Piezoelectric Resonant Sensor for Sound Velocity of Liquids

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Abstract: The sensor consists of two disc-shaped piezoelectric plates with the liquid in between. Each piezoelectric plate is a bulk resonator with two electrodes driven in thickness extensional modes. The two resonator plates are electrically connected in parallel and the total admittance is measured in the vicinity of two quasi-harmonic series resonance frequencies by a PC-controlled electric admittance measurement system. Two quasi-harmonic resonance frequencies are used to allow the elimination of the liquid density assumed to be unknown.

SENSOR CONSTRUCTION

Fig. 1 shows a cross section of the piezoceramic sensor and a photograph of the sensor as well as of the single pieces by which the sensor is assembled. The sensor consists of two plano-parallel piezoceramic resonators vibrating in thickness extensional mode. The liquid to be measured is confined between these two resonators. Both PZT piezoelectric ceramics (lead-zirconate-titanate) and lithium niobate (Z-cut) have been utilized as piezoelectric plate materials. Energy trapping in the center of the circular disk was achieved by so-called Gaussian electrodes (in the case of plano-parallel resonators) or alternatively by a plane-plane-convex plate shape in the PZT version and by a plane-convex plate shape in the lithium-niobate version. The inner Au-electrodes are in contact with the liquid and electrically grounded. The outer electrodes are interconnected and the electric admittance of the resonator is defined between the inner and outer electrode pairs. The fundamental frequencies are 2 or 4 MHz for the single PZT plates and 4 MHz for the single lithium-niobate plates, respectively. The extensional thickness mode purity was checked directly by corresponding mode pattern measurements using a laser speckle vibration amplitude measurement system [1].

RESONANCE FREQUENCIES AND MEASUREMENT ELECTRONICS

The primary measurandes are two appropriately chosen quasi-harmonic resonance frequencies of the composite resonator filled with the liquid under test. If the two piezoelectric resonators used are tuned exactly to the same resonance frequency and driven in a symmetric way, one can calculate the series resonance frequencies from the well known equation [2, 3]

\[
p_L \nu_L \tan \frac{\nu_L}{\nu} + \frac{K}{\rho v} \nu_L \tan \frac{\nu_L}{2v} = 0 \quad \text{with} \quad K = 1 - k^2 \tan \frac{\nu_L}{2v}, \quad \tilde{K} = 1 - k^2 \tan \frac{\nu_L}{2v}.
\]

In this equation the total electrical and mechanical losses are neglected. \( \nu_L \) is the sound velocity and \( \rho_L \) is the mass density of the liquid. The respective quantities for the resonator material are \( v \) and \( \rho \), these quantities as well as the resonator thickness \( l \), the half thickness of the liquid layer \( l_L \) and piezoelectric...
coupling constant $k$ are known. Therefore the sound velocity of the liquid inside the sensor can be calculated out of two measured series resonance frequencies. In addition to the determination of the sound velocity of the liquid, the mass density of the liquid can be obtained from the same primary measurands. However, at present the accuracy of the density value is one order of magnitude lower than that of the velocity (the latter is typically 0.1% for water, acetone, glycerin). The measurement electronics are based on a PC-controlled electric admittance measurement system that determines the series resonance frequencies associated with maxima of the conductance [4].

RESULTS

As an example, Fig. 2 shows the measured admittance and conductance for water in the frequency range from 1.8 MHz to 6.3 MHz. The maxima of the conductance are marked in the admittance locus plot by squares with a cross and labelled with $f_3$, $f_4$ and $f_5$, respectively. The index of this frequency nomenclature gives the number of half wave lengths generated at the corresponding resonance. (Values of these frequencies for water are given explicitly in Table 1). The nearer a series resonance frequency of the filled sensor is to a series resonance frequency of the unloaded piezoelectric plate, the higher is its admittance. In the last column of Table 1 reference measurements using a high precision density and sound analyzer DSA 48 from Anton Paar GmbH, Graz, Austria, are given.

<table>
<thead>
<tr>
<th>Used pair of frequencies</th>
<th>$f_3$: 1851715 Hz</th>
<th>$f_4$: 2584800 Hz</th>
<th>$f_5$: 3314312 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_l$ [m/s]</td>
<td>1496.74</td>
<td>1496.86</td>
<td>1496.32</td>
</tr>
<tr>
<td>$\rho_l$ [kg/m$^3$]</td>
<td>1061.79</td>
<td>980.38</td>
<td>905.54</td>
</tr>
</tbody>
</table>

The sensitivity of the sensor principle to relative velocity changes is more than one order of magnitude higher than to relative density changes. Thus, the sensor is especially attractive for high resolution sound velocity measurements.

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REFERENCES


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