Transactions of the Korean Nuclear Society Spring Meeting
Taebaek, Korea, May 26-27, 2011

FEM Simulations of Leaky Lamb Wave in Ultrasonic Waveguide Sensor

Jin-Ho Bae, Young-Sang Joo*, Jong-Bum Kim
Korea Atomic Energy Research Institute, 105-1 Dukjin Dong, Yuseong, Daejeon, Korea 305-353
**Corresponding author: ysjoo@kaeri.re.kr*

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 [1-2]. Recently, a noble plate-type ultrasonic waveguide sensor has been developed for versatile applications in an under-sodium viewing application [3].

The beam profile of a A_0-mode leaky Lamb wave of the waveguide sensor affects the resolution of visualization image in under-sodium viewing. In the design and manufacture of the waveguide sensor, the finite element method (FEM) modeling and simulation of the propagation of a leaky Lamb wave is required for the estimation and optimization of the waveguide sensor design parameters. In the previous research, the simple 2D modeling and simulation of the waveguide sensor had been carried out [4]. In this work, FEM simulation of the propagation and radiation of the leaky Lamb wave in the waveguide sensor is performed for the vertical and lateral beam profile analysis using the pseudo 3D modeling including the wedge.

2. Leaky Wave Generation in Ultrasonic Waveguide Sensor

Ultrasonic waveguide sensor consists of a thin strip plate, a wedge and an ultrasonic sensor, as shown Fig. 1. When the waveguide sensor is submerged in a liquid, the leaky waves create a longitudinal wave within the liquid by the mode conversion. A longitudinal ultrasonic beam resulting from the mode conversion is emitted at an angle θ to the waveguide normal, given as:

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

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

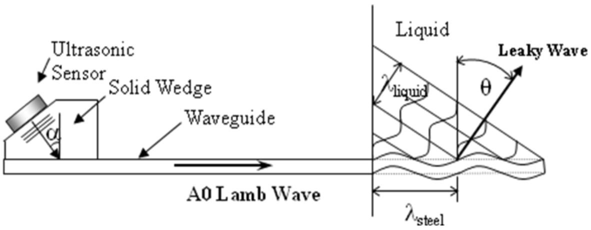


Fig. 1. Leaky wave in the waveguide sensor.

In a waveguide sensor application, the A_0 mode leaky Lamb wave has been utilized for the single mode generation and effective radiation capability. Fig. 2 shows the dispersion curves of the phase and group velocity for the A_0 mode leaky Lamb wave in the SS304 plate.

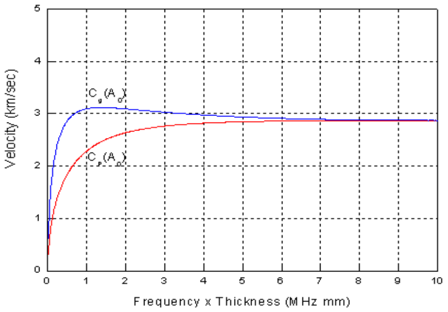


Fig. 2. Dispersion curves of phase and group velocity for A_0 mode leaky Lamb wave in an SS304 plate of waveguide sensor.

3. FEM Modeling

The finite element method (FEM) is a numerical simulation method that has been widely and successfully utilized to solve the static and dynamic problems in mechanical, aeronautical and automotive industries. In the finite element analysis of elastic wave propagation, the explicit dynamic method is computationally efficient due to the relatively short dynamic response times, and is widely used for analyzing the transient dynamic problem. The weak form for a plane harmonic elastodynamic problem obtained through the application of the principle of virtual work can be written using a matrix notation as

$$\int_{\Omega} \delta\boldsymbol{\varepsilon}^T \boldsymbol{\sigma} d\Omega = \int_{\Gamma} \delta\mathbf{u}^T \mathbf{t} \sigma d\Gamma + \varpi^2 \int_{\Omega} \rho \delta\mathbf{u}^T \mathbf{u} d\Omega \tag{2}$$

where $\mathbf{u} = [u_x, u_y]^T, \mathbf{t} = [t_x, t_y]^T, \boldsymbol{\varepsilon} = [\varepsilon_{xx}, \varepsilon_{yy}, \varepsilon_{xy}]^T$ and $\boldsymbol{\sigma} = [\sigma_{xx}, \sigma_{yy}, \sigma_{xy}]^T$

Let us consider a homogeneous plate of 2h thickness under a plane wave as shown in Fig 3. In order to reproduce the structure of the Lamb waves, trial functions **u,** corresponding to plane harmonic waves propagating in the x direction and towards $x \rightarrow -\infty$ are used [6].

$$\mathbf{u}(x, y, t) = \hat{\mathbf{u}}(y) e^{i(kx+\omega t)} \tag{3}$$

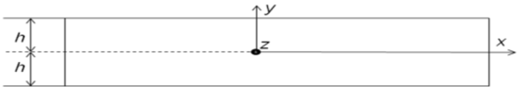


Fig. 3. Geometry of a plate with 2h thickness.

