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Equivalent Network Representation of a Liquid-Level Sensor Operating in Trapped-Energy-Mode Thickness Vibration

エネルギー閉じ込め型圧電振動子を用いた液面レベルセンサの等価回路表示について

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1. Introduction

As an alternative to the pulse-echo method, the authors have presented a new technique[1,2] for the measurement of liquid level on the millimeter scale or less. The method employs a piezoelectric thickness vibrator operating in a trapped-energy mode. The evanescent field created in the resonator is utilized effectively for detecting a small-scale variation in liquid level. In this paper, the sensor is represented by an equivalent electric network[3,4], and thereby, its operation is simulated.

2. Outline of the Sensor and its Equivalent Network Representation

The sensor presented by the authors[1,2] is illustrated in **Fig. 1**. A thickness wave vibrator operating in trapped-energy mode is supported vertically by clamping its fringe and dipped in a liquid of which the surface level is to be measured. A small leakage of the vibration energy will occur at the evanescent field in the surrounding unelectroded region, and the amount of the leakage will vary depending on how deep the evanescent region is in the liquid. Because of the radiation loss, the mechanical quality factor Q_m and/or the conductance G at the resonance observed at the electric port will vary in accordance with the dipping depth.

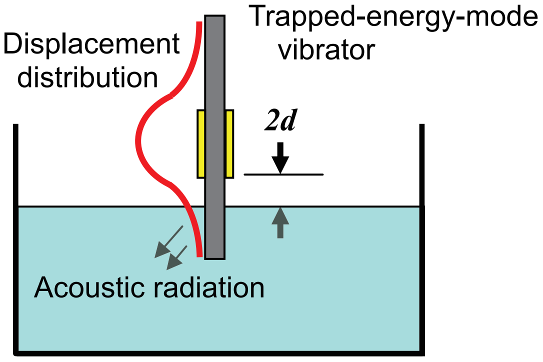

Fig. 1 Liquid-level sensor presented by the authors.

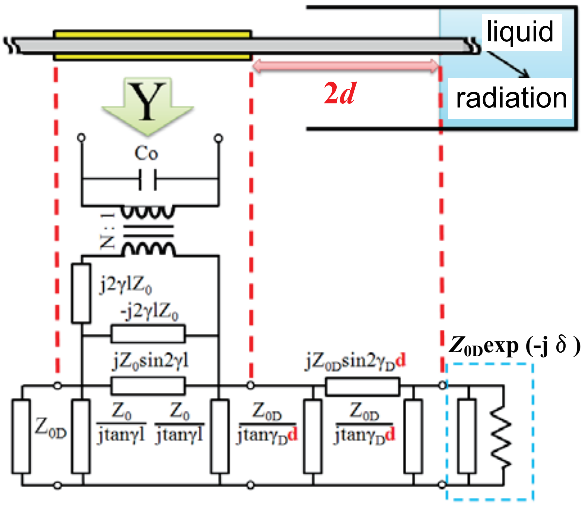

Fig. 2 Equivalent network representation of the sensor.

Figure 2 shows the equivalent network for the sensor illustrated in Fig. 1. It consists of a combination of distributed-constant equivalent-network elements[3,4] each representing the propagation of a thickness-wave mode along the sensor plate of thickness $2H$. The surrounding portion is supposed to have an infinite length and expressed by characteristic impedance Z_{0D}. In this network, Z_{0D} becomes imaginary in the frequency range where energy-trapping works. In order to take the radiation loss into consideration, a phase angle (-δ) is applied to Z_{0D} for the portion dipped in a liquid. The section between the electrode edge and the liquid surface is expressed by a transmission line representing the unelectroded plate of length $2d$. Variation of the electric properties on the immersion depth $2d$ is evaluated by varying the depth-to-thickness ratio d/H.

A thickness-extensional-wave trapped-energy resonator composed of a thickness-poled PZT plate (NEPEC-6, TOKIN) of 1 mm thickness is employed as a two-dimensional model of the sensor. The ratio of the electrode width $2l$ to the plate thickness $2H$ is supposed to be 3. Since the

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vibration loss is not taken into consideration intrinsically in the resonator model in Fig. 2, a small amount of resistance is added at the electric port so that the resulting Q_m value becomes 750.

