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On the use of Cylindrical Trapped-Energy Resonator for Liquid-Level Sensing
円筒形エネルギー閉じ込め振動子による
液面レベルセンシングについて

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1. Introduction

A new method for detecting a small-scale variation in liquid level has been presented by the authors’ group [1]-[8]. The method employs a piezoelectric thickness-wave resonator operating in a trapped-energy mode. In the trapped-energy vibration mode, an evanescent field is created in the unelectroded surrounding region of the vibrator. When this evanescent-wave region is dipped in a liquid, a small leakage of vibration energy occurs depending on the dipping depth. Therefore, small variations in liquid level are detected by observing the changes in the resonance characteristics of the vibrators, such as quality factor Q_m and the electric conductance G.

In this paper, a new attempt is presented to detect the liquid level using a cylindrical-type piezoelectric resonator operating in a trapped-energy mode.

2. Resonator Configuration and Experimental Setup

The trapped-energy resonator was made of a PZT cylinder (TOKIN NEPEC-6) of 10.0 mm outer diameter, 30.0 mm length, and 0.85 mm thickness, and polarized in the thickness direction, as shown in Fig. 1. A stripe electrode was put around the center of the outer surface, and the inner surface was covered entirely with an electrode. The width of the outer electrode was 4.0 mm and 2.0 mm. The electric admittance characteristic for the resonator having a 4.0 mm electrode observed in the air is shown in Fig. 2. The resonance frequency f_R was 3.722 MHz, and the quality factor Q_mR at f_R was about 300. Spurious-free response peculiar to the trapped-energy resonator is obtained around the resonance point.

The resonator was supported vertically by clamping its one end without affecting the main mode of vibration. Then, the cylinder was dipped in the liquids to be tested from its bottom (lower) end, as shown in Fig. 3. The sample liquids employed were water, glycerin, olive oil, and honey.

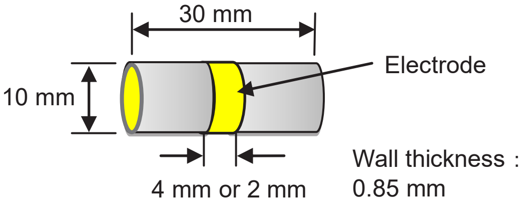

Fig. 1. Configuration of the cylindrical trapped-energy resonator.

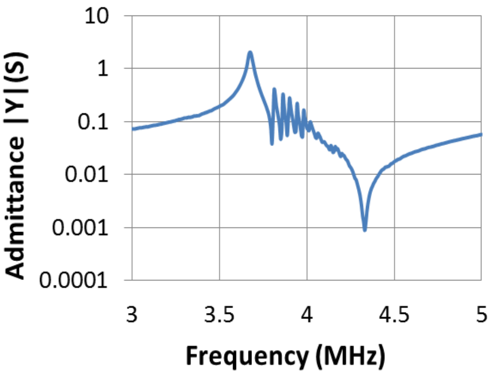

Fig. 2 Electric admittance characteristic of the trapped-energy resonator observed in the air (electrode width: 4.0 mm).

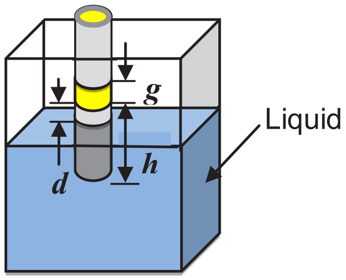

Fig. 3 Experimental setup for detecting the liquid-level variation.

The dipping depth d was varied step by step using a pulse-motor stage moved in the vertical direction. Instead of Q_mR, the variation in G against d at the resonance point was measured using an impedance analyzer (IM3570, HIOKI E.E. Corp., Japan) because it corresponds to the variation in Q_mR as long as Q_mR is large. The measurements were conducted at room temperature. The clamping of the resonator in this manner would be applicable only to trapped-energy vibrators because conventional vibrators with full electrodes on both surfaces will degrade the quality factor and therefore deteriorate the sensitivity.

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3. Experimental Results and Discussion

Fig. 4 shows the frequency responses of the conductance G for several values of the dipping depth d in water. Here, d is measured from the lower end of the electrode, h denotes the length from the electrode to the bottom end of the resonator, and g is the electrode width (4.0 mm in this case). When the water level is at the bottom of the resonator ($d=h$) and at $d=h/2$, the conductance curves are almost the same and not affected by the water loading. However, the resonance curve gradually loses its height by increasing the dipping depth.

