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Analysis of Sliding Mode Triboelectric Energy Harvester under Various Simulation Conditions

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Abstract- Low-cost and easy to manufacture energy-harvesting triboelectric device is developed to transform mechanical energy into electrical energy. A lateral sliding mode triboelectric energy harvester (SM-TEH) is fabricated based on a double-dielectric-layered structure. Dielectric layers are comprised of Nylon sheets and PTFE sheets attached to copper (Cu) electrodes. A slider-crank mechanism is considered to provide mechanical movement that has been designed and to understand the effect of varying operating conditions on the output performance of SM-TEH. The experimental results are compared with simulation results at various rotational speeds from 40 to 70 rpm and at separation-distance varied from 7 to 10 cm to evaluate the model's reliability in predicting SM-TEH's output performance. The stability and durability test is performed for SM-TEH. The feasibility of the developed SM-TEH is proved by lighting up 40 red Light-Emitting Diodes (LEDs). SM-TEH has vast applications in self-powered electronic devices and systems.

Keywords- Energy harvesting; Triboelectric effect; Electrostatic effect

I. INTRODUCTION

With the rapid advancement of wearable devices, artificial intelligence, and the Internet of Things (IOTs), it is essential to investigate novel approaches and fabrication methods for supplying versatile and long-lasting power sources. Energy harvesting is a cost-effective and environmentally sustainable way of converting different natural energies into usable electricity [1,2]. Triboelectric energy harvester (TEH) is a promising technique for harvesting mechanical energy and convert it into valuable electricity. Numerous qualities such as low manufacturing cost, abundant choice of material, eco-friendly nature, higher efficiency, and higher power density make it an intelligent choice for today's community [3,4]. Based on mechanical motion, TEH has been classified into four categories such as contact–separation mode TEH, [5,6] single-electrode mode TEH, [7] sliding mode TEH, [8,9], and freestanding mode TEH [10]. These four categories can be combined into two basic modes.

The working mechanism of TEH is based on contact electrification and electrostatic induction. Based on contact electrification, sliding mode TEH can harvest mechanical energy via electrostatic induction to produce an alternating current (AC) called sliding mode AC-TEH, and when using electrostatic breakdown to produce direct current (DC) called as sliding-mode DC-TEH. In particular, the sliding DC-TEH can directly transform mechanical energy into direct current or even constant current, allowing electronics to be instantly powered without any rectifier or energy storage equipment. While several attempts have been made to increase the output capacity of the sliding-mode TEH successfully, including the novel configuration with radial-arrayed sectors on contact surfaces and the charge pumping technique, the energy loss caused by air breakdown and low reliability severely limit its practical use [11–12].

This article describes the fabrication of a sliding mode TEH (SM-TEH) based on a slider-crank mechanism, which could be used to extract energy from lateral sliding motion. The lateral sliding of the triboelectric layers within each crank rotation will produce electric output due to the movable frame's linear motion. The electric output from each crank revolution could be elevated by our specific design of the slider-crank mechanism (to be addressed later). The RMS voltage, current, power, and energy for the SM-TEH at various sliding speeds were investigated for different separation distances than simulation and experimental measurements. Later, it illustrates the time-dependent variation of the output voltage across various capacitors.

II. EXPERIMENTAL SECTION

Figure 1 illustrates the complex components of the sliding mode TEH, which includes PTFE sheet, Teflon sheet, copper (Cu) film, and acrylic glass. The PTFE and Teflon serve as the triboelectric pairs, and the Cu film is used as the conductive electrode. Acrylic glass has been chosen as a substrate material due to its excellent strength, lightweight, easy handling, and affordable price. Two pieces of acrylic glass were used as substrates with dimensions of 12 cm × 12 cm. Cu film is attached to acrylic glass for the top layer, and a PTFE sheet of 1 mm thickness was used as the negatively charged material. The Copper film was attached below the nylon film of 1 mm thickness utilizing an adhesive for the bottom layer electrode.

