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Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 183-184
6-8 December, 2010

Liquid-Level Sensing Using Inharmonic Modes of Trapped-Energy Resonators

エネルギー閉じ込めモードの非調和振動を利用した場合の液面レベル・センシング特性

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1. Introduction

The measurement of liquid level on the millimeter scale or less has become an important subject in biological and chemical fields. As an alternative to the well-known pulse-echo method, the authors have presented a new technique[1,2] that employs a piezoelectric thickness vibrator operating in a trapped-energy mode for detecting a small-scale variation in liquid level. There exist two types of energy trapping; one is applied to conventional forward-wave-mode thickness vibrations[3] and the other is to backward-wave-mode thickness vibrations[4,5]. Both types of energy-trapping produce inharmonic modes around the main resonance when the electrode size (conventional type) or the unelectroded gap size (backward-wave type) becomes large compared to the plate thickness. In this paper, some results for application of inharmonic modes of energy-trapping to liquid level sensing are presented.

2. Inharmonic Modes in Energy Trapping

A conventional trapped-energy-mode thickness vibrator[3] is shown in **Fig. 1(a)**. It produces inharmonic overtone modes when the electrode-diameter to thickness ratio becomes large. **Figure 1(b)** shows an electrode configuration for a trapped-energy resonator applied for backward-wave-mode thickness vibrations[4,5]. The surrounding region of the plate should be electroded and short-circuited so that the wave number there becomes imaginary. In this case, inharmonic undertone modes are created when the width of the unelectroded gap becomes large. **Figure 2** shows the admittance characteristic for a conventional trapped-energy resonator composed of a thickness-poled PZT plate (NEPEC-6, TOKIN) of 30 mm diameter and 1 mm thickness, having the electrode of 8 mm diameter (designated hereafter as “resonator A”). In addition to the fundamental resonance at 1.99 MHz, an inharmonic overtone mode is observed at 2.13 MHz. **Figure 3** shows the impedance characteristic for a backward-wave-type trapped-energy resonator composed of a $PbTiO_3$ plates of 30 mm diameter

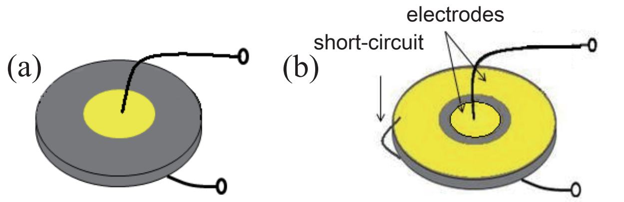

Fig. 1 Trapped-energy resonators of conventional type (a), and backward-wave type (b).

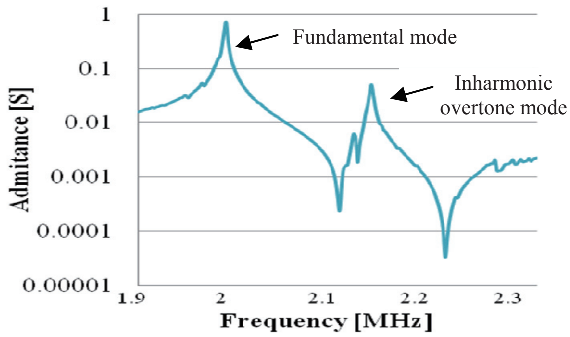

Fig. 2 Admittance characteristic for a conventional trapped-energy resonator.

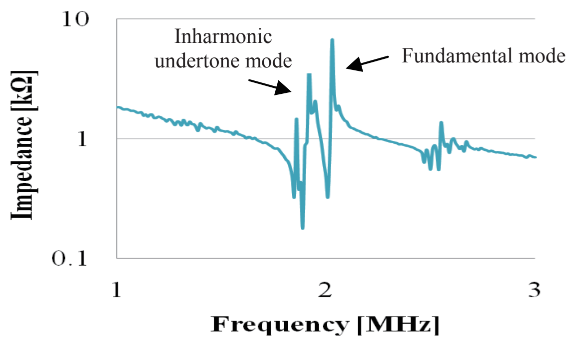

Fig. 3 Impedance characteristic for a backward-wave type trapped-energy resonator.

and 1 mm thickness (Fuji Ceramics M-6), having the center electrode of 4 mm diameter and the gap of 2 mm width for insulation (resonator B). An inharmonic undertone mode is observed at 1.92 MHz, in addition to the fundamental mode at 2.03 MHz. Because the decay factor, i.e., the imaginary wave number determining the profile of the evanescent field differs between the fundamental and inharmonic modes, performance for the liquid level sensing is considered to be different depending on which of the two modes is employed.

