Piezoelectric generators for biomedical and dental applications: Effects of cyclic loading

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Received: 20 October 2005 / Accepted: 28 February 2006
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Abstract This paper presents the results of a study of the effect of cyclic loading parameters on the performance of piezo crystals. The output power of the crystals was observed to increase with parameters such as the cyclic frequency and the dynamic load range. However, the output power also decreased with increasing mean load. The efficiency of the crystal was calculated based on the mechanical energy applied to the piezo crystal. The ratio of the electrical output to mechanical energy input was taken as the efficiency of the crystal. This ratio was seen to increase with the cycling frequency, and also with the dynamic load range. However, increasing mean load caused the efficiency to drop significantly. The implications of the results are discussed for possible applications implanted bioMEMS and microelectronics systems.

1 Introduction

The conversion of kinetic energy to electrical energy has been investigated by a number of researchers for electrical power generation [1–6]. Within this framework, piezoelectric materials have been investigated as essential elements for high-power pulse generation [1–6]. Electrical energy is generated when an applied force overcomes internal inductance or capacitance of a material. For a piezoelectric material, the internal fields are stored in the ohmic lattice of the material. Mechanical deformation of the material (by the applications of static or dynamic loads) generates the output voltage required to power the piezoelectric pulse generator. Experiments have been performed by Xu et al. [7], who applied quasi-static or dynamic stress to lead zirconia titanate (PZT) piezoelectric ceramics. They reported that dynamic and quasi-static loading produced equal magnitudes of output voltage. They also reported that the dynamic loading produced a unidirectional voltage, while the quasi-static case generated a bi-directional voltage.

However, Engel et al. [5] have reported different results for similar experiments performed on piezoelectric systems under dynamic and quasi-static systems. They discovered that the dynamic loading yielded a much higher output voltage (up to 10 times more) than the quasi-static case. They compared their experimental measurements of power generation with predictions from simulations. Their theory suggests that the material thickness to cross sectional area: ratio (TAR = h/piezoe/A) can be used to maximize output power. A higher TAR results in a higher output voltage, while a lower output current. In an effort to maximize output power, the voltage and current have to be maximized. The overall effect of thickness to area ratio (TAR) will be dominated by the larger contribution of voltage to the product of voltage and current. In other words, piezoelectric power output increases with increasing TAR.

Two models have been proposed to explain the behavior of piezoelectric generators [5]. The first is a mechanical model that provides information on the displacement (deformation) of the material due to applied force and thus the generated voltage, while the second is an electrical model that is used to identify electrical conditions that are needed to generate maximum current [5]. These models provide insights into how loading/deformation can result in piezoelectric power generation under static loading conditions. However, models that explain the possible ranges of responses under cyclic