The size of the fabricated device was 10.1 cm × 10.1 cm. Finally, the two fabricated parts were combined into the SM-TEH, driven in the lateral sliding mode, as shown in Figure 2. Finally, the conductive wires were attached to the two metal layers as conductors for subsequent electrical measurements. The device's entire preparation process is cost-effective, less manufacturing time, and straightforward, making it possible to be scaled up for huge-scale production and practical applications.

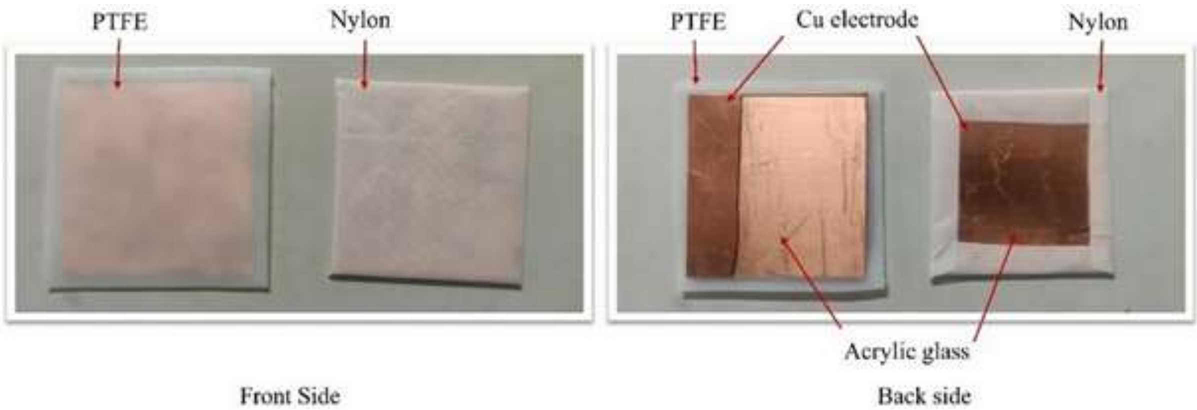

Figure 1. Component details of SM-THE

Usually, a linear actuator is used to run experiments for sliding-mode TEHs. Here, we designed a setup in which rotation is converted to sliding motion to decrease marginal costs. The designed kinematic system assembly for sliding mode TEH consists of a fixed frame, crank, and a movable frame (connecting rod). The TEH device's top electrode Cu film was connected underneath the slider. Triboelectric films with bottom Cu electrodes were mounted about 6 mm apart on the guide's edge, upon which the slider moved. As a result, the slider on the guide traveled a variable separation distance of 7 - 10 cm. To prevent unnecessary interference, a 0.3 mm gap was maintained between the slider and the guide. This setup was observed to be considerably less costly than a linear actuator, and it could provide a range of rotational speeds (in RPM).

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Different rotation of the crank is used for TEH output comparison. To examine the effects of input rotation on the working mechanism and TEH output, the input rotation was varied between 40-70 rpm. An Arduino software (Arduino mega-3630) was used to provide input at various rotational speeds (rpm). A potentiometer is used to vary the rotational speed. The DC motor was powered by a 12-volt DC power supply (S-60-12, i-cat vision). SM-THE's electrical output was measured using a digital storage oscilloscope (DSOX1204G, Keysight) with a variable resistance probe (K6100A, Tektronix). The experiment is carried out at a relative humidity of approximately ~40 percent in the air and room temperature (20–25 °C). A commercial phone camera has been used to shot optical images and videos.

