Generation of Leaky Lamb waves by a piezoelectric wafer active sensor in a fluid-loaded anisotropic plate

Luo Ying* a), Xu Baiqiang**, Xu Chenguang**, Xu Guidong**

*Faculty of Civil Engineering & Mechanics, Jiangsu University, Zhenjiang 212013, China
**Faculty of Science, Jiangsu University, Zhenjiang 212013, China

Summary The application of Leaky Lamb waves in NDT and NDE has attracted widespread interest owing to its characters such as long-range inspection, multimode, and dispersion. In this study, a finite element model is developed to simulate the generation of Leaky Lamb waves by a piezoelectric wafer active sensor in an anisotropic plate immersed in ideal fluid. The numerical simulation establishes a quantitative relation between the excitation, the material parameters and the waveform.

NUMERICAL MODEL

The key of Leaky Lamb wave technology in non-destructive testing (NDT) and non-destructive evaluation (NDE)[1-2] of composite materials lies in the understanding and analysis the propagation characteristics of waveform. Traditional analytical method is often be used to obtain the dispersion curves of Leaky guided waves. However, analytical methods are difficult to deal with the waveform in anisotropic media. Aiming at this problem, the finite element method is introduced to obtain the waveform of Leaky Lamb waves in an anisotropic plate with ideal fluid loaded on both sides.

Theoretical model

Consider a piezoelectric wafer active sensor (PWAS) which is bonded on a transversely isotropic plate with fluid loaded on both sides. The PWAS is induced by the thickness polarization electric field and induced longitudinal expansion. Taking the symmetry of the model into consideration, the displacement field in the solid medium and the fluid medium can be described by 2D-elastodynamics equation respectively. The shear modulus in fluid domain is zero since there is no shear stress in ideal fluid. Taking into account the boundary conditions in fluid and solid (shear stress components on the fluid-solid boundary are zero, while the normal stress and normal displacement components are continuous), the displacement fields can be obtained by using finite element method.

Meshing and Time step

Temporal and spatial resolution of the finite element algorithm is critical to the convergence of these numerical results [3]. Choosing an adequate integration time step is very important for the accuracy of the solution. In general, the accuracy of the model increases with smaller integration time steps. With too long time steps, the high frequency components are not resolved accurately enough. On the other hand, too small time steps are a waste of calculation time. Therefore, a compromise must be found.

Excitation source and the Material parameters

A Gaussian windowed sinusoidal signal is used as the excitation voltage signal, and the center frequency and bandwidth of excitation source can be controlled by the parameter. The material of solid plate is transversely isotropic medium, while the fluid is water.

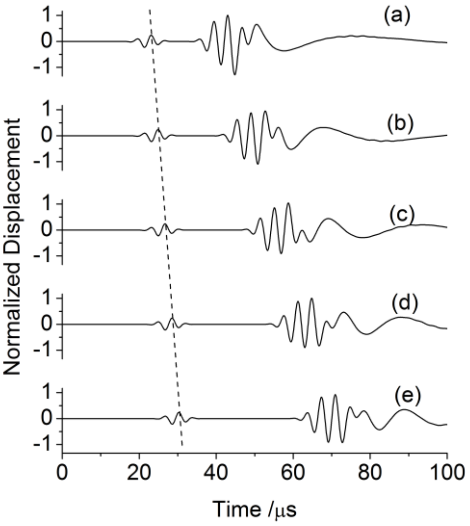
NUMERICAL SIMULATION RESULTS AND DISCUSSION

The displacement waveform of Leaky Lamb waves is obtained based on the above-described theories. The results show that two modes of Leaky Lamb waves exist simultaneously in the calculation frequency range. One is S0, which is a Non-dispersive and barely attenuation mode, the other is A0, which is a dispersive and attenuation mode. The S0 mode is hardly affected by water loading when the frequency thickness product is less than 0.5 MHz mm. This is because the displacement of this mode in the low frequency region is mainly in the direction along the interface, and this tangential motion does not couple between solid and fluid. On the other hand, the amplitude of A0 mode decreases obviously due to water loading. This is because the A0 mode has significant transverse displacements and causes more energy leakage to the surrounding liquid.

Since different modes have different phase velocities and wavelengths, when the width of PWAS is equal to the odd multiple of half wavelengths, the corresponding modal amplitude will be larger. By changing the center frequency of excitation source, the amplitude of S0 and A0 mode also change correspondingly. Numerical results are consistent with the theoretical and experimental work by Giurgiutiu[4], and also provide a basis of mode selection by frequency for leaky waves in applications.

---

a) Corresponding author. Email: luoying@ujs.edu.cn.



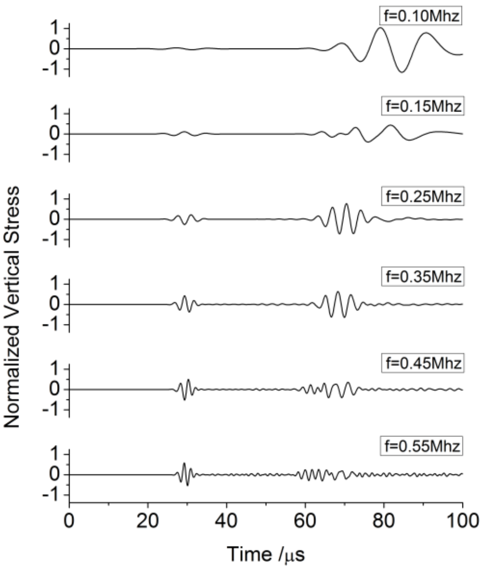


Fig1 Vertical stress waveform at the interface with different exciting frequencies
Fig2 Vertical displacement waveform with different source-receiver distances

The displacement waveform along different directions in transversely isotropic medium is also calculated. For anisotropic materials, the elastic parameters vary along different directions in the medium, which affects the propagation characteristics of Leaky guided waves. Numerical simulation results show that the propagation speed, amplitude and dispersion characteristics of Leaky Lamb waves are affected by material anisotropy.
.

CONCLUSIONS

The finite element method is a very efficient algorithm in dealing with the problem of anisotropic materials and multi-physics coupling, by adopting which the displacement waveform of Leaky Lamb waves induced by a PWAS is obtained. The numerical results showed a good agreement with previous theoretical and experimental work, and provide a basis for leaky waves in NDT and NDE applications.

References

[1] P.C. Xu, K.E. Lindenschmidt, and S.A. Meguid. A new high-frequency analysis of coatings using leaky Lamb waves [J]. J. Acoust. Soc. Am.,1993, 94(5): 2954–2962.

[2] Bar-Cohen.Y, Mal.A.K, and Chang, Z. Composite material defect characterization using Leaky Lamb Wave dispersion data[J]. Proceedings of SPIE on Nondestructive Evaluation of Materials and Composites II，San Antonio, Texas, 1998, 3396:180-186.Nygus G.: Numerical Analysis Using Finite Element Method. *PhD Thesis*, NTU Mech. Eng. Dept., Lagos, 1983.

[3] C. Johnson. Numerical Solution of Partial Differential Equations by the Finite Element Method[M],Cambridge University Press, New York, 1987

[4] Victor Giurgiutiu, Lamb Wave Generation with Piezoelectric Wafer Active Sensors for Structural Health Monitoring [J]. Proceedings of the SPIE 10th Annual International Symposium on Smart Structures and Materials and 8th Annual International Symposium on NDE for Health Monitoring and Diagnostics, March 2–6, San Diego, CA, paper 5056-17.