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Control of guided wave propagation with layered path in a plate

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1. Introduction

Controlling of the wave propagation by artificial material with extraordinary properties and functions is a kind of well-known research field about electromagnetic wave, in which the photonic metamaterials are created to achieve the certain purpose of the research. Photonic metamaterials provide special properties such as negative permittivity and negative permeability which can have some special influences on electromagnetic wave like visible light[1), 2)].

Analogous to the photonic metamaterials, the acoustic metamaterials with some special functions in an acoustic field are created. Following the ideas about controlling the electromagnetic wave, the research on controlling the elastic waves start to be held. The acoustic metamaterials can show some special properties such as negative density and negative bulk modulus. The unique performances of acoustic metamaterials had attracked a great deal of attention from many researchers[3), 4)].

Co-authors of this study also performed the numerical analysis of elastic wave control using a stacked plate region between bulk materials[5)], where a large number of thin plates with different thickness are stacked periodically to form a oblique wavefront of the transmitted wave. Following the previous research, this work deals with wave field in a plate with a stacked plate region to control the transmitted Lamb waves. To confirm the idea of the wave control using a stacked plate region, three-dimensional calculation is conducted for the Lamb wave propagation.

2. Methodology

Lamb waves have such a unique characteristic as dispersion, which is usually unpleasant in nondestructive testing and Lamb wave devises because it causes the complexity of wave field. While in this study, we utilize it to control wave field[5)]. **Fig. 1** shows the phase velocity dispersion curve of A0 mode for an aluminum alloy plate at 100 kHz with the horizontal axis of thickness *d*. As shown in this figure, the phase velocity of the A0 mode varies with the plate thickness *d*. Especially in the thin plate range of the dispersion curve of A0 mode, the dispersion characteristic is very strong.

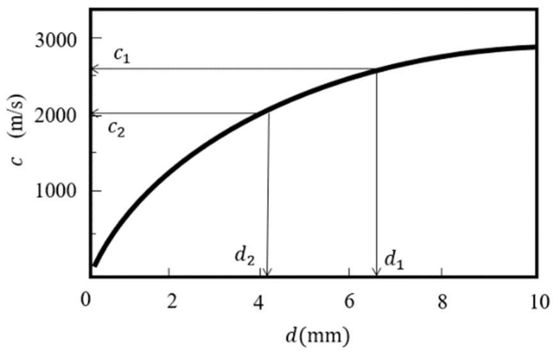

Fig. 1 Dispersion curve of A0 mode for an aluminum alloy plate. Phase velocity versus plate thickness. Frequency is fixed at 100 kHz.

Now, we utilize the dispersion characteristic of A0 mode in thin plates to control the phase of wave field. **Fig. 2** shows the basic idea of the Lamb wave control using the layered path consisting of thin plates with different thickness. The A0 mode is incident into the layered path region with the same phase. Each layered path consists of the thin plates with the identical thickness and width, and these paths have layers of different thickness. In Fig. 2, there are three paths, and the first, second and third path consists of four, three, and two plates, respectively. In a path consisting of plates with an identical thickness, the Lamb wave propagates with the same phase velocity in all plates, and A0 mode has almost uniform wave distribution in the thickness direction. Therefore, we can expect that the incident A0 mode invades into the all plates in each path with keeping uniform wave distribution in the thickness direction. Since the phase velocity of all three paths are different, the Lamb waves arrive with phase differences at the exit of the region.

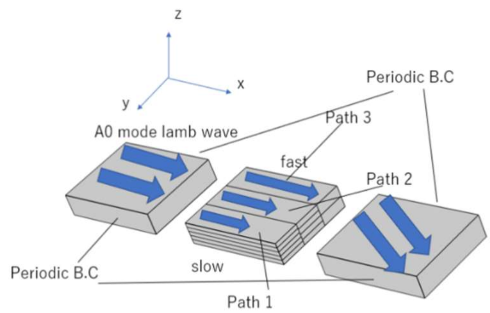

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Fig.2 Idea of wave control in a plate with layered path

When considering periodic boundary conditions at both edges of the fundamental component as shown in Fig. 2, the wave structures in the transmitted Lamb waves are limited as discussed in the previous study[5)]. **Fig. 3** shows the possible wave structures in the *y* direction. Due to the limitation of the periodic boundary condition, the plane wave can propagation with a discrete order of *n*, where the phase matches at the periodic boundaries. Depending on the frequency range used, higher order modes cannot propagate in the *x* direction.

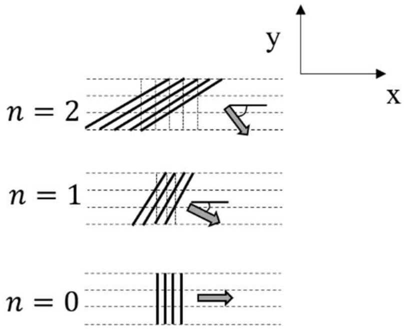

Fig.3 Phase difference of the wave propagation

3. Result

Numerical calculation using COMSOL Multiphysics® was performed to confirm the Lamb wave control using layered paths. Because the three-dimensional calculation is very time consuming, the number of elements in different calculation region are different. Most of the elements which means the densest calculation is given in stacked area to increase the accuracy of the observation of the influences on wave propagation from the stacked structure.

The result of four different paths model is shown in **Fig.4**, the red color and blue color represent the positive and negative displacements in *z* direction, respectively. From the view in *z* direction, the wave propagation in each path has different phase velocity and different wavenumber. The direction of the wave propagation only slightly changed but not easy to be observed because in the transmission region, the mode of the wave propagation is the combination both the *n*=0 mode and *n*=1 mode and the *n*=0 mode is with most proportion. As a result, the angle between the wave propagation and the +*x* direction is between which with *n*=0 mode and *n*=1 mode and very closed to +*x* direction.

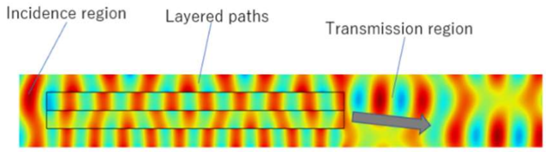

Fig.4 Wave motion through the layered paths

4. Conclusion

This study investigates the method of controlling the direction of propagation of Lamb wave in thin plate. The wave propagation in plate is formulated and the dispersion equation and the dispersion curve of A0 mode Lamb wave are conducted. Structure of the stacked area is decided by dispersion curve by controlling the thickness of each layer. The different phase velocities can be observed in different paths and the phase differences can be produced in the exit of the stacked region. However, the wave front can`t be clearly observed. The model is still needed to be optimized and modified to achieve the goal predicted by theory.

References

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