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DEVELOPMENT OF BIDIRECTIONAL DIRECT CURRENT TRIBOELECTRIC NANOGENERATOR

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ABSTRACT
The development of the bidirectional direct current triboelectric nanogenerator (BDC-TENG) to be used as self-powered sensor in the application of electronic skin is investigated. Several dielectric materials were used to slide on each other to generate the feedback signal by triboelectrification. The performance was enhanced by induction introduced by permanent magnets wrapped by copper coils.

In the present study, BDC-TENG is proposed to generate voltage, where the direction of the electric current depends on the sliding direction. The experiments showed that voltage remarkably increased with increasing the intensity of the permanent magnet inserted under the friction surface. Significant voltage increase was observed when the number of turns wrapped on the magnet increased. It is recommended to develop the design of BDC-TENG by inserting permanent magnet wrapped by copper coil to increase the induction in the sliding area. The proposed BDC-TENG can be suitable to be applied in e-skin design as a self-powered sensor.

KEYWORSD
Bidirectional direct current triboelectric nanogenerator, permanent magnet, copper coil, self-powered sensor, feedback signal, electronic skin.

INTRODUCTION
The performance of triboelectric nanogenerator (TENG) depends on converting sliding of dissimilar dielectrics on each other into electric current. The design of e-skin can be modified by using the electrostatic charge (ESC) generated from sliding of objects on e-skin to be applied as feedback signal in order to control the grasping force. TENG was developed by using second charge-collecting electrode (CCE) on the other end of the friction surface (FC), [1, 2], to provide bidirectional output. A direct current triboelectric nanogenerator (DC-TENG) was proposed to generate bidirectional voltage of signal that depends on the sliding direction, [3]. Polyurethane sponge substrate was used to increase the contact area. Besides, copper electrodes showed higher voltage than aluminium ones, while the voltage increased as the width

and length of the electrode increased, [4]. The sliding of the DC-TENG on the friction surface induced direct current, [5 – 9].

Generation of DC current to work as feedback signal is essential in the design of e-skin to control the handling of the objects, [10]. The function of e-skin was developed by resistive, capacitive sensors, triboelectrification and electrostatic induction, [11 - 22]. Added to that, e-skin was enhanced to detect finger touch, [23, 24]. Besides, the mechanism of gripper was developed to guarantee safe objects grasp by controlling the gripping force. The feedback signal generated from the triboelectrification that generated ESC of double layers at the sliding surfaces, [25]. It was recommended that ESC measured can be applied as feedback signal. An e-skin of latex as outer layer to guarantee safe grasping of the object due to the high friction was studied, [26]. It was revealed that the highest ESC values were measured for PTFE and Kapton as friction surfaces. Two charge collecting electrodes were used to increase ESC in the external circuit.

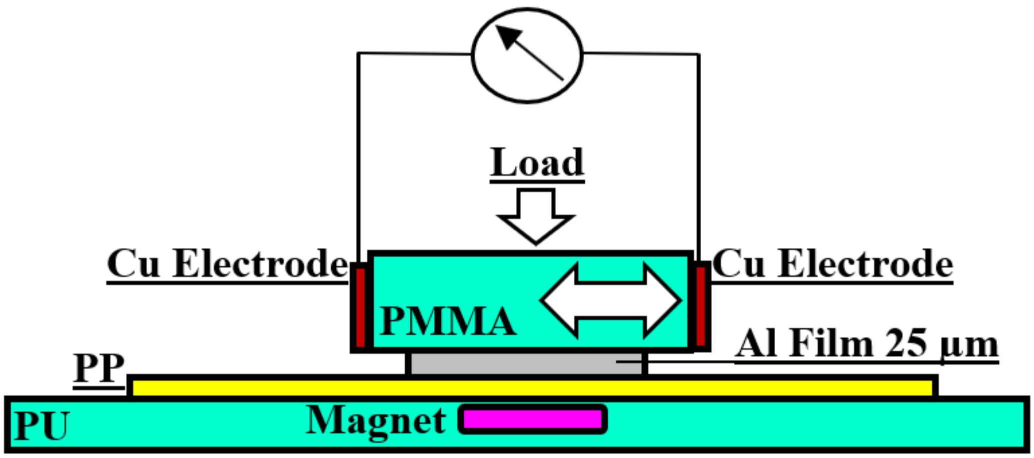
The present work proposes BDC-TENG to induce direct current as feedback signal to be used in the application of the e-skin. It is proposed to insert a permanent magnet and copper coil under the friction surface to increase the ESC generated by induction.

