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Simulation of Liquid-Level Sensors Operating in Trapped-Energy Vibration Modes by Finite Element Method

有限要素法によるエネルギー閉じ込め型
液面レベルセンサの動作シミュレーション

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1. Introduction

The authors' group has been studying on the original device[1,2] presented for the measurement of liquid level on the millimeter scale or less that employs a piezoelectric thickness vibrator operating in a trapped-energy mode. It has been demonstrated that the evanescent field created in both conventional[1)] and backward-wave-type[2)] trapped-energy resonators operating in fundamental and inharmonic modes[3)] can be utilized effectively for detecting a small-scale variation in liquid level. The sensor has been modeled by an equivalent electric network representing the propagation of a thickness-vibration mode along the piezoelectric plate[4)]. The variation in the electric properties with the liquid level has been computed using this network model, and the feasibility of the model is confirmed. In this paper, as another approach, the sensors are analyzed by using a finite element method (FEM), and thereby, their operation is simulated.

2. Sensor Configuration and Modeling for FEM

The sensors presented by the authors[1,2)] are illustrated in **Fig. 1**. A thickness wave vibrator

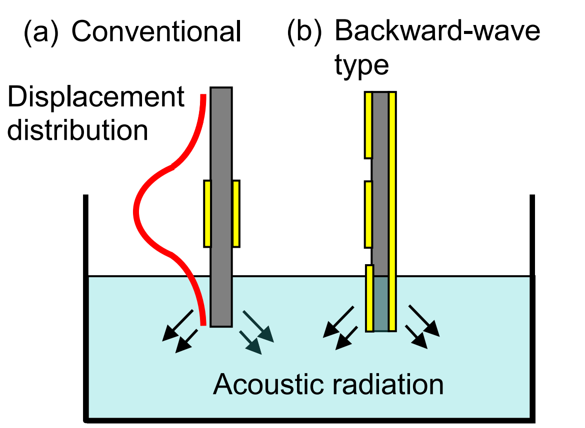

Fig. 1 Liquid-level sensors presented by the authors.

operating in a trapped-energy mode of conventional type (a) or backward-wave type (b) is supported vertically by clamping its fringe and dipping in a liquid of which the surface level is to be measured. A depth-dependent small leakage of the vibration energy is expected at the evanescent field in the surrounding region, and this causes the variation in electric properties such as the admittance *Y* or impedance *Z*.

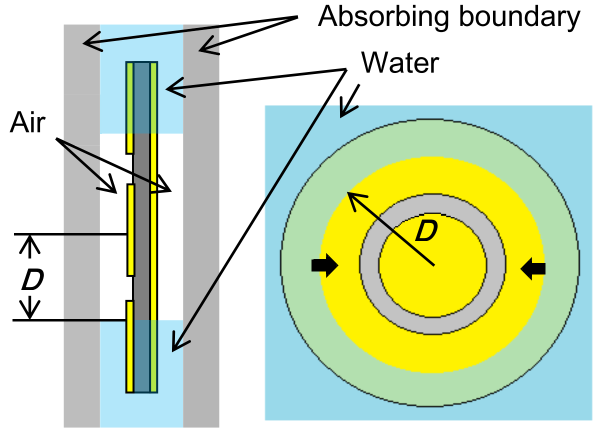

Fig. 2 Backward-wave-type model for FEM analysis.

The sensors were analyzed using a finite element method (FEM). The software employed was PZFlex. One type of the sensors was composed of a conventional trapped-energy resonator made of a $Pb(Zr,Ti)O_3$ (PZT) plate and the other was a backward-wave type composed of a $PbTiO_3$ plate. **Figure 2** illustrates the model for the backward-wave type sensor. The actual sensors studied so far are disk-shaped piezoelectric plates having round electrodes. The liquid surface contacting the resonator plate is, of course, flat in the actual sensors. As the first stage of the simulation, however, the models treated here are assumed to have an axially symmetric geometry in which the liquid makes round contact to the plate such as shown in this figure. Therefore, it is assumed that the test liquid will start to cover the resonator from its fringe and moves

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axisymmetrically toward the center of the resonator.

It is assumed that the plate diameter and thickness are 30 mm and 1 mm, respectively. The $Pb(Zr,Ti)O_3$ plate is assumed to be NEPEC-6, TOKIN. It has round electrodes of 4 mm diameter on both surfaces. For the $PbTiO_3$ plate, material constants reported in ref. (5) is employed. It has a center electrode of 4 mm in diameter and an insulation gap of 2 mm in width on one surface. In both models water is assumed as the test liquid. The boundary condition on the central unloaded part is air. The liquid-loaded part is considered to be sandwiched by thin annular layers of water, and an absorbing condition is applied to their outer ends.

