Modeling And Simulation Of Magnetoelectric Materials In COMSOL For Vibration Energy Harvesting

Vishwas Bedekar[1], Nan Chen[1]

[1]Middle Tennessee State University

Abstract

Recent studies for smart materials have found promising results in terms of vibration energy harvesting using piezoelectric effect. Previous research has demonstrated a potential for broadband piezoelectric energy harvesting solutions for small scale electronic devices using various optimizations of the geometry and materials. When coupled with magnetoelectric effect (ME), i.e. a magnetic field inducing electric polarization of the material, the device can tap into not only utilizing piezoelectric effect but also magnetoelectric effect for enhanced voltage or charge generation. In this research, a magnetoelectric sandwich composite made of lead-zirconate-titanate doped with zinc and niobium (PZT-PZN) and nickel as shown in the attached figure. COMSOL Multiphysics was used to model and simulate magnetoelectric composite beams. First, the natural frequency of the beam was determined using eigen function followed by simulating the structure at this frequency to harvest energy from mechanical vibrations. A series bimorph piezoelectric transducer was designed and was further sandwiched between nickel plates to induce ME effect. A simple rectangular geometry with dimensions of 60 X 2 X 0.825 mm3 was chosen to form a baseline model with a tip mass of 0.4 grams to tune the resonance frequency to 143.6 Hz. A time dependent convergence study for 2 mm displacement of the free end of the bimorph resulted in the device generating 47.2 Vrms at 0.5 M-Ohm optimum resistance and an average electric power of 3.69 mW in two mechanical cycles. The magnetoelectric coefficient was recorded as 1180 V/cm.Oe. The rectangular geometry was further modified to a trapezoidal shape with a longer width of 40 mm and a shorter width of 4 mm. At a natural frequency of 383 Hz, this device produced average voltage output of 14.69 Vrms at 13.9 k-Ohm resistance and average power of 16.89 mW in COMSOL simulations. These results show promising trends in researching new geometry and new mechanisms to efficiently harvest energy from ambient resources. Experimental validation would further strengthen these findings for on-board energy harvesting applications.

Reference

1. N. Chen and V. Bedekar, Design, Modeling, and Simulation of Two-Piece Trapezoidal Piezoelectric Devices for Sensing and Energy Harvesting, Advances in Materials Science and Engineering, Article ID 9743431, 14 pages, 11 Feb 2020.
2. N. Chen and V. Bedekar, "Modeling, Simulation and Optimization of Piezoelectric Bimorph Transducer For Broadband Vibration Energy Harvesting in multi-beam and trapezoidal approach", Journal of Materials Science Research, Vol 7, No 2 (2018).
3. N. Chen and V. Bedekar, "Modeling, Simulation and Optimization of Piezoelectric Bimorph Transducer For Broadband Vibration Energy Harvesting," Journal of Material Science Research, vol. 6, no. 4, Oct. 2017.
4. V. Bedekar et. al., “Design and fabrication of bimorph transducer for optimal vibration energy harvesting” IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, Vol: 57, Issue: 7, pp 1513 – 1523, July, 2010.
5. V. Bedekar et. al., “Metal – Ceramic Magnetoelectric Composite Gradiometer”, Review of

Scientific Instruments, 81, 033906, 2010.
6. V. Bedekar et. al., “Magnetoelectric Gradiometer”, EPJ B, Vol:71, Issue:3, Aug 2009.
7. V. Bedekar et. al., “Multimodal Energy Harvesting System”, Proc. SPIE 8035, 80350T, April 2011.
8. N. Chen and V. Bedekar, "Modeling of a Two-piece Trapezoidal Piezoelectric Bimorph Broadband Vibration Energy Harvester", COMSOL conference, Boston, MA, October 2018.
9. V. Bedekar, "Study of Magnetoelectric Effect for Sensing and Energy Harvesting Applications", Mechanical and Aerospace conference, October 2017, Las Vegas, NV.
10. N. Chen and V. Bedekar, “Modeling, Simulation and Optimization of Piezoelectric Bimorph Transducer For Broadband Vibration Energy Harvesting using multibeam and trapezoidal approach”, COMSOL, Boston, MA, 2017.