EXPERIMENTAL

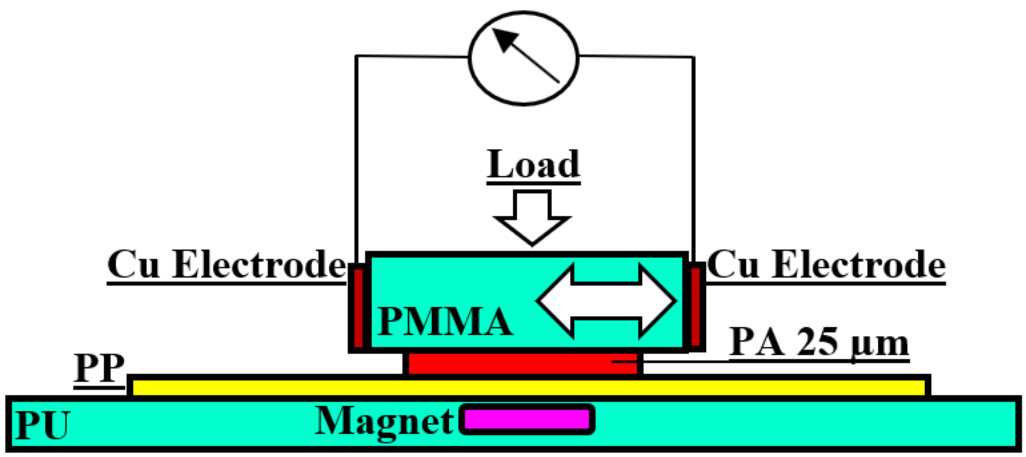
The BDC-TENG, investigated in the present work study in order to generate the DC current to be used as feedback signal, consisted of two dielectrics, the first was aluminium (Al) film of 25 μm thickness adhered to polymethyl methacrylate (PMMA) block of 20 × 15 × 5 mm^3 working as the sliding surface. Copper film of 20 μm thickness was adhered to polyethylene (PE) sheet of 0.25 mm thickness to be used as output electrodes adhered to the two sides of the PMMA to collect ESC generated from sliding of Al on the other dielectric in the two directions of motion. The other friction dielectric was polypropylene (PP) of 25 μm thickness adhered to polyurethane (PU) foam of 5 mm thickness.

Three permanent magnets used to provide the system by induction were of 120 mG intensity each of 18 × 9 × 3 mm^3 was inserted in the PU foam under the PP film. Copper wires of 0.15 mm diameter and 50 turns was wrapped on the magnet in longitudinal and transverse directions to enhance the intensity of the induction. Al film was replaced by polyamide (PA) film of 25 μm thickness.

Further experiments were carried out by using Kapton to slide on PMMA sheet of 2.0 mm thickness. The details of the tested BDC-TENG are illustrated in Figs. 1 - 3. Load was applied by weights of 2, 4, 6, 8 and 10 N, while the sliding distance was 10 mm.



a.



b.

Fig. 1 Details of the tested TENG provided by permanent magnet, a. Al/PP and b. PA/PP.

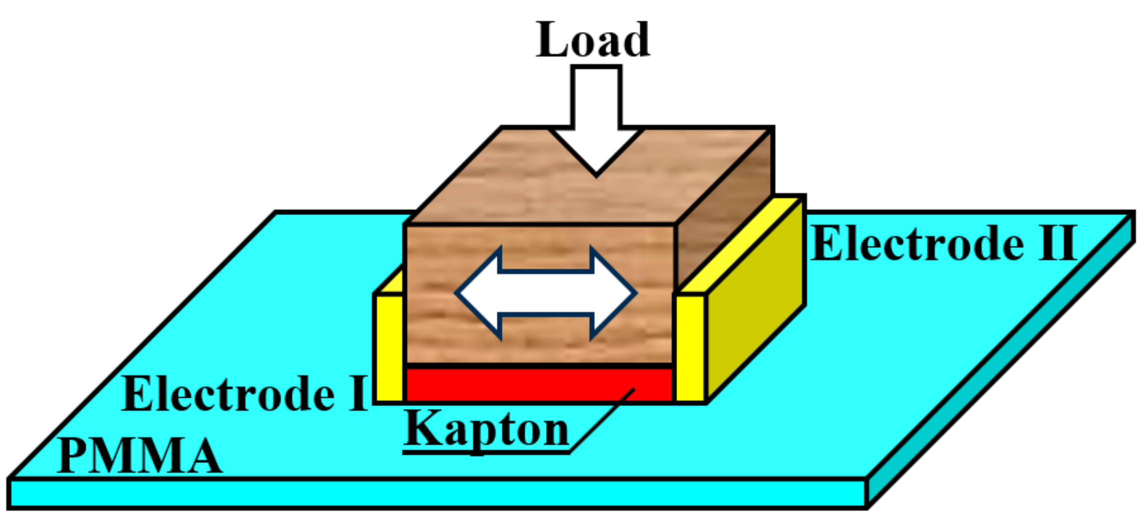


Fig. 2 Details of the proposed DC-TENG.

