Feasibility Test of a Waveguide Sensor for Ranging Inspection in a Sodium-cooled Fast Reactor

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1. Introduction

The Sodium-cooled Fast Reactor (SFR) can effectively reduce radioactive wastes by the recycling process of spent fuels generated from pressurized water reactors. In the refueling process of an SFR, the assurance of clearance between the reactor core and the Upper Internal Structure (UIS) is very important because the rotating plug on the reactor head should be rotated to load new fuels as well as to unload spent fuels. However, the assurance of clearance between the reactor core and the UIS is very difficult because liquid sodium is optically opaque. One possible solution to check the clearance is the use of the ultrasonic wave technique [1-3]. Since the ultrasonic wave can propagate through opaque sodium, obstacles between the reactor core and the UIS can be detected. In this work, a 10 m long horizontal beam waveguide sensor [4, 5] was developed and its feasibility for ranging inspection in an SFR is studied through several under-water experiments.

2. Horizontal Beam Waveguide Sensor

For ranging inspection, the ultrasonic wave should propagate and detect obstacles between the reactor core and the UIS. Therefore, the sensor must radiate the ultrasonic wave horizontal to 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 15 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

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

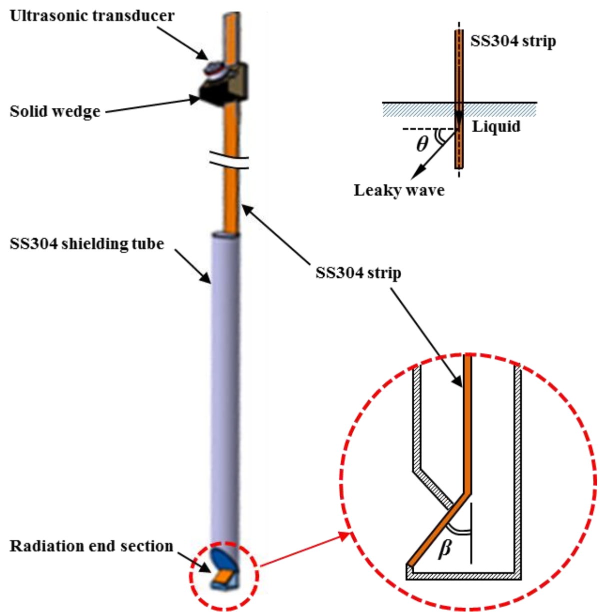
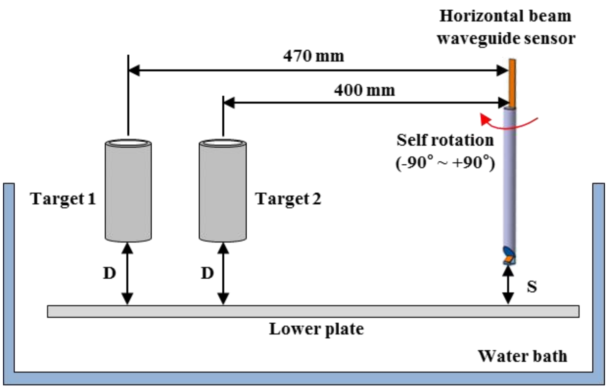


Fig. 1. The horizontal beam waveguide sensor.

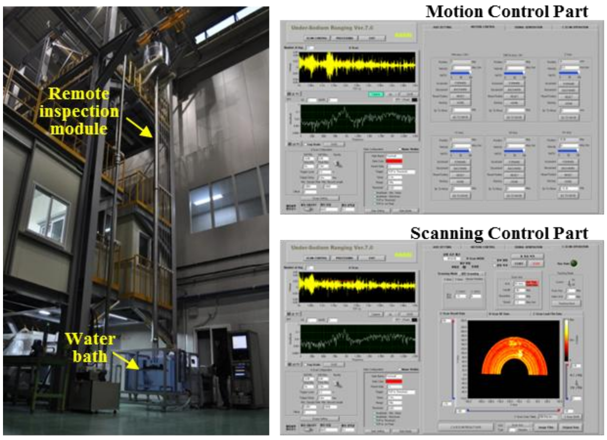
Here, V_L is the longitudinal wave velocity in a surrounding liquid and c_p is the phase velocity in the strip with the thickness of d at a given excitation frequency of f. Since the phase velocity in a 1.5 mm thick SS304 strip at 1 MHz is c_p = 2351 m/s and the longitudinal wave velocity in water is V_L = 1480 m/s, the radiation angle is calculated as θ = 39° from Eq. (1). Therefore, the angle of the radiation end section can be determined as β = 39° to radiate the ultrasonic wave horizontally.

