Ultrasonic Beam Radiation of an A_0 Leaky Lamb Wave in a Plate Waveguide Sensor

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1. Introduction

As the sodium coolant of a sodium-cooled fast reactor (SFR) is opaque to light, a conventional visual inspection cannot be used for carrying out an in-service inspection of the internal structures under a sodium level. An ultrasonic wave should be applied for an under-sodium viewing of the internal structures in a reactor vessel. Immersion sensors and waveguide sensors have been applied to the under-sodium visualization. The immersion sensor has a precise imaging capability, but may have high temperature restrictions and an uncertain life. The waveguide sensor has the advantages of a long lifetime and stable application [1-3]. Recently, a new plate waveguide sensor has been developed for the versatile applications in the under-sodium viewing application [4]. In the plate waveguide sensor, the A_0 leaky Lamb wave is utilized for the long distance propagation and the effective radiation capability in a fluid. And a new technique is presented which is capable of steering an ultrasonic beam of a waveguide sensor without a mechanical movement of the sensor assembly [4]. In this paper, the experimental study of the radiation beam profile of the A_0 leaky Lamb wave in a plate waveguide sensor is carried out.

2. Ultrasonic Waveguide Sensor

Plate waveguide sensor consists of a thin strip plate, wedge and ultrasonic sensor, as shown Fig. 1. Lamb wave (or plate wave) is generated in a plate by an excitation from the transducer where the compression wave is impinging at an angle within the wedge. The generated Lamb wave at the top of the plate propagates downwards towards the radiating surface side contacting a liquid. The particle motion of Lamb wave is elliptical, with components in the direction of wave propagation and normal to the plate surface. The normal component of Lamb wave in the plate creates a local disturbance within a liquid, thus the acoustic energy is lost to the liquid. When a waveguide sensor is submerged in a liquid, the waves create the longitudinal wave within the liquid by the mode conversion. The longitudinal ultrasonic beam resulting from the mode conversion is emitted at an angle θ to the waveguide normal, given as:

$$Sin\ \theta(fd) = \frac{V_L}{C_p(fd)} \qquad (1)$$

where V_L is the longitudinal wave velocity in a liquid and C_p is the phase velocity of the Lamb wave.

In the waveguide sensor application, the zero-order anti-symmetric A_0 mode has been utilized for the single mode generation and an effective radiation capability. Figure 2 shows the dispersion curves of the phase and the group velocity for the A_0 mode. In the dispersive region of the A_0 mode where the frequency is below 2.0 MHz, the phase velocity depends on the frequency. In this region, a fine frequency tuning of the excitation pulse creates a change of the phase velocity. The beam radiation angle θ of a leaky wave can be changed by the phase velocity of the A_0 mode in accordance with Eq.(1).

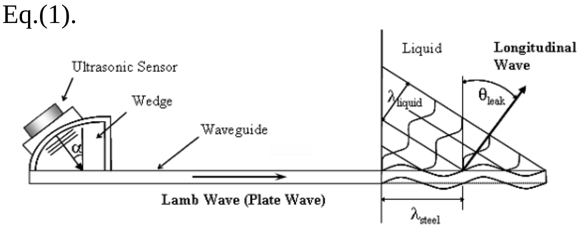


Fig. 1. Leaky Lamb wave propagation in the waveguide sensor and radiation in a fluid by a mode conversion

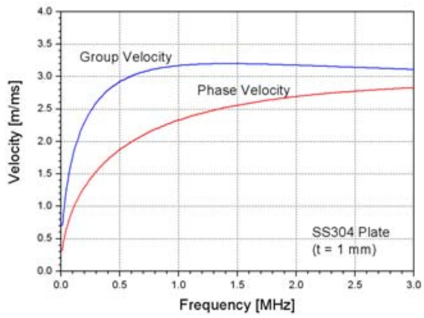


Fig. 2. Dispersion curves of phase and group velocity for A_0 mode

3. Experimental Setup

An experimental facility was setup for a measurement of the radiation beam profile and the steering of a plate waveguide sensor. Figure 3 shows the bock diagram of the experimental hardware setup. It consists of an X-Y-Z scanning system, a pulser/receiver (RITEC RAM-10000 system), a computer, a Lecroy oscilloscope and a plate waveguide sensor. Winspect™ program was used for A, B, C-Scan imaging software. The plate waveguides are a 400 mm long and 15 mm wide stainless steel plate, 1 mm and 1.5 mm thick. The transducer is excited by tone burst signals.

