A non-resonant rotational triboelectric energy harvester with high output performance

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Abstract. Energy harvesting technology has received significant attention around the globe over decades. However, it meets with difficulties of achieving high output performance under non-resonant frequency. In this paper, a non-resonant rotational triboelectric energy harvester with high output performance, which relied on the coupling of triboelectrification and electrostatic induction, was presented. The harvester introduced a cylindrical stator and disk-shaped rotor, which are made of NdFeB. Without complicated movement mechanism, the stator and rotor, of a higher pair have theoretical line contact by magnetic attractive force. Under a hand shake frequency of about 8Hz, the peak-peak value can reach to 140V. The maximum power of 0.31mW was obtained at a resistance of about $10^7 \Omega$. In addition, the voltage can reach up to 154V when running at a speed of 8 km/h on the treadmill. The harvester can be potentially used as a power supply to intelligent wearable devices.

1. Introduction

Energy harvesting technology has received significant attention of the researchers around the globe over decades because of the rapid growth of mobile electronic devices [1-4]. Many energy harvesting devices based on different conversion mechanisms such as electromagnetic [5-6], piezoelectric [7-8], or triboelectric effects [9-10] have presented. Nanotechnology for harvesting mechanical energy using nanogenerator emerged recently [11]. For example, triboelectric nanogenerator(TENG) have been proved as an efficient, light, cost-effective and robust approach to harvest ambient mechanical energy [12]. In order to achieve high power efficiency, the natural frequency of an energy harvester should be designed to match with the environment vibration source [13-14]. It becomes a great challenge to design an energy harvester with high energy output and non-resonant frequency. The key solutions are to improve the energy output density and energy conversion efficiency of devices.

In this study, we demonstrated a non-resonant rotational triboelectric energy harvester with high output performance based on triboelectrification and electrostatic induction. Under an external excitation, the rotor magnet is able to rotate and impact/separate with two TENGs. The output performance of harvester can be improved significantly.

2. Device and working principle

The schematic diagram of the harvester is shown in Figure 1. It consists of a cover, two TENGs, a TENG fixer, a copper foil, a stator magnet, a rotor magnet, and a casing. TENG consists of one-piece membrane structure formed by Fluorinated Ethylene Propylene (FEP) and copper (Cu) electrode. The
stator and rotor are both made of NdFeB magnet. The cylindrical stator magnet is fixed in the center of the casing, and the disk-shaped rotor magnet is attached on the edge of the stator by magnetic attractive force. Without assembling any shaft or bearing structure, the stator and rotor magnets formed a higher pair have theoretical line contact. It enables the rotor magnet easily rotate around the center stator magnet at low frequency vibration and avoids unnecessary surface friction. The copper foil was attached to the rotor magnet, so the foil can easily and directly impact against the FEP back and forth while rotating. Because of the triboelectrification, the AC voltage output can be generated from the TENG.

**Figure 1.** Schematic drawing of the triboelectric energy harvester.

**Figure 2.** Schematic diagram of the working principle for the TENG
The working principle of TENG is based on the couple of electrification effect and electrostatic induction. The design of the TENG is based on the relative sliding motion of grated surfaces. Here, as schemed in Figure 2, the process of electricity generation is illustrated. At the first position, the sliding Cu foil and FEP film are completely isolated. Upon contact between the FEP film and the Cu foil, charge transfer takes place. Due to the difference on triboelectric polarities, electrons are injected from Cu into the surface of FEP. Since the two sliding surfaces are completely contacted, triboelectric charges with opposite polarities are fully balanced out, making no electron flow in the external circuit. Once a relative sliding occurs as a result of rotation, the negative charges on the FEP will drive free electrons on the back electrode to the sliding electrode through the external circuit due to electrostatic induction, neutralizing positive triboelectric charges on the sliding electrode and leaving positively induced charges behind on the back electrode. The flow of the induced electrons lasts until the two sliding surfaces completely separated. As the relative rotation continues, the Cu will come into contact with next FEP film. Therefore, in a cycle of electricity generation, AC electric output is generated.

3. Experiment and results

The experimental results in Figure 3(a) show the open-circuit voltage of the harvester when there is only one TENG is applied. Figure 3(b) shows the open-circuit voltage of two TENGs. The peak-peak value can reach to 140 V, which was a high output performance, at a hand shake frequency of about 8Hz. From Figure 3, it is known that the number of the TENG will influence the frequency of the voltage instead of the value of the voltage; also, the number of the TENG will influence the smoothness of the rotation. So two TENGs were applied in the following experiments.

![Figure 3(a)](image1.png) The open-circuit voltage of the harvester when one piece of TENG was applied.  

![Figure 3(b)](image2.png) The open-circuit voltage of the harvester when two pieces of TENG were applied.

Figure 4 shows the peak voltage and power under different external load resistances with hand shaking vibration frequency of 8 Hz. The maximum power of 0.31 mW was obtained at a resistance of about $10^7$ Ω. Figure 4 shows the open-circuit voltage of the harvester at different speeds. People swing hands when running. Figure 5 was measured on a treadmill, which the harvester was worn on the wrist. It can be seen that the harvester is non-resonant and low-frequency, the output was appreciable at any speeds, and the amplitude of the voltage is improved as the speed increasing, which means more energy is generated. The voltage can reach up to 154 V when running at a speed of 8 km/h.
4. Conclusion

In this paper, we presented a rotational triboelectric energy harvester, which can achieve high output performance under non-resonant frequency. Two TENGs are designed to impact with copper foil, resulting in a significant improvement of electrical output. Under a hand shake frequency of about 8 Hz, the peak-peak value can reach to 140 V. The maximum power of 0.31 mW was obtained at a resistance of about $10^7 \Omega$. When running on the treadmill, the voltage can reach up to 154 V at a speed of 8 km/h. The harvester is so sensitive to human motion that it can be potentially used as a power supply to intelligent wearable devices.

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