Advanced Electromechanical Model for Torsional Crystal Viscosity Sensors

A. Laesecke [S,C], H.-D. Seelig
National Institute of Standards and Technology (NIST), Physical and Chemical Properties Division
325 Broadway, Boulder, Colorado 80305-3328, U.S.A.
Arno.Laesecke@Boulder.NIST.Gov

The torsional vibration of two cylindrical piezoelectric quartz crystals with different sizes was measured in vacuo at drive voltages from 5 mV to 1.1 V and over a wide temperature range. The crystals exhibited increasingly nonlinear resonances with increasing drive voltage, which cannot be represented with the available linear electromechanical model for torsional crystal viscosity sensors. However, to apply these sensors for measurements in gases, their performance in vacuo has to be known as accurately as possible.

An advanced nonlinear electromechanical model for the crystal oscillation was developed and applied to the experimental data. It describes the crystal oscillation in terms of a combined Duffing-Van der Pol nonlinearity with displacement-dependent stiffness and damping. These were incorporated into the equivalent electrical circuit of the viscosity sensor. The advanced nonlinear model can represent the measured resonances at all drive voltages. It allows identifying linear and nonlinear contributions to the crystal vibration, which is important to ensure the correct operation of the transducer. Similarly, the model can be applied to analyze crystal resonances in gases and liquids for contributions due to viscous shear on the crystal surfaces and other types of damping. The availability of this analytical tool improves the theory of the instrument and reduces the uncertainty of viscosity measurements with torsionally vibrating crystals.