Development and Applicability Demonstration of a Remote Inspection Module for Inspection of Reactor Internals in an SFR

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1. Introduction

Since liquid sodium is optically opaque, the ultrasonic inspection technique has been mainly employed for inspection of reactor internals in a Sodium-cooled Fast Reactor (SFR). Until now, two types of ultrasonic sensors have been mainly developed; immersion and waveguide sensors. An immersion sensor can provide a high-resolution image, but it may have problems in terms of reliability and life time because the sensor is exposed to high temperature during inspection [1-3]. On the other hand, a waveguide sensor can maintain its performance during long-term inspection in high temperature because it installs an ultrasonic transducer in a cold region even though such a high-frequency ultrasonic wave cannot be used owing to the long propagation distance [4-6]. In this work, a remote inspection module employing four 10 m long waveguide sensors was newly developed and several performance tests were carried out in water to demonstrate the applicability of the developed remote inspection module to inspection of reactor internals in an SFR.

2. Remote Inspection Module

The developed remote inspection module consists of four 10 m long plate-type waveguide sensors, an upper driving device and a lower guiding structure as shown in Fig. 1. For multiple inspection applications, three types of waveguide sensors were employed; a horizontal beam waveguide sensor for ranging inspection, two vertical beam waveguide sensors for viewing inspection and a 45° angle beam waveguide sensor for identification inspection. In the upper driving device, six step motors and encoders were installed to control movements of waveguide sensors individually and simultaneously. And the lower guiding structure which supports four waveguide sensors can decrease the inspection error by making them straight without any unnecessary movements during inspection. By double rotation and self-rotation of waveguide sensors, the developed remote inspection module can perform ranging, viewing and identification inspections.

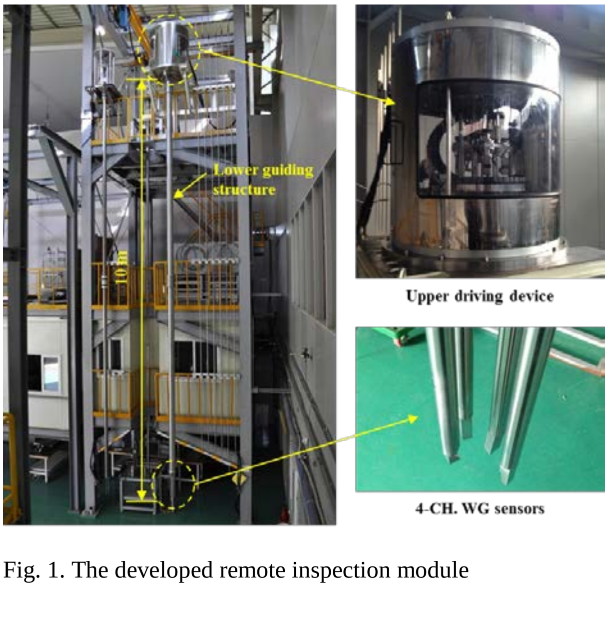


Fig. 1. The developed remote inspection module

3. Demonstration Tests and Results

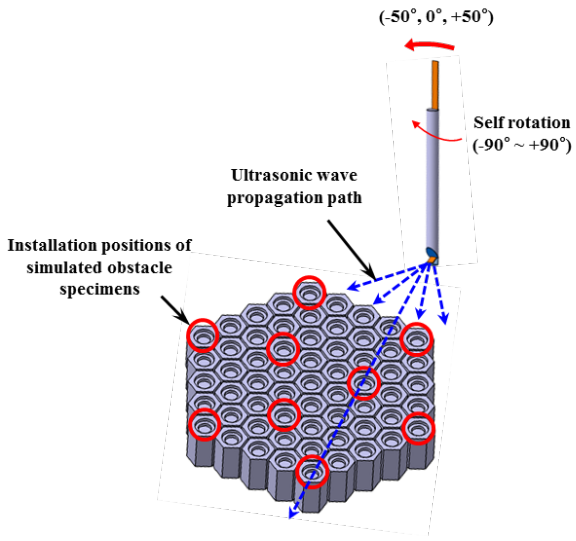
To demonstrate the applicability of the developed remote inspection module to inspection of reactor internals in an SFR, several performance tests were carried out in water for simulated nuclear fuel assembly specimens.

3.1 Ranging Inspection

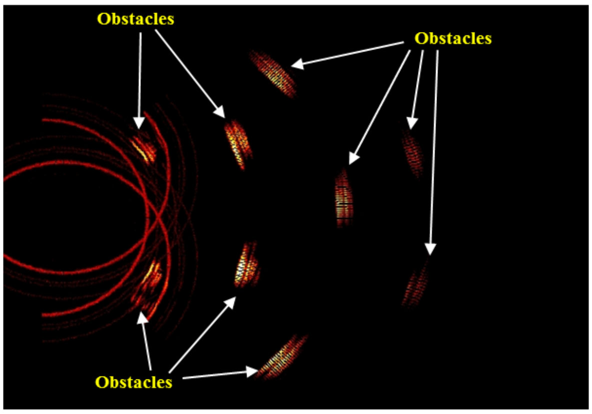
The ranging inspection monitors whether any obstacles exist between the upper internal structure and the reactor core. In the ranging inspection, a horizontal beam waveguide sensor is first moved at the pre-determined position and then the inspection is performed using the self-rotation of the sensor.

