Advances in Piezoelectric Systems: An Application-Based Approach.

Piezoelectricity is a fascinating research topic with wide-branching applications due to the unique property of bidirectional energy transfer. Piezoceramics can be used as both actuators and sensors without imposing any constraints on their supporting circuity. This property, coupled with their low manufacturing costs and high robustness has enabled widespread usage in applications ranging from simple spark lighters or pressure sensors to much more complicated energy harvesting systems and piezoelectric transformers. One governing property of piezoelectric devices is the existence of a mechanical frequency of resonance, or the natural frequency of the device paired with an antiresonance, which are material and size-dependent. From an electrical standpoint, the equivalent behavior of a piezoelectric device depends on how close or far from its natural resonance the device is excited in terms of frequency. Based on this classification, three distinct, useful electrical behaviors can be identified: a capacitive behavior prominent at frequencies far from resonance, a resistive behavior encountered at resonance and antiresonance peaks and an inductive behavior, encountered at frequencies between the two. These three distinct behaviors encountered in any piezoelectric device represents the basis of discussion in the thesis. Therefore the present PhD dissertation is an application-based approach to researching all three behaviors individually, while finding solutions to the challenges encountered along the way. First, the capacitive behavior is studied, with the Piezoelectric Actuator Drive motor as a direct application. At low frequencies, piezoelectric devices are ideal as micro- and nanoscale positioning actuators but they are plagued by high levels of hysteretic nonlinearities. A model is developed to estimate this behavior, followed by a low-cost forward compensation method which achieves a positioning error reduction by a factor 20. Next, the characteristics of the PAD motor are researched and a method of extracting mechanical quality information and predict overload through feedback signal analysis is demonstrated. The next behavior studied is the inductive behavior, specifically dealing with a bidirectional dc-dc power converter employing a piezoelectric transformer as major component. The main contribution here is achieving optimum tracking, hard-switching minimization and power ow control during bidirectional operation of a self-oscillating converter. Feasibility of using the converter in an MRI scanner is demonstrated. The third and nal behavior researched is the resistive behavior. This is widely encountered since most piezoelectric motors, ultrasonic baths and some energy harvesting systems operate at resonance. Friction control through squeeze-Im application is achieved in an electrostatic surface actuator for the rst time ever. This enables system functionality without glass gap material and concomitantly reduces minimum electrostatic operating voltage by 70%.

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