2P5-9

Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 337-338
18-20 November, 2009

Ultrasound beam analysis affected by vibration mode on PZT single plate

PZT 単板トランスデューサの振動モードが超音波ビームに与える影響

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1. Introduction

Ultrasound array transducers are widely used as ultrasonic transmitters. High-accuracy beamforming capable of scanning the beam direction has been widely available based on well-established dicing technology for fabricating array transducers. On the other hand, lead zirconate titanate (PZT) plate transducers without dicing are still used for applications without beam scanning due to low-cost. Typical applications of plate transducers are sound sources in systems for evaluating ultrasound effects for several kinds of drugs or cells in test-tubes. However, acoustic fields in these systems are not always homogeneous. As a result of this inhomogeneity, the effect of ultrasound on exposed drugs or cells is not uniform. Because it is difficult to image fields during exposure, reproducibility or reliability of these systems is not sufficient.

If a transducer acts as an ideal acoustic source, complex near field pattern can be calculated based on Huygens principle. A standing wave formation can also be calculated from a wave equation with a boundary condition. The oscillation of plate transducers is more complex than that of diced transducers because lateral oscillations in the plate are not isolated from longitudinal oscillations with dicing. This difference between diced and plate transducer causes complex and unpredicted plate oscillation which can not be treated as an ideal acoustic source.

We investigate the mechanism causing inhomogeneous beam patterns using acoustic field measurements and numerical simulations of transducer vibrations. In particular, we investigate the acoustic field generated by a complex plate motion different from an ideal sound source.

2. Suppression of Lamb wave generation using higher order thickness resonance mode

Ultrasound beams transmitted from PZT circular plates with a diameter of 24 mm and thicknesses of 4, 2 and 1mm were imaged with the Schlieren method[1]. Each PZT plate was held in aluminum housing and its back surface was an air cavity. Transducers with thicknesses of 2 and 1 mm were driven at their fundamental resonance frequencies, 1 and 2 MHz, respectively. On the other hand, the transducer with a thickness of 4 mm was driven at its third harmonic resonance frequency, 1.5 MHz. Using third order harmonics, transducers with widely varying thickness in a similar frequency domain can be compared. Lamb wave generation is strongly affected by thickness. The relation between inhomogeneous beam patterns and Lamb wave generations was investigated through acoustic field measurements.

Surface vibrations of transducers in similar conditions as the experiments were computed with a numerical simulation code PZFlex[2], which is a wave-equation solver including piezo-electric effects. Through analysis of these results, the efficiency of Lamb wave generation in each condition was investigated.

3. Results and discussion

Figures 1, 2 and 3 show Schlieren images of 1-, 2- and 1.5-MHz ultrasound beams transmitted from 2-, 1- and 4-mm-thick transducers, respectively. Figures 1 and 2 show large inhomogeneous distributions in the lateral direction parallel to the transducer surface in addition to typical near field patterns consistent with the acoustic field theory. 1-MHz, a total of four beams were observed. Two of the beams propagated from the near to far range, and the other two were observed only in the near field. Figure 2 shows two beams in all ranges. On the other hand, a single homogeneous beam was observed from the near field to 5 cm from the transducer surface, as shown in Fig. 3. Similar results to those mentioned are indicated as plots of beam profiles in the lateral direction, as shown in Fig. 4. These results show that inhomogeneous beams were generated from thin transducers. These inhomogeneous beam are not consistent with acoustic fields transmitted from ideal acoustic sources.

Figure 5 shows numerical simulation results of the oscillation on each transducer surface of the same experimental configuration. When the thickness of the transducer was 1 or 2 mm, displacement modulation patterns were found, and these periods were 1 and 2 mm, respectively. These modulations on the PZT surface suggest that there is a link to Lamb wave propagation on the PZT surface.

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On the other hand, modulation or ripples disappeared in the center of the PZT surface of 4-mm thick transducer. Both experiments and simulation results showed that beam inhomogeneity is highly related to Lamb wave generation. To achieve homogenous plane wave propagation, plate transducer configuration without Lamb wave is necessary.

4. Discussion

Through the use of third order harmonic of thickness resonance, the homogeneity of plane wave beam transmitted from high a ratio of thickness to diameter of plate transducer was improved. Simulation results showed that the configuration of beam inhomogeneity measured with experiments was consistent with Lamb wave generation on the transducer surface. However, the beam inhomogeneity pattern imaged using the Schlieren method was not consistent with the displacement profile on the PZT surface computed with simulation. In particular, the number of beams in the Schlieren image was different than the number of peaks in the surface displacement modulation in the simulation results. The generation mechanism of beam inhomogeneity should be studied in detail.

