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An Electromagnetic Micro-Power Generator for Low Frequency Vibrations with Tunable Resonance

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Abstract

This paper presents an electromagnetic (EM) micro-power generator with tunable resonance frequency which can harvest energy from low frequency environmental vibrations. The reported power generator up-converts low frequency environmental vibrations before mechanical-to-electrical energy conversion by utilizing two diaphragms with different resonance frequencies. Power is generated through electromagnetic induction by a magnet attached to the low frequency diaphragm, and a 50 turn, 2.1 Ω coil, and a magnetic piece on the high frequency diaphragm. Both of the diaphragms are fixed to a common frame via rubber springs, which makes the resonance frequency of each diaphragm tunable. The fabricated prototype generates 5.2 mV and 3.21 µW RMS power by up-converting 13 Hz, 7.5 mm peak-to-peak vibrations to 200 Hz. Tunability of the resonance frequency is experimentally verified by operating the same device at 2-30 Hz external vibrations.

Keywords: Energy Harvesting; Electromagnetic Power Generation; Frequency-up Conversion; Tunable Resonance Frequency

1. Introduction

Vibration based energy harvesting has found application in many different areas [1], and has been proposed as a major renewable energy source for mobile platforms together with photovoltaic and thermoelectric sources [2]. However, most of the environmentally available vibrations are at low

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frequencies (1-20Hz), limiting the generated power levels. This paper presents a tunable EM micro-power generator for low frequency vibrations. The efficiency of the proposed generator is optimized by utilizing rubber springs, enabling the adjustment of the diaphragm resonance frequency ratios to a desired value. Proposed micro-power generator is a good candidate for harvesting energy from a wide variety of environmental vibration conditions covering low frequency environments such as human motion, building vibrations, and relatively high frequency applications such as structural health monitoring and process monitoring of vehicle engines.

2. Structure of the Power Generator

Fig. 1(a) depicts the structure of the proposed power generator consisting of two diaphragms. The upper diaphragm carries a magnet while the lower one carries the pick-up coil and the magnetic piece for actuation. The upper diaphragm resonates with vibrations in the range of 1-30 Hz. On the other hand, the lower diaphragm has a higher natural resonance frequency range of 20-200 Hz. The exact resonance frequency values of the diaphragms are set by adjusting their rubber springs. When the upper diaphragm starts resonating with external vibrations, the magnet pulls and releases the magnetic piece, making the lower diaphragm resonate at its resonance frequency, realizing the magnetic frequency up-conversion [3, 4]. Power is generated through electromagnetic induction, with relative position change of the magnet and the coil. Both of the diaphragms are fixed to a common frame via rubber springs. Fig. 1(b) and (c) present the constructed prototype of the power generator.

