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Experimental Verification of Ranging Inspection Technique for Sodium-cooled Fast Reactor using Horizontal Beam Waveguide Sensor

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1. Introduction

For the periodic safety assurance of a Sodium-cooled Fast Reactor (SFR), the In-Service Inspection (ISI) of an SFR should be applied according to the ASME code rules and guidelines [1]. During the refueling process in an SFR, the activity of clearance assurance between the reactor core and the Upper Internal Structure (UIS) should be performed for the safe operation of rotating plug on the reactor head. As the liquid sodium coolant of an SFR is not transparent to the light, however, conventional visual examination methods cannot be used for the inspection of reactor core and in-vessel structures under a sodium level. The ultrasonic inspection technique is a unique method to inspect the in-vessel structures and to check the clearance between the reactor core and the UIS. Recently under-sodium viewing and ranging techniques using the ultrasonic waveguide sensors have been proposed for the inspection of the reactor core and internal components in the SFR [2~5].

In this work, a 10 m long horizontal beam waveguide sensor was developed for the detection of obstacles between the reactor core and the UIS. To demonstrate the performance of the developed horizontal beam waveguide sensor, several under-water experiments were carried out using a reduced UIS and reactor core mockup.

2. Waveguide Sensor for Ranging Inspection

For ranging inspection, the ultrasonic wave should propagate and detect obstacles between the reactor core and the UIS. Therefore, the sensor must radiate the horizontal ultrasonic wave into the gap between the reactor core and the UIS. To this end, a 10 m long plate-type horizontal beam waveguide sensor, as shown in Fig. 1, has been developed. It consists of a 10 m long stainless steel strip (SS304), a solid wedge, an ultrasonic transducer and an SS304 shielding tube. The width and thickness of the strip are 19 mm and 1.5 mm, respectively. The thin shielding tube with 24.5 mm in diameter and 1 mm in thickness is employed to prevent energy leakage into a surrounding liquid during wave propagation along the strip.

To radiate an ultrasonic wave horizontally, the angle (β) of the radiation end section of the sensor should be carefully determined. This angle can be calculated using Snell's law which indicates the radiation angle (θ) of the wave into a surrounding liquid from the strip as

$$\theta\left(fd\right) = \sin^{-1}\left(\frac{V_L}{c_p\left(fd\right)}\right) \quad (1)$$

where V_L is the longitudinal wave velocity in a surrounding liquid, c_p is the phase velocity of the A_0-mode Lamb wave in the strip with the thickness of d at a given frequency f. Using equation (1), the angle of the radiation end section was determined to be β = 37° to radiate the ultrasonic wave horizontally.

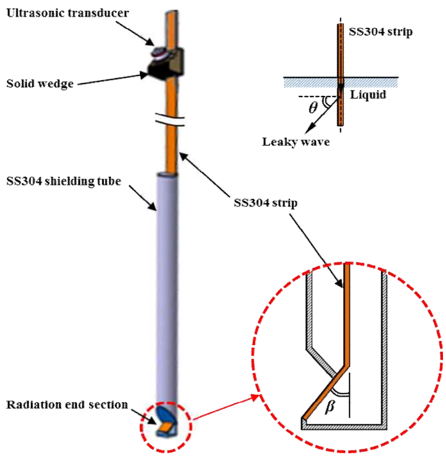
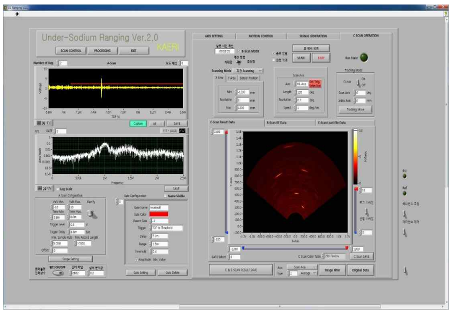


Fig. 1. The horizontal beam waveguide sensor.

