Piezoelectric Vibration Energy Harvester Based on Thickness-Tapered Cantilever

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Introduction

The concept of vibration energy harvesting deals with the conversion of mechanical energy to electrical energy in order to power small and autonomous electronic devices. Piezoelectric vibration energy harvesters (VEH) are normally cantilever based structure where the stress is maximum at the fixed base and decreases towards the free end. Uniformly distributed stress on the piezoelectric cantilever beam improves generated power [1,2].

The thickness profile of the VEH is modified to get uniform distribution of stress on the beam. VEHs having uniform thickness and thickness-tapered beam are studied.

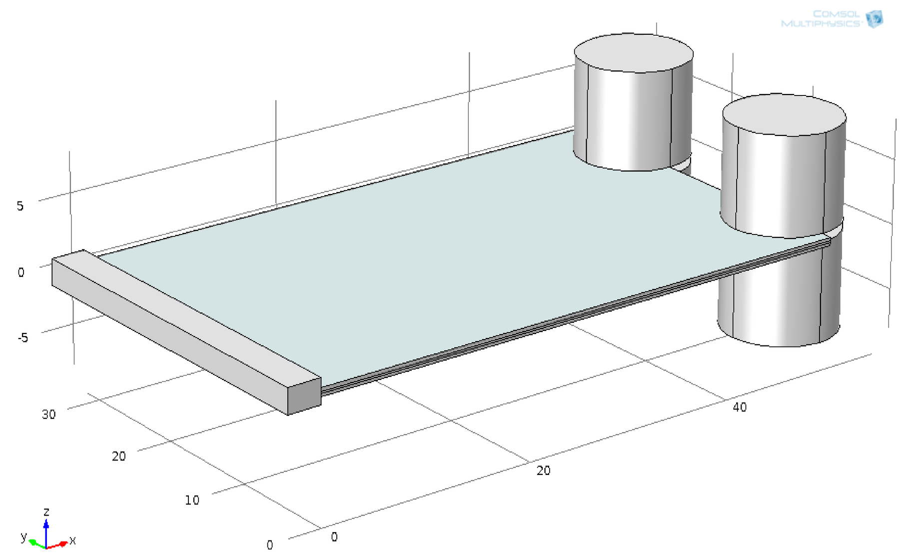

Figure 1 (a). VEH with uniform thickness beam

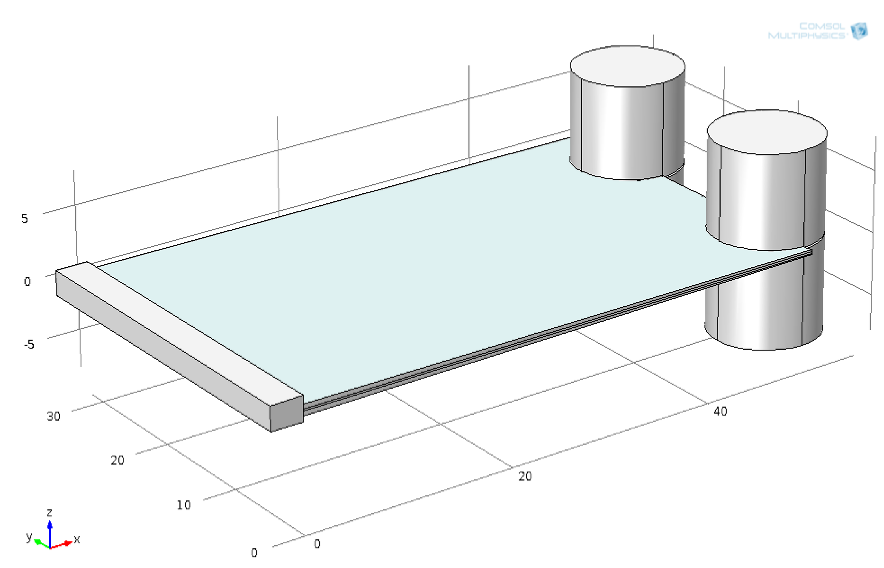

Figure 1 (b). VEH with thickness-tapered beam

Geometry of VEH

The uniform thickness piezoelectric VEH geometry consists of two piezoelectric layers and a substrate layer having uniform thicknesses and widths. The geometrical and physical parameters are as given in Table 1.

On the other hand the has substrate layer of uniform thickness and a linearly varying thickness of the piezoelectric layer along the length. Modified parameters for thickness-tapered VEH are given in Table 2.

