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Optical/RF MEMS and Nanophotonics + Energy Harvesting and Power MEMS

An Electromagnetic Energy Harvester for Omnidirectional Wind Scavenging

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Abstract

In this paper, we introduce a novel electromagnetic energy harvester with windmill-structure for powering wireless sensors. The proposed energy harvester design can effectively scavenge the wind energy by adjusting its orientation according to the wind direction with an empennage. The Poly(methyl methacrylate) (PMMA) windmill-structure with four magnets can rotate in a high speed under wind excitation and thereby generate power efficiently through the coils nearby. A miniature energy harvester prototype is fabricated using 3D printing technique. In the performance testing experiment, a peak output voltage of 4.4V and a peak output power of 900.5 mW are achieved after further increaing the coil turns, which fulfills the power requirement of wireless sensors network application.

Keywords: ***Energy harvesting, Electromagnetic, Windmill-structure, Omnidirectional, Wireless sensors network***

1. Introduction

In recent years, energy harvesting technology for powering the sensor nodes of wireless sensors network (WSN) has drawn more and more attention. Comparing with batteries, the energy harvesters can scavenge energy from the environment to provide unlimited power and thereby dramatically reduce the maintenance cost for WSNs [1].

As one of the most green and renewable energy sources, wind energy can be developed as suitable power source for the energy harvester. In terms of the electricity generation method, for conventional energy harvesters, piezoelectric material is the most utilized for power generation. However, the high resistance (~MΩ or more) of piezoelectric material results in a very low output current, which cannot satisfy the minimum requirement of a small sensor. On the contrary, due to the low internal resistance (~Ω), the electromagnetic method can realize much higher output current than piezoelectric way, as well as the power output [2]. Therefore, in this paper, we propose a windmill-structured electromagnetic energy harvester which can transfer ambient wind energy into electricity to power small autonomous sensors in WSN applications. A miniature energy harvester prototype has been successfully fabricated and experimentally characterized.

2. Design and fabrication

As shown in Fig. 1, the energy harvester design consists of a windmill-structured blade mounted on a frame by an axis, magnets attached at the end of each blades and a fixed coil at the bottom of the frame. The wind flow acts as excitation source which helps the windmill-structure to rotate and as a result, four end-magnets pass near the coils by turns. The moving of magnet changes the resultant magnetic flux observed at the fixed coil thereby generating electricity by electromagnetic phenomenon. Unlike piezoelectric materials, the copper coil has much lower internal resistance and can achieve higher current. In this way, a higher output current can be generated than conventional piezoelectric energy harvesters. Moreover, an empennage and a lubricated axis are mounted under the frame, which can rotates the energy harvester towards the real-time wind direction. Therefore, the designed energy harvester can effectively converts omnidirectional wind energy into electricity.

In order to test the performance of the design, a prototype of this energy harvester is fabricated using a Projet^{TM} HD 3500 Plus Professional 3D printer (3D Systems, Corp, Rock Hill, USA). The material used for the 3D printing technology is Poly(methyl methacrylate) (PMMA). Additionally, four identical Neodymium-Iron-Boron (NdFeB) magnets are fixed on each blade-end of the windmill-structure. The poles of four end-magnets are kept the same. In the center of the windmill-structure, a lubricated bearing is placed as the rotation axis. Under the windmill-structure, a copper coil having a number of 300 turns is mounted in the frame.

3. Experiment setup

In the performance testing experiment, as Fig. 2 shows, the energy harvester is placed in a fixed position. At the same position line, a Testo 410-1 anemograph (Testo, Inc, Germany) is mounted to measure the wind velocity applied to the energy harvester. In order to simulate the natural wind, the wind is generated by an adjustable speed electric fan in front of the device by varing the input DC voltage. According to the Beaufort Wind Scale that developed in 1805 by Sir Francis Beaufort, U.K. Royal Navy, the nature wind in daily life is usually below 18 m/s [3]. Therefore, we selected this wind velocity as the maximum input in our experiment. The output voltage and power generation frequency under different wind velocities is measured by a Tektronix TDS 2014B oscilloscope (Tektronix, Inc, USA).

4. Results and discussion

With various input wind velocities in a range of 0-18 m/s, the output voltage and power in open circuit have been measured. According to the electromagnetic theory, the number of coil turns has influence on the output voltage. Therefore, in order to meet the minimum requirement of powering a small electric device (~1.5 V), we optimize the number of coil turns. In this experiment, 3 coils with various number of turns (300, 600, 1000) are utilized to observe the output voltage (1000 is the maximum number due to the volume constrain). The resistance values for these coils are 4.7 Ω, 10.4 Ω, 21.5 Ω, respectively. With various input wind velocity, as shown in Fig. 3 and Fig. 4, the coil with 1000 turns can generate a highest output among the 3 coils. A peak output voltage of 4.4 V and a peak output power of 900.5 mW are achieved (corresponds to a maximum output current of 204.7 mA, much higher than that of conversional piezoelectric method). Moveover, due to the guiding function of the empennage, even the direction of applied wind is changed in the experiment, the energy harvester can freely vary its orientation according to input wind direction and still maintain the output.