Fig. 3 Permanent magnet wrapped with copper coil.

RESULTS AND DISCUSSION

The object of the proposed BDC-TENG is to generate double simultaneous voltage, where the current direction depends on the sliding direction. When the friction surface moves to the right, electrode I collects ESC from other friction one, Fig. 1. While the movement to the left causes that electrode II collects ESC in different signal. Therefore, the addition of the second electrode, the bidirectional output can be obtained.

The voltage difference between the two electrodes in condition of the sliding of Al film slid on PP is shown in Fig. 4. Voltage significantly increased with increasing the applied load. As the intensity of the magnet inserted under the PP surface increased, voltage increased. The highest values of voltage measured at 10 N load were 83, 89 and 97 mV at 0, 120 and 240 mG magnetic field intensity respectively.

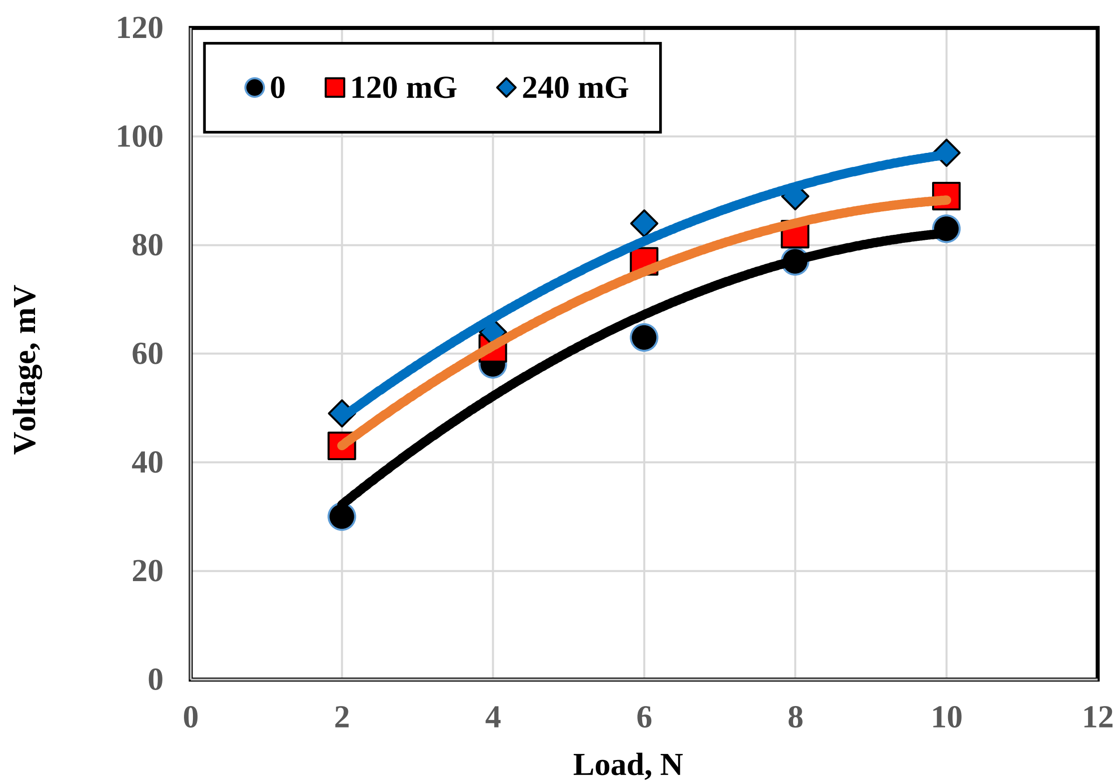


Fig. 4 Voltage difference between the two electrodes when Al film slid on PP.