Fig. 2(a) shows an experimental setup for the ranging inspection. The inspection was carried out for nine simulated obstacle specimens placed at the marked positions in Fig. 2(a) over the simulated reactor core by rotating the sensor from -90° to +90° with an interval of 0.5°. The ultrasonic wave centered at 1 MHz was radiated horizontally and the reflected wave was measured for each angle. Since more than two obstacles can exist on the same ultrasonic wave propagation path as shown in Fig. 2(a), the same inspections were conducted at different three positions (-50°, 0°, +50°) to find all nine obstacles.

Fig. 2(b) shows the ranging inspection results. Three inspection results obtained at different three positions were all combined. From the results, one can see that the nine simulated obstacle specimens are well identified by the developed remote inspection module.



(a)



(b)

Fig. 2. (a) Experimental setup for ranging inspection. (b) Experimental results of ranging inspection.

3.2 Viewing Inspection

The viewing inspection is used to obtain images of the reactor core. In the developed remote inspection module, two vertical beam waveguide sensors were employed for viewing inspection, which provides a more rapid inspection.

Fig. 3 shows the experimental setup for viewing inspection. The inspection was performed at 1MHz for seven simulated nuclear fuel assembly specimens using double rotations of two vertical beam waveguide sensors, which are rotated by small and large rotating plugs. For the inspection, the large rotating plug is first rotated at 0.5°, and the small rotating plug is rotated 100° in one direction (clockwise direction) with an interval of 0.5°. Then, the large rotating plug is rotated 0.5° again in the same direction, and at this time the small rotating plug is rotated 100° in the other direction (counterclockwise direction). This rotation process is repeated until the large rotating plug is rotated 360°.

The resulting image of the viewing inspection is also shown in Fig. 3. From the result, it can be seen that the

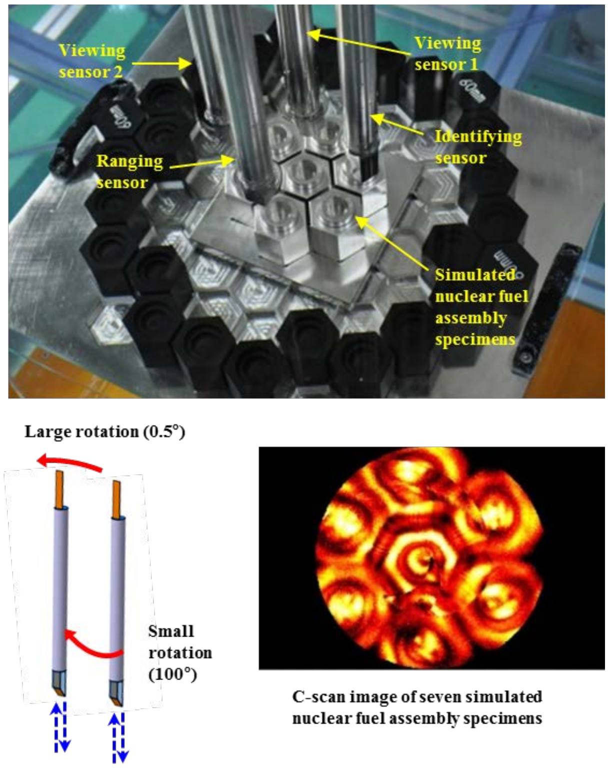


Fig. 3. Experimental setup and resulting image of viewing inspection.

seven simulated nuclear fuel assembly specimens are well identified by the developed remote inspection module.

3.3 Identification Inspection

Since the loose part is usually small, the identification of its shape is quite difficult using only the viewing inspection. Therefore, the identification inspection may be additionally required to identify the shape of any loose parts that may exist inside the reactor, such as pins or nuts.

The experimental setup for identification inspection is shown in Fig. 4(a). When any loose part is detected by the viewing inspection, the identification inspection is performed by rotating the 45° angle beam waveguide sensor 360° around the detected loose part. The rotation of the sensor is conducted by rotating the large rotating plug with an interval of 0.5°. At each angle, the ultrasonic wave centered at 1 MHz is radiated at 45° and the reflected wave from the loose part is measured. In this identification inspection, a hexagon nut (M12), a square block (13 mm × 13 mm × 7 mm), a pin (length = 13 mm, Ø6 mm), and a washer (thickness = 2.3 mm, ID = 10.5 mm, OD = 17.5 mm) were used as possible loose parts.