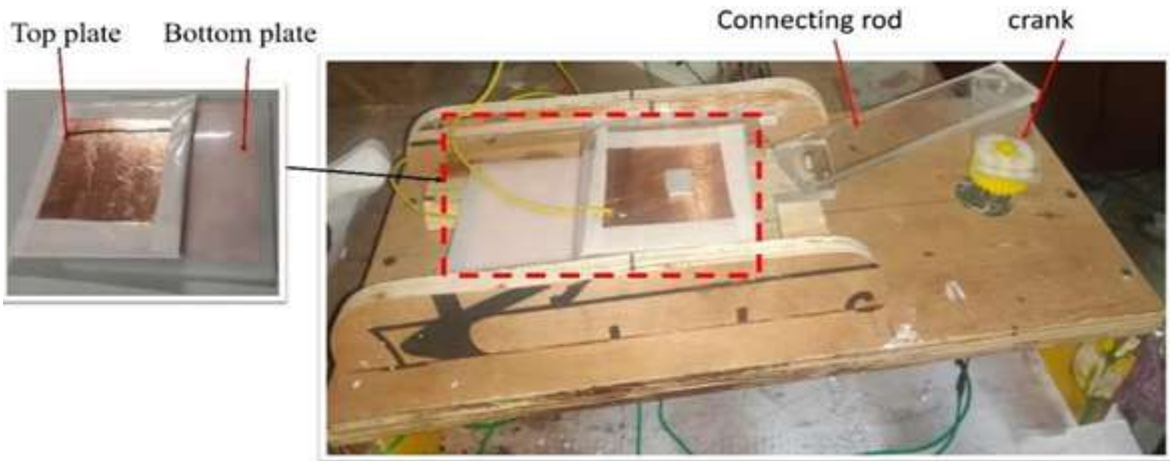

Figure 2. Setup for Slider crank mechanism of sliding mode triboelectric energy harvester along with fixture

III. RESULTS AND DISCUSSIONS

For validation, groups of sliding mode experiments are conducted to ensure consistency and accuracy of the proposed formulations for the output performance of sliding mode triboelectric energy harvester (SM-TEH). To describe the SM-TEH's electrical output, we first use an electric motor to provide turning motions. Because of the designed device, the rotating movement can then be converted into lateral sliding motion, resulting in the lateral motion of the SM-TEH. Nylon and PTFE sheets glued on acrylic plates are dielectric materials of the tribo-pair used in the experiments.

The tribo-pair is attached to the horizontal slider-crank mechanism platform for the reciprocating lateral sliding mechanism during the investigation. The size of the tribo-pair is designed as 10.1×10.1 cm2 with the various sliding displacement varies from 7 cm to 10 cm. The dynamic testing system with asymmetric acceleration/deceleration mode imposed the sliding motion using the slider-crank mechanism.

The SM-TEH is operated at four separation distances of 7, 8, 9, and 10 cm, at four different rotational speeds of 40, 50, 60, and 70 rpm. The voltage generated has been measured using an oscilloscope, with an additional external load resistance of 2.5 - 10 MΩ, and for the various operating conditions, where the peak-to-peak voltage was recorded.

