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A handy motion driven hybrid energy harvester: dual Halbach array based electromagnetic and triboelectric generators

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A handy motion driven hybrid energy harvester: dual Halbach array based electromagnetic and triboelectric generators

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Abstract. In this work, we have proposed and experimentally validated of hybrid electromagnetic and triboelectric energy harvester using dual Halbach magnets array excited by human handy motion. Hybrid electromagnetic (EM) and triboelectric (TE) generator that can deliver an output performance much higher than that of the individual energy-harvesting unit due to the combination operation of EM and TE mechanisms under the same mechanical movements. A Halbach array concentrates the magnetic flux lines on one side of the array while suppressing the flux lines on the other side. Dual Halbach array allows the concentrated magnetic flux lines to interact with the same coil in a way where maximum flux linkage occurs. When an external mechanical vibration is applied to the hybrid structure in the axial direction of the harvester, the suspended mass (two sided dual-Halbach-array frame) starts to oscillate within the magnetic springs and TEG part. Therefore, the TEG part, the Al film and microstructure PDMS film are collected into full contact with each other, generating triboelectric charges due to the various triboelectricities between them. A prototype of the hybrid harvester has been fabricated and tested. The EMG is capable of delivering maximum 11.5mW peak power at 32.5Ω matching load resistance and the TEG delivering 88µW peak power at 10MΩ load resistance.

1. Introduction

Extracting energy from mechanical vibration has drawn much remark over the last few decades due to its sufficiency in nature and unlimited lifetime. Various vibration sources, such as water and wind flow, rotary motion, human and machine motion generate vibrations of different frequencies and amplitudes, but most vibrations are of low frequencies and large amplitudes with various cyclic movements in different directions. Widely used techniques for harvesting energy from mechanical vibrations are electromagnetic [1], electrostatic [2] and piezoelectric [3] mechanisms. The electromagnetic generator can also work from the relative movement between the magnet and the coil. Also use of Halbach magnet array in an electromagnetic energy harvester, instead of a single magnet, increases the magnetic flux density which, in turn, partially addresses the power generation issues at low frequencies [4-5]. Behaviours of handy motion show that it has very low frequency (~5Hz) and high acceleration (~2g peak) [6]. The electrostatic mechanism is based on repeated charge pumping with variable capacitors, while the piezoelectric mechanism is based on the reconfiguration of unbalanced dipole moments. Newly, the triboelectric generator (TEG) has been highlighted because of its high power and low fabrication cost. The TENG can scavenge the mechanical energy from the contact/separation between two triboelectric materials. In spite of the continuous improvement of small-scale mechanical energy harvesters, the level

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of output energy still need to be improved to meet the requirements of commercial electronic systems and to further expand their fields of application. By combining two types of mechanical-energy-harvesting units, more electricity can be extracted from one mechanical motion, which may meet the power needs of some portable electronic devices. A hybrid mechanical energy harvesting technology may enhance the overall power output [7]. Zhang et al. proposed contact-separation mode hybrid energy harvester with implanted planar coil, which is proper to generate strong instantaneous power [8]. In this work, we have proposed and experimentally validated of hybrid electromagnetic and triboelectric energy harvester using dual Halbach magnets array excited by human handy motion. This paper is mainly focused on Halbach array based hybrid electromagnetic and triboelectric energy harvester. A Halbach array is an arrangement of magnets which increases the magnetic field in one side of the array, minimizing the magnetic field to nearly zero on the other side of the array. Hybrid electromagnetic (EM) and triboelectric (TE) generator that can deliver an output performance much higher than that of the individual energy-harvesting unit due to the combination operation of EM and TE mechanisms under the same mechanical movements.

2. Hybrid energy harvester design and fabrication

In this work, with a reasonable design, the electromagnetic generator (EMG) and triboelectric generator (TEG) are integrated in a suspended structure by magnetic springs as a hybrid cell in Figure 1. The EMG consists of the two dual Halbach array and bobbin containing two coils (each 200 turns) connected in series, whereby the structure of the dual Halbach array is suspended by magnetic springs (Ø6×2 mm^2). Each Halbach array is formed using 3 block (10×5×2mm^3) magnets. Dual array structure is made by attaching the Halbach array to a hollow rectangular shape polycarbonate structure. Each TEG made of two Al films and a microstructure PDMS film. The micro-structured PDMS films were fabricated by using a Si master with the surface of pyramid structures. The mixture of PDMS elastomer and cross-linker with a 10:1 ratio (w/w) was spin-coated on to the Si master. The PDMS film with the surface pyramid micro-structures were peeled off from the Si master after it was cured at 353K for 1 hour in an oven. Dual Halbach array allows the concentrated magnetic flux lines to interact with the same coil in a way where maximum flux linkage occurs. When an external mechanical vibration is applied to the hybrid structure in the axial direction of the harvester, the suspended mass (two sided dual-Halbach-array frame) starts to oscillate within the magnetic springs and TEG part. Therefore, the TEG part, the Al film and microstructure PDMS film are collected into full contact with each other, generating triboelectric charges due to the various triboelectricities between them. During experiment, vibration was applied in horizontal direction in order to reduce the gravity effect on the Halbach array frame structure. The FEM simulation allows us to determine the exact positions of both Halbach arrays, coil positions and the spring magnets in figure 2. Figure 2 shows the results of FEMM simulation of the corresponding dual Halbach array generator structure of figure 1, showing magnetic flux density at 1.5mm distance is 0.82T.