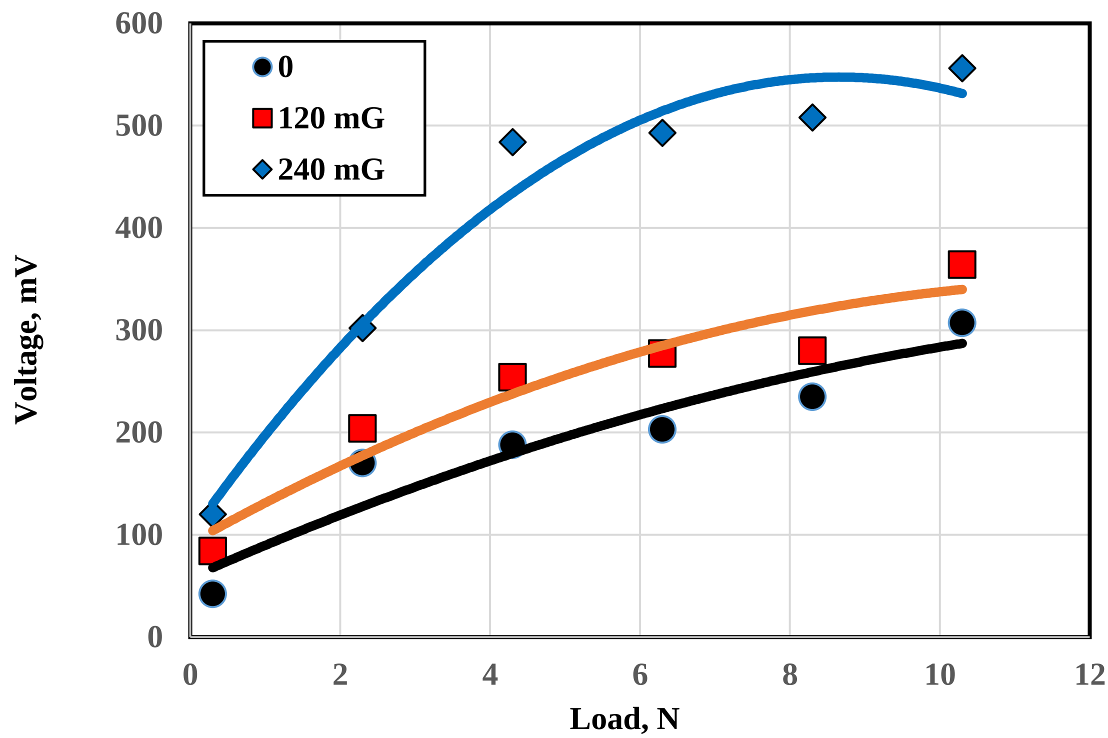


Fig. 5 Voltage difference between the two electrodes when PA film slid on PP.

