DEVELOPMENT OF A MICROSCALE ENERGY HARVESTING SYSTEM FOR PORTABLE DEVICE CHARGING: A LAPTOP CASE MODEL

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Abstract: A design study is presented for a piezoelectric energy harvesting device designed to recharge a laptop computer battery. The piezoelectric energy harvesting structure is designed to be built into the laptop case, and use the laptop computer as the seismic mass for vibration-based energy harvesting, thereby achieving a low resonance frequency in order to maximize the energy output during typical activities (walking, bicycling, riding in a car). Macro-scale models of the energy harvesting element were constructed and measured, and their performance was used to validate a SPICE-based model. The results of the model were then used as the basis for a design and comparison of the complete system using microscale PZT and AlN bimorph energy harvesters.

Keywords: Energy harvesting, piezoelectric bimorph, battery charging, PZT, AlN

INTRODUCTION

Energy harvesting (or “power scavenging”) technologies have come under intense investigation in recent years, as the proliferation of portable electronic devices and sensors has increased the demand for portable or unwired electric power. Batteries are the most common solution for portable power, and it is hoped that energy harvesting can provide an alternative solution which is infinitely renewable and does not require replacement. However, the small amount of energy available from the ambient environment and the low efficiency of most harvesting schemes has limited the application of these technologies to large (10’s of cm$^3$) wireless sensor nodes with power consumption of a few µW. In this paper, we present a battery charging system which could greatly reduce the need for use of AC power adapters, increasing user flexibility and saving energy, while extending the life of the device’s batteries, reducing landfill and the expensive recycling of the materials. In this design, piezoelectric harvesting structures are built into an external case for the computer, and the computer itself provides the seismic mass for vibration-based energy harvesting. The use of the laptop as the seismic mass allows the system to achieve very low resonance frequencies and large deflections in order to take advantage of the majority of the vibration energy available during typical daily activities where a laptop might be present, such as walking, riding a bicycle, or riding in a car.

The design presented here is called the Self-Mass System (SMS). The SMS uses a large array of small cantilevers connected to the exterior wall of the laptop computer case. The laptop is inserted into the pocket in the middle of the case, surrounded by the piezoelectric cantilevers (Fig. 1). When the system is subject to external vibrations (such as traveling in a car), the mass of the computer causes the piezoelectric cantilevers to deflect, generating electric current.

![Figure 1: The Self-Mass System (SMS) concept.](image-url)

THEORY

It is well known that a properly configured piezoelectric bimorph cantilever can generate a useful voltage when it is deflected in either direction. When a mass is attached to the free end of a cantilever, vibrations at the base of the cantilever will induce deflection of the free end, and for a piezoelectric material, the voltage generated at the electrodes is proportional to the strain in the material (Fig. 2). The beam deflection, the consequent strain in the piezoelectric layers, and hence the output power, will be multiplied by the quality factor ($Q$) of the cantilever if the frequency of the input vibrations is equal to the natural resonance frequency of the cantilever. This is why the majority of vibration energy harvesters are designed to have a resonance frequency near the vibration of interest [1]. As a result, many vibration energy harvester designs are relatively large (cm-scale), in order to accommodate a
large proof mass and low stiffness cantilever (e.g., [2],[3]). Furthermore, in many practical applications, the typical vibration frequencies are very low, and/or multiple frequencies are present in the ambient environment, so performance predictions for devices designed for “ideal” vibration environments may be unsatisfactory.

BIMORPH MODELING

The design of a piezoelectric bimorph energy harvester can be approximated using the analytical expressions developed in [6]. These assume a sinusoidal input acceleration at frequency \( \omega \), and the power output is given by:

\[
P = \left[ \frac{M \omega}{F^2} \right] \frac{k_e^2 r}{4\zeta^2 \left( r + \frac{\pi}{2} \right)^2},
\]

where \( F \) is the input force, \( M \) is the effective mass, \( k_e^2 \) is the electromechanical coupling, and \( \zeta \) is the damping factor. In order to refine this estimate, the SPICE model for piezoelectric generators developed by Blystad and Halvorsen [5] was used (Fig. 3). This model allows the use of arbitrary input acceleration data and provides the prediction of the performance of different cantilevers under different input conditions.

