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ENHANCING THE PERFORMANCE OF THE TRIBOELECTRIC NANOGENERATOR

Elzayady N.[1], Al-Kabbany A. M.[2], Ali W. Y.[2], Ali A. S.[3] and Hamdy K.[2]

[1]Mechanical and Aerospace Dept., Institute of Aviation Engineering and Technology, Giza, EGYPT.
[2]Production Engineering and Mechanical Design Dept., Faculty of Engineering, Minia University, Minia 61111, Egypt.
[3]Mechanical Engineering Dept., Faculty of Engineering, Suez Canal University, EGYPT.

ABSTRACT
The present paper aims to develop the performance of the triboelectric nanogenerator (TENG) based on triboelectrification and magnetic field. PMMA sheet was inserted under the triboelectrified area to permit the lines of magnetic field to flow from one pole of the magnet to the other with the same intensity. Besides, steel sheets of different thickness were replaced the PMMA sheet to investigate their effect on the generated voltage.

The present experiments revealed that the proper position of the permanent magnet was to be above the steel sheet closer to the friction surface. The steel sheet redirected the lines of flux of the permanent magnet and distributed the magnetic field on the friction surface providing an extra magnetic field superimposed on the field supplied by the permanent magnet. Added to the magnetic field, an electric field was generated by ESC. All those magnetic and electric fields are responsible for the increase of the voltage. Voltage significantly increased with increasing the steel thickness for contact-separation and sliding. The steel sheet represents an extra magnet. It redirects the lines of flux into easier path into the friction surface. It seems that the steel sheet concentrates the field lines on the friction surface, where thick steel sheet can hold higher magnetic flux than thin sheets.

KEYWORDS
Magnetic field, permanent magnet, steel sheet, voltage, triboelectric nanogenerator.

INTRODUCTION
The triboelectrification of the contact surfaces occurs when charges are transferred from one surface to another, [1 - 5]. The intensity and sign of the electrostatic charge (ESC) is classified by the triboelectric series that specifies the materials according to their ability to gain positive or negative ESC after contact or sliding with another material, [6 - 8]. The mechanism of triboelectrification is still unknown, [9].

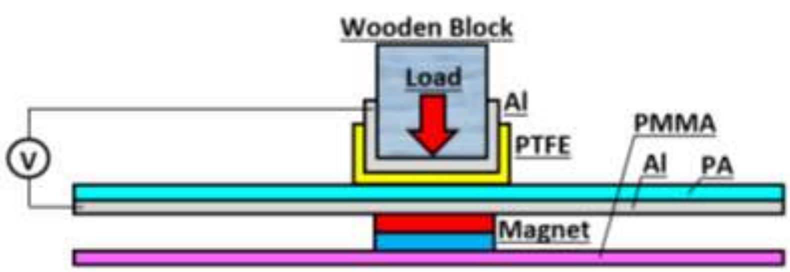
The triboelectrification can cause fires, [10, 11], and destruct electronics, [12, 13]. It can be reduced by blending two materials having different charge in one surface, [14 - 16]. Besides, it can be applied to defeat viruses, [17 - 21], and manufacture the triboelectric nanogenerator (TENG), [22 - 24]. Triboelectrification and electrostatic induction are applied in TENG to induce a voltage difference between two terminals such as energy harvesters, [25 - 28], and self-powered sensors, [29 - 32].

Electromagnetic induction is used to make hybrid electromagnetic-TENGs, [33 - 39]. It was found that the position of the permanent magnets relative to the triboelectrified area influenced the voltage difference, [40 – 41]. In addition to that, replacing the steel sheet by PMMA generated significant voltage increase.

