensor is confirmed. The comparison tests between the waveguide sensor and the commercial immersion ultrasonic sensor are carried out.

2. Ultrasonic Waveguide Sensor and Leaky Wave

Ultrasonic waveguide sensor consists of an ultrasonic sensor, a wedge and a thin strip plate, as shown Figure 1. The wedge is clamped to the top of the waveguide. The A_0 Lamb wave is generated in a plate by an excitation from the transducer where the compression wave is impinging at an angle within the wedge. Lamb wave generated at the top of the plate propagates toward the radiating surface side contacting a liquid. If the end of a waveguide sensor is in contact with a liquid, the Lamb waves become leaky Lamb waves because the energy of the Lamb wave leaks from the solid plate to the liquid in the longitudinal wave by a mode conversion.

The radiation beam resulting from the mode conversion is emitted at an angle θ to the waveguide normal, given as:

$$\theta = \sin^{-1}\left(\frac{V_L}{C_p}\right) \tag{1}$$

where V_L is the longitudinal wave velocity in a liquid and C_p is the phase velocity of the Lamb wave. In the dispersive region of the A_0 mode, the phase velocity depends on fd which is the products of the frequency and the thickness of the plate. In this region, a fine frequency tuning of the excitation pulse causes a change to the phase velocity. The beam radiation angle θ of a leaky wave can be changed by the phase velocity of the A_0 mode in accordance with Eq. (1) [5]. Reflection ultrasonic waves are received via the face of the impinging plate surface by the reciprocal mode-conversion process.

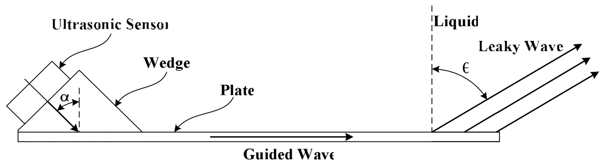


Figure 1. Generation of the guided wave and propagation of the leaky wave

3. Experimental Setup and Comparison Test

The comparison test of the waveguide sensor for the volumetric ultrasonic inspection was carried out as shown in Figure 2.

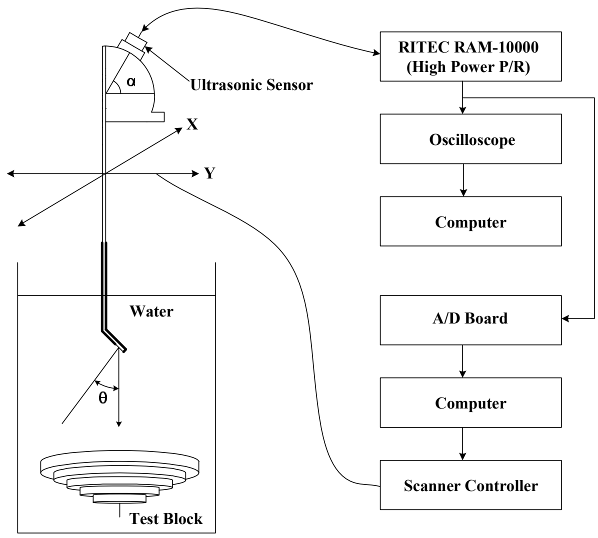
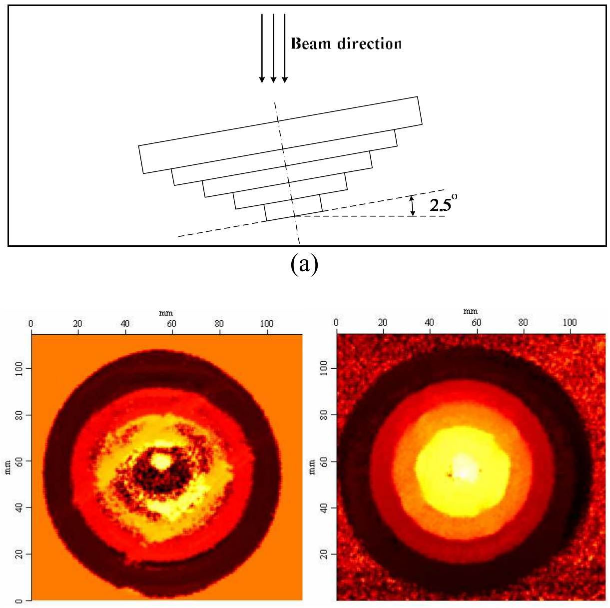


Figure 2. Experimental setup for the volumetric inspection by using waveguide sensor

Experimental system is composed of a high power pulser/receiver, a 3-axis scanner, an oscilloscope and a waveguide sensor assembly. The pulser/receiver has a frequency tunable function and can be applied for the verification experiment of the beam steering technique of the waveguide sensor. A computer connected with pulser/receiver controls the frequency, amplitude and number of cycles of the tone burst pulse. The transducers use a commercial PZT sensor whose center frequency is 1MHz. The ultrasonic transducer is driven by tone burst pulse. The stainless plate (thickness: 1mm) was used for guiding the wave and submerged region of the plate was shielded except the radiation area. A stepped round cylinder block made of acrylic materials was used. The Winspect^{TM} software was used for a control of the scanner and the C-scan imaging.



(a) (b) (c)

Figure 3. (a) Geometry of the test block. (b) C-scan image with the immersion sensor whose center frequency is 5 MHz. (c) C-scan image with waveguide sensor whose beam radiation angle is tuned.

As shown in Figure 3 (a), the test block is tilted to 2.5° and the beam direction is from top to bottom.
Figure 3 (b) shows the C-scan image using the immersion sensor whose center frequency is 5 MHz. Because the direction of reflection waves swerved from the perpendicular, the C-scan image is slightly distorted. While on the other, the C-scam image using the waveguide sensor is clear remarkably. The assembly was primarily set to radiate toward the vertical direction with 1 MHz and the beam radiation angle is tuned by just adjusting (0.85 MHz) the frequency of the incident signal.

4. Conclusion

For an under-sodium visualization of a SFR, a new plate-type waveguide sensor assembly has been developed. This waveguide sensor assembly can be used for a volumetric inspection of reactor internals. Comparison experiments have been performed to confirm the application possibility of the waveguide sensor. Volumetric ultrasonic tests for a stepped round block by the immersion sensor and waveguide sensor were carried out. The inspection resolution of the waveguide sensor is equivalent to that of the commercial immersion sensor. For the tilted block, the volumetric C-scan image of the immersion sensor was not clear but that of the waveguide sensor was clear by using the radiation beam steering technique.

ACKNOWLEDGEMENT

This study was supported by the Korean Ministry of Education, Science & Technology (MEST) through its National Nuclear Technology Program.

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