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Therapeutic array transducer element using coresonance between hemispherical piezoceramic shell and water sphere
半球殻圧電セラミックと水の体積振動との共振を利用した超音波治療用圧電素子

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1. Introduction

For therapeutic ultrasound array transducers, it is required to reduce the electrical impedance of their elements so that the transducer can produce high ultrasonic power at a relatively low drive voltage. For this purpose, a new concept of piezoceramic element using its breathing mode has been proposed.1) A finite element analysis showed that a concave hemispherical piezoceramic shell with a diameter in the order of a wavelength in water is effective for obtaining good acoustic matching with water. High acoustic coupling was achieved without an impedance matching layer by utilizing the coresonance between the breathing-mode oscillation of the hemispherical piezoceramic shell and the volume oscillation of a water sphere half enclosed by the shell.1)

To fabricate a prototype transducer, the piezoceramic element should be supported by a flange which works as a baffle for the transducer element. Moreover, to drive the transducer, the conducting wire has to be attached on the shell using a material such as solder. These flange and solder should not significantly change the breathing-mode oscillation of the piezoceramic. However, the calculated displacements showed that there were no steady points in the piezoceramic shell. Therefore, it would be very difficult to choose the point to attach the flange or solder on. Before fabricating a prototype transducer, the effects of such loads have to be checked by a finite element simulation.

In this paper, we analyzed the effects of the housing and mass loading, by comparing the vibrational behavior of the hemispherical piezoceramic element with and without them.

2. Analysis Model

Fig. 1 shows the axisymmetric two-dimensional FEM model of the air-backed hemispherical piezoceramic element. The thickness of PZT is 0.3 mm, which was optimized to maximize the output acoustic power. It has an inner diameter of 4.0 mm and the resonance frequency at 0.50 MHz. As a piezoceramic material, we chose the PZT-4 which is a hard PZT material suitable to high power transducers. In a numerical simulation, the PZT shell was divided into radially poled small pieces. Electrodes were placed on the front and back surfaces, and either impulse voltage or continuous sinusoidal voltage at the resonance frequency was applied.

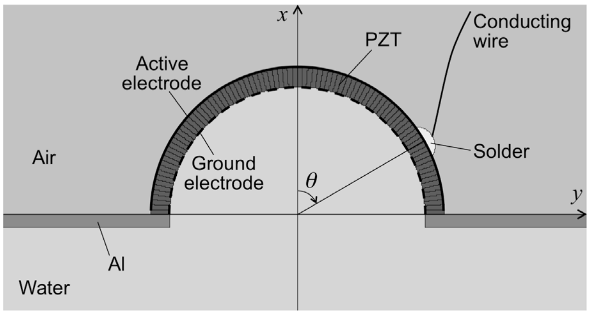

Fig. 1. Analysis model of hemispherical piezoceramic with aluminum housing and load mass.

We chose aluminum as the housing material, which was attached at the periphery of the shell and electrically connected to the ground electrode. The active electrode was connected by a conducting wire and attached by soldering. In this case, the lead is used as the solder and act as the load mass. The solder was put on the shell where the convergence angle θ is changed from 0 to 90 degrees. The mass of the lead was 24% of that of PZT in case the load mass was put at the angle of 60 degrees.

The vibrational behavior of such a transducer element with housing or load mass was numerically calculated using PZFlex, a finite element time domain piezoelectric simulator (Weidlinger Associates).

3. Results and Discussion

3.1 Effects of aluminum housing

To examine the vibrational behavior of the ceramic shell with the aluminum housing, numerical simulation has been performed by changing its thickness from 0.05 to 1.00 mm by 0.05 mm intervals. **Fig. 2** shows the electrical impedance curves obtained from the impulse response for the shell attached with 0.1 mm-thick or 0.3 mm-thick aluminum housing. The impedance for the shell without aluminum housing is also plotted for comparison. The resonance and

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anti-resonance frequencies for the shell with 0.1 mm-thick aluminum housing are almost equal to those for the shell without housing. However, the impedance for the shell with 0.3 mm-thick aluminum housing clearly shows the separated resonances between 0.5-0.6 MHz, which are not coupled each other. The similar separated resonances are also seen for the aluminum thickness over 0.25 mm.

Fig. 3 shows the sampled displacement, magnified 10^3 times, of the PZT shell with a 0.3 mm-thick aluminum housing. The original shape of the hemispherical shell is also plotted. This vibration mode is significantly different from the breathing-mode vibration of the shell without housing. The thinner the thickness of aluminum housing, the smaller the difference was. In case when the thickness of aluminum was thicker than that of PZT, relatively large difference caused by unwanted higher-order mode was observed. Therefore, the thickness of aluminum housing should be chosen to be less enough than that of PZT, less than 0.20 mm in this particular model, to avoid the separation of resonance appeared in the impedance curves.