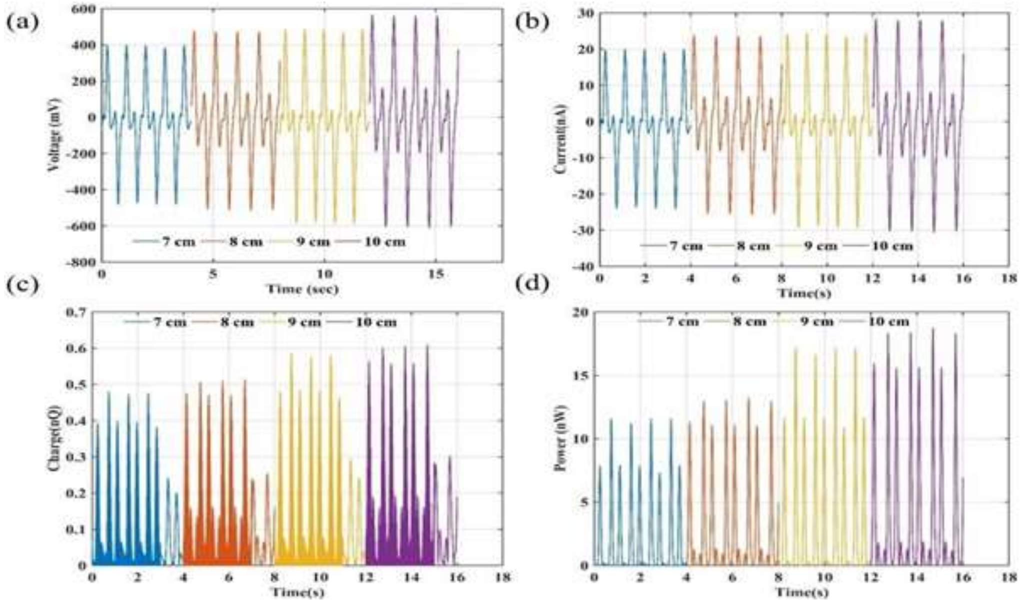

Figure 3. Electrical measurements of the sliding mode TEH array (with an external resistance of 20 MΩ and rotational speed of 70 rpm) for various separation distance. (a) Voltage, (b) Current, (c) Charge and, (d) Power

The output voltage, current, charge, and power at various separation distances are shown in Figure 3 for an external resistance of 20 MΩ and rotational speed of 70 rpm. The real-time voltage and current of the SM-TEH increase by increasing the separation distance and reaches a maximum of 590 mV and 28 nA at a separation distance of 10 cm. The measured triboelectric voltage rises during friction, with a higher negative peak and a low positive peak as shown in Figure 3a & b. Provided a constant charge flow, the contact time (corresponding to the negative peak) is less than the sliding time (corresponding to the positive peak). The output charge of SM-TEH with various separation distances was measured when the sliding process is shown in Figure 3c. When the separation distance increases, it provides a larger blank-tribo-area for the charge space-accumulation process. So transferred charge is significant rises from 0.47 nC to 0.6 nC when the separation distance is shifted from 7 cm to 10 cm. Similarly, the output power continuously increases when the separation distance increases, as shown in Figure 3d.

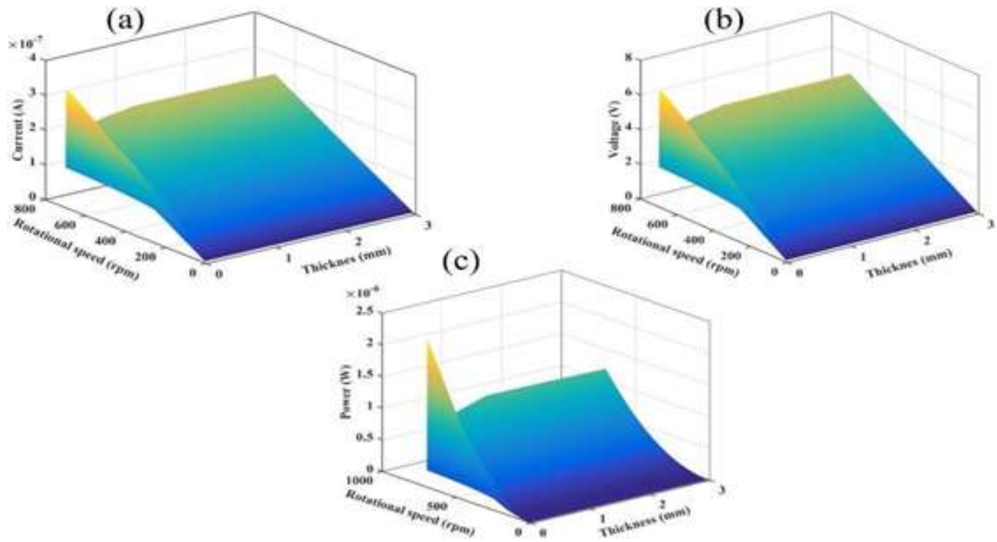

Figure 4. Effect of the rotational speed and triboelectric layer thickness on output: (a) output current (b) voltage (c) output power

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Output voltage and current are critical parameters for comparing the performance of SM-TEH under various separation distances, rotational speed, and external load resistance. At separation distance of 10 cm, the peak RMS voltage and current are 268 mV and 13.42 nA, respectively.

