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Variation in Resonance Characteristics of a Thickness-Shear Trapped-Energy Vibrator by Gradual Dipping in Liquids
- For the purpose of liquid-level sensing -
液中浸漬によるエネルギー閉じ込め型圧電厚みすべり振動子の共振特性変化について

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1. Introduction

A new attempt for detecting a small-scale variation in liquid level has been presented by the authors' group [1]-[7]. The method employs a piezoelectric thickness vibrator operating in a trapped-energy mode [8]. In the trapped-energy vibration mode, an evanescent field is created in the unelectroded surrounding region of the piezoelectric plate. When this evanescent-wave region is dipped in a liquid, a small leakage of the vibration energy occurs depending on the dipped depth, i.e., the liquid level. 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, variation in resonance characteristics of a thickness-shear trapped-energy vibrator is examined when it is dipped gradually in liquids to confirm the applicability for detecting the variation in liquid level.

2. Resonator Configuration and Experimental Setup

Typical configuration of a piezoelectric thickness-shear trapped-energy resonator is shown in **Fig. 1**. The resonator is polarized in the length direction along the plate, and two stripe electrodes spanning from one edge to the other in the width direction are formed on its both surfaces. The vibration energy is confined to the electroded region and decays exponentially in the outer regions. Because the thickness-shear vibration mode has the displacement only in the length (polarization) direction, neither a mode conversion nor a reflection occurs at the free boundaries of the width ends. Therefore, one-dimensional energy-trapping occurs and a non-variant displacement distribution will be obtained in the direction perpendicular to the poling, as shown in Fig. 1.

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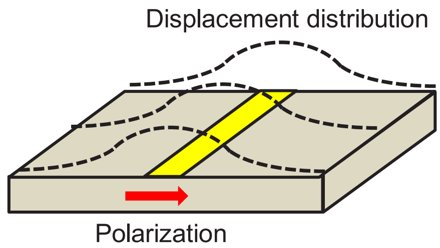

Fig. 1 Thickness-shear trapped-energy resonator with non-variant displacement distribution in the direction perpendicular to the polarization.

Suppose that a part of the resonator including both the electroded trapping region and the evanescent-wave region is dipped in a liquid from one of the width ends, as shown in **Fig. 2**. In this case, the amount of the vibration-energy leakage is expected to vary depending directly on the area of the resonator dipped in the liquid. Therefore, the resonance characteristics of the vibrator are expected to vary in proportion to the dipping depth d, i.e., the liquid level.

The thickness-shear vibrator was fabricated using a PZT plate (Fuji Ceramics C-3) of 1 mm thickness, 25.0 mm length, and 20.0 mm width, and polarized in the length direction. The width of the stripe electrodes was 2.0 mm. The electrodes were equipped with small bus bars extending to the length-side edges to obtain electrical contacts.

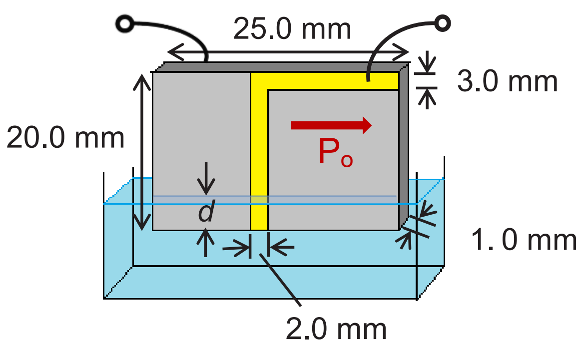

Fig. 2 Experimental setup for examining the variation in the electric properties on the depth d.

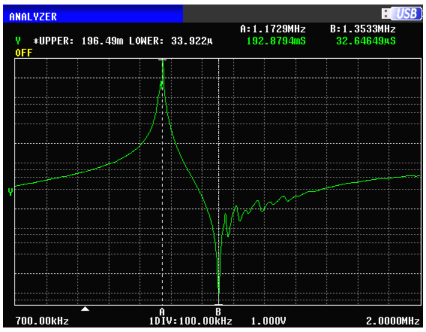

Fig. 3 Electric admittance characteristic of the trapped-energy resonator operating in a thickness-shear mode observed in the air.

