Analytical Piezoelectric Energy Harvesting from a Cantilever Composite Beam with Moving Support

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Abstract

- In this paper, the production of electrical energy from the vibrations of cantilever multi-layer composite beams with one piezoelectric layer under the forced moving support is investigated. The governing equations of the system are extracted by Hamilton's principle considering the effects of electric-mechanical coupling; and after solving by Kantorovich method, the obtained results are compared with the simulation results in Comsol software which show good convergence

Governing equations

- After solving the governing equations its generalization to determine the output voltage of the two ends of two heads of resistance for infinite vibration mode with harmonic input is visible:

- $$V(t) = \frac{\sum_{r=1}^{\infty} \frac{jm\omega\varphi_r(\gamma_r^W Y_0 + \gamma_r^\theta \theta_0)e^{j\omega t}}{{\omega_r}^2 - \omega^2 + j2\xi_r\omega_r\omega}}{\left(\frac{1 + j\omega\tau_c}{\tau_c}\right)\sum_{r=1}^{\infty} \frac{jm\omega\varphi_r}{{\omega_r}^2 - \omega^2 + j2\xi_r\omega_r\omega}}$$

Geometry dimensions:

Parameter	Unit	Value
• Beam length (L)	mm	100
Beam width (b)	mm	20
Beam thickness (h_s)	mm	0.5
Piezoelectric thickness (h_p)	mm	0.4
Concentrated mass (M_t)	g	7

The mechanical properties of Graphite/Epoxy composite (1) andpiezoelectric layer (2)

- (1)

Parameter	Unit	Value
Density (ρ_s)	Kg/m^3	1600
Longitudinal Young's modulus (E_1)	GPa	185
Transverse Young's modulus (E_2)	GPa	10.5
Poisson's ratio	-	0.28

- (2)

Parameter	Unit	Value
Piezoelectric density (ρ_p)	Kg/m^3	7800
Piezoelectric Young's modulus (E_p)	GPa	66
Electrical capacity (s_{33}^S)	$F.m^{-1}$	1.32×10^{-8}
Piezoelectric constant (d_{31})	$pm.V^{-1}$	-190

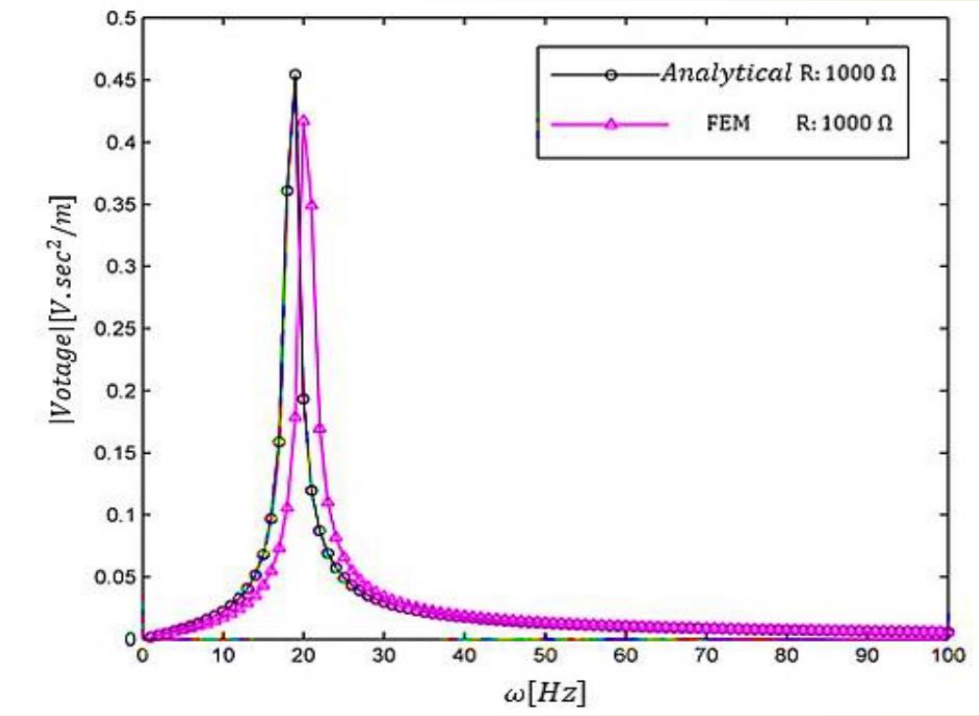
The Maximum output voltage ratio excitation amplitude [$V.\sec^2/m$] for the first three vibrational modes for layering $[0/90]_s$ by analytical and numerical methods (3)

