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Ultrasonic Waveguide Sensor with a Layer-Structured Plate

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1. Introduction

In-vessel structures of a sodium-cooled fast reactor (SFR) are submerged in opaque liquid sodium in 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 had 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, 4]. In the previous studies, the ultrasonic waveguide sensor module had been designed and manufactured. And the feasibility study of the ultrasonic waveguide sensor has been performed. To improve the performance of the ultrasonic waveguide sensor module in the under-sodium application, the dispersion effect due to the 10 m long distance propagation of the A_0-mode Lamb wave should be minimized and the longitudinal leaky wave in a liquid sodium should be generated within the range of the effective radiation angle.

In this study, a new concept of ultrasonic waveguide sensor with a layered-structured plate is suggested for the non-dispersive propagation of A_0-mode Lamb wave in an ultrasonic waveguide sensor and the effective generation of leaky wave in a liquid sodium.

2. Dispersion Characteristics of A_0 Lamb Wave in an Ultrasonic Waveguide Sensor

As illustrated in fig. 1, the A_0-mode Lamb wave propagated through the ultrasonic waveguide sensor with a single layer plate is leaked as a longitudinal wave while coming in contact with the liquid metal. In this case, the radiation beam angle θ of the leaky longitudinal wave is determined by the Snell law as follows.

$$\sin\theta(f) = \frac{V_L}{C_{ph}(f)} \quad (1)$$

Herein, the V_L denotes a longitudinal wave velocity of the liquid metal, the C_{ph} denotes a phase velocity of the A_0-mode Lamb wave, and the f denotes a frequency.

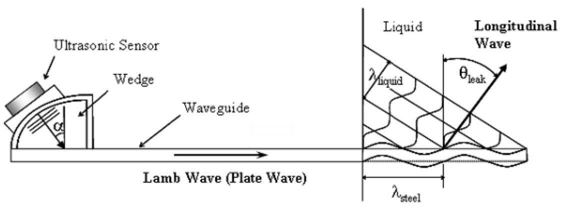
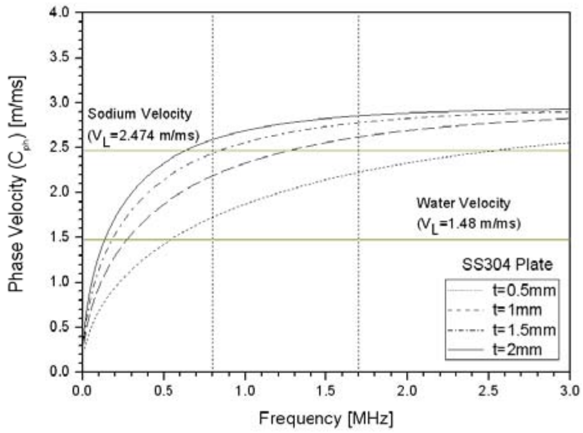
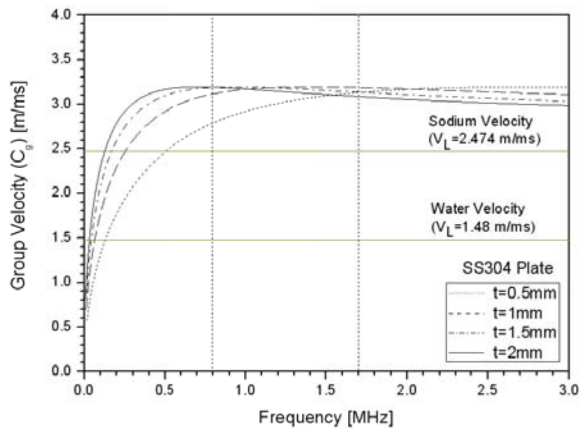


Fig. 1. Ultrasonic waveguide sensor.

Figures 2 (a) and 2 (b) illustrate the dispersion curves of phase (C_{ph}) and group velocities (C_g) of the A_0-mode Lamb wave for each thickness t of the ultrasonic waveguide sensor in the liquid sodium, respectively. In order to apply the ultrasonic waveguide sensor module to the liquid sodium, the phase velocity of the A_0-mode Lamb wave should be faster than 2474 m/s that is the longitudinal wave velocity V_L of the liquid sodium. Thus, the A_0-mode Lamb wave is mode-converted into a leaky longitudinal wave so that an ultrasonic beam can be radiated through the radiation face of the waveguide sensor. 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. The group velocity of the A_0-mode Lamb wave shall be necessarily constant so that the dispersion effect of the A_0-mode Lamb wave should be minimized in the propagation of the A_0-mode Lamb wave in the long waveguide with a length of more than 10 m.