3. Feasibility Tests and Results

Fig. 2(a) shows the experimental setup for ranging inspection. Two stainless steel hollow cylinder targets which simulate sub-structures of the UIS were installed in a large water bath. Distances of targets from the sensor were 400 mm and 470 mm and angles of targets to the center of the sensor were 17.62° and -3°, respectively. And a 15 mm thick lower plate (SS304) was placed under the targets and the sensor to simulate the reactor core. The diameter, thickness and length of the cylinder target are 50 mm, 1 mm and 400 mm, respectively. In the ranging inspection, the distance (D)



(a)



(b)

Fig. 2. (a) Experimental setup for ranging inspection. (b) Remote inspection module and under sodium ranging program Ver. 7.0.

between targets and the lower plate was varied from 50 mm to 5 mm with a decrement of 5 mm, and the distance (S) between the horizontal beam waveguide sensor and the lower plate was increased with an increment of 5 mm from 5 mm to 25 mm for each D. The sensor was then self-rotated from -90° to +90° with an interval of 0.5° at each S. The ultrasonic wave centered at 1 MHz was radiated horizontally and the reflected wave was measured for each angle. To control the 10 m long waveguide sensor and obtain inspection results, the remote inspection module and the control/analysis program called under sodium ranging program Ver. 7.0 as shown in Fig. 2(b) were used [6].

Fig. 3 shows the inspection results obtained for S = 5 mm. Resulting images were obtained using amplitudes of measured signals at all angles. From the results, one can see that there are no target images when the distance D is larger than 25 mm; two targets are well identified under D = 25 mm although only one target is indicated at D = 25 mm due to low amplitudes of reflected signals. The inspection results obtained for S = 15 mm are also shown in Fig. 4. In this case, targets are detected when the distance D is less than 35 mm. From these results,

