1P2-14

Incident-Wave-Amplitude Dependence of Closed Crack Imaging by Nonlinear Ultrasonic Phased Array with Fixed-Voltage Amplitude Subtraction

固定電圧振幅差分非線形フェーズドアレイによる閉じたき裂映像化の入射波振幅依存性

Hiromichi Nakajima[1‡], Yoshikazu Ohara[1], Sylvain Haupert[2], Toshihiro Tsuji[1], and Tsuyoshi Mihara[1]
([1]Grad. School Eng., Tohoku Univ., [2]Sorbonne University)
中島弘達[1†‡], 小原良和[1], Sylvain Haupert[2], 辻俊宏[1], 三原毅[1] ([1]東北大院 工, [2]ソルボンヌ大学)

1. Introduction

Nonlinear ultrasonics has been a primary means for measuring closed cracks that cannot be detected by conventional ultrasonic testing. Recently, its combination of phased array imaging, which is referred to as nonlinear ultrasonic phased array, has been studied, and have had efficacy demonstrated in closed cracks.[1-4] Among them we here focused on the nonlinear ultrasonic phased array with fixed-voltage amplitude subtraction.[4] In the past studies, all the measurement was done at a constant incident wave amplitude for all-elements transmission.[4] However, the incident wave amplitude is a vital parameter for the observation of nonlinear phenomena.

In this study, the incident-wave-amplitude dependence of linear and nonlinear images was examined in a closed fatigue crack by varying the number of elements (aperture) at a fixed voltage. Furthermore, the imaging results were interpreted on the basis of finite element simulation.

2. Nonlinear ultrasonic phased array with fixed-voltage amplitude subtraction

Nonlinear ultrasonic phased array with fixed-voltage amplitude subtraction is illustrated in **Fig. 1**. The all-, odd-, and even-elements of an array transducer are employed for transmission, which are referred to as T_{All}, T_{Odd}, and T_{Even}, respectively. For open cracks (linear defects), the subtraction of response for T_{All} from the sum of responses of T_{Odd} and T_{Even} should become zero. For closed cracks, T_{All} can cause the contact vibration of crack faces, resulting in the generation of nonlinear components ($2f$, $f/2$, …), whereas T_{Odd} and T_{Even} may not generate such nonlinear components due to smaller amplitude incidence than T_{All}. Note that the energies of nonlinear components generated at closed cracks come from fundamental component. Therefore, by examining the decrease in fundamental components on the basis of the subtraction, all nonlinear components can be indirectly measured. In this study, to examine the dependence of linear and nonlinear images on incidence wave amplitude, the number of elements used for transmission was increased from 32 to 128.

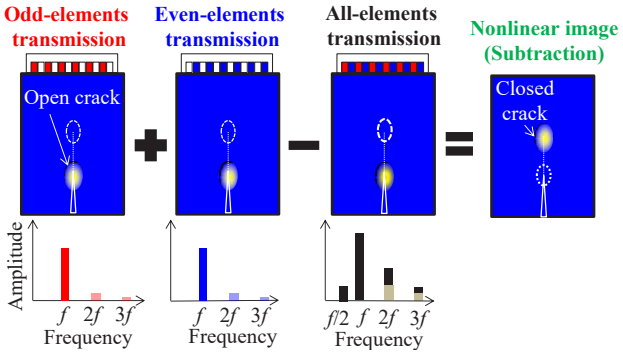

Fig. 1 Principle of nonlinear ultrasonic phased array with fixed-voltage amplitude subtraction.

3. Experimental conditions

An experimental configuration is shown in **Fig. 2**. A fatigue crack sample[5] made of aluminum alloy A7075 was used. A linear array transducer (5 MHz, 128 el) was placed on the top of specimen and the crack was imaged with varying the number of elements (aperture) from 32, 64, 96 and 128 to increase the incident wave amplitude, where a phased array hardware, OEM-PA 128/128 (Advanced OEM Solutions (AOS)), was selected since its solid performance has been demonstrated.[4] The transmission focal points were set to x=-5 to 5 mm with 0.5 mm step at z=30 mm. The excitation voltage was 3-cycle burst with 5 MHz and 145 $V_{p\text{-}p}$. A band-pass filter from 2.5 to 7.5 MHz was employed to extract fundamental components from received waves. The imaging area was selected to 10 mm x 25 mm with 0.1 mm step around the crack.