(a) Phase velocity

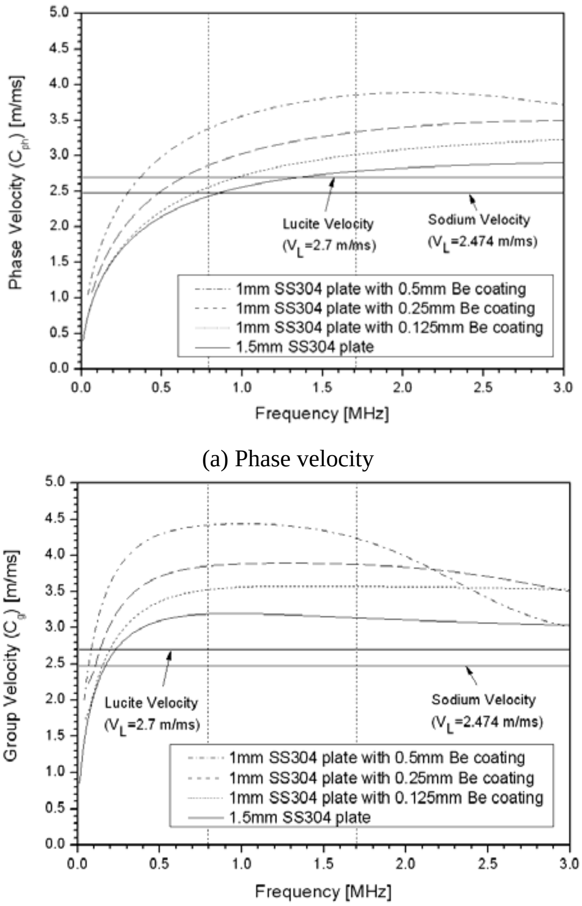


(b) Group velocity

Fig. 2. Dispersion curves of the A_0-mode Lamb wave of SS304 plates in ultrasonic waveguide sensor.

3. Ultrasonic Waveguide Sensor with a Layered-Structured Plate

For the performance enhancement of a 10 m long ultrasonic waveguide sensor in sodium environment, the waveguide sensor formed of an SS304 stainless steel plate provided with beryllium (Be) coating layers is suggested. Figures 3 (a) and 3 (b) illustrate the dispersion curves of phase (C_{ph}) and group velocities (C_g) of the A_0-mode Lamb wave propagated through the waveguide provided with the Be coating layer. The beryllium (Be) is a material, 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.



(a) Phase velocity

(b) Group velocity

Fig. 3. Dispersion curves of the A_0-mode Lamb wave of Be-coated SS304 plates in ultrasonic waveguide sensor.

Accordingly, when the waveguides are formed of an SS304 stainless steel plate (1 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 can be radiated through the radiation face of the waveguide sensor in a liquid sodium. The change range of the radiation beam angle of a leaky longitudinal wave is increased. Accordingly, the radiation beam steering function of the ultrasonic waveguide sensor device can be normally operated. The phase velocity of the A_0-mode Lamb wave propagated through the waveguide provided with the beryllium coating layer is faster than that is the longitudinal wave velocity (2.7 m/ms) of the Lucite wedge. Accordingly, it is possible to use the wedge made of a solid, which can be stably used for a long operation time under a high-temperature environment. 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 (0.8 to 1.7 MHz), thereby reducing the waveform distortion due to the long-distance propagation of more than 10 m.

4. Conclusion

A new ultrasonic waveguide sensor device 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. As a coating layer made of beryllium (Be) is formed on outer surfaces of a waveguide, the phase velocity of the A_0-mode Lamb wave propagated through the waveguide is increased and the frequency range with a constant group velocity of an A_0-mode Lamb wave is extended. Accordingly, the well-developed radiation beam of a leaky longitudinal wave can be generated. And the excitation frequency range of an incident pulse of the A_0-mode Lamb wave propagated to a long distance through the waveguide provided with the coating layer made of beryllium (Be) is increased. So, the dispersion effect of the A_0-mode Lamb wave propagated to a 10 m long ultrasonic waveguide sensor can be minimized, and the distortion of the waveform of an excitation pulse can be minimized.

ACKNOWLEDGEMENT

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