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Proposal of low-frequency phased array for highly attenuative materials and its fundamental study for large amplitude incidence

高減衰部材評価のための低周波超音波フェーズドアレイの提案と大振幅化の基礎検討

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1. Introduction

Imaging by ultrasonic phased array with the order of MHz has been used for the inspection of metals. However, the inspection of weld of nuclear power plants and concrete is difficult since they are highly attenuative for MHz range frequencies. For such materials, the use of low frequency (LF) would be effective because the attenuation is weak for LF. However, LF array transducer that all elements are arranged in a case[1)] cannot avoid the inter-element crosstalk because of its low attenuation.

Another key to increase signal-to-noise ratio (SNR), is large amplitude incidence. However, conventional array transducers cannot withstand high-voltage excitation because of its low dielectric breakdown voltage. Eventually, the effective excitation voltage has been typically limited to less than 100 V.

To overcome those issues, we propose new LF phased array with individual elements for highly attenuative materials. We designed LF array transducers in consideration of using a transformer. We fabricated them and demonstrated their usefulness in terms of higher excitation voltage and enough SNR in waveform of received signal.

2. LF phased array system with individual elements

Fig. 1 shows the schematic of LF phased array system. To avoid the inter-element crosstalk that is the biggest issue particularly for LF excitation and realize a high dielectric breakdown voltage required for large-amplitude incidence, we propose an array transducer with an air gap between elements by individually casing each element with a piezoelectric material that has a lower resonance frequency than 1 MHz. These elements are connected to phased array hardware, Thus, LF phased array system can visualize internal flaws in highly attenuative materials.

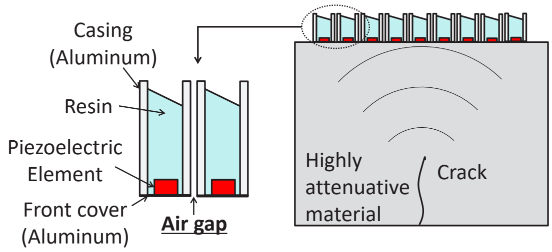

Fig. 1 LF phased array system with individual elements.

3. Designing and fabricating prototype of element of LF array transducer

It is important to select an appropriate frequency for the inspection of attenuative materials. Although LF can reduce the effect of attenuation, it also lowers the imaging capability in terms of sensitivity and sizing. In this study, we selected an frequency of 500 kHz to obtain a good balance between less attenuation and imaging capability.

It is also critical to select an appropriate piezoelectric material to obtain a large-amplitude incidence. Soft PZT (C9) is a strong candidate because it has a high piezoelectric strain constant. Although it cannot be readily used as high-frequency monolithic transducers due to the lower electrical impedance (EI) than pulsars, it can be used as the elements of LF array transducer since its EI should be high because of LF and its small size. Therefore, soft PZT (C9) was selected in this study.

To achieve larger incident amplitudes, EI matching and high-voltage excitation should be considered. To this end, a transformer with turns ratio 1: n was adopted, because it not only can lower the EI of LF array transducer to $1/n^2$ but also can boost the excitation voltage by n times when the EI of transducer is sufficiently higher than that of pulsar. To prove this concept, we fabricated the element(1) with an area of 80 mm^2 (Fig. 1 left).

The element(1) with the small size should show a low directivity, which is suited for a wide range imaging. On the other hand, to achieve a high SNR in the limited imaging area, a high directivity is required. Hence, we fabricated the element(2) with an larger area of 360 mm^2 than element(1).

4. Evaluations of the elements fabricated

We firstly measured the EI of elements (1) and (2) with and without a 1:4 transformer, as shown in **Fig. 2**. As a result, the EI of element(1) with 1:4 transformer was 45 Ω, which is close to the EI of a pulsar. On the other hand, the EI of the element(2) was 6 Ω as expected.

