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Numerical Simulation of Lamb Wave Propagation in Flat Plate by Scanning Aerial Ultrasonic Source Technique

空中超音波波源走査法による平板内ラム波伝搬の
数値シミュレーション

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1. Introduction

We have developed a method for detecting defects from the scattering of guided waves propagating in a thin metal plate excited by non-contact aerial ultrasonic irradiation. In that method, the receiver is scanned two-dimensionally as the guided waves propagate from the irradiation source (wave source) under aerial ultrasonic wave irradiation.[1] The propagation of the guided waves is imaged by measuring the vibration velocity at each position, and defects are detected from that propagation image. However, when scanning the receiver, there are surface state effects. Also, measurements take a long time. A way to improve both those issue is a wave source scanning method.[2] In this method, the receiver is fixed and the transmitter is scanned two-dimensionally, thereby addressing both of the aforementioned problems. Herein, we propose a method that involves using aerial ultrasonic waves in combination with the wave source scanning method, and we use three-dimensional numerical simulations by the finite-element method (FEM) to compare the proposed method and the conventional method.

2. Wave source scanning method

An improved method is the wave source scanning method, which is based on the reciprocity theorem, as shown in Fig. 1. This says that when detecting ultrasonic waves transmitted between two different points (points A and B), the same detection waveform is obtained even if the transmitting and receiving sensors are exchanged.

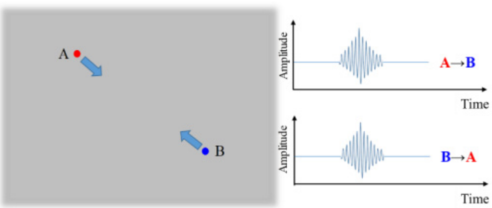

Fig. 1 Schematic of reciprocity theorem for sound field.

3. Simulation by FEM and conditions [3]

We used COMSOL Multiphysics 5.4 to conduct three-dimensional simulations by FEM of the propagation of ultrasonic waves in a solid. The basic governing equations for simulating the vibration of a solid due to ultrasonic waves are written as

$$\rho \frac{\partial^2 u_i}{\partial t^2} = \nabla \cdot S_{ij} + F_{\mathbf{v}} \tag{1}$$

$$S_{ij} = C_{ijkl}\varepsilon_{kl} \tag{2}$$

where ρ is the material density, u_i is the displacement vector, S_{ij} is the stress tensor, and $F_{\mathbf{v}}$ is the volume force vector. In eq. (2), the stress tensor S_{ij} is expressed as the tensor product of the elasticity tensor C_{ijkl} and the elastic strain ε_{kl}.

The simulation model is shown in Fig. 2. The model is made of 3-mm-thick duralumin plate in the dimensions shown, and a 0.5-mm-thick thinning area is provided at the position shown. The analysis is performed for the conventional method and for the wave source scanning method.

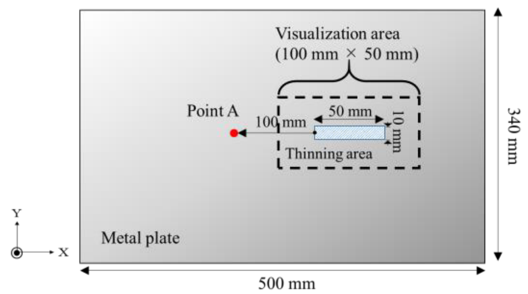

Fig. 2 Schematic of simulation model.

In the analysis of the conventional method (Fig. 3(a)), a wave source with a diameter of 6 mm is set around point A, and a propagation image in the visualization area is obtained when a fixed point is excited. In the analysis of the wave source scanning method (Fig. 3 (b)), based on the reciprocity theorem, the simulation is performed while moving the 6-mm-diameter excitation source from coordinates (0,0) to (100,50) in the visualization region in 2-mm steps. Every time the position of the vibration source changes, the vibration waveform at point A is extracted, and this is repeated for all coordinates. A propagation is obtained from the time waveform obtained at each coordinate pair, thereby allowing us