3. Experimental Verification

For the experimental verification of the ranging inspection performance of the developed horizontal beam waveguide sensor, a reduced mockup simulating the gap (50 mm) between the bottom of the UIS and the top of the reactor core was manufactured. Figure 2(a) shows the reduced UIS and reactor core mockup installed in a large water bath. In the reduced mockup, 9 Control Rod Drive Mechanism (CRDM) drivelines with real sizes (outer diameter = 50 mm) and shapes are placed at real locations. And the inspection software called under-sodium ranging Ver. 2.0 (see Fig. 2(b)) was newly developed to control the rotation of the waveguide sensor and to analyze the inspection results.

(a)



(b)

Fig. 2. (a) Reduced UIS and reactor core mockup. (b) Under-sodium ranging Ver. 2.0.

Since the CRDM drivelines are main possible obstacles that can disturb the rotation of the rotating plug, ranging inspection tests were conducted for several cases in accordance with the insertion/ withdrawal of CRDM drivelines into/from the reactor core.

For the test, first, the developed horizontal beam waveguide sensor was installed at a specific position as shown in Fig. 3. The distances of CRDM drivelines from the sensor are listed in Table 1; the farthest distance between the CRDM driveline and the sensor is over 1.5 m. And the maximum and minimum angles of CRDM drivelines to the center of the sensor were 28° and -28°, respectively. The sensor was then self-rotated from -60° to +60° to fully cover all CRDM drivelines with an interval of 0.2°. During the self-rotation of the sensor, the ultrasonic wave centered at 1 MHz was radiated horizontally from the radiation end section and reflected waves from obstacles were measured for each angle. Finally, the measured signals were analyzed by the inspection software.

Figure 4 shows one of ranging inspection test results conducted for the case of 5 CRDM drivelines (#1, #2, #5, #7 and #9) insertions. The resulting image was obtained using amplitudes of all measured signals between -60° and +60°. From the results, one can see that 5 CRDM drivelines are well identified including the farthest one located over 1.5 m. Although it is not shown here, other test results conducted for several cases of insertion/withdrawal of CRDM drivelines also showed the good detectability for obstacles.

Table 1. Distances of CRDM drivelines from the sensor

Driveline No.	#1, #3	#2	#4~#7	#8, #9
Distance (mm)	615	787	1160	1520

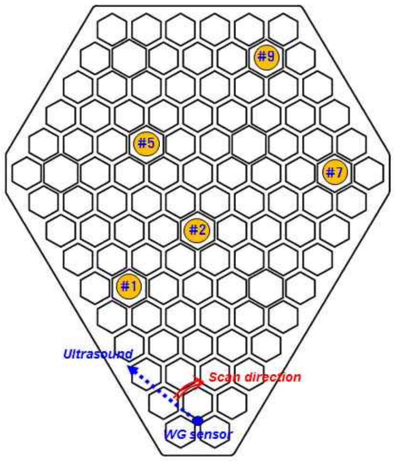


Fig. 3. Positions of the sensor and inserted CRDM drivelines.

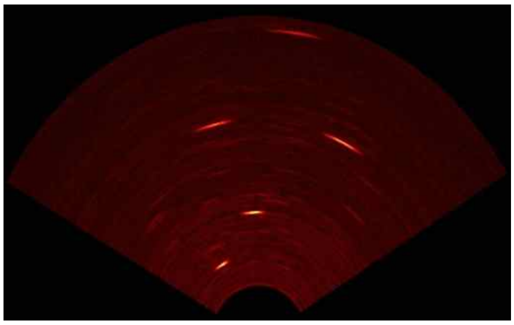


Fig. 4. Ranging inspection test results.

4. Conclusions

The 10 m long horizontal beam waveguide sensor has been designed and fabricated for the ranging inspection in the SFR. The performance of the developed horizontal beam waveguide sensor was experimentally investigated in water for real-sized CRDM drivelines which might be main obstacles in the gap between the bottom of the UIS and the top of the reactor core. The test results showed that all CRDM drivelines including the farthest one located over 1.5 m away from the sensor were well identified by the proposed ranging inspection technique using the developed horizontal beam waveguide sensor.

Acknowledgement

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