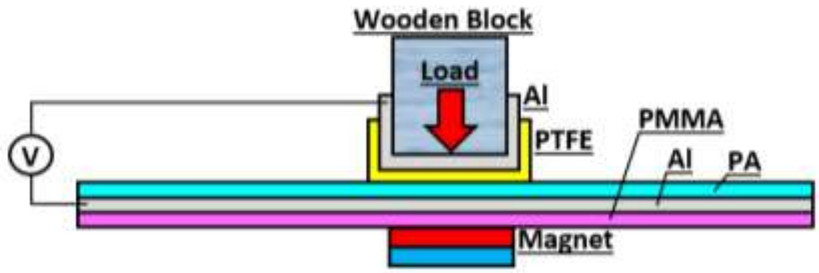
The present paper aims to enhance the performance of the triboelectric nanogenerator (TENG). PMMA sheet was inserted under the friction surface to allow the lines of magnetic field to flow from one pole of the magnet to the other with the same intensity. Then steel sheets of different thickness were replaced the PMMA sheet to inspect their effect on the generated voltage.

EXPERIMENTAL

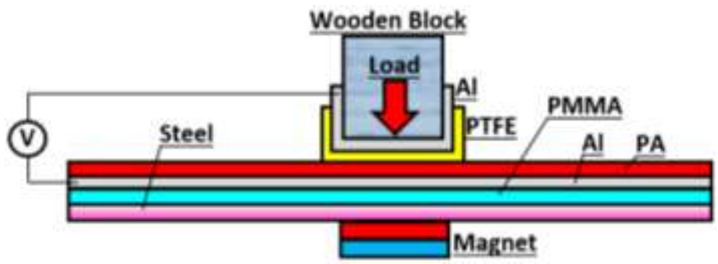
The test specimens consisted of polytetrafluoroethylene (PTFE), as the first dielectric surface, adhered to wooden cube of 40 × 40 × 40 mm^3 coated by aluminium film (Al) of 0.1 mm thickness as the first electrode. The second dielectric surface was polyamide (PA) textile adhered to PMMA sheet of 1.1 mm thickness (second electrode) coated by Al of 0.1 mm thickness as the second terminal, Fig. 1, a and b. The voltage difference was measured between the first and the second electrodes. The PMMA sheet was replaced by steel sheet of different thicknesses ranging from 2.3 to 11.1 mm to investigate the effect of shielding of the steel on the output voltage, Fig. 1, c, d and d. The load value was (0.4 N). The test procedure of contact-separation was done by applying the load for 5 seconds before the measurement of the voltage. In sliding, the distance was 100 mm. Permanent magnets were used of 60 mG magnetic strength.



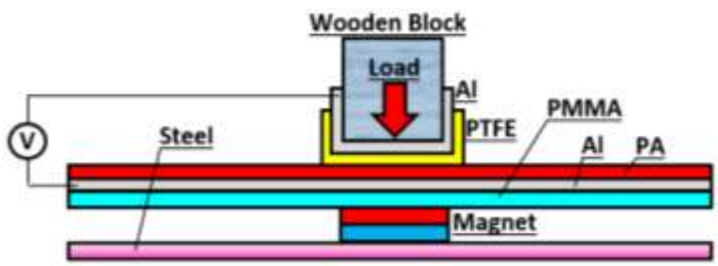
a. Magnets above PMMA sheet,



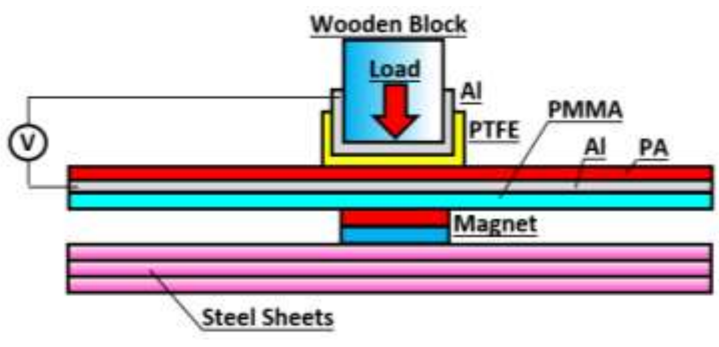
b. Magnets under PMMA sheet,



c. Magnets under steel sheet,



d. Magnets above steel sheet,



e. Magnets above steel sheet of different thickness,

Fig. 1 Arrangements of the test procedure.