4. Simulation and Results

The common FEM program ANSYS and LS-Dyna are used in this numerical simulation [5]. For simulation of the propagation and radiation of an A_0-mode Lamb wave in an ultrasonic waveguide sensor, a 1.0 mm thick and 250mm long SS304 plate and the water were modeled together, as show in Fig 4. The Solid164 element is used for the explicit pseudo 3-D modeling of solid structures. The element is defined by eight nodes having the following degrees of freedom at each node translations, velocities, and accelerations in the nodal x, y, and z directions. An excitation force in the xy-direction with the time dependence $F(t) = A\sin(2\pi \cdot t)$ for four periods (t<4/f) was applied to the excitation surface of wedge model.

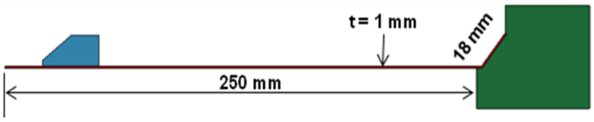
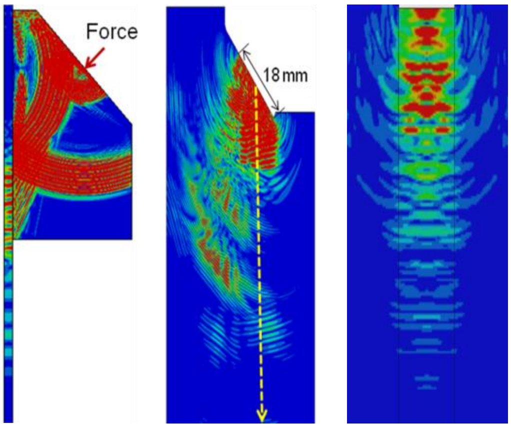


Fig. 4. The dimensions of simulation model.

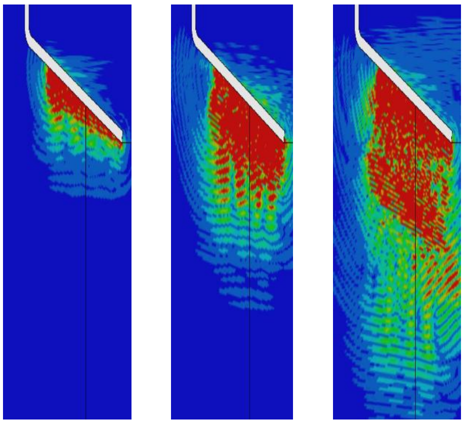
Material parameters (Young's modulus E=2.1×10^{11} N/m^2, Poisson ratio of 0.33 and density of 7800 kg/m^3) were chosen as appropriate for the SUS304 plate. A transient (time dependent) analysis was performed using a step size of 1/10f. The mesh sizes of the simulations were chosen to give a maximum element size of 0.08 mm, resulting in approximately 639,000 elements.



(a) Wedge (b) Vertical Beam (c) Lateral Beam

Fig. 5. Simulation results of the propagation and radiation of an A_0-mode Lamb wave in an ultrasonic waveguide sensor submersed in water.

Fig. 5 shows the simulation results of the wave propagation of in a plate including a wedge and the radiation of the vertical and lateral beams in an ultrasonic waveguide sensor submersed in water. Fig. 6 shows the simulation results of the vertical radiation beams of the leaky Lamb wave in water at the various transient times (t = 10, 30 and 50μs) in the case of 1MHz frequency excitation.



(a) t=10μs (b) t=30μs (c) t=50μs

Fig. 6. Simulation results of the vertical beam profile of an ultrasonic waveguide sensor submersed in water.

The pseudo 3D modeling makes the lateral beam profile simulation possible as compared with the previous 2D modeling. The smaller-size element modeling gives the separation of the main beam and the side beam in the vertical beam profile as well as the great improvement in the spatial resolution.

5. Conclusion

The FEM modeling and simulation of the propagation and radiation of A_0-mode Lamb wave in an ultrasonic waveguide sensor has been performed. The lateral beam profile can be obtained by the pseudo 3D modeling and simulation. This precise element modeling and pseudo 3D FEM simulation can be useful utilized in the estimation and optimization of the waveguide sensor design parameters. In the future work, the various 3D modeling of the ultrasonic waveguide sensor will be carried out.

ACKNOWLEDGEMENT

This study was supported by the Korean Ministry of Education, Science & Technology (MEST) through its National Nuclear Technology Program.

REFERENCES

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

[2] 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.

[3] Y. S. Joo, et al., "Development of ultrasonic waveguide sensor for under-sodium inspection in a sodium-cooled fast reactor", NDT&E International, 44, pp 239-246, 2011.

[4] J. H. Bae, Y. S. Joo, J. B. Kim, and H. N. Rhee, "Simulations of Propagation and Radiation of A0-mode Lamb Wave in Ultrasonic Waveguide Sensor", Transaction of KNS Autumn Meeting, 2010.

[5] ANSYS Analysis User's Manual, Version 12 Inc, 2009.

[6] J. M. Galan and R. Abascal, "Elastodynamic guided wave scattering in infinite plates," Int. J. Numer. Meth. Engng. Vol. 58, pp.1091–1118, 2003.