Parameter	Description	Value	Unit
L	Beam length	50.8	mm
b	Beam width	31.8	mm
h_p	Piezoelectric layer thickness	0.26	mm
h_s	Substrate layer thickness	0.14	mm
M	End mass	12	g
Y_s	Young's modulus of substrate material	105	GPa
Y_p	Young's modulus of piezoelectric material	66	GPa
ρ_s	Mass density of piezoelectric material (PZT-5A)	7800	kg/m³
ρ_p	Mass density of substrate material (Brass)	9000	kg/m³
$\ddot{y}$	Amplitude of acceleration applied at the base	1 ***g***	m/s²

Table 1. Geometrical and material parameters used in the simulation

Parameter	Description	Value	Unit
h_{p0}	Thickness of piezoelectric layer at the fixed end	0.39	mm
h_{p1}	Thickness of piezoelectric layer at the free end	0.13	mm
M	End mass	19.6	g

Table 2. Modified parameters used in the simulation of thickness-tapered VEH

Simulation

Uniform and thickness-tapered types of piezoelectric VEHs are modeled in COMSOL using Piezoelectric Devices (*pzd*) and Electrical Circuit (*cir*) physics. The series connected piezoelectric layer are made of PZT-5A, and the substrate is made of brass. The first resonance frequency of vibration is obtained from Eigen Frequency Analysis, while the displacement of the end mass and generated power are obtained from Frequency Domain Analysis. The applied input excitation is sinusoidal of frequency 45.75 Hz and the acceleration level is 1 ***g***.

Simulation Results

The uniform thickness VEH is simulated first and the plot of generated voltage versus frequency across 1 kΩ load resistance is shown in figure (2). The generated power varies with the value of connected load resistance and is maximum for the optimal value. The displacement profile due to base excitation is shown in figure (3).

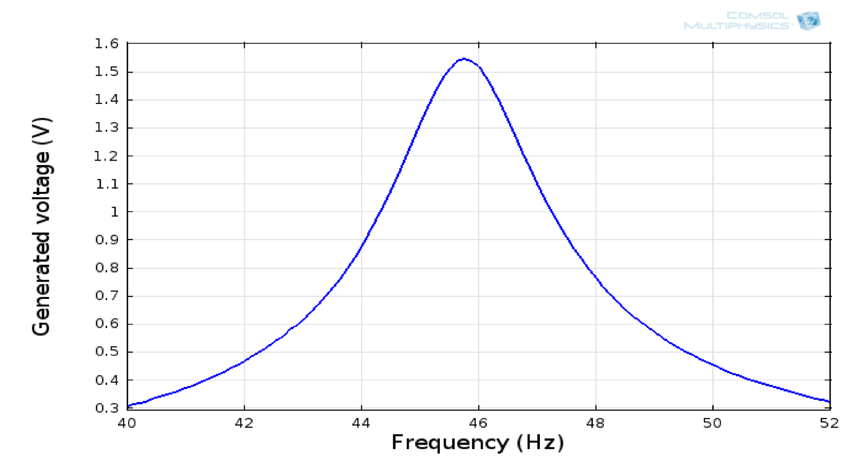

Figure 2. Plot of generated voltage versus frequency for 1kΩ load.

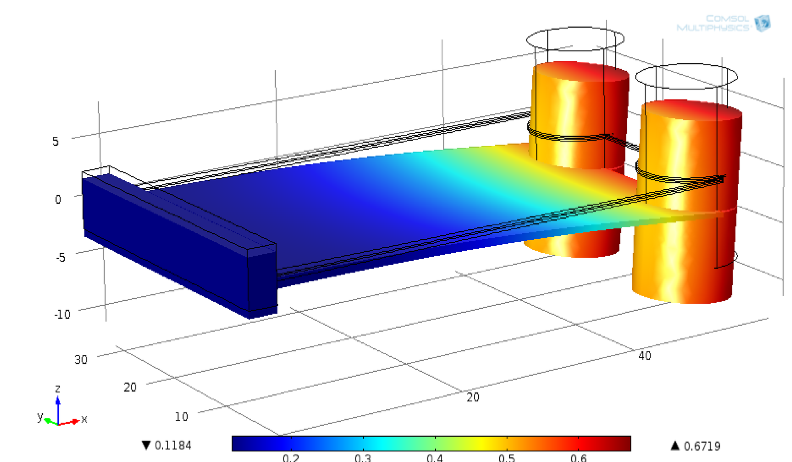

Figure 3. Displacement profile of the uniform thickness VEH.

Power Comparison

The variation of generated power with load resistance for uniform thickness and thickness-tapered VEH is plotted in figure (4). The peak power for the uniform thickness VEH is 21.95 mW and the peak power for the thickness-tapered VEH is 28.83 mW.