(3)

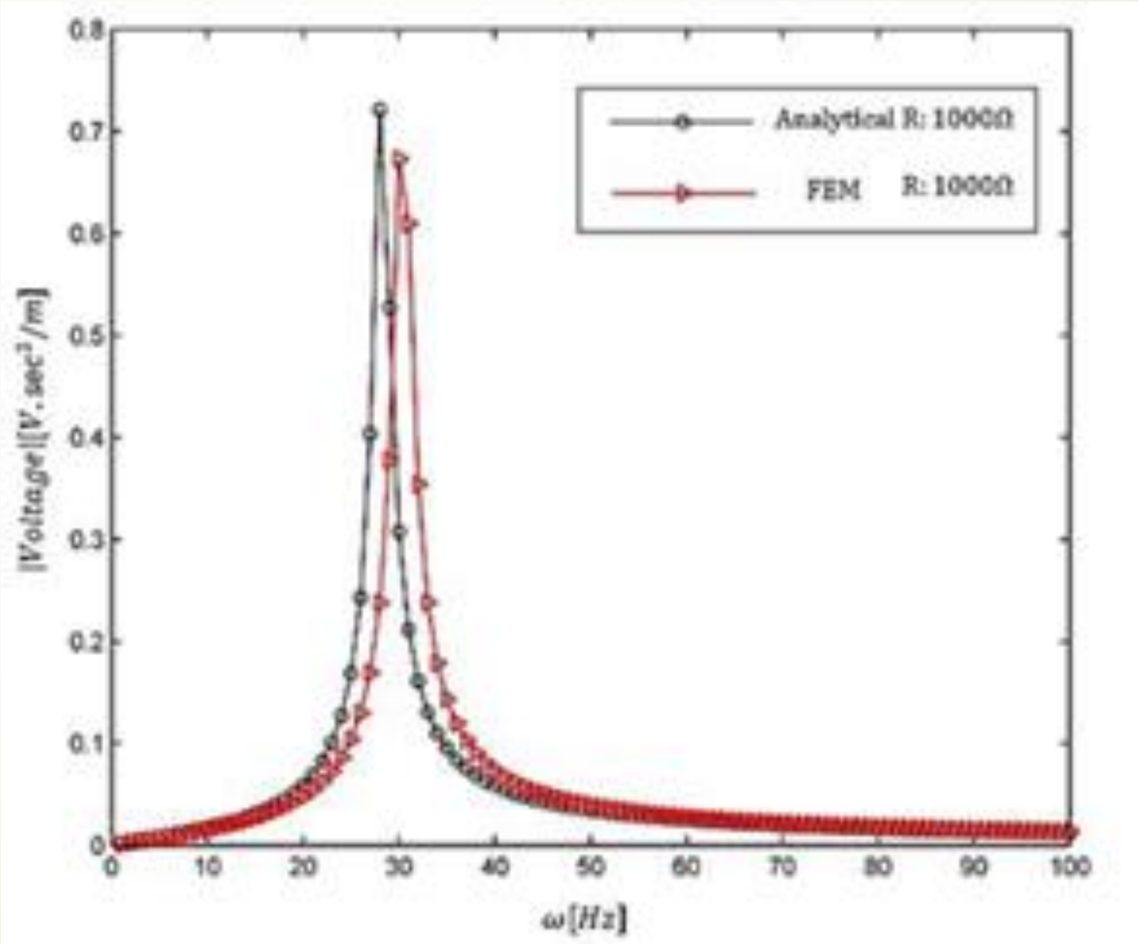
Vibrational mode	Analytical method	Numerical method
First mode	0.88	0.823
Second mode	0.007	0.0064
Third mode	6.42×10^{-4}	5.86×10^{-4}