Figs. 4(b)-(e) show the radiation patterns of the reflected waves from loose parts. From the results, one can see that six large signals for the hexagon nut, four large signals for the square block, and two large signals for the pin were measured, respectively. This is because the reflected wave is the largest at the surface perpendicular to the ultrasonic wave propagation path. In the case of the washer, unlike the other cases, almost the same amplitudes of signals were measured because the washer has a circular shape, which means that all surfaces are perpendicular to the ultrasonic wave propagation path.

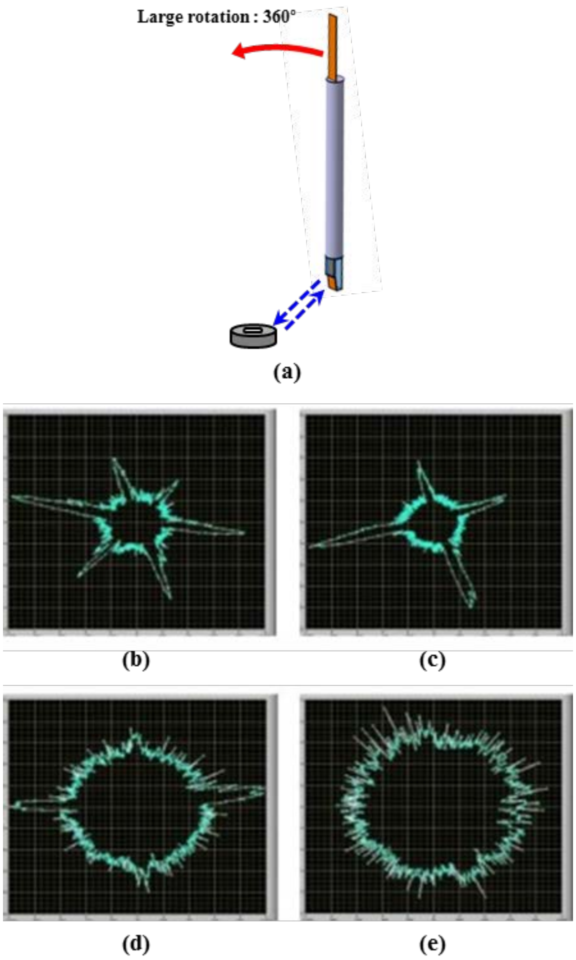


Fig. 4. (a) Experimental setup for identification inspection. Radiation patterns of reflected waves from (b) hexagon nut, (c) square block, (d) pin and (e) washer.

4. Conclusions

In this work, a remote inspection module for inspection of reactor internals in an SFR was newly developed. The developed remote inspection module employs four 10 m long waveguide sensors for multiple inspection applications: a horizontal beam waveguide sensor for ranging inspection, two vertical beam waveguide sensors for viewing inspection and a 45° angle beam waveguide sensor for identification inspection. Several performance tests such as ranging, viewing and identification inspections were carried out for simulated nuclear fuel assembly specimens in water, and the applicability of the developed remote inspection module to inspection of reactor internals in an SFR was demonstrated.

Acknowledgement

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REFERENCES

[1] K. Swaminathan, A. Rajendran, G. Elumalai, The development and Deployment of an Ultrasonic Under-Sodium Viewing System in the Fast Breeder Test Reactor, IEEE Transaction on Nuclear Science, Vol. 37, No. 5, pp. 1571-1577, 1990.

[2] H. Karasawa, M. Izumi, T. Suzuki, S. Nagai, M. Tamura, S. Fujimori, Development of Under-Sodium Three-dimensional Visual Inspection Technique Using Matrix-arrayed Ultrasonic Transducer, Journal of Nuclear Science and Technology, Vol. 37, No. 9, pp.769-779, 2000.

[3] K. Swaminathan, C. Asokane, J.I. Sylvia, P. Kalyanasundaram, P. Swaminathan, An Ultrasonic Scanning Technique for In-Situ ‘Bowing’ Measurement of Prototype Fast Breeder Reactor Fuel Sub-Assembly, IEEE Transactions on Nuclear Science, Vol. 59, No. 1, pp. 174-181, 2012.

[4] Y.S. Joo, C.G. Park, J.H. Lee, J.B. Kim and S.H. Lim, Development of ultrasonic waveguide sensor for under-sodium inspection in a sodium-cooled fast reactor, NDT&E International, Vol. 44, No. 2, pp. 239-246, 2011.

[5] K. Wang, H. Chien, T.W. Elmer, W.P. Lawrence, D.M. Engel, S. Sheen, Development of ultrasonic waveguide techniques for under-sodium viewing, NDT&E International, Vol. 49, pp. 71-76, 2012.

[6] Y.S. Joo, J.H. Bae, J.B. Kim and J.Y Kim, Effects of beryllium coating layer on performance of the ultrasonic waveguide sensor, Ultrasonics, Vol. 53, No. 2, pp. 387-395, 2013.