New Methodology to Determine the Dielectric Constant and Loss at the Resonance/Antiresonance Frequency Range

H. Daneshpajooh[1*], K. Uchino[1], and M. Choi[1]
[1] International Center for Actuators & Transducers, The Pennsylvania State University
141 Materials Research Laboratory, State College, PA, 16802, USA
*Hossein Daneshpajooh: hxd33@psu.edu

Resonance behavior of piezoelectric materials has a considerable significance for various applications such as transducers and sensors. However, the hysteresis nonlinearity and loss influence significantly their efficiency at high power applications. The hysteresis loss at small vibrations resonance is mainly dependent on the mechanical loss. However, at high vibration velocities, the extensive dielectric loss contribution in loss dominates, which results in heat generation. Therefore, investigation of dielectric, mechanical and piezoelectric losses at the resonance and antiresonance conditions can play a crucial role in the enhancement of piezoelectric devices' efficiency.

In this research, we focus on determining dielectric permittivity and its loss factor at the resonance and anti-resonance frequencies, using a new methodology based on a burst method. In the burst method, the sample is driven for a short period and then by introducing a short-circuit or an open-circuit system immediately after resonance/antiresonance, the vibrations decay in pure mechanical mode. Therefore, the effect of temperature rise on high power resonance behavior of piezoelectric ceramics can be eliminated.

The phase lags of force factor and voltage factor were derived for determining the extensive dielectric loss in the k_{31} mode piezoelectric ceramic bars (plate with $a \ll b \ll L$ dimensions, poled along the thickness). We introduced the complex parameters to investigate the loss mechanism in burst mode, as follow, $\varepsilon^{X^*} = \varepsilon^X(1 - j\tan\delta')$, $s^{E^*} = s^E(1 - j\tan\phi')$, $d^* = d(1 - j\tan\theta')$ and $\varepsilon^{x^*} = \varepsilon^x(1 - j\tan\delta)$where, X, x and E superscriptions are representative of constant stress, constant strain and constant electric field boundary conditions. Also, $\tan\delta'$, $\tan\phi'$, $\tan\theta'$, and $\tan\delta$ are intensive dielectric, elastic and piezoelectric loss and extensive dielectric loss, respectively. In previous studies the permittivity information should be obtained at an off-resonance low frequency, however in this research, we focused on measurement of the extensive dielectric loss directly at the resonance frequency.
In the burst method, the short-circuit current and vibration velocity (at resonance condition) are related through the force factor ($A = i_0/v_0$), and the open-circuit voltage and vibration displacement (at antiresonance condition) are related through the voltage factor ($B = V_0/u_0$). Accordingly, the extensive dielectric loss can be measured directly at high fundamental frequencies, using both the force factor and voltage factor phase lag.

$$\tan\delta = -Im\left\{\frac{A_{31}}{B_{31}}\right\} \times \frac{a}{bL} \times \frac{1}{\varepsilon_0 \varepsilon_{33}^{x1}}$$

In order to measure this phase delay, the phase delay of strain, respect to electric field and current of piezoelectric samples is measured at resonance and antiresonance frequencies, using laser Doppler vibrometer.

The research is supported by Office of Naval Research under Grant No. N00014-14-1-1044.