The SM-TEH consists of two dielectric materials (Nylon and Teflon), which change the output signal's contact pressure. Inefficient or no uniform electrodes, resulting in charge density errors, affect electron exchange between Teflon and copper. Finally, the assumed surface charge density during the experiment process may be changed due to friction. There are certain constraints on the assumption that all surfaces with different signs have the same charge.

All of these attributes contribute to the disparity between experimental and simulation results. However, when the external resistance is in the region of 1 GΩ to 100 GΩ, the increase in rotational speed considerably impacts the electrical output of the TEH. Figure 4 depicts the trends of current, voltage, and power; the higher the rotational speed N (rpm), the higher the output peak value at the optimal triboelectric layer thickness. In SM-TEH, the total charge transfer Q is evaluated by the maximum sliding distance (xmax (t)). The maximum sliding distance is fixed at 10 cm; the total transmitted charge is also improved.

IV. POTENTIAL APPLICATIONS OF SM-THE

Before being used to power electronic devices, the electricity produced by SM-TEHs must be regulated and retained in an energy storage system. The total amount of charges is the most important key factor for charging an energy storage system rather than peak current and voltage. Here, we demonstrate SM-TEH's potential application, first used to charge capacitors. The circuit diagram and voltage curves at the rotation speed of 70 rpm and the maximum separation distance of 10 cm are shown in Figure 5, where the various capacitor (0.221, 0.47, 1, 2.2, 3.3, 10, 22, 47 μF) can be charged up to 2 V within 100 s. The figure represents the time-dependent variation of the output voltage across various capacitors. In Comparison to high-capacity capacitors, the output voltage across low-capacity capacitors increases gradually. For example, the voltage across 0.221 μF capacitors rises quickly to 1 V in 2s and reaches a peak of 2 V in 10s.

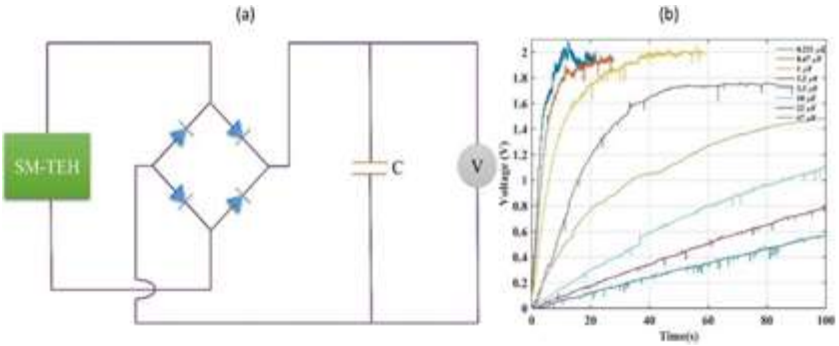

Figure 5. (a) Circuit diagram of the self-powered system for powering electronics. (b) Charging curve of a various commercial capacitor by the SM-TEH with capacitor is act as charge source

V. CONCLUSION

This new design of SM-TEH in lateral sliding mode has several other significant advantages. First, there is no need for a gap between the two layers in this novel SM-TEH to eliminate the requirement of elastic supporting components (such as springs) between the two layers to ensure effective charge separation. Therefore, this makes the TEHs device much more accessible to packaging. Second, there is no requirement for a vast amount of mechanical energy input to trigger this type of SM-TEH, increasing energy harvesting capacity. Instead, the mechanical energy requires only to rectify work carried out through the sliding friction between the two layers. Third, this device has a simple structure, is easy to fabricate, has a small volume, is stable in performance, and is durable. With these key benefits, this type of SM-TEHs can harvest mechanical energies for various working designs, such as the relative rotation of two contacting plates, piston vibration, axial rotation around its tube, and many more. In the future, this type of SM-TEH is used to harvest mechanical energy from wind, tidal waves, various human activities, and many more.

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