Geometric Optimization of Piezoelectric Energy Harvesting System

Rana N. Badran and Hani A. Ghali

Faculty of Electrical Engineering,
The British University in Egypt (BUE)
INTRODUCTION: WHAT IS ENERGY HARVESTING?

- The process of converting available ambient energy into usable electrical energy through the use of certain materials.

- Materials used for energy harvesting are able to:
  - Convert mechanical energy to Electrical energy
  - Convert temperature gradients to electrical energy.
  - Convert solar energy to electrical energy
The most versatile technique for vibrational energy harvesting is using piezoelectric materials.

**Advantages**
- Virtually inexhaustible energy source
- No adverse environmental effect
- Simple transduction mechanism
- Relatively easy to implement in different applications in comparison to other harvesting techniques

**Disadvantages**
- Harvested power is in the order of a few tens of micro-milli watts
- Harvested power tends to be unregulated and unpredicted
- Optimization techniques are necessary
- The device needs to be excited at certain frequencies
Piezoelectric materials generate electric charges when exposed to stresses or strains, the effect is called “piezoelectricity”.

The phenomenon of piezoelectricity was discovered by brothers Pierre and Jacques Curie in 1880.

When bending a piezoelectric cantilever upwards, a positive electrical potential voltage is generated. However, when the cantilever is bent downwards an electrical potential of the opposite polarity is generated.

The effect is due to the coupling of both mechanical and electrical fields.
The objective of this paper is to study the effect of geometrical optimization of an array configuration for a unimorph piezoelectric cantilever element. Steps for achieving this are:

1) Connect a previously optimized cantilever in a two-element and a three element array to increase energy conversion efficiency

2) Optimize the element spacing for the array configuration for maximum output

The device will be simulated in 3D configuration using COMSOL Multiphysics.

Most publications were concerned with the optimization of the harvesting circuits mounted on the piezoelectric harvesters. However; little interest has been given to optimizing the actual design of the piezoelectric device.
Two array configurations are going to be simulated.

The first is a mechanical series connection of two identical elements.

The second is a mechanical series connection of three identical elements.

Single elements are a unimorph cantilever, with two layers. The bottom steel layer is 0.2 mm thick.

Length and width will remain constant throughout the simulation. Piezoelectric layer thickness is the optimized value of 0.1 mm.

The element spacing is going to be varied from 0.5-2 mm to find the optimum value.
OPTIMIZATION OF PIEZOELECTRIC ENERGY HARVESTER

Settings to calculate the charge output

- Customizable variable D is defined on the top boundary of the piezoelectric layer, to measure the electrical displacement of the cantilever (C/m²)

\[ D = dT + \varepsilon_T E = \frac{q}{A} \ (C/m^2) \]

\[ q = \iiint_S D \ dA \]

- D: The electrical displacement (C/m²)
- q: The amount of electric charge.
- A: The surface area in m²

Settings to calculate the open circuit voltage

- A global variable is set on one point on the piezoelectric layer to calculate the open circuit voltage.

\[ V = \frac{q}{C} \ (V) \]

- q = Accumulated charge on piezoelectric terminal (C)
- C = Capacitance of piezoelectric device (μF)
ARRAY CONFIGURATION FOR A PIEZOELECTRIC ENERGY HARVESTER

Setting Boundary Conditions & Applying Mesh

Two-Element Array

- Same boundary condition as that of the previously optimized cantilever except:
  - Mesh elements along the width is doubled.
  - Body load is 1/2 that of the original (150 N/m³), since the volume is almost doubled

Three-Element Array

- Same boundary condition as that of the previously optimized cantilever except:
  - Mesh elements along the width is tripled.
  - Body load is 1/3 that of the original (100 N/m³), since the volume is almost tripled.
ARRAY CONFIGURATION FOR A PIEZOELECTRIC ENERGY HARVESTER

Eigenfrequency Analysis

Two-Element Array

- 298.3 Hz
- 302.8 Hz
- 1852.3 Hz

Three-Element Array

- 298.6 Hz
- 306.4 Hz
- 308.4 Hz

- 1863 Hz
- 3254.4 Hz
- 3460.7 Hz

- 1845.3 Hz
- 1893.4 Hz
- 1925.2 Hz
SIMULATION RESULTS

Results when exciting at fundamental resonance frequency

Output Voltage vs. Element Spacing

Output Charge vs. Element Spacing

Stored Energy vs. Element Spacing
CONCLUSION

- For the array configuration the optimum element spacing is 0.5 mm.
- When simulating at optimum element spacing and at the fundamental resonance frequency, the output charge, voltage and the stored energy are greatly optimized.

Charge, Voltage and Max. Tip Displacement
CONCLUSION (CONT.)

- The total stored energy increases with the number of elements.
- Results are much higher than those obtained when simulating the single unimorph cantilever. The total energy stored was increased to more than 30 times for the two-element array and to more than 1800 times for the three element array (in comparison to a single element).

<table>
<thead>
<tr>
<th></th>
<th>Single Element</th>
<th>Two Element Array</th>
<th>Three Element Array</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Stored Energy</td>
<td>0.04716 fJ</td>
<td>1.54 fJ</td>
<td>854.5 fJ</td>
</tr>
</tbody>
</table>
Questions?
Thank you!