As we know, the natural wind in our environment is unsteady. Therefore, to study the response time of this device is quite necessary. In the experiment, the response time (the taken time for voltage from zero to the peak value) is measured, as can be seen in Fig. 5. With the increase in wind velocities, the response time to peak voltage as well as the peak voltage shows an increment at initial stage. However, the response time decreases when the wind velocity is up to about 12 m/s, the response time will decrease, which shows a different trend compared with the voltage. In addition to this, to demonstrate the possibility for real application, a LED (1.2 V, 10 mA) is connected to the windmill-structured energy harvester. With a minimum wind velocity of 7.5 m/s, the LED can be lightened continuously. Therefore, this windmill-structured energy harvester can be potential power for the sensor nodes in WSN. The response time for lighten LED is also measured, as shown in Fig. 5 (blue line). As the increase in wind velocity, the response time for lightening LED will decrease.

5. Conclusion

In this paper, we have presented the design, fabrication and characterization of an electromagnetic windmill-structured energy harvester which can effectively generate power under omnidirectional wind excitation. Optimization experiment is carried out to further improve the output. A maximum output voltage of 4.4 V and a maximum output power of 900.5 mW are achieved, which fulfill the requirements of low-power autonomous sensors. Moreover, a small scale LED is lightened when the energy harvester faces a wind over 7.5 m/s velocity.

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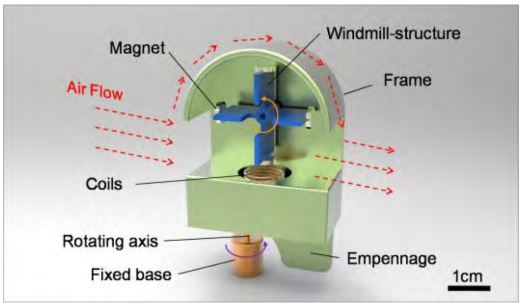

Fig. 1. The schematic of the windmill-structured energy harvester working towards an input wind.

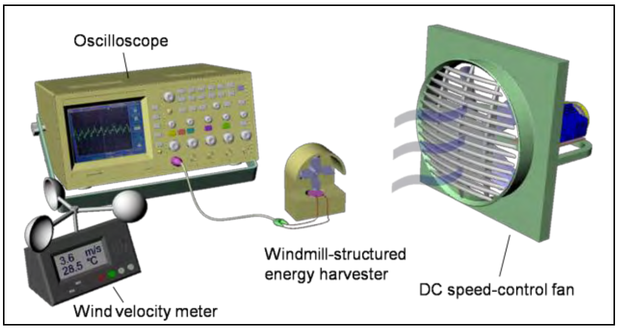

Fig. 2. The schematic of the performance testing experiment setup.

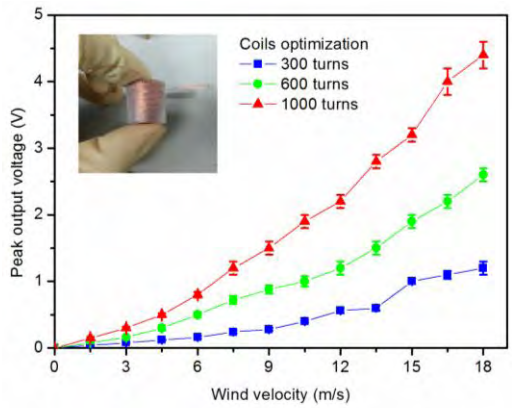

Fig. 3. The peak output voltage versus input wind velocity with different number of turns of the copper coils.

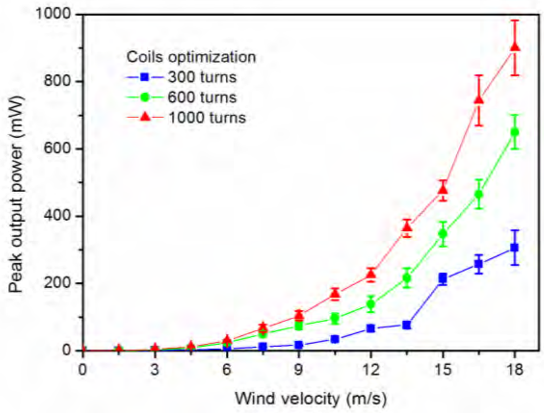

Fig. 4. The peak output power versus input wind velocity with different number of turns of the copper coils.

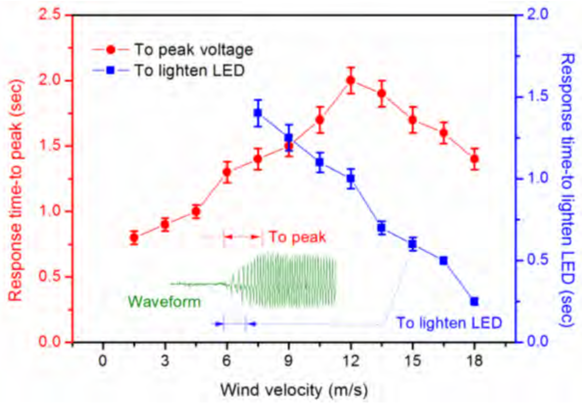

Fig. 5. The response time to peak voltage and to specific voltage of the energy harvester with various input wind velocities.