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A Study of Defect Detection in Metal Plate Using Nonlinear Ultrasonic Waves

非線形超音波を用いた 金属平板中の欠陥検出についての一検討

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1. Introduction

Recently, Lamb waves have been used for nondestructive evaluation (NDE). More information can be obtained in a single measurement using Lamb wave methods compared with conventional point-to-point inspection.

Infinitely small amplitude ultrasonic pulse waves are useful for finding open cracks in most conventional NDE methods. However, dislocations, voids or closed cracks (microcracks) are not easily detected. Recently, nonlinear ultrasonic (second-harmonic or sub-harmonic) pulse waves have been studied for use in NDEs. The second harmonic ($2f_0$) is generated by nonlinear vibrations in microcracks, referred to as contact acoustic nonlinearity (CAN), for finite-amplitude ultrasonic waves of fundamental frequency f_0. Several studies of nonlinearity using Lamb waves have been carried out.

We have recently constructed a real-time detection system for second-harmonic ultrasonic pulse waves using a double-layered piezoelectric transducer (DLPT). [1)] We also analyzed the effective detection of the second-harmonic ultrasonic pulse waves generated by plastic-deformed metals and bolt-nut connectors using DLPT and the pulse inversion averaging (PIA) method. Moreover, we have investigated the second-harmonic components of Lamb waves generated from fatigue-tested magnesium plates using DLPT. [2)]

In this study, Lamb waves are transmitted into a carbon steel plate, and second-harmonic components generated from closed cracks in the welded part are detected.

2. Generation and Propagation of Lamb Waves

The dispersion curves of the phase velocity, c_p, and the group velocity, c_g, in the carbon steel plate (longitudinal wave velocity c_L = 5770 m/s, shear wave velocity c_T = 3200 m/s, and thickness d = 10 mm) are shown in **Fig. 1(a)** and **1(b)**, respectively.

In this study, two methods will be compared: (1) conventional method using Lamb wave and (2) our proposal method using Lamé mode. In conventional method, the S0-mode Lamb wave at 500 kHz as the fundamental wave is chosen. Second-harmonic wave at 1 MHz is also the S0-mode Lamb wave. On the other hand, in the Lamé mode method, the S0-mode Lamb wave at 235 kHz as the fundamental wave is chosen. Because the A1-mode Lamb wave at 470 kHz has the same phase velocity as the fundamental wave mode: the Lamé mode, which is shown by circles in Figs. 1. Furthermore, in case of the Lamé mode, the second-harmonic waves will almost not be generated in propagating process. [3)] In other words, the second-harmonic components will be only generated from closed cracks. The Lamé mode will be useful to detect the very small second-harmonic components generated from closed cracks.

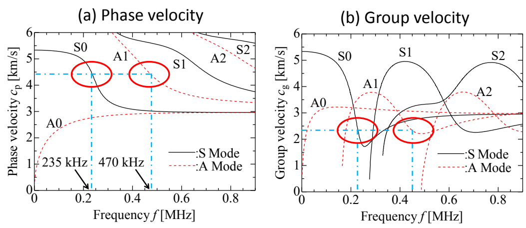

Fig. 1 Dispersion curves for Lamé mode Lamb waves in the carbon steel plate.

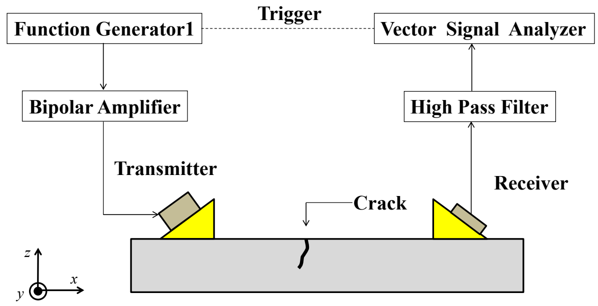

Fig.2 Experimental set-up.

3. Method

First, computer simulation using finite element method (ComWAVE™) for the acoustic field of second harmonic pulse waves in a plate near a crack. This is the conventional method of

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Lamb waves.