Complex plate oscillation may be affected by not only coupled oscillation between longitudinal and lateral direction but also lateral components of the piezo-electric tensor of PZT. Both effects will be estimated independently using simulation and reported at the USE 2009 conference.

Acknowledgments

Part of this work was supported by the New Energy and Industrial Technology Development Organization, Japan.

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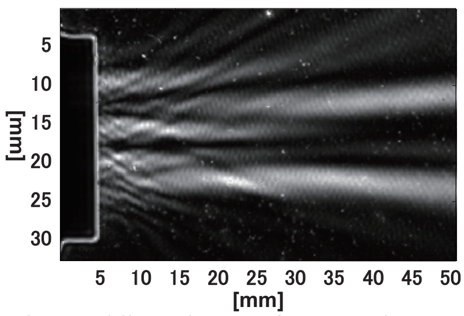

Fig. 1 Schlieren image of 1 MHz ultrasound beam transmitted from 2 mm thick transducer

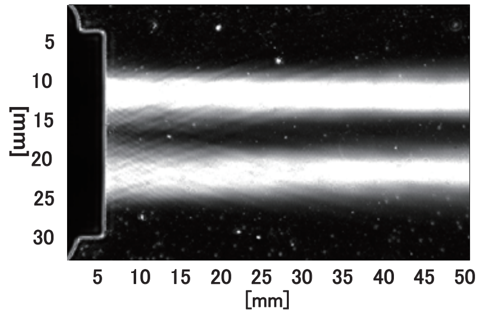

Fig. 2 Schlieren image of 2 MHz ultrasound beam transmitted from 1 mm thick transducer

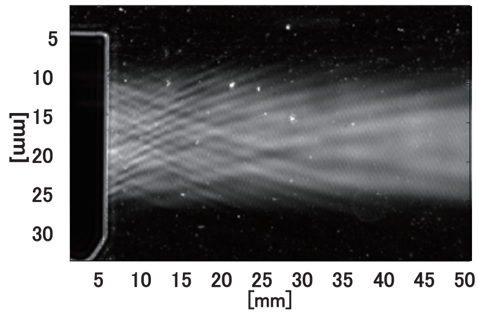

Fig. 3 Schlieren image of 1.5 MHz ultrasound beam transmitted from 4 mm thick transducer

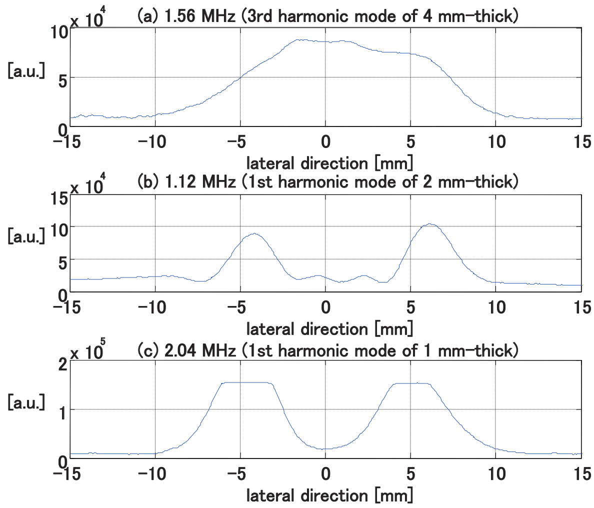

Fig. 4 Beam profile calculated from Schlieren images. (a) 1.5 MHz, 4-mm thick transducer, (b) 1 MHz, 2-mm thick transducer, (c) 2 MHz, 1-mm thick transducer.

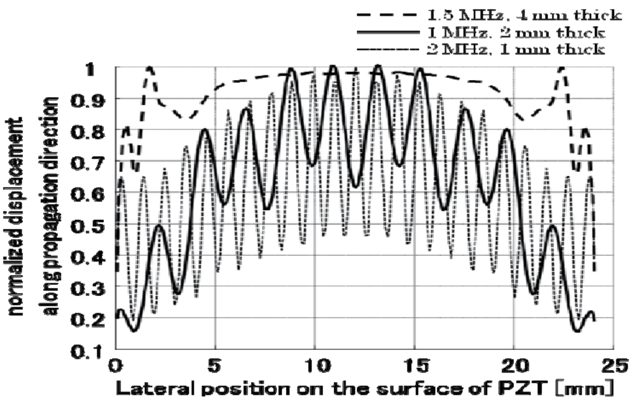

Fig. 5 Simulation results of displacement distribution on surface of single plate PZT transducers