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Detection of Second Harmonic Components Generated from Crack in Glass Plate Using Lamé Mode of Lamb Waves

Lamé モード Lamb 波を用いた
ガラス板の亀裂から生じる 2 次高調波成分の検出

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1. Introduction

Ultrasonic waves have been widely used in the non-destructive evaluation (NDE) of various materials. Measurements using plate waves, such as Lamb waves or Rayleigh waves, have recently been applied in NDE. In many NDE methods, longitudinal waves have been used for point-to-point inspection. Plate waves, on the other hand, can explore a long distance in a one-time measurement. Moreover, much information can be obtained compared with usual inspection methods using a longitudinal wave.

Infinitely small amplitude ultrasonic pulse waves are used in most conventional NDE methods. Conventional methods can be used for finding open cracks while they are not so able to detect closed cracks. Recently, nonlinear ultrasonic (second harmonic or subharmonic) pulse waves have been studied for use in NDE.[1-3] The second harmonic frequency component $2f_0$ is generated by nonlinear vibrations of closed cracks, with the finite amplitude ultrasonic waves having a fundamental frequency component f_0; this phenomenon is known as contact acoustic nonlinearity (CAN).[4]

In this paper, the real-time detection of a second harmonic component, generated from a closed crack using a finite amplitude Lamé mode of Lamb wave, was carried out employing the DLPT and pulse-echo method.

2. Dispersion Curves of Lame Waves

Dispersion curves of the phase velocity c_p and group velocity c_g in a glass plate (longitudinal wave velocity c_L = 5800 m/s, shear wave velocity c_T = 3300 m/s, and thickness d = 5.4 mm) are shown in **Figs. 1(a)** and **1(b)**, respectively. Lamb waves can be effectively excited when the incident angle θ_c satisfies the phase matching condition. This angle is calculated from Snell's law as

$$\theta = \sin^{-1}\left(c_w / c_p\right), \tag{1}$$

where c_w (= 2500 m/s) is the ultrasonic wave velocity of the coupling medium such as a wedge.

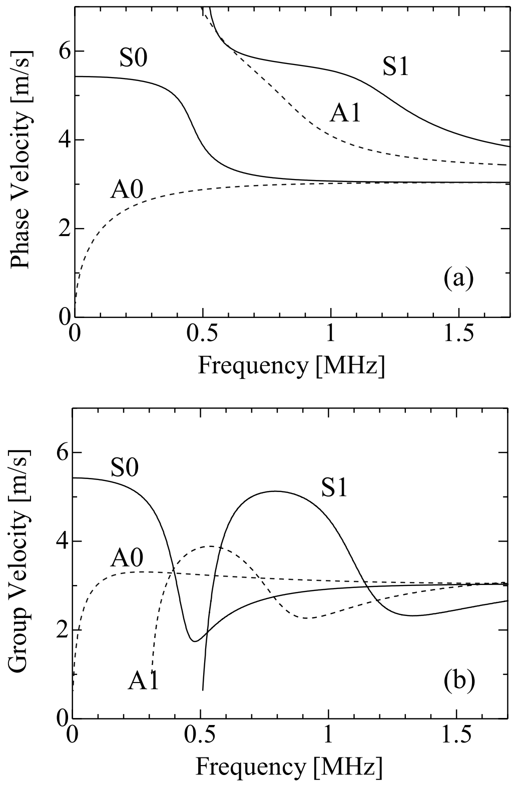

Fig. 1 Dispersion curves.
(a) Phase velocity. (b) Group velocity.

Dispersion curves for the critical angle in the glass plate are easily calculated. A frequency of f = 480 kHz is selected to generate S0 mode Lamb waves. The incident angle θ_c can be evaluated from c_p (3800 m/s) and c_w (2500 m/s) as approximately 40 degrees.

3. Experimental Method

The shape of the glass plate was approximately square (140 mm × 140 mm × 5.4 mm). The center of one side of the glass plate was nicked, and this part was loaded using a gimlet and hammer. A visible crack (open crack) was confirmed, and an invisible closed crack should have grown from the end of the open crack. A second harmonic component generated at the crack has previously been detected.[5] In this study, the DLPT on the wedge was set 40 mm from the closed crack and 110 mm from the edge of the glass plate.

