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# Development of higher frequency laminated transducer with multi-channel pulser for subharmonic image inspection

分調波画像探傷のための積層探触子を用いた大変位超音波送信システムの高周波数化

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## 1. Introduction

Since all the sizing methods of a crack in the industrial structures by ultrasonic inspection uses a crack tip diffraction echo, the reliable detection of crack tip echo relate to the accuracy of the crack sizing and sometimes large error can occur when a crack tip is closed due to the residual stress introduced by the welding process and so on. For these low S/N ratio measurements in inspection, nonlinear ultrasound especially the subharmonic wave which generates a half frequency of the input ultrasound at crack is expected to enhance the amplitude of the crack tip diffraction echo. Although we developed SPACE [1] (Subharmonic Phased Array Crack Evaluation) of subharmonic imaging technique as an industrial measurement system, subharmonic ultrasound generated only for closed crack and many industrial cracks was not effective. The special pulser of conventional SPACE can generate about tens of nm displacement wave at the crack but the crack opening of industrial crack are considered to be several nm to a sub μm in order. Consequently, subharmonic wave generation could be observed only in small number of special closed cracks.

In order to use the SPACE system for industrial inspection widely, we must develop larger displacement ultrasound incidence equipment [3]. In this study, we developed the high frequency laminated piezoelectric transducer combining the multi-channel pulser [2]. Then the availability of the developed system was investigated using several model cracks.

## 2. Improvement of laminated piezoelectric transducer system

We have been proposed the laminated piezoelectric transducer system and fabricated low frequency system because lamination procedures of thick elements were easy to fabricate[2]. However industrial applications for power generate structures inspection high frequency of MHz order ultrasound is required. Thus in this paper, we tried to developed the laminated transducer of 5 MHz at max in frequency for the inspection of SCC in stainless steel structures. First trial for fabrication of high frequency transducer using conventional procedures, reproducibility of the waveform and the absolute value of displacement for transmitted ultrasound were both low. The cause of this problem could be considered that relative thickness of adhesive layer of 5 μm and electrode of 10 μm in average were too large comparing the thickness of high frequency piezoelectric element. Basic structure of 16-layer 8 channels laminated transducer was shown in Fig. 1. Black arrow in the element means the direction of polarization. With the 8 channel pulser, firstly a top of the 8th channel in this figure was excited by pulser 8 and when generated ultrasound transmitted to the lower channel elements next pulser 7 excited 7th channel with adequate delay time. Same procedures were repeated for 8 laminated elements and 8 channel pulsers with each delay time. Thus generated ultrasound by each element overlapped to large displacement. Uniformity and the thickness of the

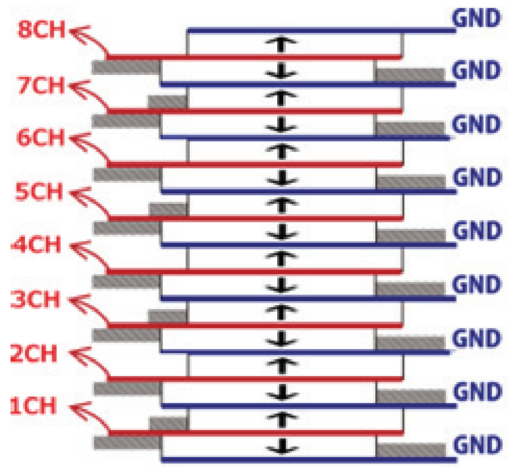


Fig. 1 Structures of 8 channel laminated transducer.

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adhesive and electrodes layers relate the ultrasonic waveform especially for laminated transducer because 8 channel laminated transducer have 16 interfaces of adhesive and electrodes layers as shown in Fig.1. To decrease the thickness of adhesive and electrodes layers for the fabrication of higher frequency transducer, adhesive was changed to low viscosity resign and vapor deposition was also introduced for electrode fabrication process. Using new procedures, the thickness of adhesive layer and electrode became 1μm and 70nm in average respectively. We excited each element by burst wave of 5 MHz in frequency and 300V in peak to peak amplitude independently and the surface waveform of the laminated transducer was measured by laser vibrometer as shown in Fig. 2. Some distortions were observed comparing with the burst excitation waveform.

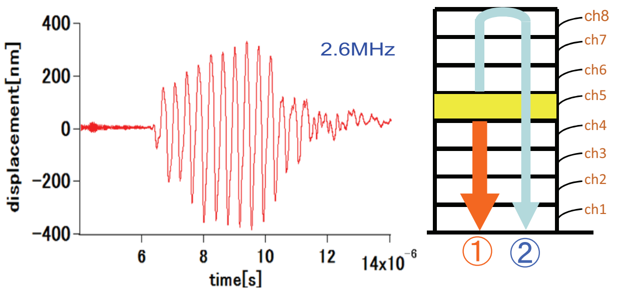


Fig.2 Transmitted waveform of 8 channel laminated transducer

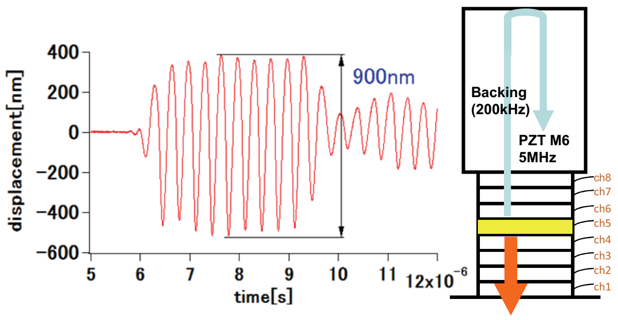


Fig.3 Transmitted waveform of 8 channel laminated transducer with backing structure

Back reflection waves on the upper surface of the laminated transducer for each element might be a cause of these distortions. To reduce this reflection in the laminated transducers, damper was introduced on the top of the laminated transducer. Waveform for this transducer as shown in Fig.3 could reduce the distortions in Fig.2. As to the amplitude of ultrasound displacement, large displacement of 900nm in peak-to-peak was obtained. Furthermore, we fabricated 5 MHz transducer and investigate the basic acoustic properties.

## 3. Combination of laminated transducer system and SPACE

Developed laminated transducer system of high frequency ultrasound up to 5MHz for high amplitude ultrasound transmission was combined to the conventional SPACE measurement. To investigate the availability of this system for an ultrasonic inspection, we applied to measure some industrial cracks.

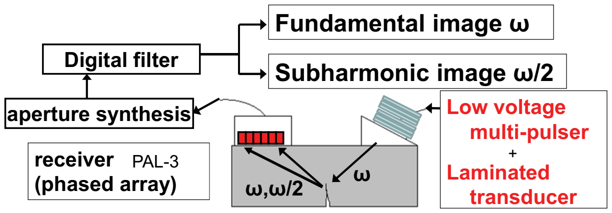


Fig.4 Combination of laminated transducer system and conventional SPACE

As the results, the developed high amplitude SPACE apt to generate subharmoinic ultrasound even at open crack. And the subharmonic image of crack tip will enhance the signal to noise ratio of crack tip echo which directly relate to the accurate detection and sizing for the crack in inspection.


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