As an example of the computed results, variations of the electric impedance characteristics for the backward-wave-type sensor model are shown in **Fig. 3** for several distances *D* from the center of the resonator to the front edge of the water-loaded region. Here, the horizontal axis is the frequency and the vertical axis is the absolute value of impedance *Z* (upper figures), and its real part *R* around the anti-resonance frequency (lower figures). It is noted that smaller *D* (larger area of the water-covered part) gives smaller difference in impedance level at the resonance and the anti-resonance frequencies. The peak level of *R* of the anti-resonance becomes lower for smaller *D*.

Figure 4 shows the variation in *R* with the distance *D*. Gradual decrease in *R* is obtained in accordance with the decrease in *D*.

3. Conclusions

Variation in *Z* with the size of the liquid-covered area of the liquid-level sensor has been computed using FEM, and it is revealed that the computed plots have a similar trend to the experimentally observed results. More practical model will be employed in the next stage.

Acknowledgements

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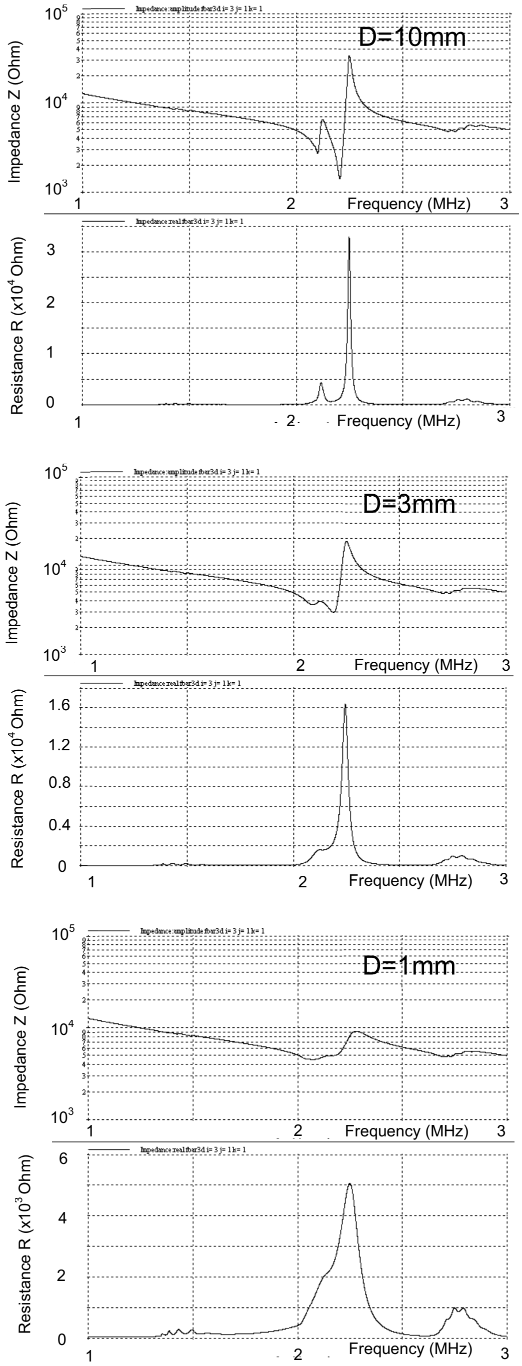

Fig. 3 Characteristics of *Z* and *R* for *D* of 10, 3, 1 mm.

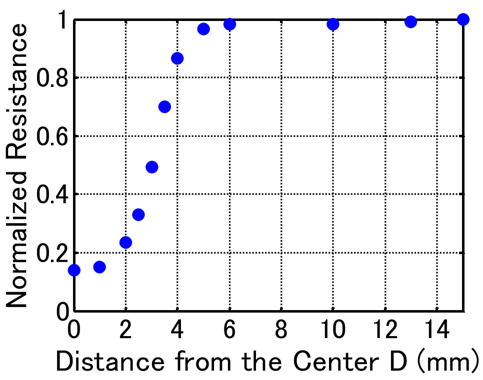

Fig. 4 Variation in *R* with radius *D* of the unloaded area.