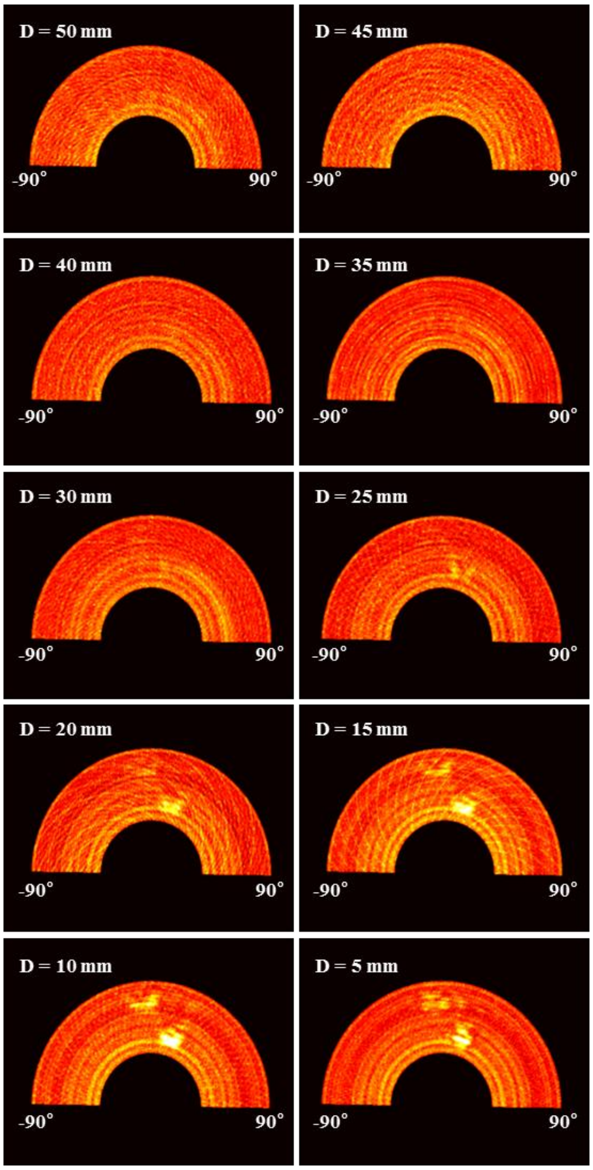


Fig. 3. Experimental results for S = 5 mm.

one can conclude that targets are well identified if the vertical distance between the sensor and the target is less than 20 mm; although it is not shown here, other results for S (S = 10 mm, 20mm and 25 mm) also showed similar aspects. Therefore, one can say that it is possible to apply the developed 10 m long horizontal beam waveguide sensor for ranging inspection in an SFR although the inspection range should be improved.

4. Conclusions

In this work, the feasibility of the 10 m long horizontal beam waveguide sensor for ranging inspection was experimentally studied in water. Two hollow cylinder targets were inspected using the remote inspection module and the under sodium ranging program. Through several feasibility tests, it was shown that the clearance can be assured if the vertical distance between the sensor and the target is larger than 20 mm.

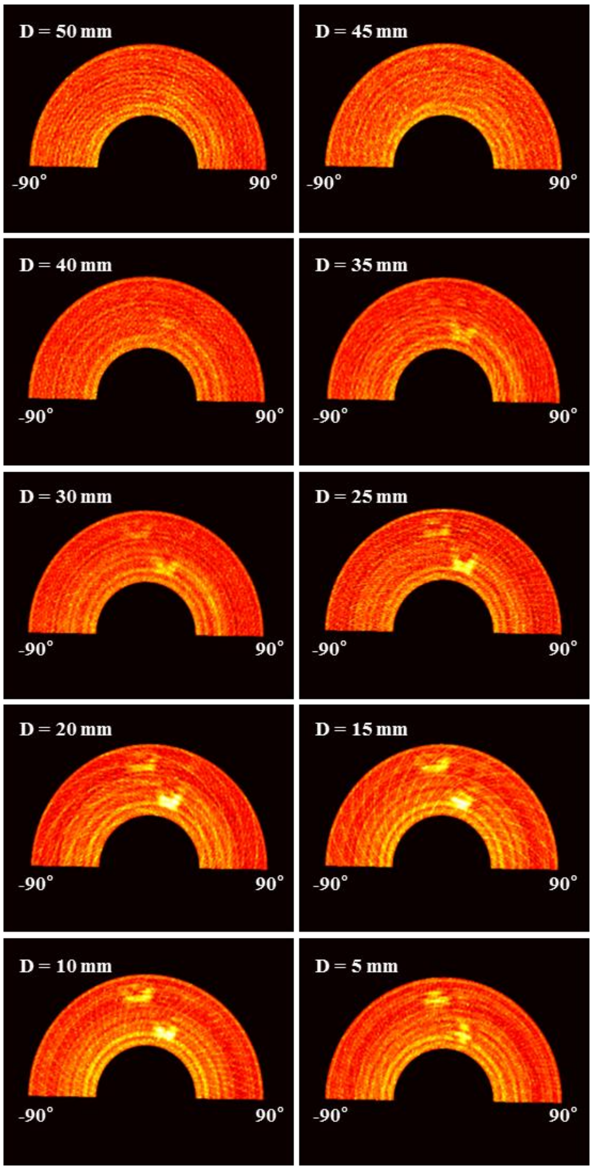


Fig. 4. Experimental results for S = 15 mm.

But for real applications, further studies are required to improve the inspection range over 400 mm.

Acknowledgement

This study was supported by the National Research Foundation (NRF: No. 2012M2A8A2025636) grant funded by the Korea government (Ministry of Science, ICT and Future Planning).

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