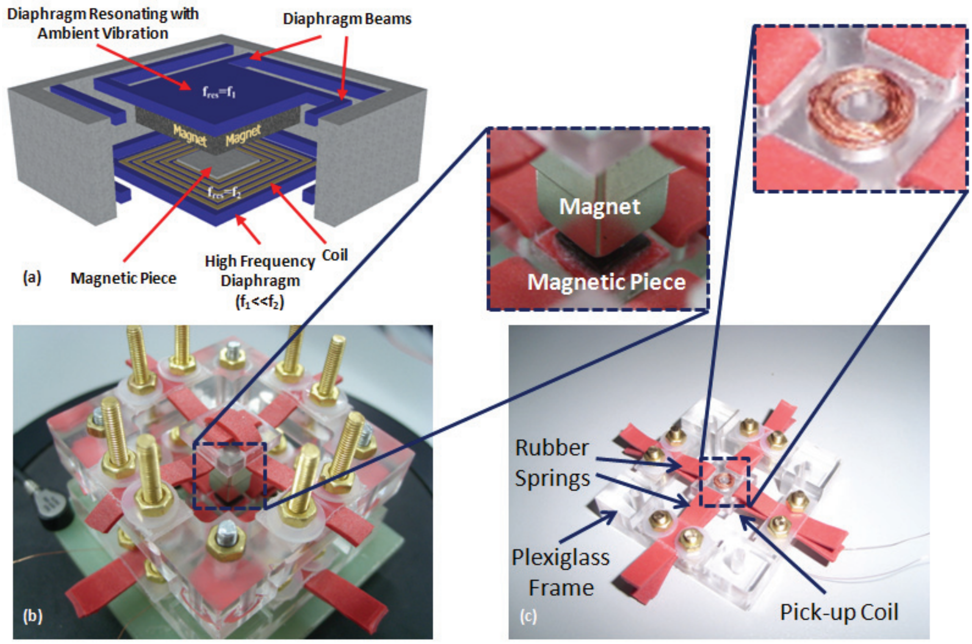

Fig. 1. (a) The proposed generator structure, the constructed prototype: (b) the whole system, (c) the lower diaphragm.

3. Experimental Results

Proposed micro-power generator structure has been tested and feasibility of the frequency up conversion has been verified. Tunability of the resonance frequency is experimentally verified by operating the same device at 2 Hz, 13 Hz, and 30 Hz external vibrations via adjusting the rubber springs for the desired resonance frequency. Table 1 gives a summary of the different prototype configurations and the corresponding test results. Fig. 2(a) and (b) present the output voltage waveform of the two sample generator configurations operating at 2 Hz and 13 Hz, respectively. For a 2 Hz, 3 mm peak-to-peak external vibration condition, corresponding to a very low rms acceleration value of 0.017g, the prototype proved to generate 0.34 mV rms voltage and 13.7 nW rms power, with an up-converted resonance frequency of 23 Hz. When the vibration conditions are set as 13 Hz frequency and 7.5 mm peak-to-peak displacement, the generated output voltage and power reaches to 5.2 mV and 3.21 µW, with the lower diaphragm resonance frequency adjusted as 200 Hz. It should also be noted that the adjustment of the distance between the two diaphragms is also necessary as well as adjusting their resonance frequencies for proper operation of the power generator.

Table 1. Specifications and the performance parameters of the tested prototype.

Excitation frequency	**2 Hz**	**13 Hz**	**30 Hz**		
Magnet type	NdFeB (1.18 T)				
Magnet dimensions	8x8x16mm^3		8x8x24mm^3		
Magnetic piece material	Nickel		NdFeB (1.18 T)		
Magnetic piece dimensions	2.5x2.5x0.5 mm^3		2.5x2.5x2.5 mm^3		
Distance btw. magnet and coil turn	2 mm	5 mm	8.5 mm		
Catch distance between two diaphragms	0.5 mm		4 mm		
Number of coil turns	50		50	100	250
Coil resistance	2.1 Ω		2.3 Ω	3.3 Ω	7.9 Ω
Coil wire diameter	120 µm				
Coil inner diameter	2 mm		3.3 mm		
Coil outer diameter	4 mm		4.5mm	5.4mm	9.5mm
Device dimensions	32x32x22mm^3				
Upper diaphragm f_{res} (f_1)	2 Hz	13 Hz	30 Hz		
Lower diaphragm f_{res} (f_2)	23 Hz	200 Hz	90 Hz		
Input displacement	3 mm	7.5 mm	7.3 mm		
Input peak acceleration	0.024 g	2.54 g	13.2 g		
Input RMS acceleration	0.017 g	1.78 g	9.34 g		
Peak output voltage	2 mV	34.5 mV	13 mV	37 mV	104 mV
Peak output power*	476 nW	141.6 µW	18.3 µW	104 µW	342 µW
RMS output voltage	0.34 mV	5.2 mV	3.2 mV	6.8 mV	29 mV
RMS output power*	13.7 nW	3.21 µW	1.1 µW	3.5 µW	26.6 µW

* For an equivalent resistive load.