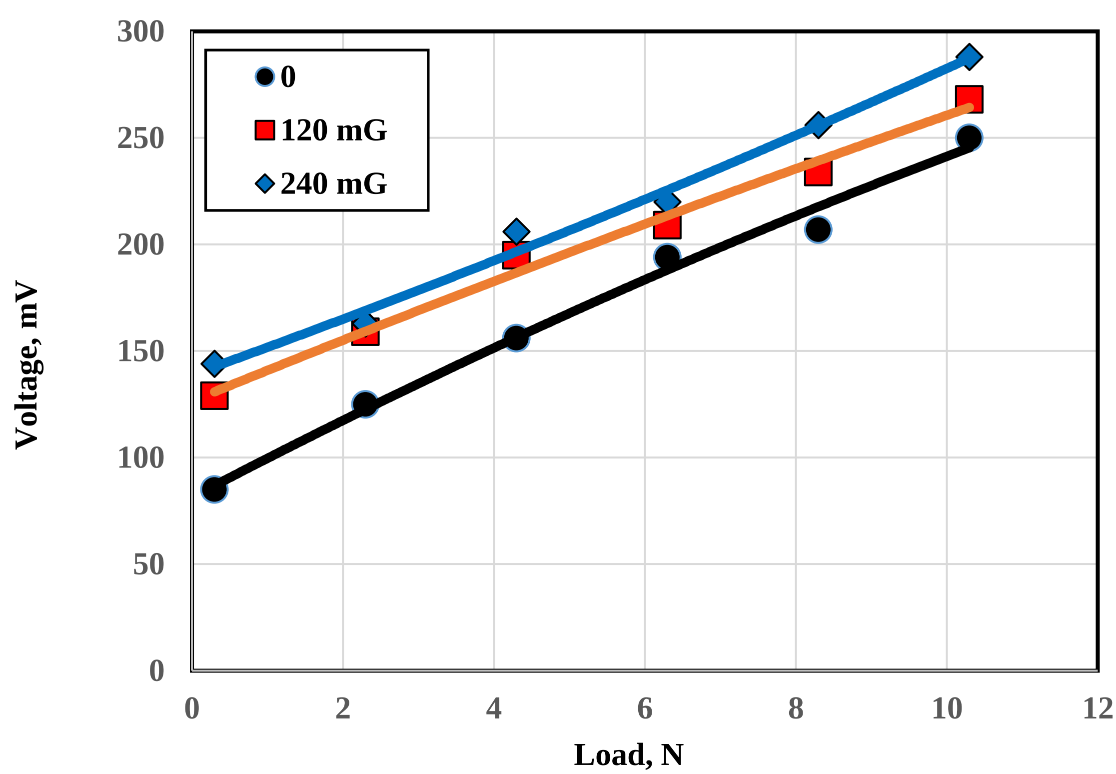


Fig. 6 Voltage difference between the two electrodes when Al film slid on PMMA.

When Al was replaced by PA, voltage represented relatively higher values, Fig. 5. The voltage increase can be explained on the bases that when two dissimilar materials contact each other, electrons transfer begins, where the difference in their work functions drives the transfer. Electron transfer happen on the surfaces of insulators. Triboelectric series was proposed to determine the polarity of the charge of the two contacting surfaces that is transferred from one surface to another, [27], where the upper one in the triboelectric series will be positively charged while the other will be negatively charged. The magnitude of the generated ESC depends on the gap between the two contacting surfaces. Because PA lies in the top of the triboelectric series while PP lies in the bottom of the series the gap between PA and PP is longer than that between Al and PP. Therefore, the voltage as measure of the generated ESC increased. The magnetic field generated from the induction of the permanent magnet may be responsible for voltage increase. The same trend was observed when Al film slid on PMMA, Fig. 6. The values of the generated voltage were lower than that measured for PA slid on PP.

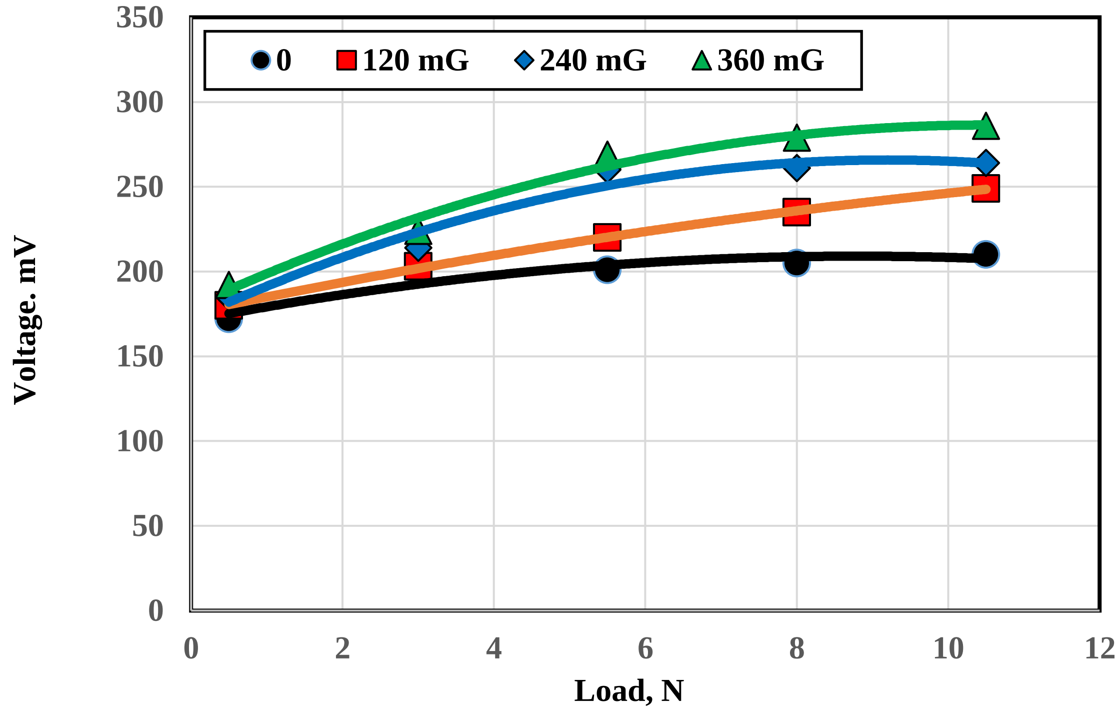


Fig. 7 Voltage difference between the two electrodes when Kapton slid on PMMA.