Simulation results with Comsol:

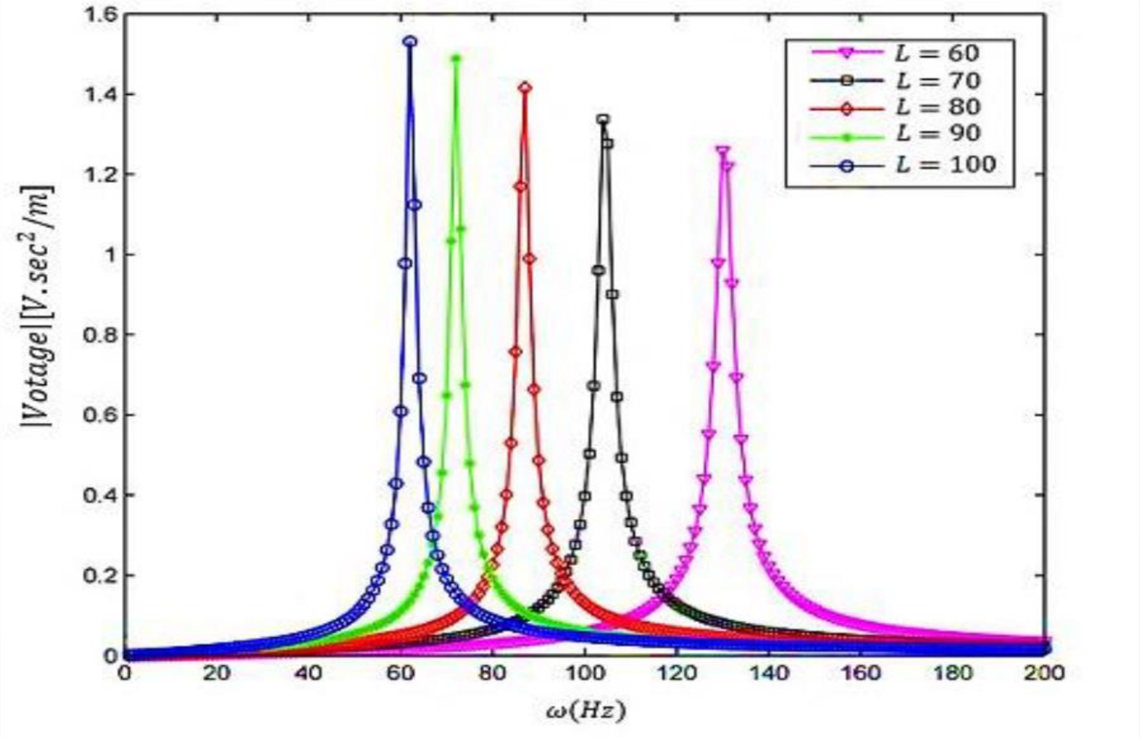
The output voltage circuit based on frequency for $[45/-45]_s$ layering



