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Second Harmonic Components Detection of Lamb Waves from Fatigued Metal Plates

疲労負荷を与えた金属板から生じる 2 次高調波 Lamb 波の検出

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1. Introduction

Magnesium has recently been used as a weight-saving material in notebook personal computers or component parts of cars. This follows research on the mechanical behavior of magnesium as deformations and cracks result in significant accidents.

Infinitesimally small amplitude ultrasonic pulse waves, which are useful for finding open cracks, are used in most conventional NDE methods. However, dislocations and closed cracks (micro cracks) are not easily detected. Recently, nonlinear ultrasonic (second harmonic or sub-harmonic) pulse waves have been studied for use in NDE [1-4]. The second harmonic frequency component $2f_0$ is generated in nonlinear vibrations of micro cracks and surfaces of solids, in a process called contact acoustic nonlinearity (CAN) for the finite-amplitude ultrasonic waves with fundamental frequency component f_0.

In this paper, Lamb waves are transmitted through pure magnesium plates subjected to various degrees of fatigue testing and the second harmonic components generated within the plates are detected. Increase in second harmonic components and its possible use in determining mechanical properties of magnesium are discussed.

2. Double-Layered Piezoelectric Transducer

The DLPT, which can transmit finite-amplitude ultrasonic waves and receive a second harmonic component, was used to construct a simple pulse-echo system. The DLPT was composed of two $PbTiO_3$ thickness-mode piezo-ceramic plane disks that have the same characteristics (resonance frequency f_0 = 1 MHz). Both disks were stacked and bonded together with electroconductive silver paint so that their respective polarizations were bonded to each other in opposite directions. The DLPT was electrically connected in parallel or in series as shown in Fig. 1(a) and 1(b). Their frequency-admittance

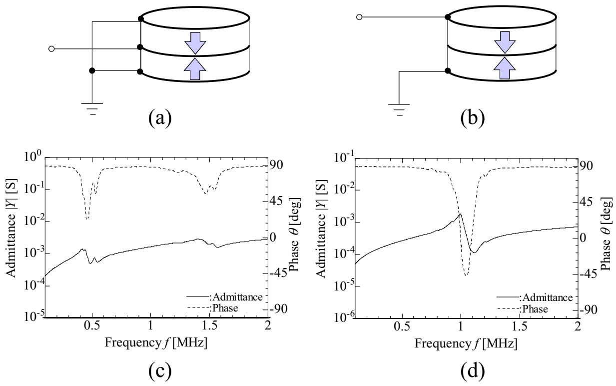

Fig.1 Double-layered piezoelectric transducer (a) in parallel and (b) in series connection. And their frequency-admittance characteristics (c) in parallel and (d) series connection.

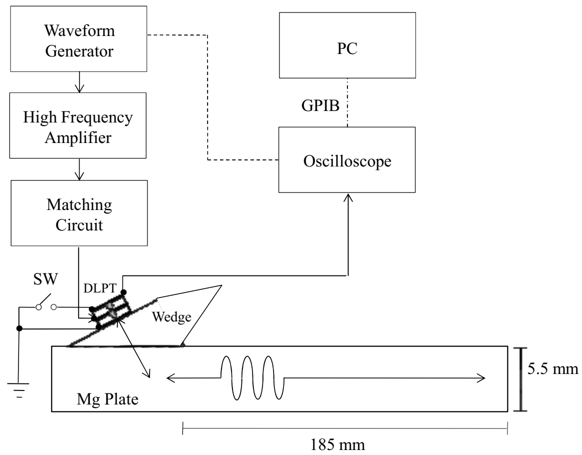

Fig. 2 Experimental set-up.

characteristics when connected in parallel and in series are shown in Fig. 1(c) and 1(d). The resonance frequency changed to 500 kHz (f_0 /2) when connected in parallel, but remained at 1 MHz (f_0) when connected in series [5]. An effective fundamental transmission (500 kHz) was obtained when the DLPT was electrically connected in parallel while efficient second harmonic reception (1 MHz) was obtained when the DLPT was connected in series [6].