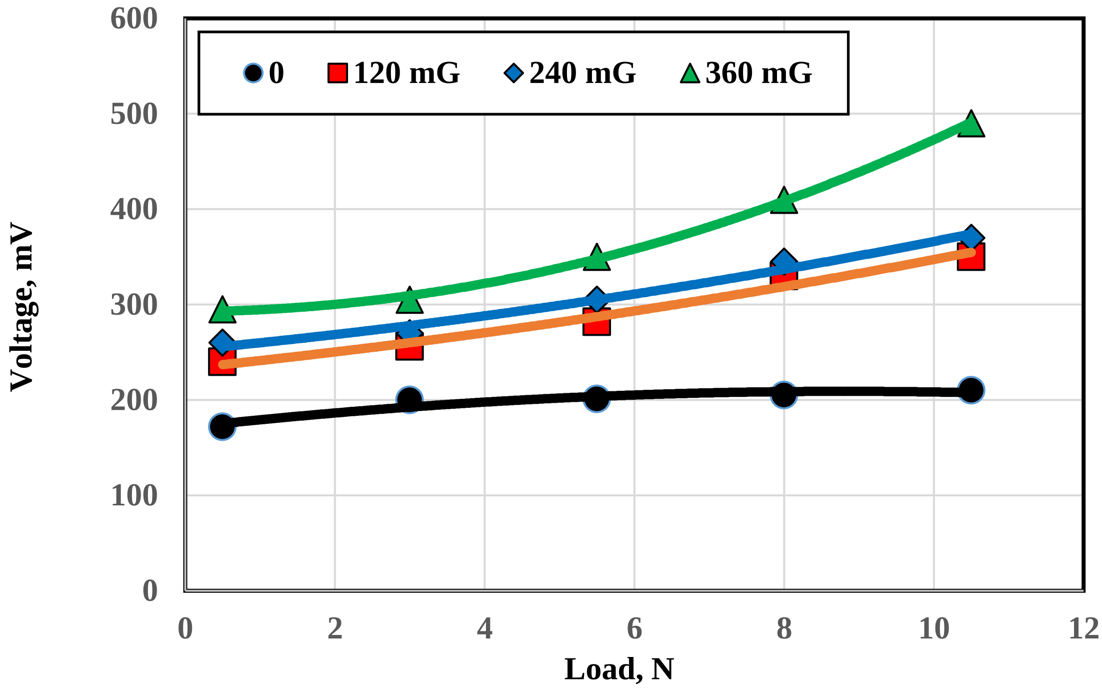


Fig. 8 Voltage difference between the two electrodes when Kapton slid on PMMA.

The results of experiments carried out to measure the voltage generated from sliding of Kapton on PMMA sheet of 2.0 mm thickness are illustrated in Figs. 7 – 11. The permanent magnets were inserted in the PU foam under the PMMA sheet. They were wrapped by copper wires of 0.15 mm diameter and 50 turns in longitudinal and transverse directions. When the motion was in the direction of the copper wire, Fig. 7, voltage slightly increased with increase of the intensity of the magnetic field. Figure 8 shows that when the one magnet was wrapped by the copper wire, the voltage showed significant increase. The highest voltage value was 490 mV at 10 N load and 360 mG field intensity. It is known that intensity of the generated ESC depends on the strength of the electric or magnetic field affecting the sliding surface. Based on Faraday, the change of the electric field induces an electric current in the coil initiating extra voltage. Inserting the magnet as well as the cupper coil is responsible for the voltage increase.

When the motion was in the direction perpendicular to the copper wire, Fig. 9, voltage displayed slight decrease with increasing the magnetic field intensity. Increasing the number of turns from 50 to 100 showed significant voltage increase, Fig. 10. The highest voltage value was 520 mV at 10 N load and 360 mG field intensity. The voltage increase can be due to the increase of electric field resulting from the increase of the copper wire turns. The movement of the coil through the magnetic field induces electric current that flows into the coil causing voltage increase, where the voltage increase depends mainly on the electric field that is much influenced by the number turns of the coil.

