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Nonlinear Surface-Acoustic-Wave Phased Array with Fixed-Voltage Amplitude Subtraction Method

電圧固定振幅差分法による非線形表面波フェーズドアレイ

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1. Introduction

Surface-acoustic-wave phased array (SAW PA) for contact testing was proposed for measurement of crack length, and linear SAW PA was verified in a fatigue crack and a stress corrosion crack (SCC).[1)] To measure closed crack length, the combination of SAW PA with nonlinear ultrasonics would be useful. Among nonlinear components, subharmonics and superharmonics have been widely investigated. Although large-amplitude incidence is required for subharmonic generation, it is not easy to excite large amplitude in SAW PA with a wedge because of mode conversion and leaky loss. On the other hand, although the threshold of superharmonics is lower than that of subharmonics, the superharmonics generated in transducers, liquid couplants can hide that generated in closed cracks. As another issue, a piezoelectric transducer cannot receive all nonlinear components with different frequencies due to the frequency characteristics of the piezoelectric transducer. Recenlty, as a promising technique to solve the above problems, a fixed-voltage amplitude subtraction method of utilizing the feature of phased array has been proposed for the measurement of closed-crack depth with bulk waves.[3,4)]

In this study, we propose a combination of SAW PA with the fixed-voltage amplitude subtraction method and demonstrate its advantages in inspection of a closed SCC specimen.

2. Nonlinear SAW PA with fixed-voltage amplitude subtraction method

The concept of SAW PA with the fixed-voltage amplitude subtraction method is shown in Fig. 1. The all-, odd-, and even-elements of an array transducer are employed for transmission. For linear defects, the subtraction of all response from the sum of odd and even responses becomes zero. On the other hand, for nonlinear defects such as closed cracks, the received waveforms for all-element transmission distort, which corresponds to the generation of nonlinear components in frequency region, due to the nonlinearity caused by the contact vibration of crack faces. Note here that the energies of nonlinear components are distributed from that of the fundamental wave. Therefore, by filtering the responses at around the fundamental frequency and thereafter subtracting all response from the sum of the odd and even responses, all nonlinear components can be measured. The advantage of this method is that there is no need to directly receive all nonlinear components with various frequencies that cannot be measured by a piezoelectric transducer with a limited frequency bandwidth. Also the effect of nonlinearity other than closed cracks, which are liquid couplants, transducers, etc., can be avoided because the excitation voltage is fixed. Thus, the nonlinear SAW PA can selectively visualize closed cracks in the vicinity of surface.

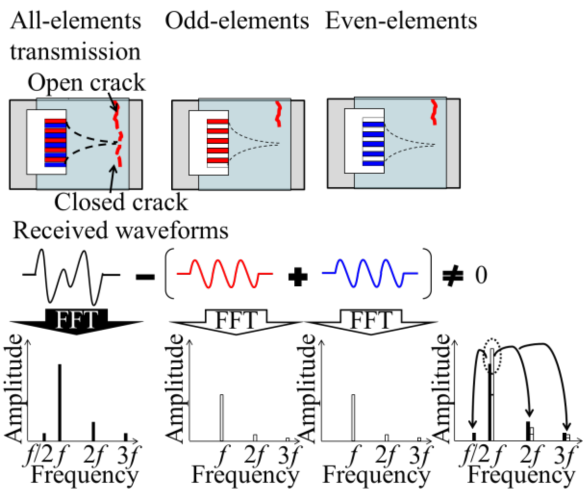

Fig. 1. Principle of nonlinear SAW PA.

3. Experimental conditions

We used a specimen (A7075) with a slit and a specimen (SUS304) with an SCC extended from the tip of fatigue precrack.[5)] A linear array transducer (2.5 MHz, 32 elements) was placed on a polystyrene wedge with a critical angle of Rayleigh wave.[1)] 183 transmission focal points with θ=-30~30° (1° step) and r=15~35 mm (10 mm step) were set. The imaging area was 20 mm × 20 mm (0.5 mm step) just beneath the wedge. The excitation voltage was three-cycle burst with a center frequency of 2.5 MHz and 150 V. The band-pass filter with 1.5-3.5 MHz was selected to extract only the fundamental component.