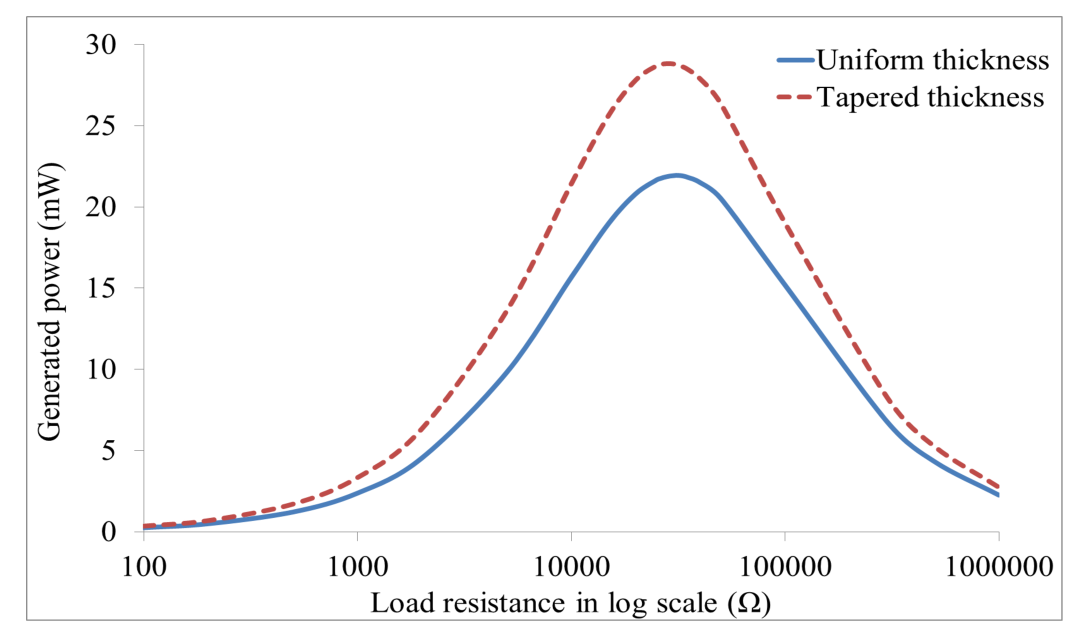

Figure 4. Plot of generated power for uniform and thickness-tapered VEHs.

Stress Comparison

The stress profile of the uniform thickness and thickness-tapered VEHs are shown in figure (5) and figure (6) respectively. The average stress on the surface is 4.25 MPa for uniform thickness VEH and 6.06 MPa for thickness-tapered VEH. The peak stress is 9.65 MPa in the uniform thickness VEH and 8.82 MPa in thickness-tapered VEH.