The electric admittance characteristic observed in the air is shown in **Fig. 3**. Spurious-free response peculiar to the trapped-energy resonator is obtained. The resonance frequency f_R and the anti-resonance frequency f_A were 1.172 MHz and 1.353 MHz, respectively. The quality factors Q_{mR} at f_R and Q_{mA} at f_A were 300 and 800, respectively.

The resonator was supported vertically by clamping its top corners. Then, the plate was dipped in the liquids to be tested from its lower end, as shown in Fig. 2. The clamping of the plate in this manner would not be applied to a conventional thickness-mode vibrator composed of a fully-electroded plate because it always degrades the quality factor.

The sample liquids employed were glycerin, olive oil, and honey. The immersion depth d was varied step by step using a pulse-motor stage moved in the vertical direction. The measurements were conducted at room temperature.

3. Experimental Results and Discussion

Some examples of the variation in $|Y|$ on the depth d at f_R obtained for glycerin (a), olive oil (b), and honey (c), are shown in **Fig. 4**. It is noted that $|Y|$ decreases gradually according to the depth d, i.e., the increment of the liquid level. The variations in $|Y|$ are almost linear in the measured range. Just as the lower end of the resonator touched the liquid surface, $|Y|$ value dropped from the value in air which was 208 mS. It is shown that the decrement of the $|Y|$ values are different for the three liquids.

In summary, feasibility of liquid-level detection using a trapped-energy vibrator operating in a thickness-shear mode has been confirmed for viscous liquids. Almost linear variations in $|Y|$ on the depth d have been observed in the measured range. Further investigation is required for clarifying the effect of viscosity, acoustic impedance, and dielectric properties of liquids on the measurement results.

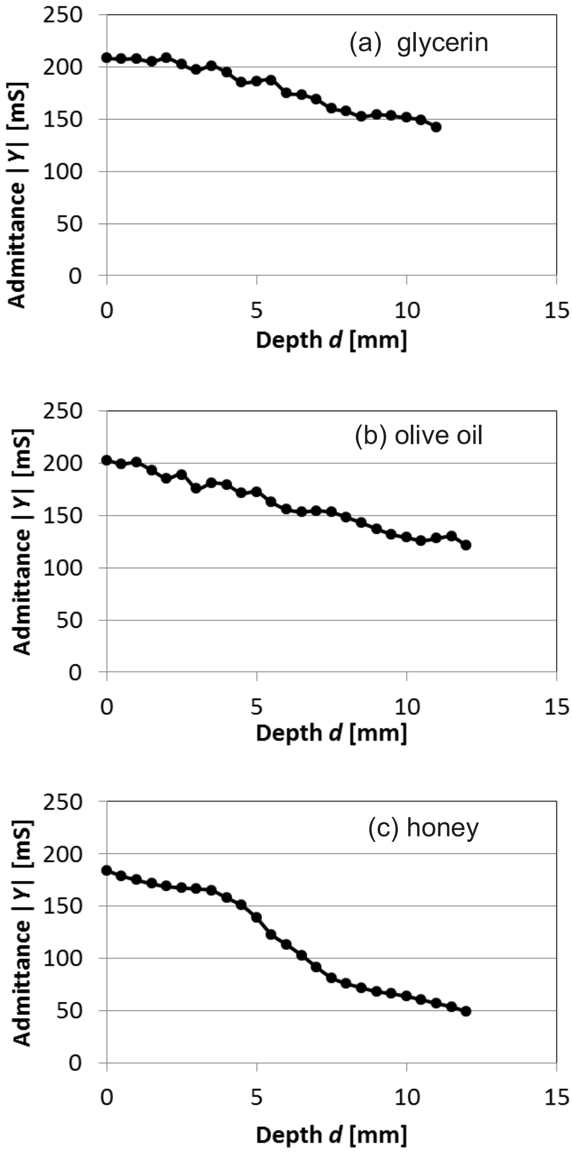

Fig. 4 Variations in $|Y|$ with the depth d obtained at the resonance frequency f_R. Sample liquids: (a) glycerin, (b) olive oil, and (c) honey

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