4. Experimental results

Imaging results of the slit are shown in Fig. 2. The slit was clearly visualized in The linear image (Fig. 2 (a)) obtained by all-elements transmission clearly indicated the slit response, whereas the nonlinear image (Fig. 2(b)) did not indicate the slit response. This is reasonable because the slit is a linear defect. This also suggests that the superharmonics generated in the transducer and the liquid couplant was eliminated.

After confirming the fundamental performance of the nonlinear SAW PA, the SCC specimen was imaged, as shown in Fig. 3. The linear image (Fig. 3(a)) dominantly indicated the fatigue precrack. This shows that the fatigue precrack was open. On the other hand, the nonlinear imaging (Fig. 3(b)) indicated only the SCC. This suggests that the SCC was dominantly closed.

For the further proof of this concept, we examined the amplitude spectra of the delay-and-sum waveform at the points A in Fig. 2 and B in Fig. 3, for each transmission mode, as shown in Fig.4. The amplitude spectra for all-elements transmission and the summation of odd- and even-transmissions were the same in the slit specimen (Fig. 4 (a)). On the other hand, the significant difference at the fundamental frequency was observed between all-elements transmission and the summation of odd- and even-elements transmission, as shown in Fig. 4(b). This can be understood by assuming the larger energy of the fundamental component was distributed in all-elements transmission than in the summation of odd- and even-elements transmission due to the contact vibration induced by large-amplitude incidence. It is noteworthy that the difference in the fundamental components cannot be interpreted as the subharmonic generation because the difference of the amplitude was much smaller in the subharmonic frequency than in the fundamental frequency. This suggests that the main origin of the fundamental difference was attributed to the superharmonic generation, although it was not received due to the limited frequency bandwidth of the array transducer.

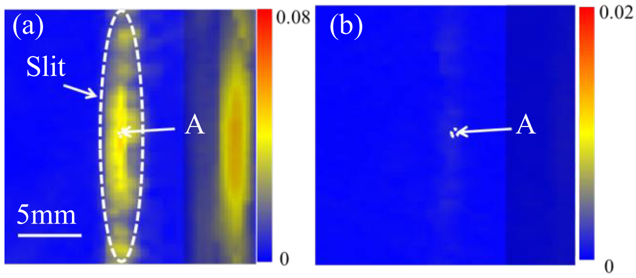

Fig. 2. Imaging results of the slit; (a) linear and (b) nonlinear images.

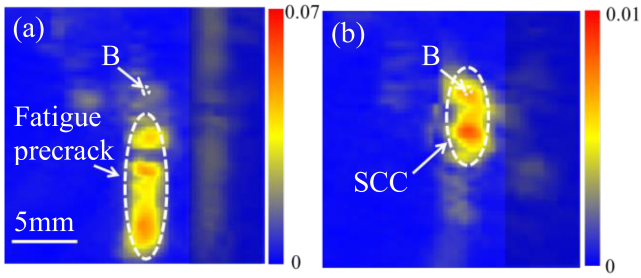

Fig. 3. Imaging results of the crack; (a) linear and (b) nonlinear images.

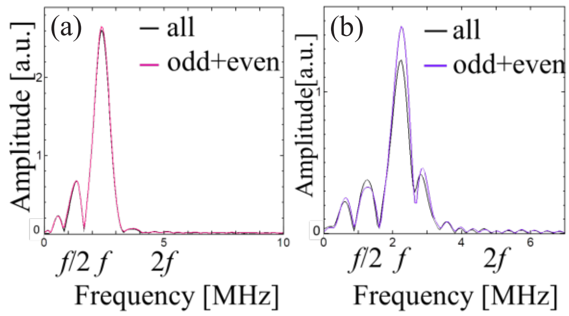

Fig. 4. Amplitude spectra of shift-summed waveform; (a) the slit and (b) the SCC.

5. Conclusions

We proposed nonlinear SAW PA with the fixed-voltage amplitude subtraction method. It was demonstrated in a slit and closed SCC specimens.

Acknowledgment

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