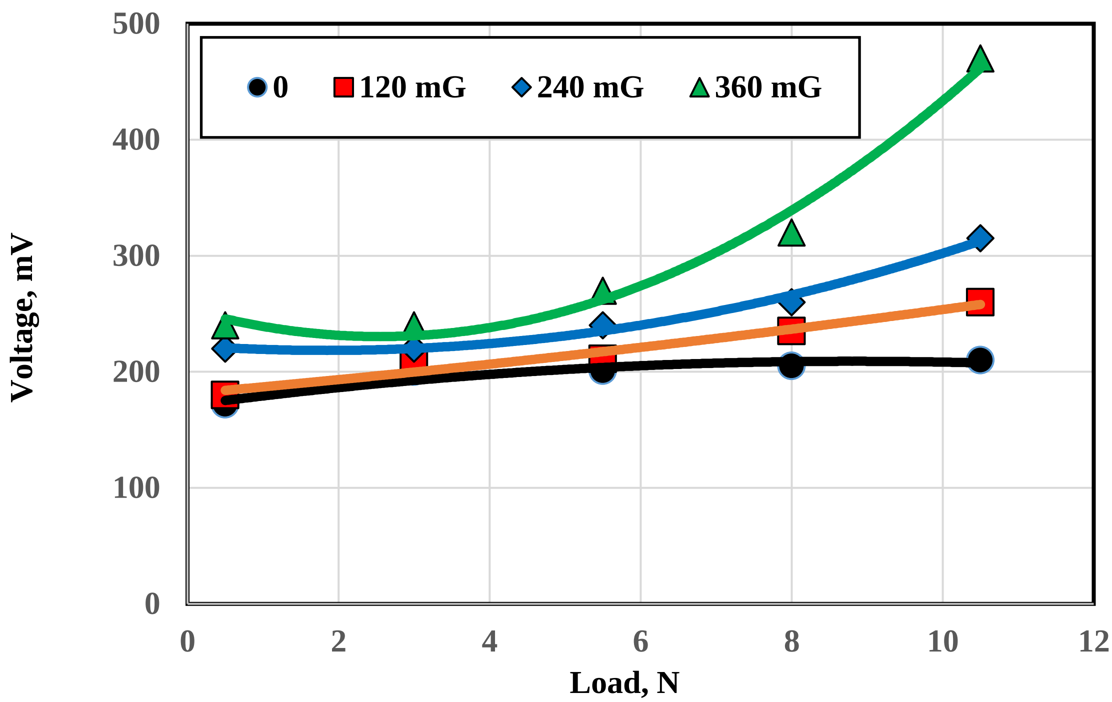


Fig. 9 Voltage difference between the two electrodes when Kapton slid on PMMA.

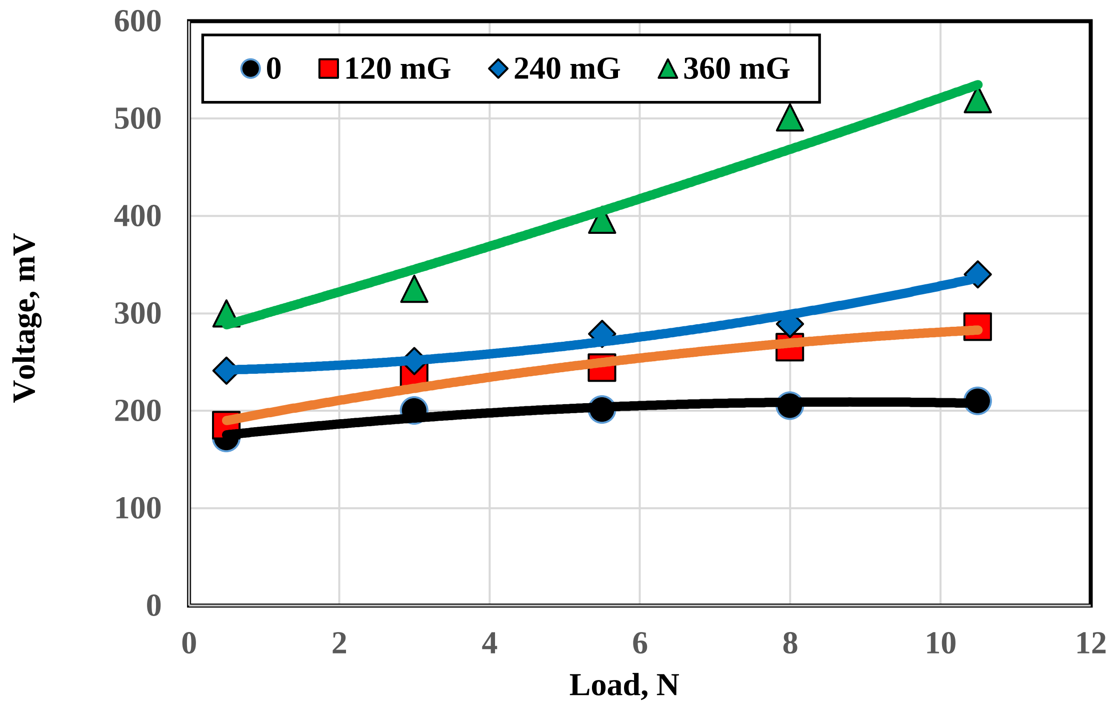


Fig. 10 Voltage difference between the two electrodes when Kapton slid on PMMA.