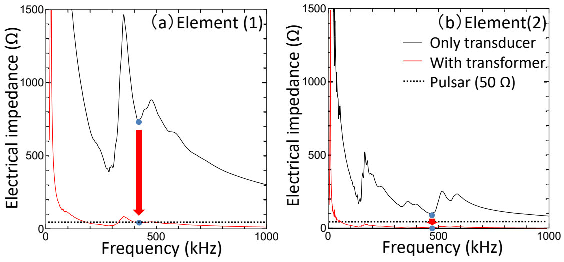

Fig. 2 Electrical impedance of elements (1) and (2).

Then we measured the effective excitation voltage for each element by a differential probe, as illustrated in **Fig. 3**, where the excitation voltage was set to 400 V in a pulsar setting. As a result, as shown in **Fig. 4(a)**, the effective excitation voltage of 1600 V was achieved for the element(1), showing that the 1:4 transformer effectively worked and the high dielectric breakdown was demonstrated. Note that the voltage is significantly high, given that the excitation voltage is about 100 V in conventional phased array imaging. On the other hand, for the element(2), as shown in **Fig. 4(b)**, the effective excitation voltage was 1300 V due to the low EI, which was lower than that for the element(1). Even so, the high excitation voltage of more than 1000 V was realized.

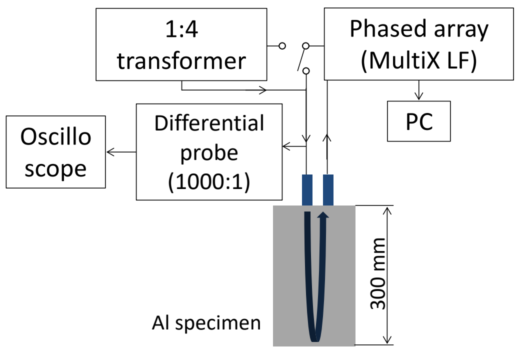

Fig. 3 Experimental configuration for measuring effective excitation voltage and bottom echoes.

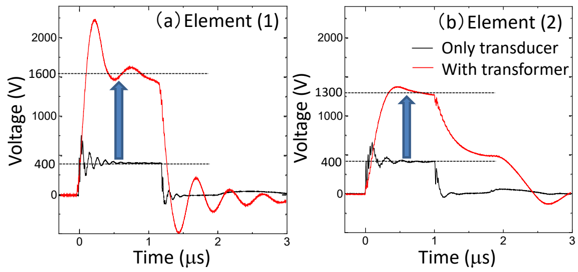

Fig. 4 Effective excitation voltage.

Finally, we measured the bottom echo to confirm the output of each transducer in the configuration of Fig. 3. For the element(1), as shown in **Fig. 5(a)**, high amplification factor due to the transformer was obtained. The SNR was sufficiently high. This suggests that the element(1) is suited for a wide area imaging. On the other hands, for the element(2), as shown in **Fig. 5(b)**, the bottom echo was larger than that for element(1), although the amplification factor due to the transformer was less than that for the element(1). This suggests that the element(2) is suited for a limited area imaging with a high SNR. Thus, an appropriate selection of element size depending on the case would be useful for practical application.

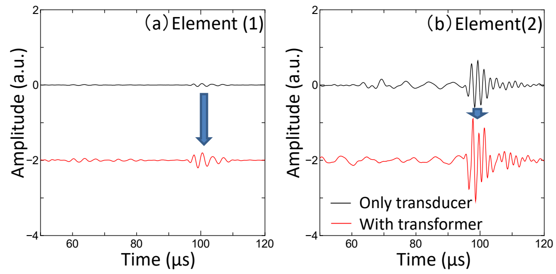

Fig. 5 Bottom echoes.

5. Conclusions

In this study, we proposed the LF phased array system with individual elements. By appropriately designing the piezoelectric element and the transformer, very high excitation voltages and sufficient outputs were realized. In future, we will demonstrate its imaging capability in inspection of attenuative materials.

Acknowledgment

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References

1) S.L.Crawford, A.D.Cinson, T.L.Moran, M.T.Anderson, A.A.Diaz : PNNL-20238 (2011).