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Observation of closed crack distribution by steering intense ultrasound and with shoe to house transmitter and receiver

大振幅超音波の偏向角制御と送受信一体型探触子シューによる閉じたき裂の分布観察

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1. Introduction

To keep the safety of structures such as airplanes and atomic power plants, it is needed to evaluate the strength of materials by measurement of crack depths. However, common ultrasonic methods can not detect closed cracks influenced by compressive residual stresses and so on. It is a source of serious errors. For this problem, nonlinear ultrasound[1)] which utilizes contact vibration between closed crack faces caused by inputting intense ultrasound has attracted attention. We considered that subharmonic waves[2,3)] at half frequency of input wave occur only from cracks and have high temporal resolution. And we developed a novel imaging method SPACE (Subharmonic Phased array for Crack Evaluation). In early studies, we have shown the benefit in imaging of closed fatigue cracks[4,5)] and stress corrosion cracks[5)] .

In this study, we improve the scanning performance of SPACE for field inspections. We fabricate lithium niobate $LiNbO_3$ single-crystal (LN) transmitter array to steer intense ultrasound electrically. We also fabricate a shoe to move transmitter and receiver together. Finally, we observe closed crack distribution in crack length direction precisely.

2. Steering intense ultrasound

Figure 1 shows the configuration of SPACE. We input intense ultrasound by LN with high withstand voltage attached to polyimide wedge and receive scattered waves by PZT receiving array. We extract linear scatter from open cracks (fundamental wave) and nonlinear scatter from closed cracks (subharmonic wave) by the digital filter, and then image open and closed cracks by focusing on reception respectively.

In this study, we fabricated an 8-channel LN transmitter array to control steering angle electrically for imaging closed cracks over a wider area. Then we examined its steering performance.

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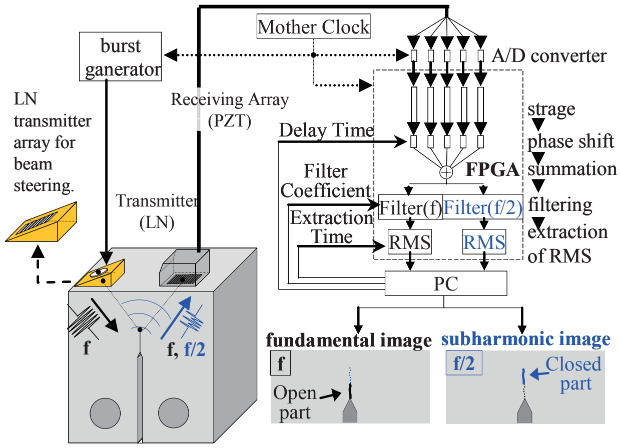

Fig. 1 Experimental configuration of SPACE.

Experimental configuration is shown in **Fig.2 (a)** and the material of the specimen is A7075. We applied voltage of 7 MHz, 400 V, 3 cycle with a delay law for steering,

$$t_n = \frac{1}{c}\left\{ d\sin\theta_s\left(n-\frac{N-1}{2}\right)+\frac{d^2}{2F}\cos^2\theta_s\left(n-\frac{N-1}{2}\right)^2\right\}+t_0$$

where t_n is the required time delay for the nth element (n=1, 2, …, 8), t_0 is a constant to keep the delays positive, c is wave speed in the medium, d is element pitch, θ_s is steering angle, N is the number of element and F is the focal length (actually we input a focal point at angle of θ_s). We measured the displacement amplitudes by a laser interferometer at positions equivalent to from 30° to 88°.

The results are shown in **Fig. 2 (b)**. Longitudinal axis indicates the peak-to-peak displacement amplitudes and horizontal axis indicates positions with equivalent steering angles. Open circles show displacement distribution for a beam steered at θ_s = 41° and it peaked at about 32 nm at the position 41°. Likewise in steering angle θ_s = 59°, the position of the peak corresponded with the steering angle θ_s and it achieved the displacement of 24 nm. In steering angle θ_s = 74° and 87°, however, the peaks appeared at position 70° and 76° respectively. It is due to be steered at 45° by the wedge.

Thus we demonstrated that our 8-channel LN transmitter array can steer intense ultrasound of more than 20 nm at 30° to 60°.