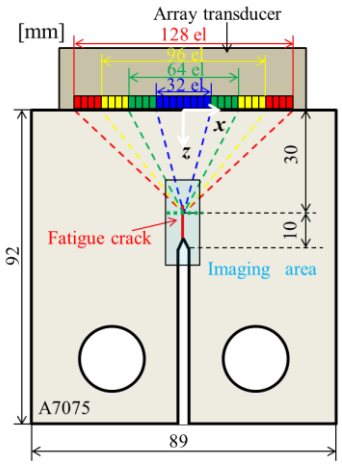

Fig. 2 An experimental configuration

4. Experimental results

Figure 3 shows linear (T_{All}) and nonlinear ($=T_{Odd}+T_{Even}-T_{All}$) images obtained for 32, 64, 96 and 128 elements. In all the linear images, a strong response at the notch and a weak one at a part of the fatigue crack appeared, whereas the crack tip was invisible. On the other hand, in the nonlinear image for 32 elements, the upper part A of the crack was selectively visualized with successfully cancelling the responses appeared in the linear image. However, the signal-to-noise ratio (SNR) was insufficient. In the nonlinear image for 64 elements, the response at crack B deeper than A appeared in addition to the increase in the response at A. In the nonlinear images for 96 and 128 elements, the responses at A and B were further increased. This suggests that the increase in the incident wave amplitude allows one to visualize closed cracks with a sufficiently high SNR.

As a discussion, we examined the incident-wave-amplitude dependence of the crack responses in the nonlinear images in detail. In Fig. 3, it seems that the crack responses increased from 32 to 96 elements, whereas they had a small difference between 96 and 128 elements. For this interpretation, the incident wave amplitude was examined for 32 to 128 elements by finite element simulation software (ComWAVE). As the result (**Fig. 4**), the incident wave amplitude linearly increased until 64 elements, and then it was saturated. This is because elements around the edge of the array transducer have a small contribution to the focusing in the case of large aperture (96 and 128 elements). This result was in a good agreement with the tendency of Fig. 3. In future, the optimal aperture for nonlinear ultrasonic phased array needs to be investigated further.

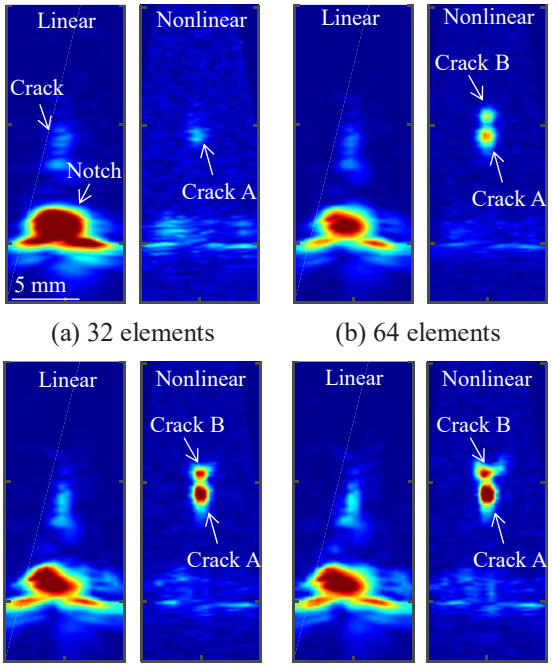

Fig. 3 Imaging results of the crack

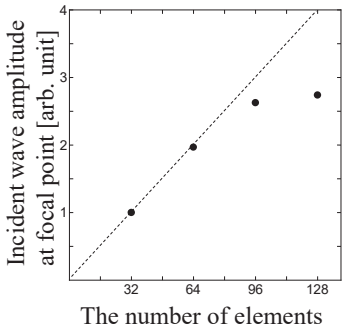

Fig. 4 Relationship between incident wave amplitude and the number of elements calculated by a simulation.

5. Conclusions

We examined the incident-wave-amplitude dependence of nonlinear ultrasonic phased array with fixed-voltage amplitude subtraction. Consequently, it was clarified that a high SNR can be achieved in closed-crack imaging by increasing the incident wave amplitude.

Acknowledgment

The authors thank AOS for a kind support with respect to the phased array hardware (OEM-PA).

References

1) Y. Ohara, et al.: APL **90**, 011902 (2007).
2) Y. Ohara, et al.: APL **103**, 031917 (2013).
3) J. N. Potter, et al.: PRL **113**, 144301 (2014).
4) S. Haupert, et al.: NDT&E Int. **87**, 1 (2017).
5) Y. Ohara, et al.: Ultrasonics **51**, 661 (2010).