Secondly, the experimental set-up is shown schematically in **Fig. 2**. The electrical signals were generated from a function generator and were amplified to 140 V_{pp} with a bipolar amplifier. These signals were applied to the transmitting transducer. The transducers used as the transmitter and receiver were both $PbTiO_3$ piezoelectric disks of $\phi = 15$ mm with resonance frequencies of (1) 500 kHz and 1 MHz, (2) 235 and 470 kHz, respectively. Ultrasonic burst pulses (8 cycles) were transmitted through the carbon steel plate via a polystyrene wedge. The second harmonic of the Lamb wave was generated by nonlinear vibrations in the closed crack and was detected by the receiver. The received pulses were passed through a high-pass filter (the cut-off frequency was 1.0 kHz) to remove the DC component. Finally, the received pulse waveform and its spectrum were captured by a vector signal analyzer. The second harmonic could be observed in real time using the fast Fourier transform (FFT) function of the vector signal analyzer. In experimental (2), the pulse inversion averaging (PIA) method [1] was applied to enhance the second harmonic signal. The PIA method involves time averaging the received wave to cancel out the fundamental and odd frequency components.

The carbon steel plate used was a 100 mm × 200 mm × 10 mm standard test piece for nondestructive evaluation (Sonaspection company, PL 18399). The Lamb waves were transmitted along the x-axis.

4. Results and Discussion

The results of acoustic field of second harmonic pulse waves in a plate near a crack are shown in **Fig. 3**. Second harmonic components were distributed back and forth of the crack.

The example of measured waveforms and spectra in conventional method are shown in **Fig. 4(a)** and **4(b)**, respectively. **Figure 4(c)** shows the detected second-harmonic signal when the transducers are moved at 20-mm intervals along the y-axis, which are less-accurate results, therefore closed cracks will be hardly explored using second-harmonic components.

On the other hand, the results of our proposal method as shown in **Fig. 4(d)**. The detected second-harmonic signals were higher-accurate compared with the conventional method (Fig. 4(c)). The second-harmonic components at y = 20 mm was higher by approximately 7 dB compared with the other measurement points. This result coincided well with the crack location denoted in the manual data sheet of the test piece. Consequently, we have demonstrated the availability of our method for

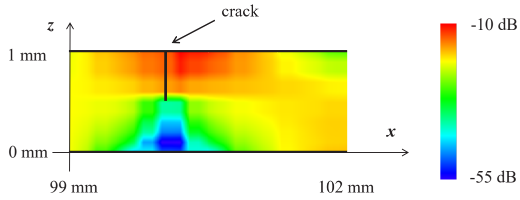

Fig.3 Computer simulation result of acoustic field of second harmonic components in a plate near a crack using finite element method.

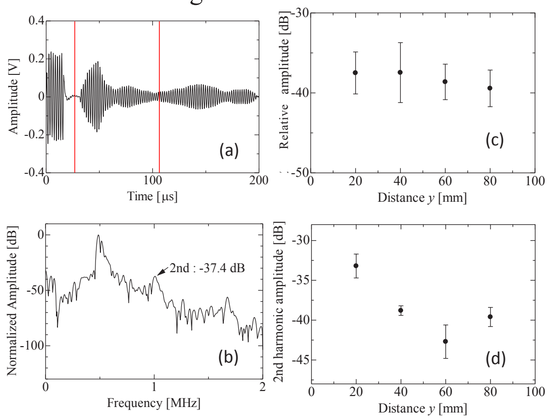

Fig. 4 (a) Received waveform, (b) its spectrum and (c) relation between second-harmonic components and Lamb wave propagation area for conventional method. (d) Relation between second-harmonic components and Lamb wave propagation area for our proposal method using Lamé mode.

closed crack detection in welding defects.

5. Conclusions

Lamb waves were transmitted into a carbon steel plate with welding defects and the second-harmonic signal generated from closed cracks was detected. In the area containing a closed crack, the second harmonic intensity was increased by approximately 7 dB compared with the crack-free areas. In future studies, we will introduce optical detection techniques, such as laser Doppler vibrometry, to increase the precision of locating the closed crack with second-harmonic detection.

Acknowledgment

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