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C-Scan Performance Test of Under-Sodium Ultrasonic Waveguide Sensor in Sodium

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1. Introduction

Reactor core and in-vessel structures of a sodium-cooled fast reactor (SFR) are submerged in opaque liquid sodium in the reactor vessel. The ultrasonic inspection techniques should be applied for observing the in-vessel structures under hot liquid sodium. Ultrasonic sensors such as immersion sensors and rod-type waveguide sensors have developed in order to apply under-sodium viewing of the in-vessel structures of SFR [1, 2]. Recently the novel plate-type ultrasonic waveguide sensor has been developed for the versatile application of under-sodium viewing in SFR [3]. In previous studies, the ultrasonic waveguide sensor module was designed and manufactured, and the feasibility study of the ultrasonic waveguide sensor was performed [4, 5]. To improve the performance of the ultrasonic waveguide sensor in the under-sodium application, a new concept of ultrasonic waveguide sensors with a Be coated SS304 plate is suggested for the effective generation of a leaky wave in liquid sodium and the non-dispersive propagation of A_0-mode Lamb wave in an ultrasonic waveguide sensor [6].

In this study, the C-scan performance of the under-sodium ultrasonic waveguide sensor in sodium has been investigated by the experimental test in sodium. The under-sodium ultrasonic waveguide sensor and the sodium test facility with a glove box system and a sodium tank are designed and manufactured to carry out the performance test of under-sodium ultrasonic waveguide sensor in sodium environment condition.

2. Under-Sodium Ultrasonic Waveguide Sensor

For the performance enhancement of the ultrasonic waveguide sensor in a sodium environment, the waveguide sensor formed of an SS304 stainless steel plate provided with beryllium (Be) coating layers is suggested. The beryllium (Be) is a material, in which the ultrasonic velocity is fastest among materials that exist in nature. The longitudinal wave velocities of the beryllium (Be) are 12.89 m/ms. The longitudinal wave velocity of the beryllium (Be) is twice as fast as the longitudinal velocity (5.79 m/ms) of an SS304 stainless steel plate. Accordingly, when the waveguides are formed of an SS304 stainless steel plate (1.5 mm thickness) with the coating layers made of the beryllium (Be), the phase and group velocities of the A_0-mode Lamb wave propagated through the waveguides are remarkably increased as compared with those of the A_0-mode Lamb wave propagated through the SS304 waveguide plate provided with no coating layer. The ultrasonic beam of a leaky longitudinal wave could be radiated through the radiation face of the waveguide sensor in liquid sodium. Also, the phase velocity of the A_0-mode Lamb wave necessarily has a large change in magnitude so that the change range of the radiation beam angle of the leaky longitudinal wave should be increased in the liquid sodium. Accordingly, the radiation beam steering function of the ultrasonic waveguide sensor could be normally operated. Particularly, the waveguides provided with the beryllium coating layers have a characteristic in which the group velocity of the A_0-mode Lamb wave is very constant in the frequency range from 0.8 MHz to 1.7 MHz, thereby reducing the waveform distortion due to the dispersion reduction.

3. Setup of Sodium Test Facility

The sodium test facility with a glove box system and a sodium tank has been designed and constructed to carry out the performance test of ultrasonic waveguide sensor in sodium environment condition. Figure 1 shows the sodium test facility. The sodium test facility consists of a glove box with an anti-chamber, a sodium test tank with a volume of 30 liters, a sodium drain tank with a volume of around 70 liters, an electric resistance heater, a heater control unit, an Ar circulation and cooling system, a XYZ scanning system and an ultrasonic waveguide sensor.

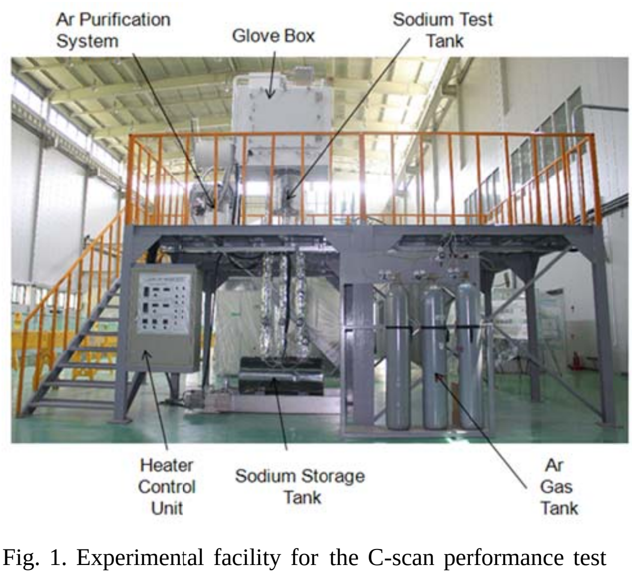
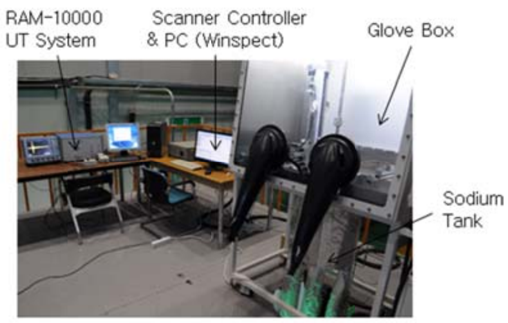