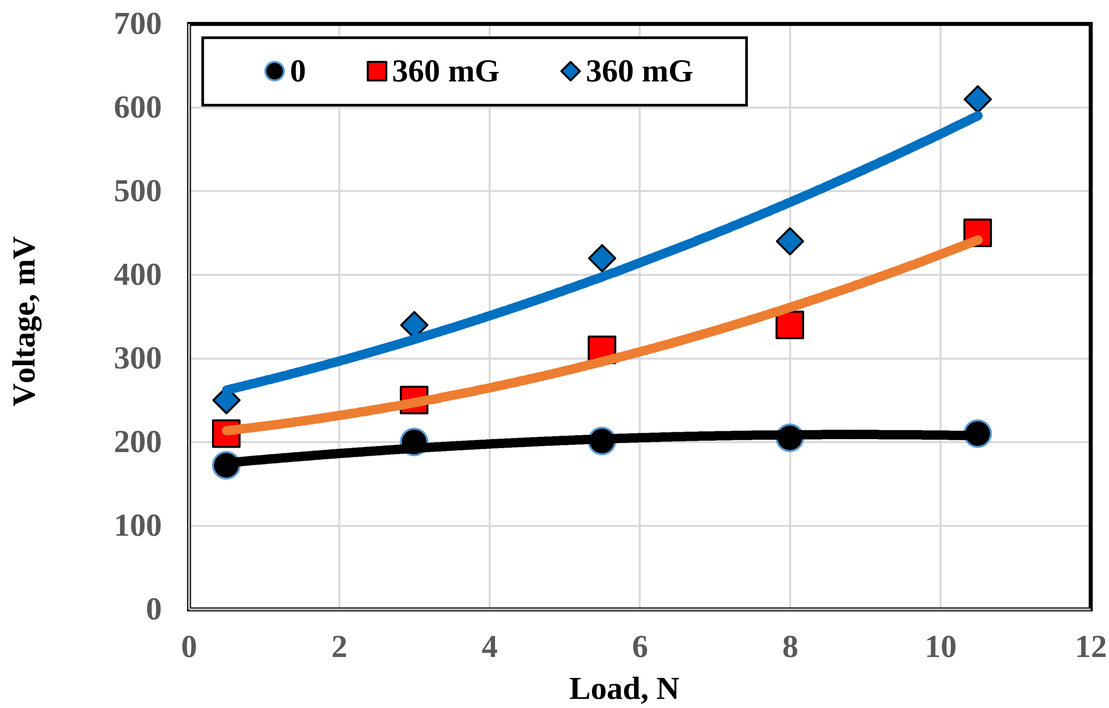


Fig. 11 Voltage difference between the two electrodes when Kapton slid on PMMA.

The highest voltage values recorded 620 mV at 360 mG when the three magnets together were wrapped by copper wire of 100 turns. That observation confirmed that the increase of the electric field initiated by the induction of the copper coil is responsible for the voltage increase. The double charge generated on the two contact surfaces in the presence of the permanent magnet as well as the coil could induce an extra electric field of value higher than that generated from triboelectrification.

The proposed BDC-TENG can generate bidirectional voltage, where direct current flows in the external circuit in two directions during sliding with different sign of ESC. Therefore, the proposed BDC-TENG can be applied in e-skin design to be used as a self-powered sensor.

CONCLUSIONS

1. Voltage difference significantly increased with the increase of intensity of the permanent magnet inserted under the friction surface.
2. Sliding of PA on PP displayed represented relatively higher voltage values than that observed for sliding of Al on PP.
3. The induction of the permanent magnet inserted under the friction surface increased the voltage.
4. When the motion was in the direction of the copper wire wrapped on the magnet, voltage showed slight increase as the intensity of the magnetic field increase, while in the perpendicular direction, voltage showed slight decrease.
5. Significant voltage increase was observed when the number of turns wrapped on the magnet.
6. The highest voltage values were measured when the three magnets were wrapped

together by copper wire.
7. It is recommended to enhance the design of BDC-TENG by inserting permanent magnet wrapped by copper coil. The proposed BDC-TENG can be suitable to be applied in e-skin design as a self-powered sensor.

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