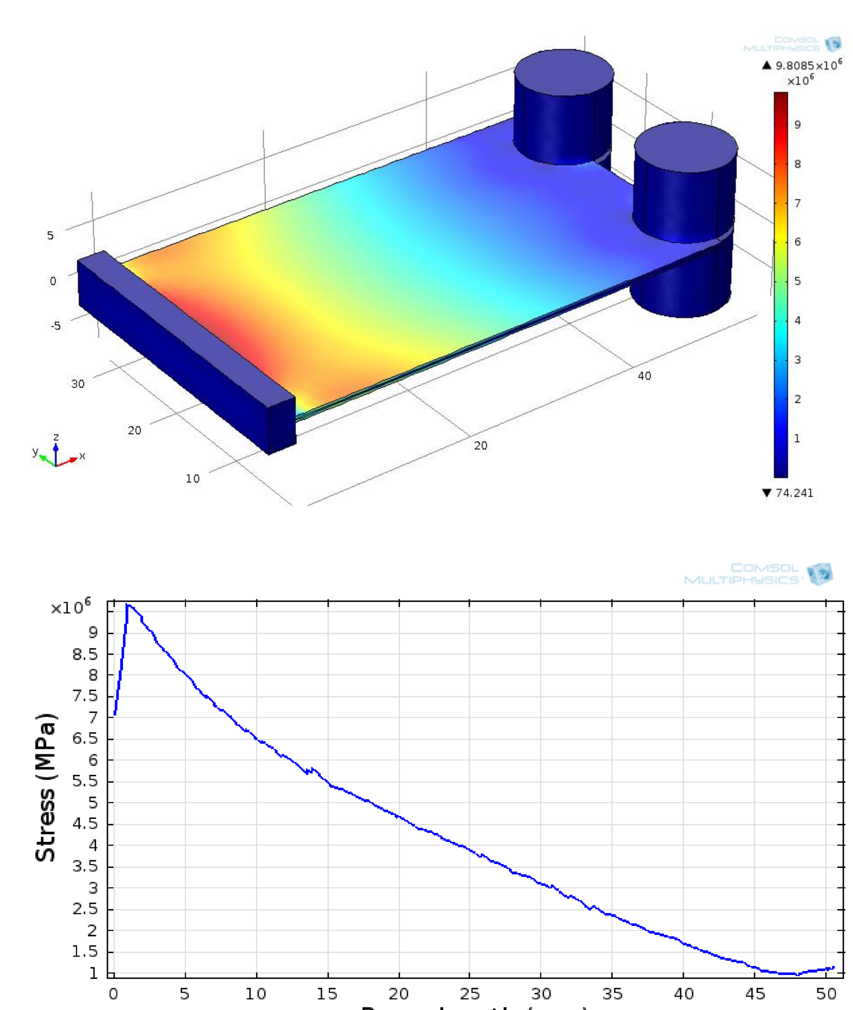

Figure 5. Stress profile on the uniform thickness VEH.

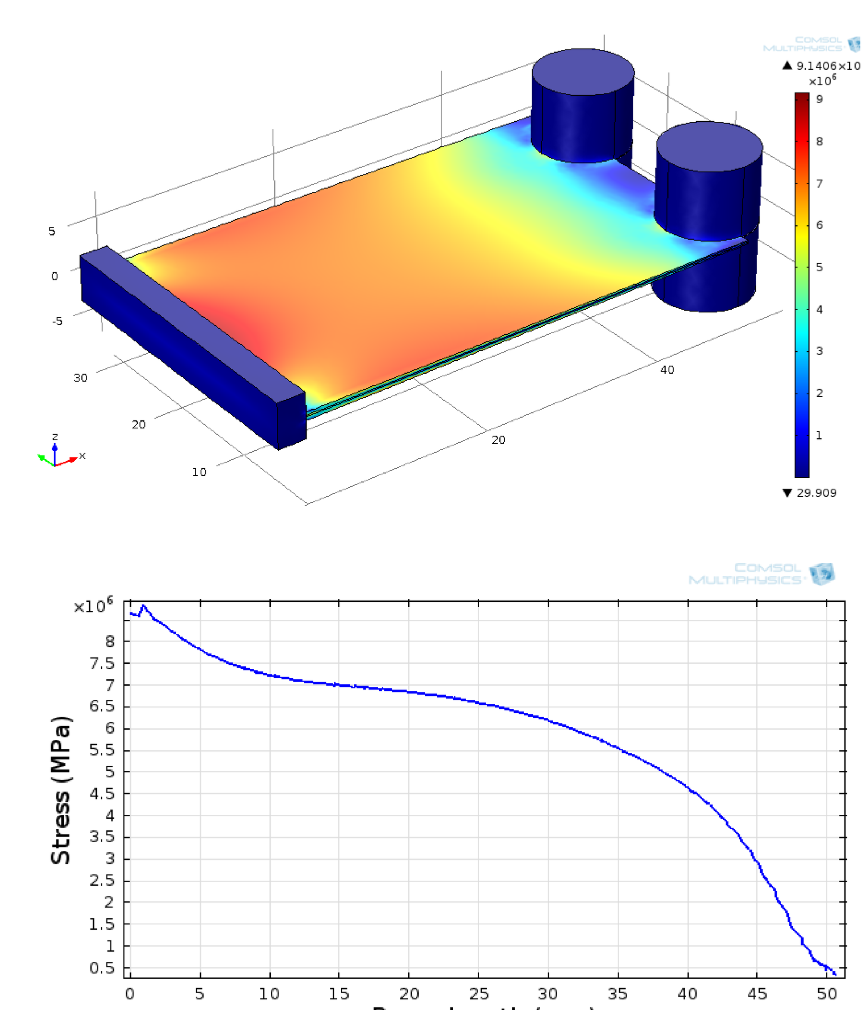

Figure 6. Stress profile on the thickness-tapered VEH.

Conclusions

The variation of generated power and stress distribution is studied for uniform thickness and thickness-tapered VEHs. The reduction of peak stress in the VEH structure increases the device reliability and the increase in the average stress increases the power generation capability.

Performance improvements in thickness-tapered VEH

- Peak stress reduces
- Stress profile is more uniform
- Average stress increases by 42%
- Generated power increases by 31%.

References:

1. D. Benasciutti, et al "Vibration energy scavenging via piezoelectric bimorphs of optimized shapes," Microsystem Technologies, vol. 16, pp. 657–668 (2010)
2. S. P. Matova et al. "Effect of length/width ratio of tapered beams on the performance of piezoelectric energy harvesters," Smart Materials and Structures, vol. 22, no. 7, (2013)