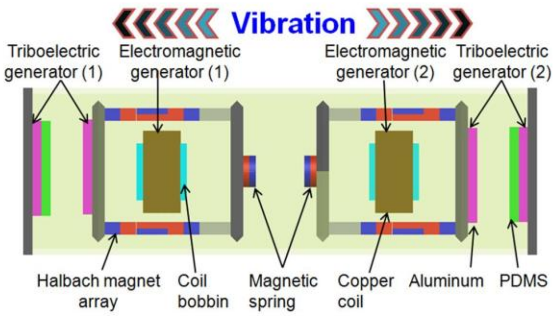

Figure 1. Schematic structure of the proposed hybrid energy harvester.

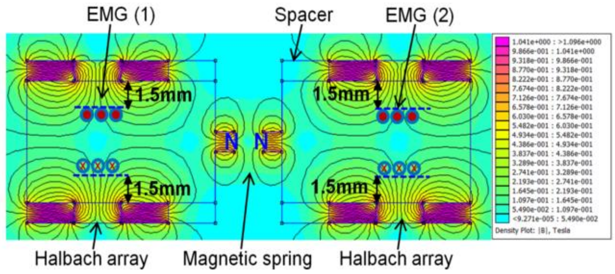

Figure 2. Finite element simulation of magnetic flux lines for both Halbach array and spring magnets by FEMM.

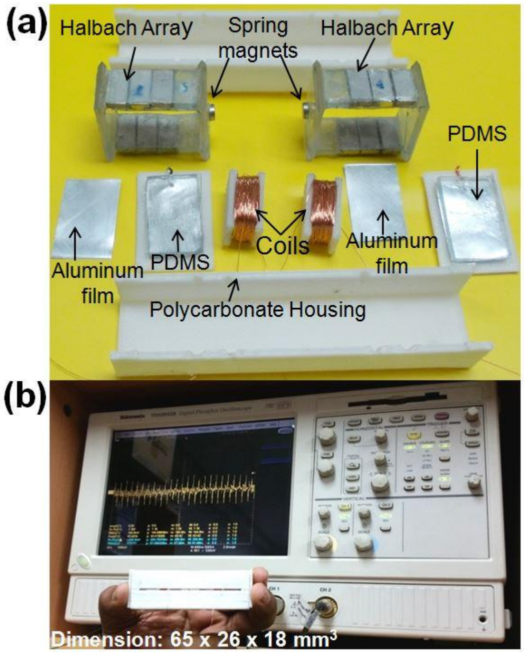

Figure 3. Photographs of the hybrid energy harvester: (a) Components before assembling and (b) fabricated prototype and handy motion test setup.

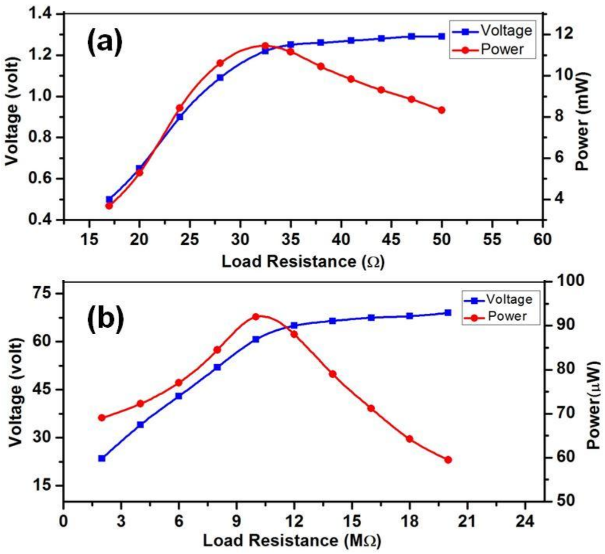

Figure 4. Load voltages (peak-peak) and powers (peak) versus load resistances generated by (a) electromagnetic (series) (b) triboelectric generator (series).

