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Measurement of nonlinear three-wave interaction by shear-vertical-wave point-focusing electromagnetic acoustic transducers

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1. Introduction

Nonlinear ultrasonic methods have been widely studied for applications to microcrack detection, fatigue damage evaluation, and so on. In particular, the nonlinear three-wave interaction method[1,2] is expected to be put into practical use due to its superior spatial and frequency selectivity compared to harmonics methods. In the measurement of nonlinear ultrasound, piezoelectric transducers, which have high ultrasonic excitation efficiency, are generally used because large-amplitude ultrasound is required to generate nonlinear ultrasonic waves. However, they need couplants to transmit and receive ultrasonic waves into the specimen, and then obtained waveforms are highly sensitive to the coupling states between the transducers and the specimen surfaces. Therefore, non-contact measurements are desired, particularly for on-site evaluations.

To solve the above problem, we propose a measuring method using the nonlinear three-wave interaction by shear-vertical-wave point-focusing electromagnetic acoustic transducers (SV-wave PF-EMATs[3,4]) as a non-contact nonlinear ultrasonic method.

2. Measurement principle

Figures 1 (a) and (b) show the layout sketch and driving mechanism of the SV-wave PF-EMAT[3,4]. It is composed of a permanent magnet and a concentric meander-line coil. By applying high-power RF tone bursts to the coil, eddy currents are induced near the surface of the metallic material, and the Lorentz forces generated by the interaction between the eddy currents and the magnetic field from the permanent magnet produce the shear deformation, which creates the SV-wave sources. Thus, the PF-EMAT can excite ultrasonic waves with no couplants. In addition, the pitches of the meander-line coil are designed so as to make the SV waves emitted from individual sound sources overlap at the focal point in phase, achieving a large displacement there.

Figure 2 shows the schematic of nonlinear three-wave interaction[1,2]. When two incident waves with frequencies of f_1 and f_2 intersect, the third waves with the frequencies of $f_1 \pm f_2$ are generated by material's nonlinearity related to anharmonicity, dislocations, microcracks, and so on, which is called nonlinear three-wave interaction. The nonlinear ultrasonic method using nonlinear three-wave interaction is a valid method over general harmonics methods in spatial selectivity and frequency selectivity: While harmonics have many potential sources other than the material such as amplifiers, transducers, couplants, and so on, the sources of nonlinear three-wave interaction are limited to the region where the two incident waves intersect and the frequencies of the third waves can be separated from harmonics of the incident waves, which allows selective evaluation of material nonlinearity.

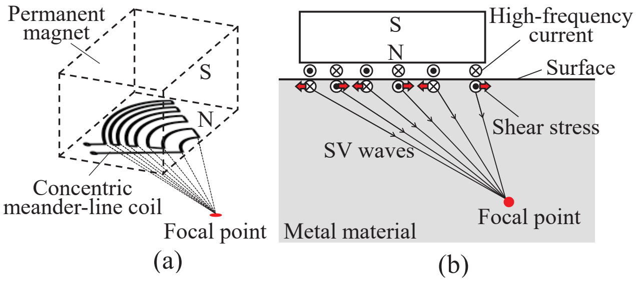

Fig.1 (a)Layout sketch and (b)driving mechanism of the SV-wave PF-EMAT.

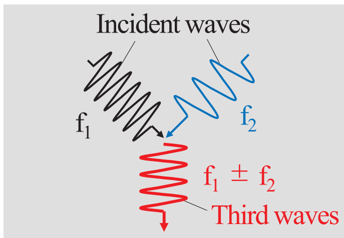

Fig. 2 Schematic of nonlinear three-wave interaction.

3. Experiments

We experimentally investigated the applicability of originally developed PF-EMATs to the generation of nonlinear three-wave interaction. **Figure 3** shows the experimental setup. The specimen was an aluminum plate of 30 mm thickness and two PF-EMATs with different driving frequencies (2 and 2.75 MHz) were placed facing

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each other so that their focal points were matched each other, at which the nonlinear three-wave interaction was generated. High-power RF tone bursts were applied to their coils. For both the peak-to-peak voltage was about 2000 V, and the number of burst cycles was 10. The incident angles of the excited waves were about 14°-36°. For receiving, we adopt a needle-type transducer (pinducer) with a piezoelectric element of Φ1.5 mm, on which a needle was attached to measure the local vibration at the focal point in a dry contact without any coupling materials.