As an example of the computed results, variations of the electric admittance characteristic are shown in **Fig. 3** for d/H of 0.05 to 3.0. Here, the horizontal axis is the normalized frequency Ω (=$\omega H/v_l$, v_l: longitudinal wave velocity), the vertical axis is the normalized admittance $Y/$ (v_lC_0/H) (C_0: damped capacitance), and δ is assumed to be 1. It is noted that smaller d/H (higher liquid level) gives lower peak level at the resonance.

The authors' group has examined by experiments the variations in electric conductance G that corresponds to the variation in Q_m. So, the frequency characteristic of G is also computed for several values of d/H. The result is shown in **Fig. 4**. Here, the vertical axis is the normalized conductance $G/$ (v_lC_0/H). Gradual decrease in G is observed in accordance with the increase in the liquid level.

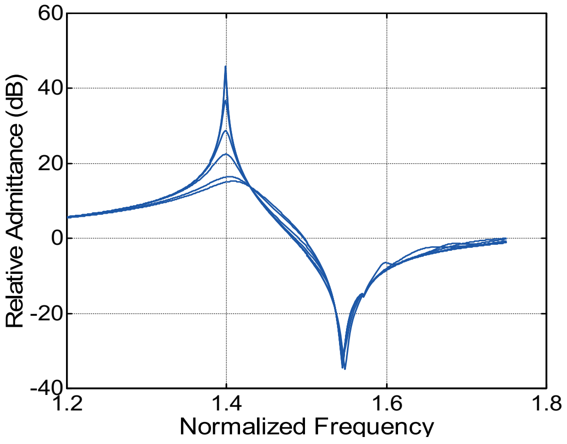

Fig. 3 Variation in Y computed for d/H of 0.05 to 3.0.

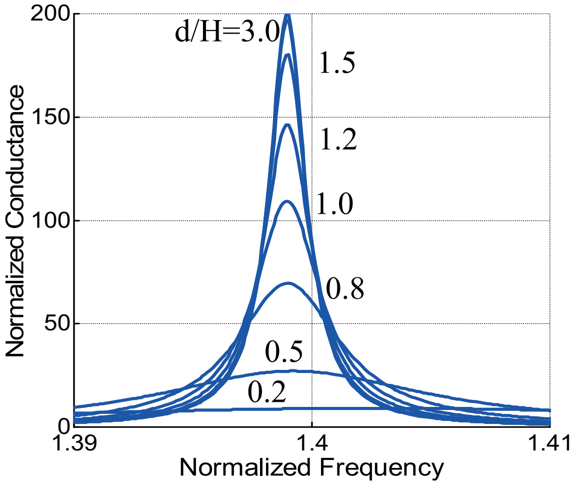

Fig. 4 Variation in G computed for d/H of 0.2 to 3.0.

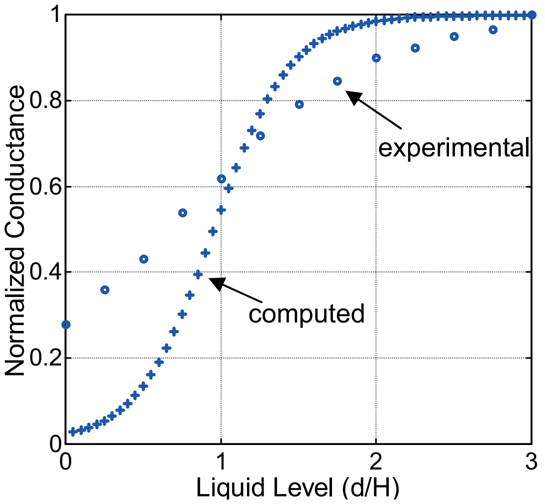

Fig. 5 Variations in G on the liquid level d/H .

3. Comparison with the Experiment

In order to compare with the experimental results, a PZT plate (NEPEC-6, TOKIN) of 30 mm diameter and 1 mm thickness having a square electrode of width $2l$ of 3 mm and depth of 6 mm was provided to obtain experimental data. The resonance frequency was 2.07 MHz and the test liquid employed was honey.

Figure 5 compares the computed results with the experimental plots. The vertical axis is the conductance normalized to the value at d/H=3. Similar trend is observed in the two sets of plots.

4. Conclusions

An equivalent network representation is presented for the liquid-level sensor operating in a trapped-energy mode thickness vibration. Variation in G on the liquid level has been computed using this network model, and it is revealed that the computed plots have a similar trend to the experimental results. There exist, however, a number of subjects to be clarified such as how the effect of liquid loading should most properly be introduced in the network model.

Acknowledgements

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