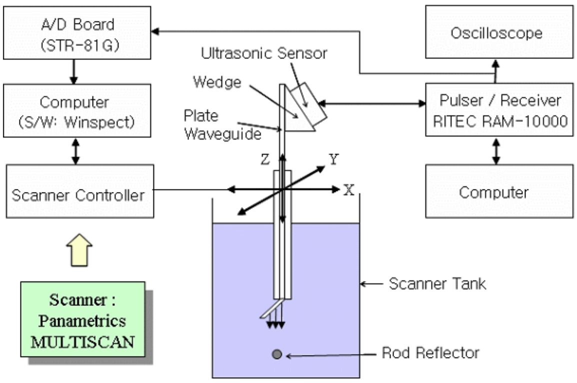
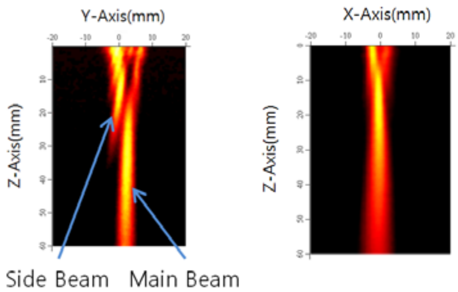


Fig. 3. Block diagram of ultrasonic beam profile measurement

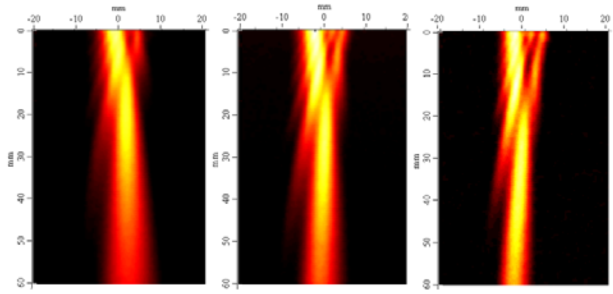
A beam profile measurement is carried out to evaluate the radiation beam-forming characteristics of the A_0 leaky Lamb wave from the plate waveguide sensor with the 1 MHz ultrasonic transducer on the wedge. The radiation beam shape of the waveguide sensor was examined by a Y-Z scanning in a 3D scanning system (Panametric MultiScan system.). The 1 mm and 1.5 mm thick plate waveguide sensors are used in the beam profile test. The end of the waveguide sensor is bent for a longitudinal wave beam to radiate vertically downward from the end section. The median and lateral beam profiles of the waveguide sensor are shown in Fig. 4 (a) and (b). This experimental result shows that the waveguide sensor forms a highly directional beam in the liquid and the profiles are in a flame shape. The beam profile of the median plane has small side lobes (Fig. 4(a)). The beam profile of the lateral plane is more divergent than that of the median plane.

The highly directional compression wave is radiated from the end section of the waveguide sensor at an angle of θ given by Eq. (1). When the excitation frequency is selected by a fine frequency tuning, the radiation angle of the ultrasonic beam is changed. Figure 5 and 6 show the radiation beam profiles for the excitation frequencies at 0.8 MHz, 1 MHz and 1.2 MHz for the 1 mm and 1.5mm thick plate. As the excitation frequency is increased, the angle of radiation beam is decreased, moving left.



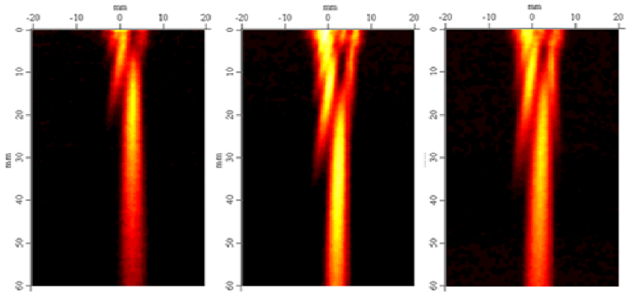
(a) Beam profile in median plane (b) Beam profile in lateral plane

Fig. 4. Beam profiles of the A_0 leaky Lamb wave in a plate waveguide sensor.



(a) 0.8 MHz (b) 1.0 MHz (c) 1.2 MHz

Fig. 5. The beam profile of the 1.0 mm thick waveguide sensor



(a) 0.8 MHz (b) 1.0 MHz (c) 1.2 MHz

Fig.6. The beam profile of the 1.5 mm thick waveguide sensor

4. Conclusion

The characteristics of radiation beam of ultrasonic waveguide sensors has been investigated by the beam profile measurements according to the plate thickness and the excitation frequency. The steering function of the ultrasonic radiation beam was successfully verified by a frequency tuning method of the excitation pulse in the dispersive low frequency range of the A_0 plate wave.

ACKNOWLEDGEMENT

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REFERENCES

[1] G. Seed, "In-Service Inspection and Monitoring of CDFR," Nucl. Energy, Vol. 25, No.2 Apr., pp. 129-135, 1986.

[2] C.H. Mitchell, "Structural Integrity of the CDFR Safety Related Structures," Nucl. Energy, Vol. 25, No.2 Apr., pp. 107-114, 1986.

[3] J.A. McKnight, et al., "Recent Advanced in the Technology of Under-Sodium Inspection in LMFBRs," Liquid Metal Engineering and Technology, BNES, London, pp 423-430. 1984.

[4] Y.S. Joo and J.H. Lee, "Beam Steering Technique of Ultrasonic Waveguide Sensor for Under-Sodium Inspection of Sodium Fast Reactor," ICONE 13-50340, 2005.