Figures 4 (a) and (b) show the waveforms received by the pinducer at the focal point when only the 2 MHz PF-EMAT and only the 2.75 MHz PF-EMAT are separately excited, respectively. For both EMATs, the focused waves were correctly received at the focal point. **Figure 4 (c)** shows the waveform received when the two PF-EMATs were driven simultaneously, and **Figure 4 (d)** shows the sum of the waveforms received when the two PF-EMATs were driven separately. There appears to be no difference between the two waveforms. But there are obvious differences in the FFT spectra; we find clearly spectral peaks around the sum and difference frequencies of the incident waves when the two PF-EMATs were driven simultaneously, as shown in **Fig. 5**. These peaks are considered to indicate the nonlinear three-wave interactions mainly due to the nonlinearity in the contact interface between the specimen and the needle of the pinducer.

4. Conclusions

We proposed the measuring method using the nonlinear three-wave interaction by SV-wave PF-EMATs and experimentally confirmed that the nonlinear three-wave interaction can be generated by the PF-EMATs. In the future, we will investigate the applications of this method to microcrack detection, fatigue damage evaluation, and so on.

References

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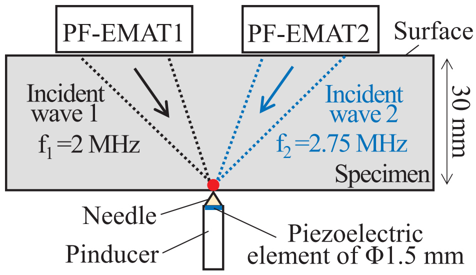

Fig. 3 Experimental setup.

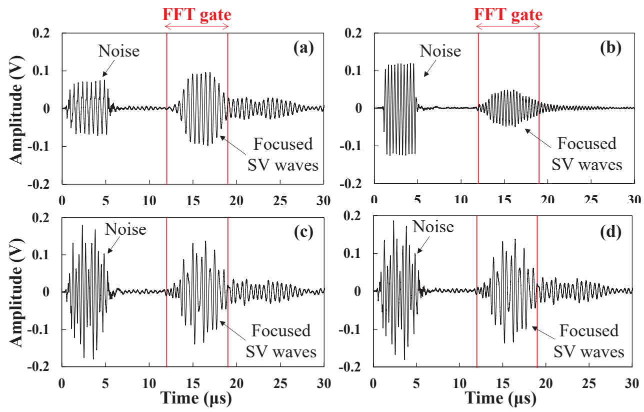

Fig. 4 Waveforms received by the pinducer at the focal point: (a)Only the 2 MHz PF-EMAT driving. (b)Only the 2.75 MHz PF-EMAT driving. (c)The two PF-EMATs simultaneously driving. (d)The sum of the waveforms (a) and (b).

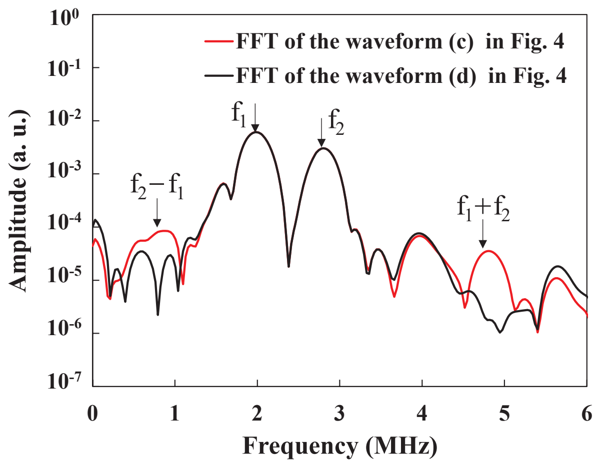

Fig. 5 FFT spectra of the waveforms (c) and (d) in Fig. 4.