3.2 Effects of load mass

To prevent the vibration modes from being changed, the load mass should be put at the point where the acceleration is minimal. **Fig. 4** shows the numerically calculated magnitude of acceleration on the PZT surface at each convergence angle, which is not attached to an aluminum housing. The absolute value of the acceleration shows the local minimum at the angle of 60 degrees.

We numerically calculated the displacement of the PZT shell with the load mass at an angle θ from 0 to 90 degrees, as shown in Fig. 1. An aluminum housing was not placed. Each model showed the displacement distorted, but the level of strain of the unwanted higher-order mode was relatively lower if the load mass was put at the angle of 0 degree and around 60 degrees. The latter is consistent with the result of Fig. 4, though it is impractical because the ring-shaped load mass was assumed in the simulation due to the axisymmetry.

4. Conclusion

We numerically analyzed the effects of housing and a load mass, which should be attached to the shell of an actual transducer element. Numerical simulation showed that attaching a flange or load mass might generate the unwanted higher-order mode of oscillation in addition to the breathing-mode oscillation. Their mass should be relatively small and located at the point where acceleration is minimal. Further investigation by fabricating a prototype transducer is needed to further discuss the efficacy of the proposed concept of transducer.

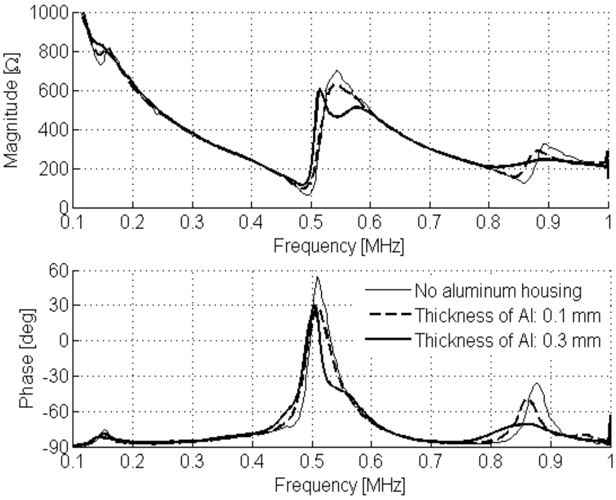

Fig. 2. Electrical impedance curves.

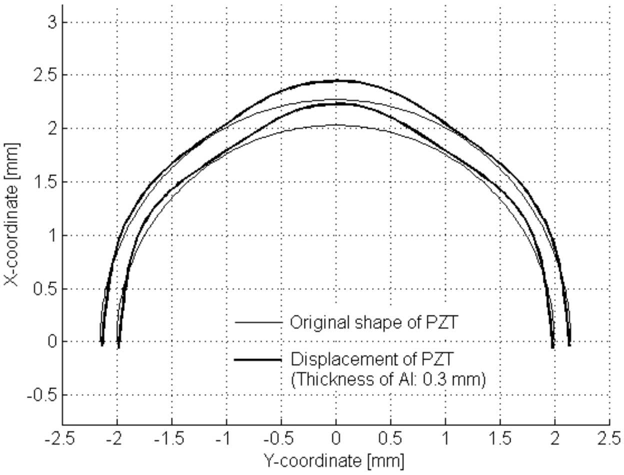

Fig. 3. Displacement magnified 10^3 times of PZT with 0.3 mm-thick aluminum housing.

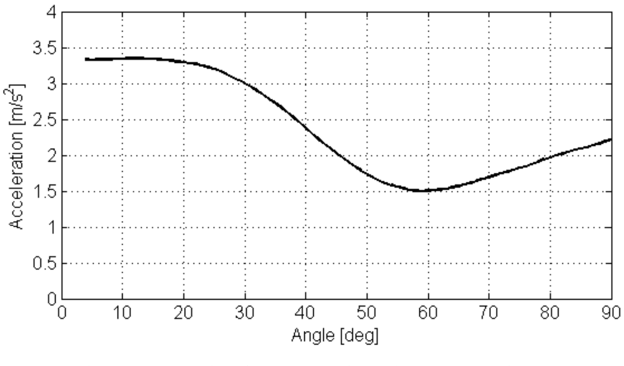

Fig. 4. Magnitude of acceleration on angle.

Acknowledgment

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Reference

1) K. Otsu, S. Yoshizawa, and S. Umemura: Jpn. J. Appl. Phys. **50** (2011) 07HC02.