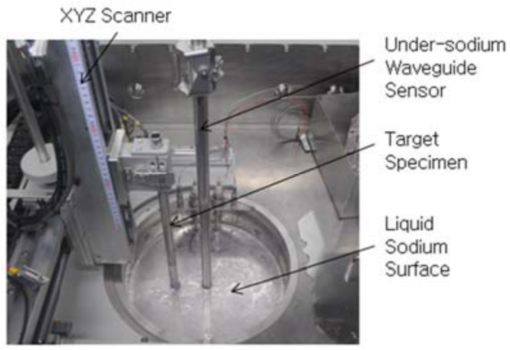
Fig. 1. Experimental facility for the C-scan performance test in sodium

4. C-Scan Performance Test

The under-sodium ultrasonic waveguide sensor was designed and manufactured and the C-scan experimental facility was setup for the performance test of the waveguide sensor. Figure 2 shows the C-scan imaging experimental setup with an ultrasonic C-scan system hardware and a scanner. The ultrasonic C-scan experimental setup is composed of a XYZ scanner, a scanner driving module, a high power ultrasonic pulser/receiver (RITEC RAM-10000), a LeCroy oscilloscope, and an 1.7 m long under-sodium waveguide sensor module. A scanner is to position and control the C-scan test target by using electric step motors. 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 software program has been used for the C-scan imaging. The 1.7 m under-sodium long ultrasonic waveguide sensor module with a beryllium coating layer was designed and manufactured. The test target with four slits and loose parts was manufactured for a comparison of the C-scanning resolution. C-scan imaging test was performed for the verification of under-sodium visualization performance of the under-sodium ultrasonic waveguide sensor. Figure 3 shows the C-scan results of test target with slits and loose parts by the under-sodium waveguide sensor module in sodium. The loose part reflectors were partially identified and also the slits were clearly resolved in the image. This result manifest that the 1.7 m long under-sodium ultrasonic waveguide sensor has the performance to achieve the C-scan image in sodium.

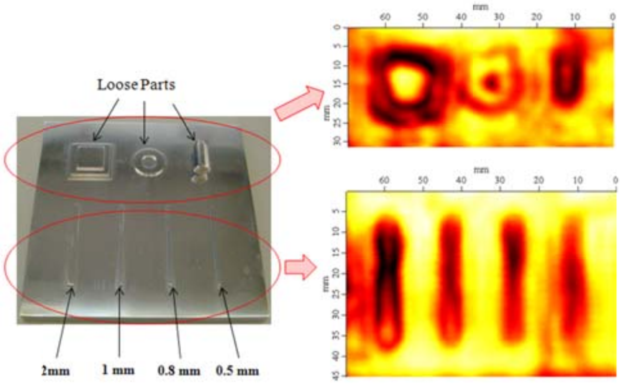


(a) UT system and glove box



(b) XYZ scanner and under-sodium waveguide sensor

Fig. 2. Experimental setup for the C-scan test in sodium



(a) Test target (b) C-Scan image

Fig. 3. C-scan image of test target with slits and loose parts by the under-sodium waveguide sensor module

4. Conclusion

The under-sodium ultrasonic waveguide sensor using the A_0 mode leaky Lamb wave has been developed for the under-sodium visual inspection of a reactor core and in-vessel structures in the sodium-cooled fast reactor. A new ultrasonic waveguide sensor wherein a coating layer made of beryllium (Be) is formed on the outer surfaces of the waveguide plate is suggested for the enhancement of the performance of ultrasonic waveguide sensor in sodium. The sodium test facility with a glove box system and a sodium tank has been designed and manufactured to carry out the performance test of ultrasonic waveguide sensor in sodium environment condition. The 1.7 m long under-sodium ultrasonic waveguide sensor module with a beryllium coating layer was designed and manufactured. The C-scan imaging test was carried out in sodium for evaluating performance of the under-sodium ultrasonic waveguide sensor.

ACKNOWLEDGEMENT

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