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2-D FEM Simulation of Propagation and Radiation of Leaky Lamb Wave in a Plate-Type Ultrasonic Waveguide Sensor

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1. Introduction

Conventional visual inspection techniques for the examination of in-vessel structures are not valid in a sodium-cooled fast reactor (SFR), which uses liquid sodium as its core coolant, because liquid sodium is optically opaque. In order to overcome this problem, various researches on under-sodium viewing (USV) using elastic ultrasonic waves have been conducted in many countries which have been developing SFR [1]. In Korea, a plate-type ultrasonic waveguide sensor has been developed for versatile applications of USV [2] and its ability to visualize targets in sodium was successfully demonstrated through under-sodium experiments [3].

The quality of the visualized image is mainly affected by beam profile characteristics of the leaky wave radiated from the waveguide sensor. However, the relationships between the radiation beam profile and many parameters of the waveguide sensor are not fully revealed yet. Therefore, further parametric studies are necessary to improve the performance of the sensor and the finite element method (FEM) is one of the most effective tools for the parametric study.

This paper introduces the 2-D FEM simulation of the propagation and radiation of the leaky Lamb wave in and from a plate-type ultrasonic waveguide sensor conducted for the radiation beam profile analysis. The FEM simulations are performed with three different excitation frequencies and the radiation beam profiles obtained from FEM simulations are compared with those obtained from corresponding experiments.

2. Plate-type Ultrasonic Waveguide Sensor

Fig. 1 presents a plate-type ultrasonic waveguide sensor consisting of an ultrasonic transducer, a solid wedge and a thin and long strip-type plate.

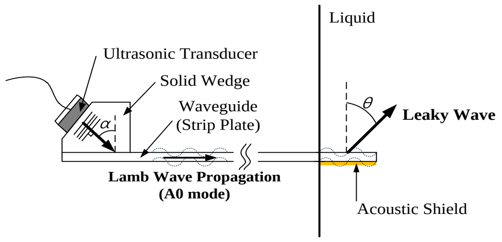

Fig. 1. Plate-type ultrasonic waveguide sensor

The ultrasonic wave generated by the transducer travels through the wedge and then is incident into the waveguide with an angle of α. At a certain incident angle α, the incident wave propagates along the waveguide as a particular guided wave mode. The developed waveguide sensor uses the A0-mode (the lowest anti-symmetric mode) Lamb wave and the incident angle for the generation of A0-mode Lamb wave is given by

$$\alpha(fd) = sin^{-1}\left(\frac{V_{wedge}}{C_p(fd)}\right)$$

where V_{wedge} is the longitudinal wave velocity in the wedge, C_p is the phase velocity of the A0-mode Lamb wave in a plate with a thickness of d at an excitation frequency of f. In the submerged region of the waveguide, the Lamb wave is radiated or leaked into the liquid with an angle of θ by mode conversion. The radiation angle θ is determined as

$$\theta(fd) = sin^{-1}\left(\frac{V_{liquid}}{C_p(fd)}\right)$$

where V_{liquid} is the acoustic wave velocity in the liquid.

The radiated acoustic wave, called leaky wave, is echoed from the target or the reflector during propagation in the liquid. Then, by measuring the reflected wave returning to the waveguide, the target or the reflector in the liquid can be identified and the image of the target can also be obtained by the scanning process.

3. FEM Simulation

Since the considered waves in this work, the A0-mode Lamb wave in the waveguide and the leaky wave in liquid can be assumed as plane waves, the plane-strain condition can effectively be applied for the simulation. Fig. 2 represents a 2-D FEM model for simulation of the propagation and radiation of the leaky Lamb wave in and from the plate-type ultrasonic waveguide sensor. The FEM simulation is performed using ANSYS Ver. 15.0 and the entire simulation model is constructed based on the experiment which was conducted to obtain the radiation beam profiles of the developed waveguide sensor [4].

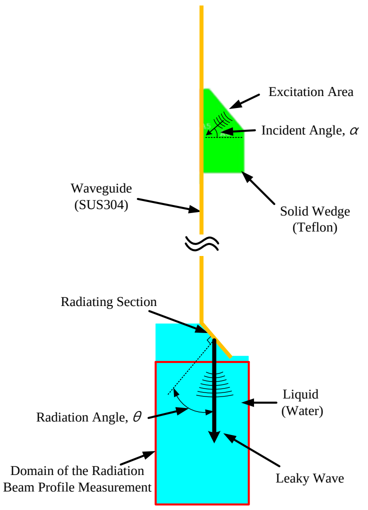

Fig. 2. 2-D FEM simulation model of propagation and radiation of leaky Lamb wave in the plate-type ultrasonic waveguide sensor

The FEM simulation is carried out for three different excitation frequencies: 0.8, 1.0 and 1.2 MHz. Newmark method is used for an implicit time integrator. The integration time step is determined to be 15 divisions to one excitation period and the maximum size of an element is 10 divisions to a wavelength at each frequency. The numbers of nodes and elements are 186,093 and 181,700, respectively. More detailed information about the simulation model is listed in Table I. The pressures at all nodes in a domain of the radiation beam profile measurement are extracted and their peak values are used to obtain the radiation beam profiles.

Table I: FEM simulation model information

Parameter	Value
Length of the waveguide	400 mm
Thickness of the waveguide	1 mm
Radiating section length	18 mm
Load type	Displacement
Material of the waveguide	SUS 304
Material of the wedge	Teflon
Material of the liquid	Water

4. Radiation Beam Profile Results

Fig. 3 compares the radiation beam profiles obtained from the experiment with those obtained from the FEM simulation. From the Fig. 3, one can see that the simulation results agree well with the experimental results in the physical characteristics such as beam patterns, radiation angles and near field distributions. Especially, it is both experimentally and analytically showed that the radiation angles are decreased as the excitation frequency increases.

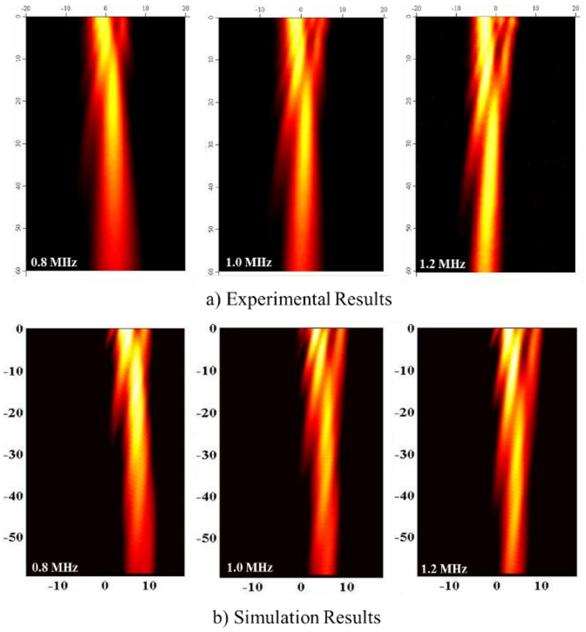

Fig. 3. Radiation beam profile results of a plate-type ultrasonic waveguide sensor

5. Conclusions

This paper deals with the 2-D FEM simulation of the propagation and radiation of the leaky Lamb wave in and from a plate-type ultrasonic waveguide sensor conducted to analyze the radiation beam profiles. The radiation beam profile results obtained from the FEM simulation show good agreement with the ones obtained from the experiment. This result will be utilized to improve the performance of the developed waveguide sensor.

Acknowledgement

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