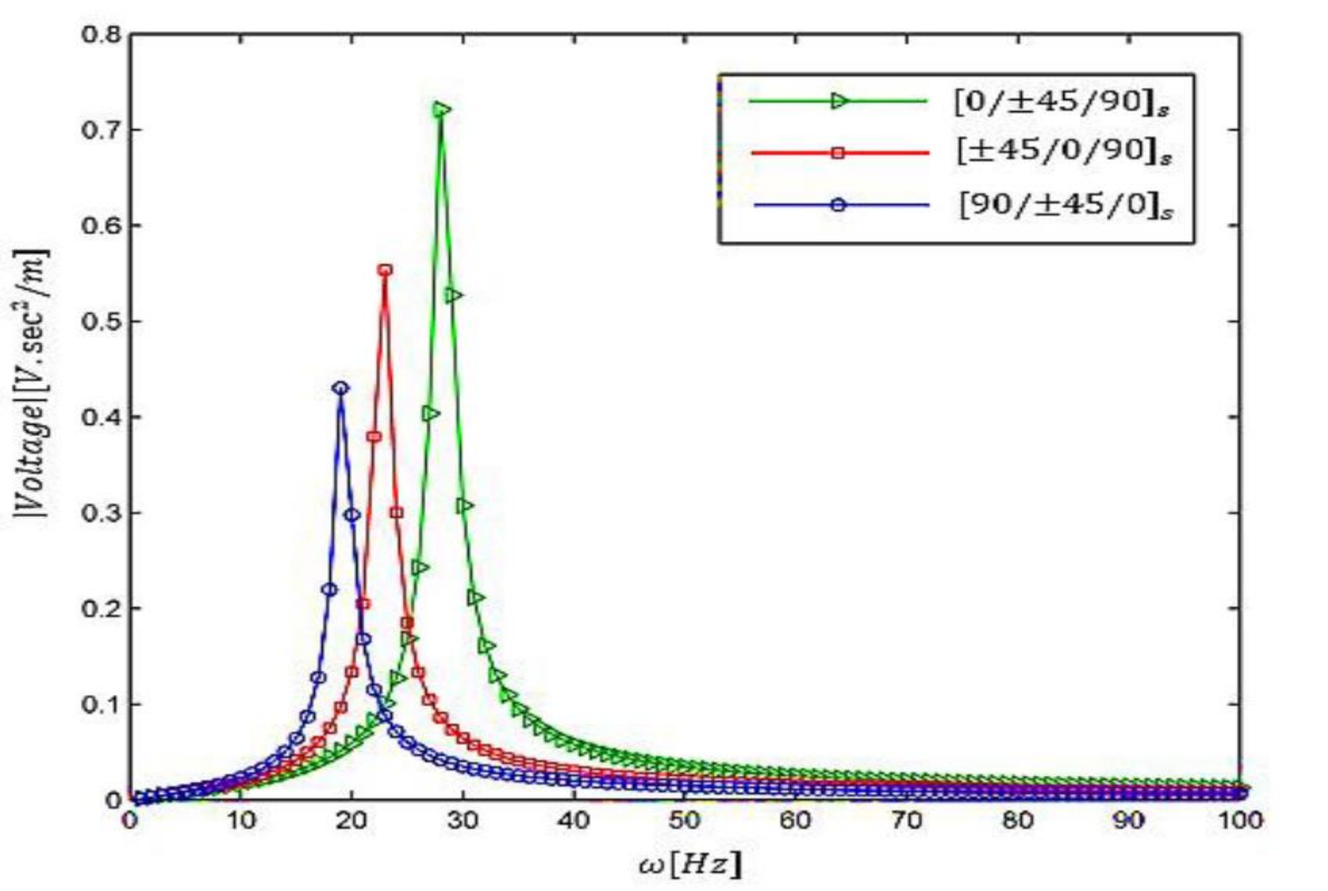
The output voltage circuit based on frequency for $[0/\pm45/90]_s$ layering:



The effect of beam length [mm] on the output voltage for $[0/90]_s$ layering



The effect of layup on the energy harvesting amount for $[0/\pm 45/90]_s$ layering



Conclusion

In this study, two types of air damping (external damping) and structural damping (internal damping) were considered. The internal damping ratio of the structure in composite materials depends on the natural frequency of the structure, the mass of the structure and, most importantly, the bending stiffness of the structure. The results showed that the use of zero-degree angle in layup reduces damping ratio, and consequently, energy harvesting from composite beam increases. The results also show that considering the conditions of structural damping and air damping:

The orientation angle of the fibers and the porcelain layer has a great effect on the amount of energy harvested. From the obtained results, it can be found that if the elasticity of multilayer equivalent in line with loading decreases, the normal frequency and energy harvesting rate of the system will also be reduced. In other words, energy harvesting can be greatly improved if using zero-degree layers.increasing the length of the structure increases the energy harvesting from the piezoelectric layer

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