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A Modified Equivalent-Network Model for the Liquid-Level Sensors Operating in Trapped-Energy Vibration Modes

エバネセント波を用いた液面レベルセンサの等価回路表現　―伝搬定数複素化の試み―

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1. Introduction

Novel sensors for detecting a small-scale variation in liquid level that employ a trapped-energy mode of conventional and/or backward-wave type have been studied by the authors' group[1-10]. The sensors have been modeled[6-10] by a distributed-constant electric network representing the propagation of thickness-vibration modes[11,12]. In these models the effect of liquid loading is expressed by putting the characteristic inpedance of the corresponding part to be complex[10]. In this paper, an improved treatment is presented for the transmission-line model that employs a complex wavenumber for the liquid-immersed region, and some results of simulation are shown.

2. Geometry of the Sensors Utilizing Trapped-Energy Vibration Modes

The sensor configurations utilizing trapped-energy vibration modes are shown in **Fig. 1** for a conventional type, (a), and a backward-wave type, (b). By dipping the evanescent-wave region of the resonators in a liquid, a depth-dependent variation in the electric admittance *Y* will occur at the resonance. In the case of backward-wave-type energy trapping[12),13)], the surrounding region of the piezoelectric plate is electroded and short-circuited as presented in **Fig. 1(b)**. An additional capacitance C_A is connected in series with the central excitation electrodes to ensure energy trapping.

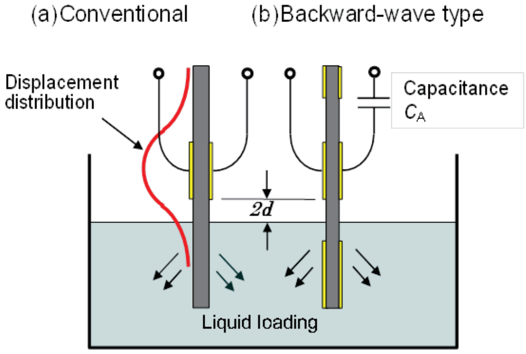

Fig.1 Liquid-level sensing by trapped-energy vibrators.

3. Equivalent-Network Modeling and Results of Analyses

The equivalent network model for the sensor utilizing the conventional trapped-energy mode is rather simple[6)]. In the backward-wave-type trapped-energy vibrator[10)], however, there exists a non-electroded gap region between the central and the surrounding electrodes. The wavenumber there can be real even when the energy-trapping works. Therefore, the wavenumber and the characteristic impedance of this region should be complex to take the leakage loss into consideration when this region is immersed in a liquid.

Figure 2 shows the equivalent network model for the sensor utilizing the backward-wave-type energy trapping[9),10)]. Here, the liquid surface may be either on the gap or on the outer electrodes. In the sensing side, two transmission lines representing the unelectroded gap of the length *2l'* are connected serially to the network elements corresponding to the central excitation electrode part. One is the transmission line representing the out-of-liquid portion of length 2*d*, where the wave number is γ' and the characteristic impedance is Z_0'. The other is the line of length 2*l*" (=2*l*'-2*d*) representing the portion in the liquid. The wavenumber and the characteristic impedance in

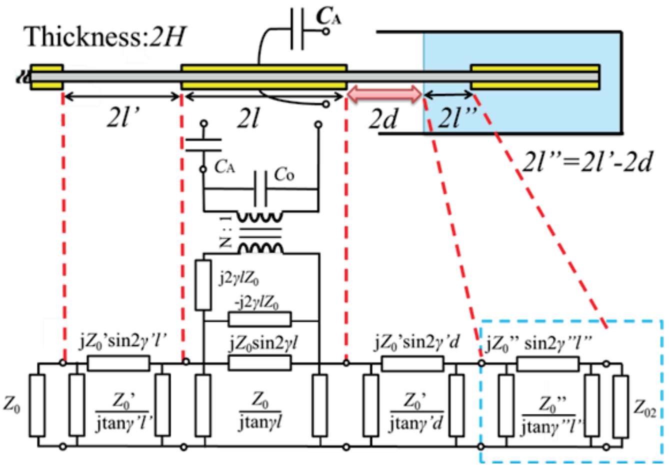

Fig.2 Equivalent network for the sensor of backward-wave energy trapping.

this part are complex values and expressed as γ'' and Z_0'', respectively. Here, γ'' is expressed by introducing a factor m as:

$$\gamma'' = \gamma'(1 - \mathrm{j}m)$$

The outermost metallized region is supposed to have an infinite length and is therefore expressed by the corresponding characteristic impedance Z_{02}.

A thickness-poled $PbTiO_3$ plate is assumed as the backward-wave-type trapped-energy resonator model. The ratio of the central electrode width $2l$ to the plate thickness $2H$ is supposed to be 4.0 and the normalized gap width l'/H is supposed to be 0.5 or 1.0. The ratio of the damped capacitance C_0 to the series capacitance C_A is 1.0. A small amount of resistance is added at the electric port to take the material loss into account.

The variations in the peak value of the electric conductance G with the liquid level at the resonance frequency are shown in **Fig. 3**. The normalized gap width l'/H is 0.5 in **Fig. 3(a)** and 1.0 in **Fig. 3(b)**. The vertical axis is normalized to the value for liquid-free condition. Here, the factor m is varied from $1\text{x}10^{-3}$ to $2\text{x}10^{-4}$.

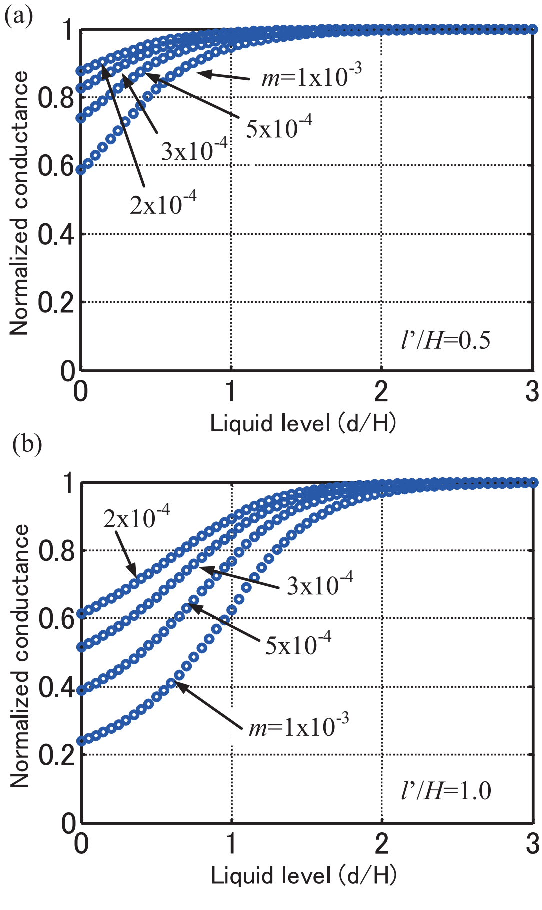

Fig. 3 Variation in G with the liquid level at resonance (l'/H=0.5 for (a) and 1.0 for (b)).

It is noted that continuous decrease in the electric conductance level is obtained as the liquid surface approaches to the central electrodes (d/H reduces to 0).

4. Conclusions

An improved treatment has been presented for the equivalent-network model of the liquid-level sensor proposed by the authors. Variation of the electric conductance on the liquid level presented in the former studies[1)-5)] is well simulated. However, further investigation is required to clarify the relationship between the elastic property of the liquid and the factor m.

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