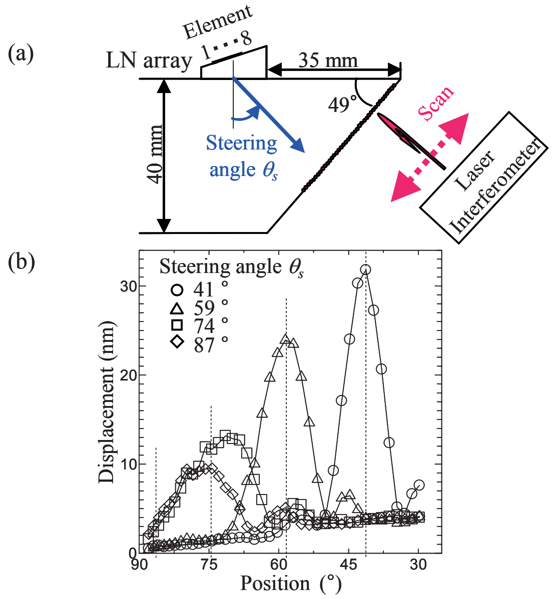

Fig. 2 Beam steering performance of 8-channel LN transmitter array. (a) Measurement configuration. (b) Displacement distribution.

3. Shoe to house transmitter and receiver

SPACE had not been suitable for real-time inspections, because it is hard to control transmitter and receiver at the same time. To solve this issue, we fabricated an acrylic shoe to house transmitter and receiver (**Fig.3**). We hold them by pushing receiver from side with screw and press top surfaces with lids. The shoe gives us to scan transducers very easily.

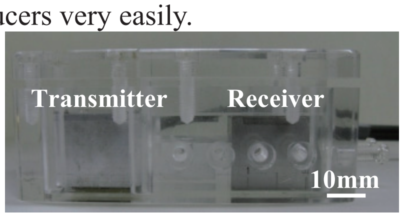

Fig. 3 Shoe to house transmitter and receiver.

4. Observation of closed crack distribution

We observed closed fatigue crack distribution in CT specimen (A7075) shown in Fig. 1 with the shoe. The Shoe house LN single element transmitter with steering angle of 45° and center frequency at 7MHz and PZT receiving array with 31elements and center frequency at 5MHz. The input signal was a three-cycle burst of a 7 MHz sinusoidal wave with a 35 $nm_{p\text{-}p}$ amplitude. We set it to make ultrasound beam to propagate 16 mm above a notch. We measured from the center part of specimen to near the back side with step of 2mm. Obtained images are shown with a notch in Fig.4. In (a), (b), (c), (d), crack tips were observed both in fundamental and subharmonic images. In (e), (f), however, crack tips observed only in subharmonic images. From these results, we found that cracks were more closed near the side than near the center. This can be understood by considering the tensile stress during fatigue test. On Side surfaces tensile stress is relaxed due to deformation in the length direction. Consequently closed cracks are formed easily. Thus we succeeded in observation of closed crack distribution.

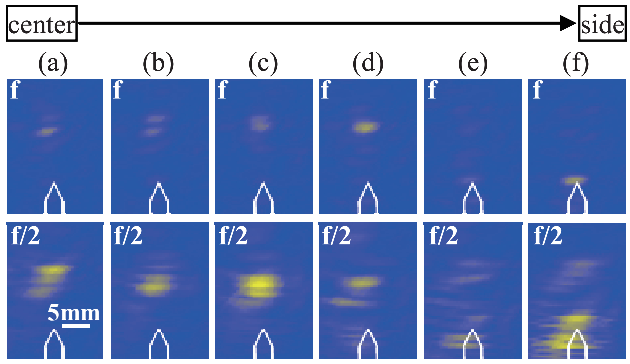

Fig. 4 Observation of closed crack distribution.
(a) 18mm ,(b) 20mm, (c) 22mm,(d) 24mm, (e) 26mm, (f) 28mm from the front side of CT specimen which is 37 mm long.

5. Conclusion

We improved scanning performance of SPACE for field inspections. Our 8-channel LN transmitter array can steer intense ultrasound of more than 20 nm at 30° to 60°.It enables to image closed cracks over a wider area without replacement transmitter. Next, we fabricated a shoe to house transmitter and receiver for easier scanning. We imaged fatigue cracks by scanning the shoe on CT specimen (A7075) from center to near side in the crack length direction. As a result crack tips were observed only in subharmonic image near side. From this result, we found that cracks are more closed near side than in center. It corresponds with fracture-mechanical interpretation. Therefore, we demonstrated the efficacy of SPACE with shoe for observation three-dimensional closed crack distribution.

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