The overall dimensions of the harvester prototype are 6.5 cm ×2.6 cm × 1.8 cm. Figure 3(b) shows that the fabricated prototype after assembling the components; the prototype is small, compact in size, and convenient as it can be held between two fingers.

3. Experimental results and discussions

We proposed testing our hybrid energy harvester prototype under a very low frequency range that is generated by a human-body-induced vibration such as human hand motion. The output voltage signals of the electromagnetic generator were measured by oscilloscope and triboelectric generator were measured a low-noise voltage preamplifier (Keithley 6514 system electrometer). All the components were assembled to make the prototype hybrid energy harvester and tested by handy motion to observe its output performance in figure 3. The hybrid EMG delivers 11.5mW peak power to a 32.5Ω matched load resistance and TEG delivers 88µW peak power at 10MΩ load resistance in figure 4. Figure 5 shows the instantaneous voltage waveform across the optimum load and the peak voltages of EMG and TEG are 1.22V and 60V, respectively. Figure 6 shows instantaneous peak power waveform across the optimum load resistance of electromagnetic generator and triboelectric generator. However, slight variations were observed between the values for the generated open-circuit voltage, and the power and value predictions of the simulation; these variations might be due to the calculation variations because of magnetic-field values, magnetic-flux densities, coil position, effect of coil inductance, phase difference, fabrication of PDMS film etc. and the improper assembly of the harvester components. The dual-Halbach-array based hybrid generator presented here showed an ability to generate meaningful power from low-frequency fitful behavior. The benefits of using magnetic springs in this dual Halbach-array structure include reliability, a simple structure, and an ease of use at low-frequency vibrations. Besides, the EMG component generated low voltage and high current while the TENG component generated high voltage and low current, according to their inherent output resistances. By combining both components in the hybrid one-body device, the advantages of both could be fully utilized without energy loss. The proposed hybrid harvester performance can be more improved by further optimization.

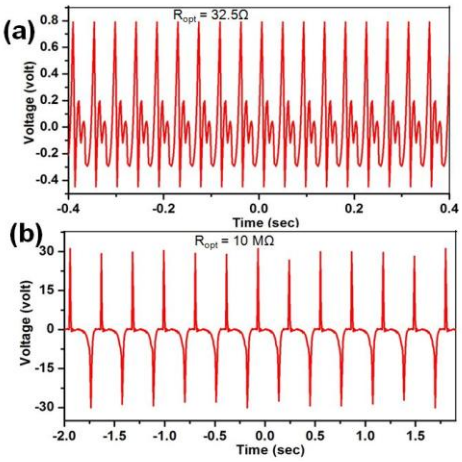

Figure 5. Instantaneous voltage waveform across the optimum load resistance: (a) electromagnetic (series) (b) triboelectric generator (series).

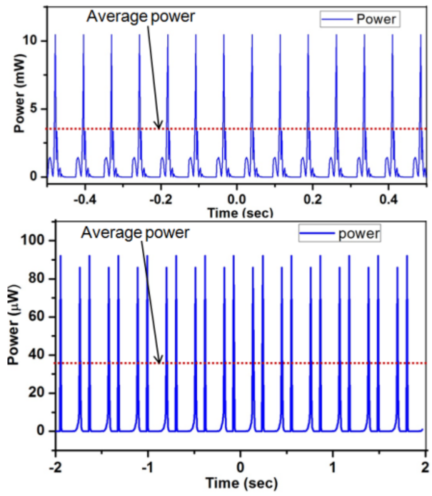

Figure 6. Instantaneous peak power waveform across the optimum load resistance: (a) electromagnetic (series) (b) triboelectric generator (series).

4. Conclusions

A Halbach array based hybrid energy harvester was designed, fabricated, and tested for scavenging significant power from low-frequency vibrations. The main goal of the work was to develop, analyze, and implement a suitable and reliable hybrid energy harvester to scavenge significant power from human hand motions such as hand-shaking which would be able to supply power to portable and wearable smart devices. The use of the dual Halbach array allows the concentrated magnetic flux to interact with the same coil, resulting in the increment of the electromotive force, which in turn increases the power generation. The proposed dual Halbach arrays based hybrid energy harvester device has been designed, fabricated, and tested. The electromagnetic generator is capable of delivering maximum 11.5mW peak power at 32.5Ω matching load resistance and the triboelectric generator delivering 88µW peak power at 10MΩ load resistance. The next stage of this work will include further optimization of the prototype to be used in energy harvesting from different human-body-induced motions such as walking, running, cycling etc. The advantages of our proposed device include its simple structure, low operating conditions and low fabrication cost.

Acknowledgements

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