Thick-film Piezoelectric Vibration Harvesting – A HUMS Application

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Abstract: A vibration energy scavenger, manufactured entirely by thick-film construction, has been developed to power autonomous subsystems in an embedded health and useage system. The device is constrained to a 2mm thickness and has been designed for a specific helicopter application. The resulting power output is capable of powering an 'off-the-shelf' microcontroller based system.

1 Introduction: The aim of the EU Framework 7 project TRIADE [1] is to produce a credit card sized module for HUMS (Health and Useage Monitoring) for a selection of aerospace applications. The requirement is for the module to be self-contained so in principle it can be embedded in the structure that it is monitoring. The system uses a rechargeable battery, which is recharged primarily by an inductive system, but included in the system is the capability for harvesting vibration energy, to augment the power in

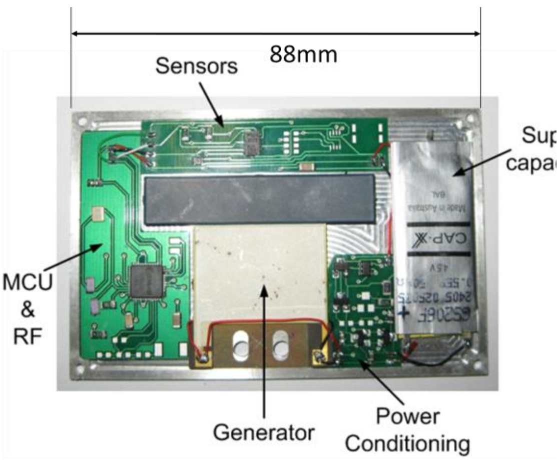

Fig. 1. The prototype self powered system

the battery and also give the option of having self powered distributed sensors that interface to the main module.

The vibration energy harvester is the subject of this paper, and uses a thick-film PZT paste, previously developed at the University of Southampton [2], deposited onto a steel cantilever as the transduction method. Displacement of the cantilever distorts the PZT which generates electrical energy. We also report the integration of a seismic mass onto the cantilever, again by screen-printing, leading to an entirely screen-printed piezoelectric energy harvester.

The prototype energy harvester has been characterised against a vibration spectrum taken from a PZL Helicopter and has been demonstrated powering a sensor based RF system (fig 1), thus validating its potential for practical applications.

2 Piezoelectric Energy Harvesting

The generator under consideration is a bimorph construction, with the steel cantilever sandwiched between two active

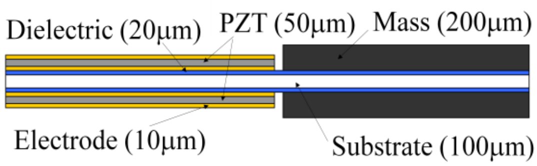

Fig. 2. Cross section of the bimorph

piezoelectric generators (fig 2). The mass is provided by screen-printing tungsten onto the generator. The tungsten paste developed has a density of 10,000kg/m^3 (52% of the bulk material), and the PZT paste has a d_{33} coefficient of about 130pC/N after poling [3]. Modelling of the generator was done using the linear model introduced by Roundy [4] which can be expressed as

$$\ddot{z} + 2\zeta_m \omega_n \dot{z} + \omega_n^2 z - \frac{d_{31}\omega_n^2}{t_{pzt}} \cdot v = b^* \cdot a \qquad (1)$$

$$R_L C_p \dot{v} + v + m R_L \frac{d_{31}\omega_n^2}{t_{pzt}} \dot{z} = 0 \qquad (2)$$

where z is the displacement of the inertial mass, m; ζ_m is the damping factor, t_{pzt} is the thickness of the PZT layer, b* is the ratio of strain to vertical displacement, a is the acceleration, R_L is the load resistance, C_p is the capacitance of the PZT layer and v is the voltage across the electrodes.

The target design for the generator was for 67Hz with an input acceleration of 0.4g ($3.9ms^{-2}$) peak, as this is one of the main resonances identified in the application. A further constraint was the peak displacement of the cantilever should be +/-2mm as defined by the package size.

3 Results

Although some generators can demonstrate non-linear characteristics, the generator described here appears linear as shown in fig 3.

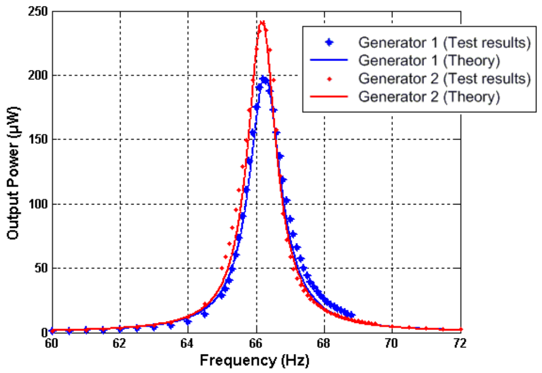

Fig. 3. Measured and theoretical power outputs from two generators

For the two generators shown, power outputs of 197µW and 240µW were achieved at a frequency of 66.2Hz for the desired input amplitude. This frequency is 1.2% off the design value. These outputs correspond to power densities of about $600\mu W/g_{pk}$ compared with $118\mu W/g_{pk}$ for the initially reported generator [5].

4 Discussion

Although these levels are not high in absolute magnitude, they are sufficient to charge and power low duty cycle systems. The circuit shown in figure 1 has at its core a Chipcon CC2430 which combines a 2.4GHz transceiver with an 8051 class microcontroller and a suit of sensors (temperature, pressure and acceleration), with power stored in a supercapacitor. It can be calculated that if the system is duty cycled in that it is sent to sleep for the majority of the time and wakes up to perform its sensing and transmission (which for example takes 10mS) then it requires 42 seconds to replenish the energy used. If the RF sub section is not used every time, then this time reduces, as it is the radio system (in this case) that uses the most power.

3 Conclusions

This work has demonstrated a vibration harvesting piezoelectric generator that has been entirely fabricated by the thick-film process, giving a robust design matched to an aeronautical application. Further, this generator has been characterised and incorporated into a vibration powered wireless sensing device with the dimensions of a credit card suitable for embedding in structures, that uses standard electronic components. Future work is moving towards demonstrating this system on an aircraft, under the TRIADE project.

Acknowledgements

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References

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