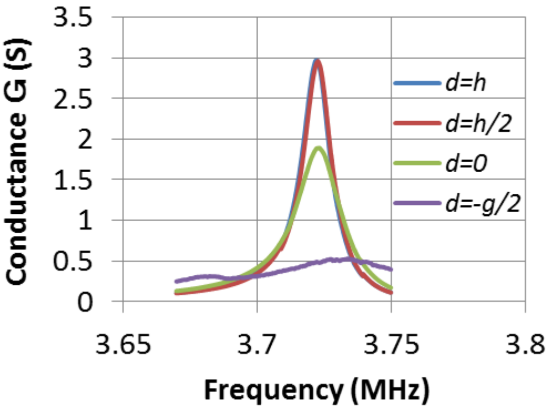

Fig. 4 Frequency responses of conductance G around f_R for several values of water level d.

Some examples of the variation in G on the depth d at f_R obtained for water, glycerin, olive oil, and honey are shown in Fig. 5 . Fig. 5(a) is obtained for the resonator having the electrode width g of 4.0 mm, whereas (b) and (c) are obtained for g of 2.0 mm. The data in (a) and (b) are for the case where both the inner and outer surfaces of the cylinders are exposed to the liquids, whereas those in (c) are for the case where the lower end of the cylinder is plugged by a clay so that the liquids would not enter inside of it. It is noted that G decreases gradually according to the increment of liquid level. The variations in G becomes steep when the liquid level is at the evanescent-wave region, i.e., around the electrode edge of the trapped-energy resonator. It is shown that the variation of the G values are slightly different for the four kinds of the liquid.

4. Summary

Feasibility of liquid-level detection using a cylindrical resonator operating in a trapped-energy mode has been confirmed. Steep variations in G on the dipping depth d have been observed in the evanescent-field range. Further investigations are required for clarifying the effect of viscosity, acoustic impedance, and dielectric properties of liquids on measurement results.

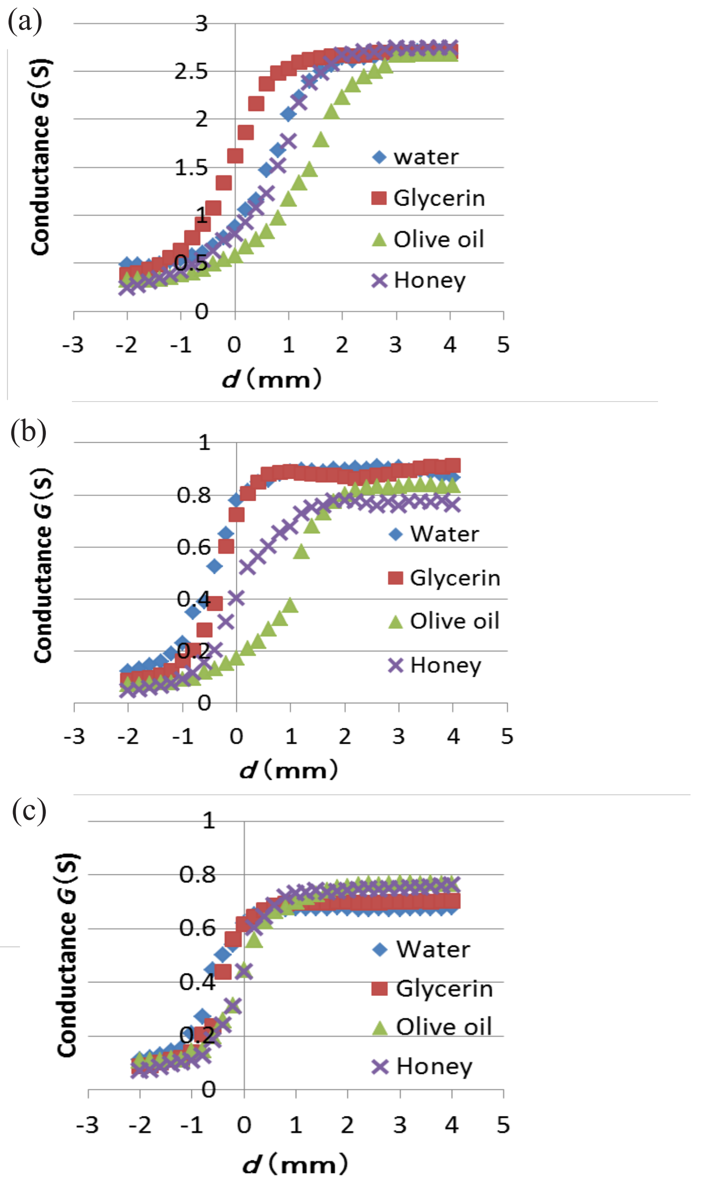

Fig. 5 Variations in G with dipping depth d. (a) electrode width g=4 mm, both surfaces are exposed (b) g=2 mm, both surfaces are exposed (c) g=2 mm, only the outer surface is exposed.

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