3. Experimental

The material under study was pure

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magnesium. The magnesium plates were extruded perpendicular to the longitudinal direction. The samples were subjected to cyclic tensile-stress under controlled conditions. The stress-amplitude, σ_a, was 28.3 MPa, the stress ratio, R, was 0, and the frequency was 30 Hz, which were controlled by a hydraulic servo fatigue tester (FT-5; Saginomiya, Tokyo, Japan) at room temperature. The fatigued samples were prepared separately using a varied number of cycles, where sample No. 1 had 0 cycles, sample No. 2 had 1×10^5 cycles, and sample No. 3 had 2×10^5 cycles.

The experimental set-up is shown schematically in Fig. 2. Transmission signals were generated using an arbitrary waveform generator and their amplitudes were amplified to 100 V with a bipolar power amplifier (NF Corporation, BA4825). These signals were applied to the DLPT in parallel connection electrically. Ultrasonic pulses of 500 kHz were transmitted through the magnesium plate via the epoxy resin wedge. S0 mode Lamb waves were generated as ultrasonic pulse waves propagated through the magnesium plates. The second harmonic components of the Lamb waves were generated by the nonlinear vibrations of the micro cracks. Reflected Lamb waves at the edge of the magnesium plate were received by the DLPT in series connection electrically. The resultant pulse waveform and spectrum were captured by an oscilloscope (Agilent, Infiniium 54845A) and the second harmonic components could be observed in real time using the FFT function of the oscilloscope. Finally, the received pulse waveforms were digitized and fed into a personal computer via a general purpose interface bus (GPIB).

4. Results and Discussion

Fig. 3 shows received waveforms and spectra after pulse inversion averaging (PIA). Figure 3(a) and 3(b) shows results from plate No. 1. The second harmonic component in Fig. 3(b) would be generated by CAN at the interface between the transducer and the wedge or the wedge and the plate [4]. This was the more commonly generated component in all three plates. Figure 3(c) and 3(d) shows respectively the results of a received waveform in No. 3 plate and its spectrum. The second harmonic component is seen in Fig. 3(d) to have been increased by 6 dB compared to that of plate No. 1 [Fig. 3(b)]. The signal would be generated from micro cracks caused by the fatigue tests. Second harmonic components have thus increased as the fatigue test cycles were increased.

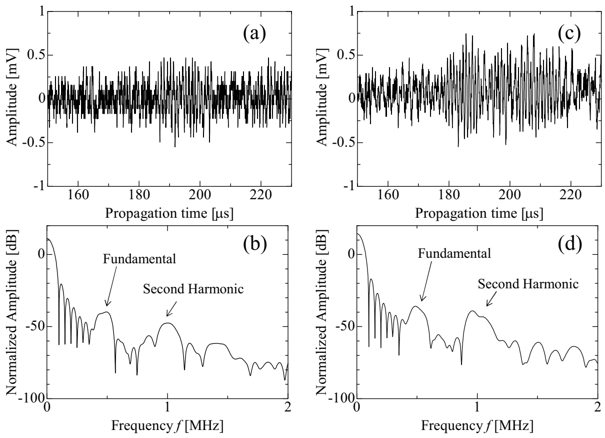

Fig. 3 Results after PIA:
(a) received waveform in No. 1 and (b) its spectrum;
(c) received waveform in No. 3 and (d) its spectrum.

5. Conclusions

Lamb waves of finite amplitude were generated in pure magnesium plates with varying distribution of micro cracks. Second harmonic components had increased as the number of fatigue test cycles producing the stress faults was increased. At 2×10^5 cycles, second harmonic components had increased by approximately 6 dB compared with an unstressed plate. From these results, we confirmed that second harmonic components had been effectively detected micro cracks in the magnesium plates.

In the future, structural analysis of sections through these plates will be performed to identify the source of the second harmonic pulse waves.

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