High Precision Tuning Fork Sensor for Liquid Property Measurements

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***Abstract*— Application of piezoelectric flexural mechanical resonators such as tuning forks to accurate measurements of liquid physical properties is discussed. It was shown earlier that liquid properties such as viscosity, density and dielectric constant can be obtained by measuring the resonator AC impedance within certain frequency range and fitting it to the resonator equivalent circuit model [1]. Error sources for the liquid property measurements and their influence on the measured value are investigated. It is shown experimentally that the reproducibility of the viscosity and density measurements using this technique can meet and often exceed the one delivered by the well established analytical instrumentation. It is also demonstrated here that better performance is resulting from the use of the whole impedance curve over a frequency range, which produces better statistics and natural averaging of the noise.**

I. Introduction

We have previously shown [1] that the complex impedance of a flexural resonator in a liquid environment could be represented by the equivalent circuit shown on Fig.1.

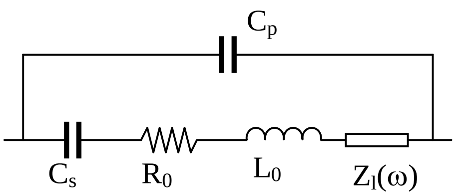

Fig. 1

The equivalent parameters C_s, R_0, L_0 represent respectively the mechanical compliance, loss and inertia of the resonator in vacuum. An additional contribution to the impedance $Z_l(\omega)$ from the surrounding liquid is given by following relationship: $Z_l(\omega) = Ai\omega\rho + B\sqrt{\omega\rho\eta}\,(1+i)$, where ω is the operation frequency, ρ is the liquid density, η is the liquid viscosity, A and B are the geometry factors that depend only on the resonator geometry and mode of oscillation.

C_p is the electrical capacity of the resonator electrodes that is affected by the electrical properties of the surrounding liquid due to the fringing field. The changes in C_p can be represented by the following relationship:

$C_p(\varepsilon) = C_p(1) + (\varepsilon - 1)\partial C_p / \partial\varepsilon$, where $C_p(1)$ is the electrodes capacitance in vacuum, ε is liquid permittivity, and $dC_p/d\varepsilon$ is the sensitivity to changes in the electrical properties of the environment.

It is evident from the equivalent circuit that the liquid property-dependent impedance component $Z_l(\omega)$ is not directly accessible for the measurement, therefore it is necessary to know the values of other equivalent circuit components to be able to extract the value of the component of interest. It is usually done by measuring the resonator response in vacuum, where $Z_l(\omega) = 0$ and extracting these values using standard techniques. Geometry factors $dC_p/d\varepsilon$, A and B are calibrated by submerging the resonator in a liquid with known properties and fitting the measured resonator response to the equivalent circuit varying $dC_p/d\varepsilon$, A and B as free parameters. Measuring the properties of an unknown liquid is done by fitting the measured resonator response to the equivalent circuit varying ε , ρ and η as free parameters[2].

II. Preliminary Discussion

The impedance of the flexural resonator depends on the frequency and following parameters: vacuum parameters C_s, R_0, L_0 ; geometry factors $dC_p/d\varepsilon$, A, B and liquid parameters of interest ε , ρ and η. Once the vacuum parameters and geometry factors are calibrated, the impedance of the resonator depends only on frequency and the three liquid properties that are found by measuring the resonator impedance in the unknown liquid. To be able to calculate the three unknown parameters the impedance value has to be measured at several different frequencies. In practice it is easier to measure the absolute value of the complex impedance, so from now on we will use $Z(\omega)$ to depict the absolute value of the complex resonator impedance.

In the functional form we have a system of equations:

$$Z_{\omega n} = Z(\omega_n, \varepsilon, \rho, \eta), \tag{1}$$

where $Z_{\omega n}$ is the impedance absolute value measured at a frequency ω_n. Obviously, depending on properties of the $Z(\omega)$ function, it is necessary to have at least three measured values to be able to solve this system of equations for the unknown ε, ρ and η. Since the measured value of $Z_{\omega n}$ always includes some error ΔZ, the accuracy of the solution may strongly depend on the choice of the frequency points ω_n at which the impedance values were measured. Any measurement error and the resulting errors in the parameters can be related in the following manner. Assuming that the impedance error

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