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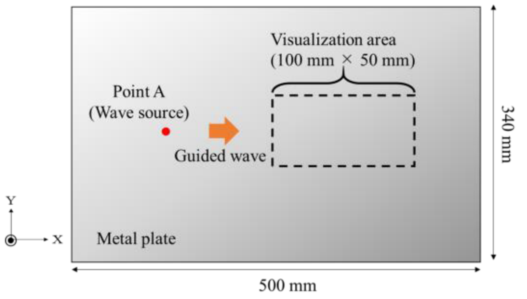
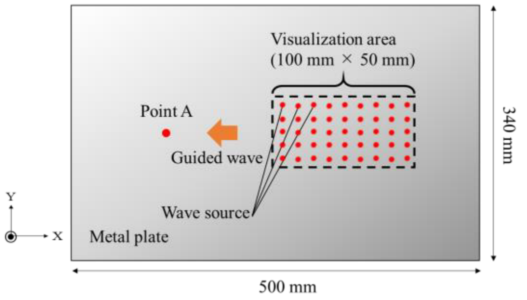
to compare it with the simulation result of the conventional method.



(a)Conventional method



(b)Wave source scanning method

Fig. 3 Schematic view of both methods

The time waveform of the sound pressure (basic frequency: 40 kHz) emitted from the focused sound source was measured with a microphone (Fig.4) and used as the vibration source. In the simulations, the time resolution was 1 μs, and the maximum simulation time was 300 μs. Also, ρ was set as the density of duralumin (2790 kg/m^3), and Young's modulus and Poisson's ratio in the elasticity tensor were set as 71.5 GPa and 0.335, respectively.

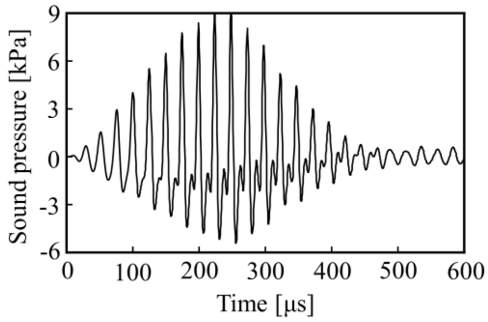
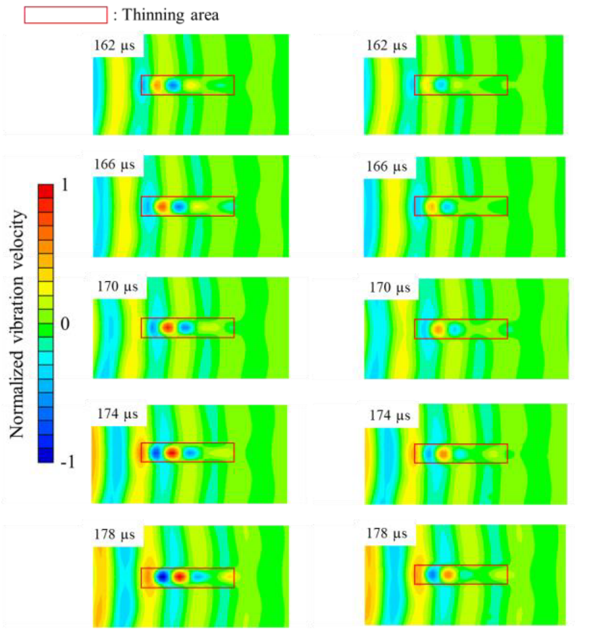


Fig.4 Wave form of the sound source

4. Simulation results

The simulation results for the conventional method and the wave source scanning method show in Fig. 5(a) and (b), respectively. The results are shown concurrently in chronological order, and the vibration velocity normalized by the maximum value of each result is shown as a color map. The results show that the two methods give almost the same guided wave (Lamb wave) [4] propagation, and in both cases the thinning area is visualized by the change in vibration mode. However, the wave source scanning method gives a lower vibration velocity in the thinning area. Based on the relationship between the sound wave irradiation area and the dimensions of the thinning area, it is expected that the reciprocity theorem does not hold completely.

Overall, the three-dimensional simulations by FEM indicate agreement between the conventional method and the wave source scanning method.



(a) Conventional method (b) Scanning aerial ultrasonic source method

Fig.5 Results of FEM simulations

5. Conclusions

We performed three-dimensional simulations by FEM of the wave source scanning method combined with aerial ultrasonic waves, and we compared the results with propagation images of guided waves (Lamb waves) obtained with the conventional method. The simulations gave the same results as those by the conventional method, and it was confirmed that when there is a thinning area, the amplitude there differs from that in the case where wave propagation is performed by applying a fixed-point excitation.

References

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