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3. Experiments

Experiments were carried out employing the two trapped-energy resonators A and B to verify the prediction. The plates were supported vertically by clamping their fringes and dipped in a liquid to be tested[1,2]. The test liquids employed were water, glycerin, castor oil, and honey. The immersion depth *h* was varied using a pulse-motor stage moved in the vertical direction. Variations in real part *G* of the electric admittance (or *R* of the impedance), against *h* at the resonance (or anti-resonance) point were measured using an impedance/material analyzer (Agilent E4991A).

4. Results

Figures 4 and 5 show the variations in *G* obtained by resonator A (conventional type) for the four different kinds of liquids. The vertical axis is normalized to the maximum values G_{max} for each of the liquids. Figure 4 shows the results for the fundamental mode, and Fig. 5 shows those for the inharmonic overtone mode. It is noted in Fig. 4 that the variations in *G* are small when the liquid surface is on the surrounding region, whereas it becomes steep when the liquid surface is on the electroded region. The results for the inharmonic mode show gradual variations in *G* even though the liquid surface is on the electroded region.

Figures 6 and 7 show the variations in *R* obtained by resonator B (backward-wave type) at antiresonance. It is noted that the variations in *R* are gradual when the liquid surface is on the surrounding electroded region, whereas it becomes a little steeper when the liquid surface is on the unelectroded gap. These two regimes might be selected depending on the purpose, i.e., for either wide-range measurement or high-sensitivity measurement. Through the experiments, it is confirmed that the variations in *G* or *R* on the liquid level are different depending on whether the fundamental or inharmonic mode is employed.

Acknowledgement

This work was supported in part by a Grant-in-Aid for Scientific Research (C) (No. 22560340) from the Japan Society for the Promotion of Science.

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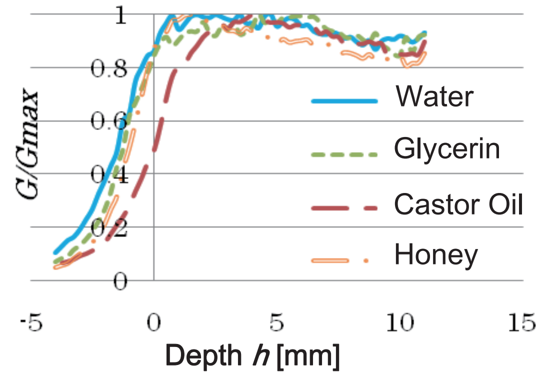

Fig. 4 Results obtained by resonator A for fudamental mode.

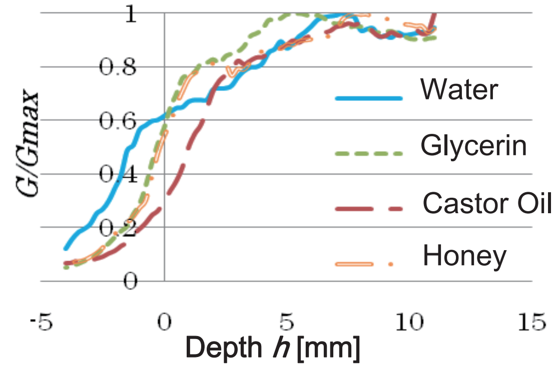

Fig. 5 Results obtained by resonator A for inharmonic-overtone mode.

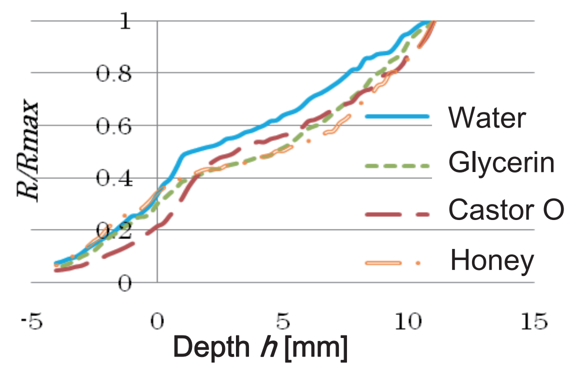

Fig. 6 Results obtained by resonator B for fundamental mode.

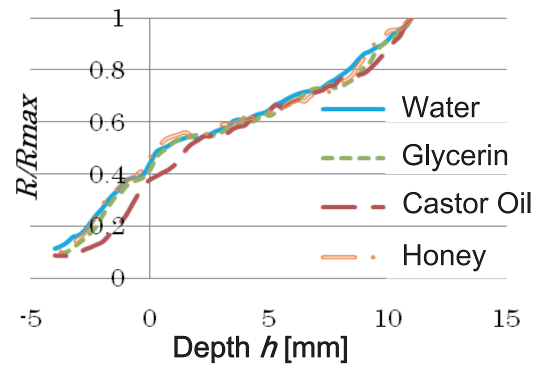

Fig. 7 Results obtained for inharmonic undertone mode.