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TECHNICAL NOTE

A novel thick-film piezoelectric micro-generator

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Abstract
The use of alternative electrical energy sources to batteries is of particular significance to remote sensor systems. A vibration-powered micro-generator, based on a screen printed piezoelectric material, is proposed for this purpose. Theoretical and experimental results show that 2 μW can be generated for a vibration frequency of only 80 Hz. The device is not optimized and significant improvements are envisaged in the future.

1. Introduction

As MEMS and smart material technologies mature, embedded and remote systems are becoming more attractive. In applications such as medical implants and structural monitoring the need to supply power can be a significant engineering problem. Traditionally, remote devices have used batteries as a source of electrical energy. These, however, offer only a limited life span to a system and the recent, rapid advances in integrated circuit technology have not been matched by similar advances in battery technology. Thus, power requirements place important limits on the capability of remote microsystems. This paper explores issues relating to generating power from vibrations. A prototype thick-film piezoelectric generator is described. The device consists of a thick-film piezoelectric layer deposited onto a thin steel beam. As the beam is shaken, the piezoelectric material is deformed and generates electrical energy.

Thick-film technology is generally regarded as being compact, robust and relatively inexpensive and thick-film hybrid circuits have found use in a wide variety of applications (televisions, automotive electronics, telephones etc). Use of the technology for developing sensing systems is a comparatively new approach [1]. Recent work in this field includes the use of thick-film piezoelectric materials with micromachined silicon structures [2, 3]. The micro-generator is essentially a resonant mechanical structure based on a cantilever beam and seismic mass. It differs from that proposed by Williams and Yates [4], who use a magnet and coil arrangement to generate the electrical power. The base substrate material is AISI 316 stainless steel of thickness 0.1 mm, with a layer of Heraeus IP222L dielectric material screen printed onto both sides (20 μm thickness each layer). The subsequent thick-film piezoelectric and electrode layers are deposited using multiple printings and firings. The device is shown in figure 1 and is nominally 23 mm long with a maximum width of 20 mm; the beam is tapered to obtain a constant strain along the length. A small mass (0.8 g) is attached to the free end of the beam. One of the factors affecting output power delivered is the resonant frequency of the beam; the higher the frequency the more power will be available. The application areas envisaged for our system include vibrating machinery and vehicles, where the frequencies of interest do not generally exceed a few hundred Hertz, and are often confined to below 100 Hz.

2. Experimental procedure

A Goodman V.50 Mk.1 (model 390) vibration generator was used to vibrate the device under test. The frequency range of vibrations was between 5 Hz and 4 kHz. The electrical charge generated within the piezoelectric layers was amplified using a Kistler Model 50 calibrated charge amplifier and subsequently fed into a Hewlett Packard HP356000A Dynamic Signal Analyser. The amplitude of vibration of the free end of the beam was measured with a linear micrometer. The resonant frequency of the device was determined by supplying

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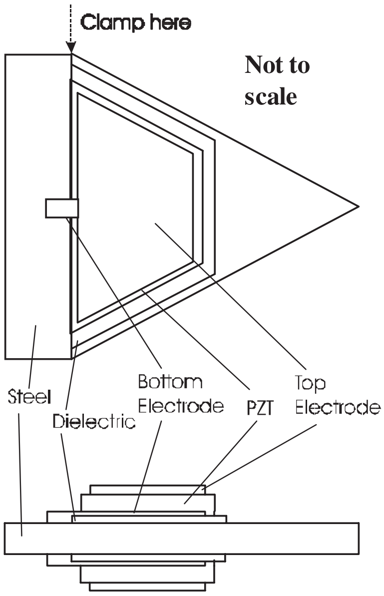

Figure 1. The beam-based piezoelectric micro-generator.

a periodic chirp to the shaker and observing output (via the charge amplifier) on the signal analyser, which subsequently performed a Fourier transform. Using this method the resonant frequency was found to be 80 Hz, which compared well with the theoretical value obtained using a simple analytical model. In order to observe the effect of resistive loading on the micro-generator, various values of load resistance were connected in parallel across the piezoelectric layers and the output signal observed on the signal analyser. The experiments were repeated for differing values of input excitation amplitude. This procedure allowed the optimum value of shunt resistance to be determined, and hence the load voltage for a given input excitation could be found.

3. Results and discussion

The effectiveness of the micro-generator is shown in figure 2, which plots output power against load resistance for several values of amplitude displacement at the free end of the beam. The power generated is a function of the magnitude of the displacement, as would be expected. The series of curves illustrate that there is an optimum value of load resistance required to extract maximum power from the vibrating beam. In this case, it was found to be 333 kΩ. The maximum power generated for a 0.9 mm amplitude displacement is around 2 μW.

Figure 3 shows how output voltage varies as a function of beam displacement for a system driving the optimum load resistance. The maximum voltage generated is around 1.2 V. For values of amplitude exceeding 1 mm the equivalent strains on the beam surface will cause the steel to exhibit nonlinear mechanical behaviour.

Although the system produces a relatively small amount of electrical power in its present form, we believe that there is scope to increase this figure. For example, the electromechanical coupling coefficient for the thick-film piezoelectric material is lower than that of bulk PZT (lead zirconate titanate). One way of improving this is to increase the densification of the films and this is part of the ongoing research within our group. For most practical systems there will be a broad band of frequencies available and hence a multi-beam configuration could be envisaged whereby the resonant frequencies of individual beams are matched to the ambient vibrations. Another improvement will result from laminating several layers of the piezoelectric material. We anticipate that these modifications will result in several orders of magnitude increase in output power.

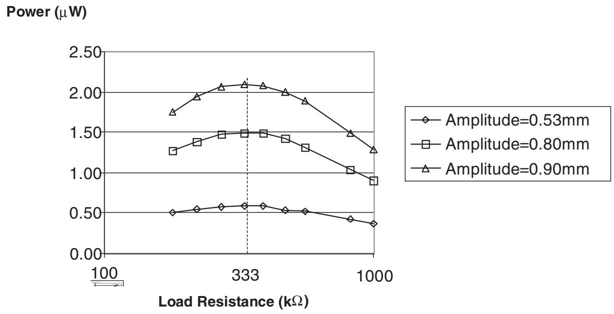

Figure 2. Output power against load resistance for varying amplitudes of vibration.

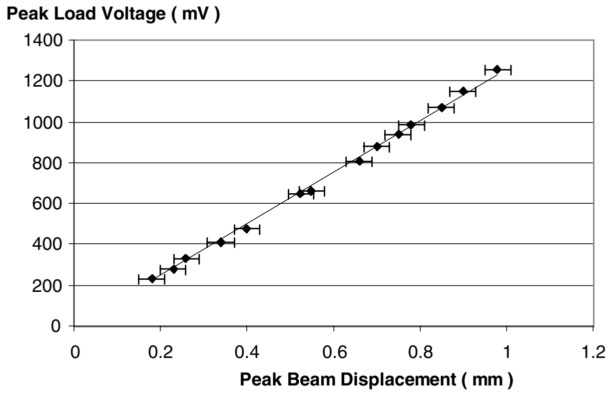

Figure 3. Load voltage versus vibration amplitude for an optimally shunted beam.

4. Conclusions

This paper has shown how a screen printable piezoelectric thick film, based on PZT 5H (supplied by Morgan Electroceramics Ltd), can be used as a mechanism for generating electric power from mechanical vibrations. The optimum load resistance has been determined experimentally and we are currently developing an analytical model of the system to validate the results. We have suggested methods for improving the power generated and are currently addressing these issues in an ongoing research programme.

Acknowledgments

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