Experimental set-up is shown in **Fig. 2**. Transmitting signals were generated using an arbitrary waveform generator and their amplitudes were amplified to 100 V with an amplifier and applied to a double-layered piezoelectric transducer (DLPT) [6]. The switch was turned and a parallel connection for the transmission of a 480 kHz ultrasonic pulse wave was produced. Ultrasonic pulses of 480 kHz were transmitted through the glass plate via the wedge. Lamb waves were generated as ultrasonic pulse waves propagating through the glass plate. The second harmonic component of the Lamb waves was generated by nonlinear vibrations at the closed crack. Before reflected pulse waves reached the DLPT, the switch was electrically turned off to enable the series connection for efficient reception of second harmonic waves (960 kHz). The received waveforms and spectra were captured by an oscilloscope and second harmonic components could be observed in real time using the fast-Fourier-transform function of the oscilloscope. Finally, the received waveforms were digitized and fed into a personal computer via a general-purpose interface bus.

This experiment was carried out for the closed crack area and a no-crack area, and each second harmonic component was compared for the two areas

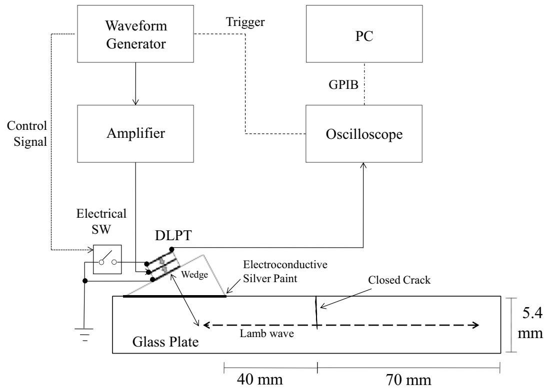

Fig. 2 Experimental set-up.

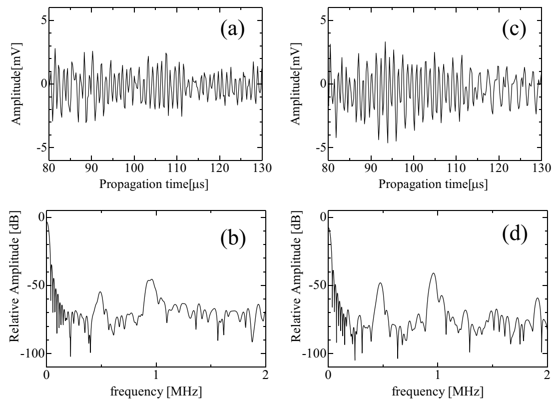

Fig. 3 (a) Received waveform and (b) its spectrum of no-crack area. (c) Received waveform and (d) its spectrum of closed crack area.

4. Results and Discussion

Figures 3 show the received waveforms and spectra after pulse inversion averaging[6]. Figures 3(a) and 3(b) show the received waveform and its spectrum for the no-crack area in the glass plate. Second harmonic components were hardly detected for the no-crack area. Figures 3(c) and 3(d) show the received waveform and its spectrum for the closed crack area in the glass plate. Second harmonic components were detected for the closed crack area. Second harmonic components of the closed crack area were approximately 6 dB higher than those of the no-crack area. Thus, the usefulness of the DLPT in the detection of second harmonic pulse waves of Lamb waves employing the pulse echo method was confirmed.

5. Conclusions

Finite amplitude Lamé mode of Lamb waves were launched into a glass plate having closed cracks using a DLPT. Second harmonic components generated from closed cracks could be detected by the DLPT. Second harmonic components of the closed crack area in a glass plate were approximately 6 dB higher than those for the no-crack area. In the future, this system will be applied to the locating and imaging of closed cracks.

References

1. M. Fukuda and K. Imani: Jpn. J. Appl. Phys. **51** (2012) 07GB06.
2. N. Matsuda and S. Biwa: Jpn. J. Appl. Phys. **51** (2012) 07GB14.
3. Y. Ohara *et al.*: Jpn. J. Appl. Phys. **51** (2012) 07GB18.
4. I. Solodov and C. A. Vu: Acoust. Phys. **39** (1993) 476.
5. K. Imano and A. Muto: Sozai Busseigaku Zasshi **20** (2007) 12 (in Japanese).
6. M. Fukuda *et al.*: Jpn. J. Appl. Phys. **45** (2006) 4556.