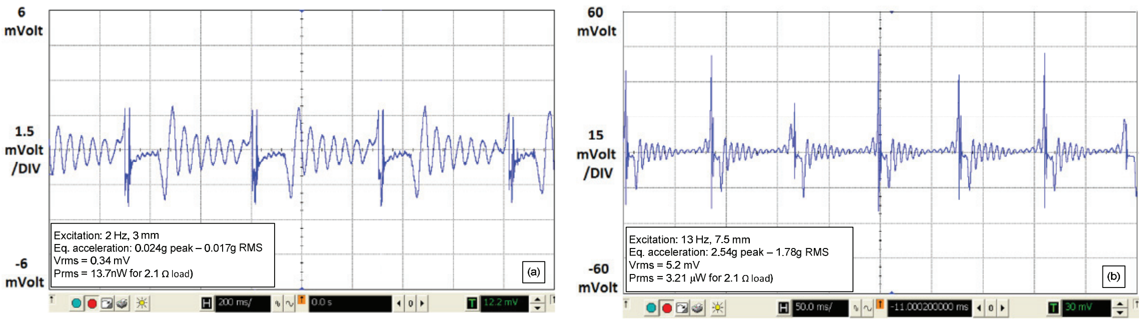

Fig. 2. Measured voltage output of the energy harvester in response to vibrations of (a) 2 Hz and (b) 13 Hz.

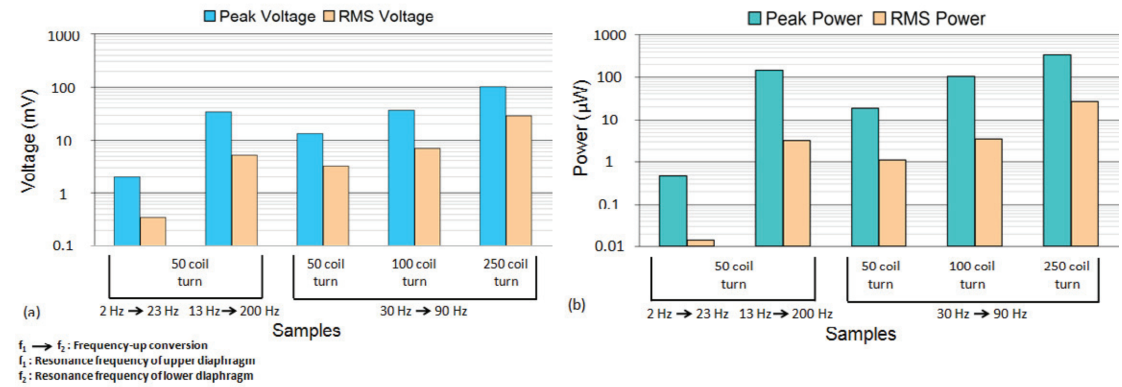

Fig. 3. Measured voltage (a) and power (b) output of the energy harvester in response to vibrations of 2 Hz, 13 Hz, and 30 Hz with varying number of coil turns.

Fig. 3 shows the generated voltage and power levels from the prototype for different resonance frequency and coil turn values. The highest rms power level of 26.6 µW is obtained for a configuration where 9.34g rms vibrations at 30 Hz are up converted to 90 Hz, and a 250-turn coil is used.

4. Conclusion

An EM micro-power generator with tunable resonance frequency is presented for efficiently scavenging energy from low frequency external vibrations. The presented generator uses two diaphragms one carrying a magnet and the other carrying a coil and a magnetic piece. The diaphragms having different resonance frequencies are connected to a common frame and the magnetic frequency up-conversion is realized via the pull and release mechanism between the magnet and the magnetic piece. The operation of the power generator is demonstrated for different external frequency ranges of 2-30 Hz with the help of rubber springs which makes the resonance frequency of each diaphragm tunable. The proposed power generator is able to fit in a wide range of energy harvesting applications covering low frequency vibrations and high frequency environments due to the adjustability of the rubber springs. The feasibility of the prototype for very low frequency and acceleration levels is verified by operating the prototype at 2 Hz with a maximum peak acceleration of 0.024g which is in the range of vibrations such as ones arousing from human motions and building and tree vibrations [5].

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