In order to validate the models, a macro-scale bimorph cantilever was constructed using commercially available Lead Zirconate Titanate (PZT) sheets from Piezo Systems [7]. Two sheets were attached to a thin aluminum plate and connected electrically in parallel with the poling of each PZT sheet in the same direction, as shown in Fig. 2. The piezoelectric bimorph was then mounted on a piezoelectric shaker (Labworks, Inc.) and driven with an Agilent 33220A function generator and amplifier (Fig. 3). The output current from the bimorph was rectified using a simple bridge rectifier. The output at various input frequencies is compared with predictions in Fig. 5.
Figure 4: Test setup for piezoelectric bimorph model validation.

Figure 5: Results from the macro-scale piezoelectric bimorph. Measurements are compared to simulations for 0.5 g input.

**LAPTOP CASE DESIGN**

The SMS laptop case design uses two arrays of piezoelectric cantilever bimorphs, one above and one below the laptop. These cantilevers act as parallel springs whose total spring stiffness is the sum of all the cantilevers in the array. The cantilevers are connected in parallel electrically to maximize their output current for charging the battery.

The vibration energy present during several typical activities was measured using a MicroStrain G-link wireless accelerometer. Typical acceleration data and corresponding frequency spectra are shown in Fig. 6. It is apparent that the vibration energy harvester system should be designed to work at low frequencies, in the range of 10-20 Hz, and to handle accelerations in the range of ± 2g.

The validated SPICE model in tandem with a SolidWorks model was used as the basis for the design of an array of bimorph cantilevers that would harvest energy from the laptop case as shown in Fig. 1. Output from the SolidWorks model was taken and translated into parameters for a SPICE model (Fig. 3) and vice versa, which allowed the design to be modified, visualized and evaluated rapidly. The complete optimization problem for this design is complex, but it is illustrative to consider an example design with the length of the individual piezoelectric bimorphs fixed at 1.2 cm in order to create a laptop case with a relatively low profile which is not bulky compared to the laptop itself. The predicted performance of such a device is given in Table 1.
Table 1. Predicted performance for the SMS with \( L = 1.2 \) cm.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PZT</th>
<th>AlN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1.2 cm</td>
<td>2.08 cm</td>
</tr>
<tr>
<td>Width</td>
<td>25.9 cm</td>
<td>25.9 cm</td>
</tr>
<tr>
<td>Thickness</td>
<td>254 ( \mu )m</td>
<td>254 ( \mu )m</td>
</tr>
<tr>
<td># Bimorphs</td>
<td>1244</td>
<td>1244</td>
</tr>
<tr>
<td>Laptop Mass</td>
<td>3.6 kg</td>
<td></td>
</tr>
<tr>
<td>Case width</td>
<td>26 cm</td>
<td></td>
</tr>
<tr>
<td>Case length</td>
<td>31 cm</td>
<td></td>
</tr>
<tr>
<td>Output power</td>
<td>0.91 ( \mu )W</td>
<td>1.52 ( \mu )W</td>
</tr>
</tbody>
</table>

CONCLUSION

The example design shown here illustrates the feasibility of the concept. A laptop computer case with sides approximately 1.2 cm thick would be able to charge a typical 900 mAH Li-ion battery at 26% of the ideal trickle charge rate while driving or biking, and 16% while walking with this pre-optimized design. While it is unlikely that this would be a replacement of the primary AC adapter method of battery recharging at this time, storing the laptop in this case would extend the operating time and reduce the total charging required. The use of AlN as the piezoelectric element surprisingly provides performance comparable to that of PZT, with the advantage of being lead-free. It is expected that further optimization of the design, including alternate cantilever dimensions, impedance matching of the harvesting circuit, and wideband input considerations would allow for even greater power generation rates. Also designs that allow for greater overall strain, such as trapezoidal bimorphs and multiple layers of bimorph arrays, could further improve power output in future design iterations.

REFERENCES


