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Vibration Analysis of Therapeutic Ultrasound Transducer by FEM
有限要素法による治療用超音波トランスデューサの振動解析

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1. Introduction

A typical single-element High Intensity Focused Ultrasound (HIFU) transducer has a spherical shell in order to focus the acoustic energy in the focal spot and thereby thermally coagulate the target tissue to be treated. Ideally, the ultrasound transducer should vibrate simply in the thickness mode, but the Lamb-wave like mode was experimentally observed in addition to the thickness mode in the vibration of a spherical transducer consisting of piezoelectric ceramic[1]. The Lamb-wave like mode may deform the ultrasonic power deposition pattern, which can potentially influence the therapeutic effect, but it has not been well investigated for an actual transducer.

In this study, we theoretically analyzed the transducer behavior by numerically calculating its vibration using PZFlex, a finite element time domain piezoelectric simulator (Weidlinger Assc. Inc.). As a result, we were able to observe a similar wave propagation mode to that of the experiment.

2. Analysis Method

We built the analytical model of HIFU transducer shown in **Fig. 1**. Numerical calculation was performed for this axisymmetric two-dimensional model. A symmetric boundary condition was applied to the left side of the model and the absorbing boundary conditions were applied to the other sides. The parameters of the spherical piezoelectric ceramic PZT were follows: resonance frequency of 3 MHz, focal length of 24 mm, and aperture of 24 mm. Air was set to the backing material and aluminum was set to a housing material. The piezoelectric material was

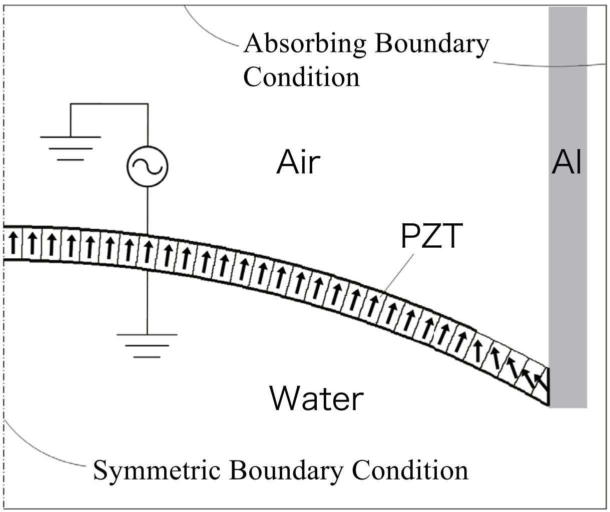

Fig. 1 Analytical model of single-element PZT transducer. Arrows show the poling direction.

polled radially except of the circumference, with placing the small PZTs for every 1 degree. In each small PZT, the polling direction is homogeneous. The electrodes were shown together with arrows in Fig. 1. An active electrode was placed on the part of the convex surface from 0° to 25° from the central axis, and continuous sinusoidal voltage at the resonance frequency was applied. The ground electrode was placed on the concave surface and circumferential side. Note that an electrode was not placed on the circumference of the convex surface from 25° to 30° from the central axis. The poling direction in the model may not be different more than a half degree from the continuously changing poling direction of the actual PZT transducer right beneath the active electrode.

We calculated the displacement of the piezoceramic surface with the concave side in water.

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3. Results and Discussion

The displacement of the spherical PZT transducer at 3 MHz under steady-state condition is shown in **Fig. 2**. (a) through (h) show the displacements at the phase increasing by 45 degrees stepwisely. An entire cross-section was illustrated for convenience.

The thickness mode, the fundamental vibration mode of the piezoelectric material, should be represented by displacement normal to the spherical surface and uniform entirely throughout the piezoelectric material. However, the obtained displacement in Fig. 2 is not uniform and a component of displacement starting from the circumference and propagating toward the center can be seen from (c) to (h) and (a). This component may correspond to the Lamb-wave like mode observed in the experiment because they propagated in the same direction.

In addition, the phase of displacement in the circumference looks opposite to that of the center. This may be because that the circumferential PZT, without a hot electrode, deformed passively by being pushed and pulled laterally by the PZT beneath the hot electrode.

4. Conclusion

The generation of a Lamb-wave like mode propagating from the circumference toward the center of the spherical PZT transducer was observed in numerical simulation as well as in the experiment. The primary cause of the Lamb-wave like mode generation should be further analized by simplifying the model in a few possible ways, and the design of the transducer may be improved on the basis of the analysis not to generate the unwanted modes which may potentially influence the therapeutic outcomes.

Acknowledgment

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Reference

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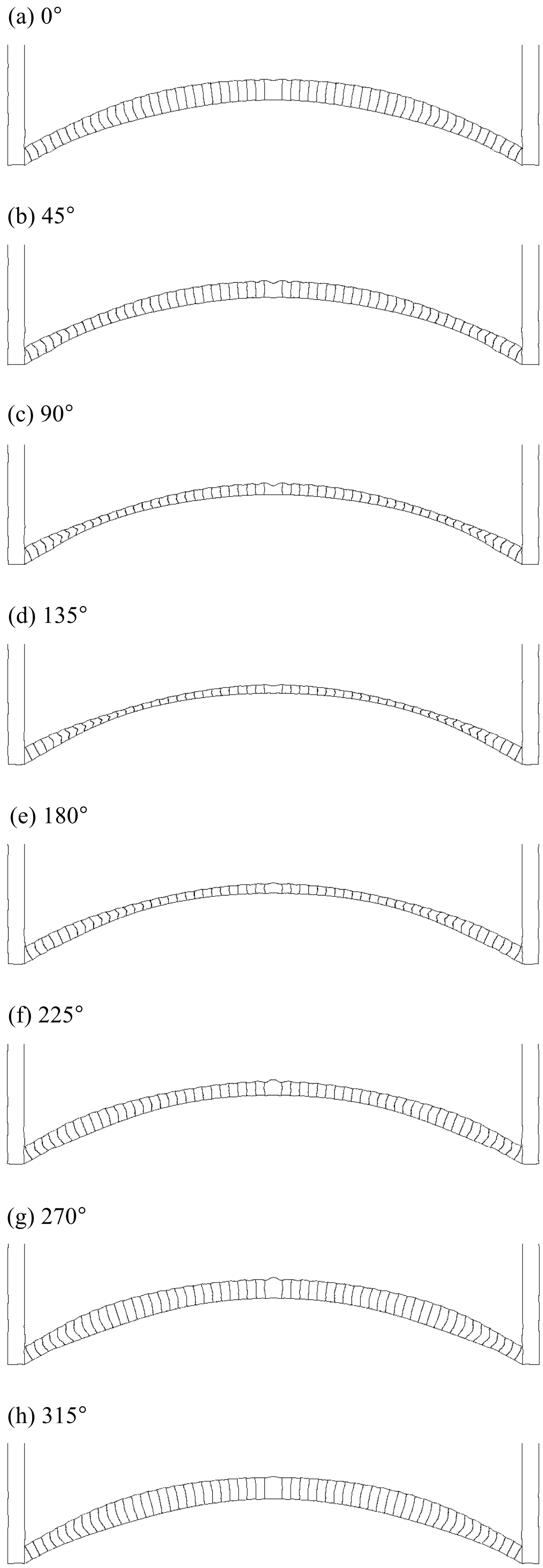

Fig. 2 PZT displacement at various phases.