RESULTS AND DISCUSSION

Voltage generated from contact-separation and sliding of PTFE on PA when magnets are placed above PMMA sheet is shown in Fig. 2. Voltage significantly increased with

the increase of the magnetic field, where the highest values were 124 and 320 mV at 240 mG magnetic intensity for contact-separation and sliding respectively. The arrangement is illustrated in Fig. 1, a. When the magnets were placed under the PMMA sheet, Fig. 1, b, slight voltage decrease was observed, Fig. 3. The highest value for contact-separation reached 120 mV at 240 mG, while sliding displayed 270 mV. Based on that observation, it can be seen that the effect of the magnets depends on their distance from the friction surface, where the intensity of the magnetic field lines is concentrated on the PA surface. Because the magnets generated uniform field lines cut by PTFE electrode, the moving ESC generated on the PTFE and PA surfaces induced electric field. Then the electric field induced extra electric current. Sliding generated higher voltage than contact-separation because the number of magnetic field lines cut by the movement of PTFE increased.

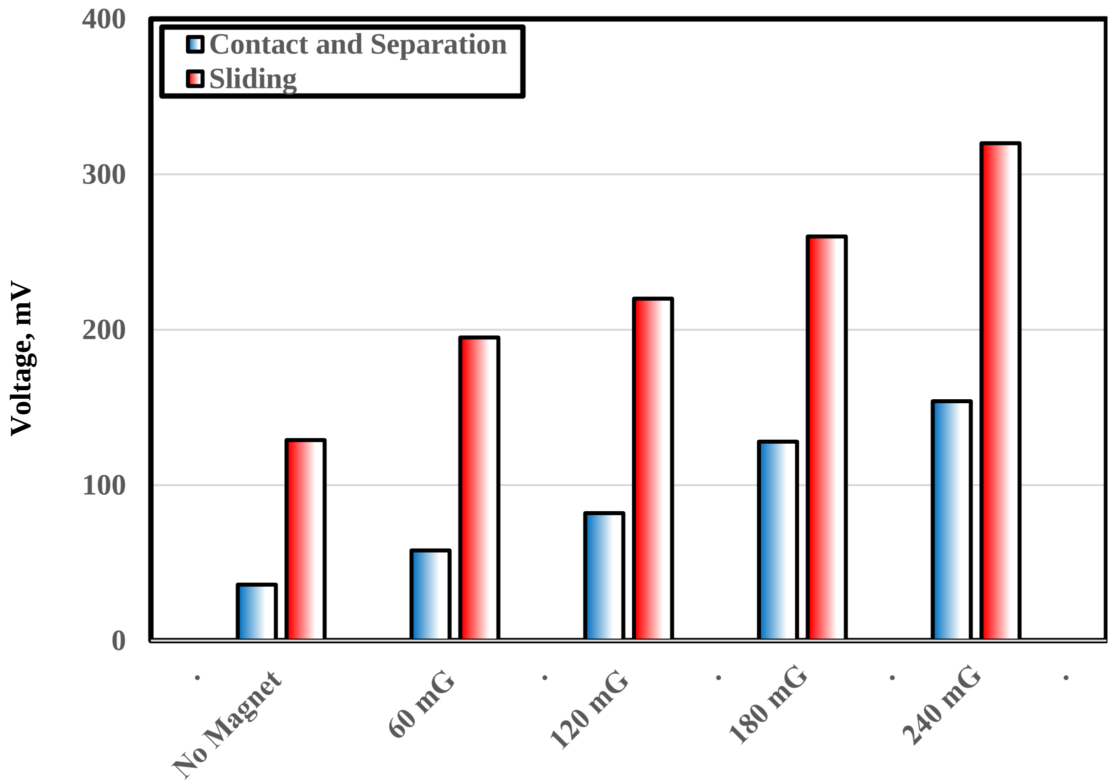


Fig. 2 Voltage generated from contact-separation and sliding between PTFE and PA when magnets are placed above PMMA sheet.

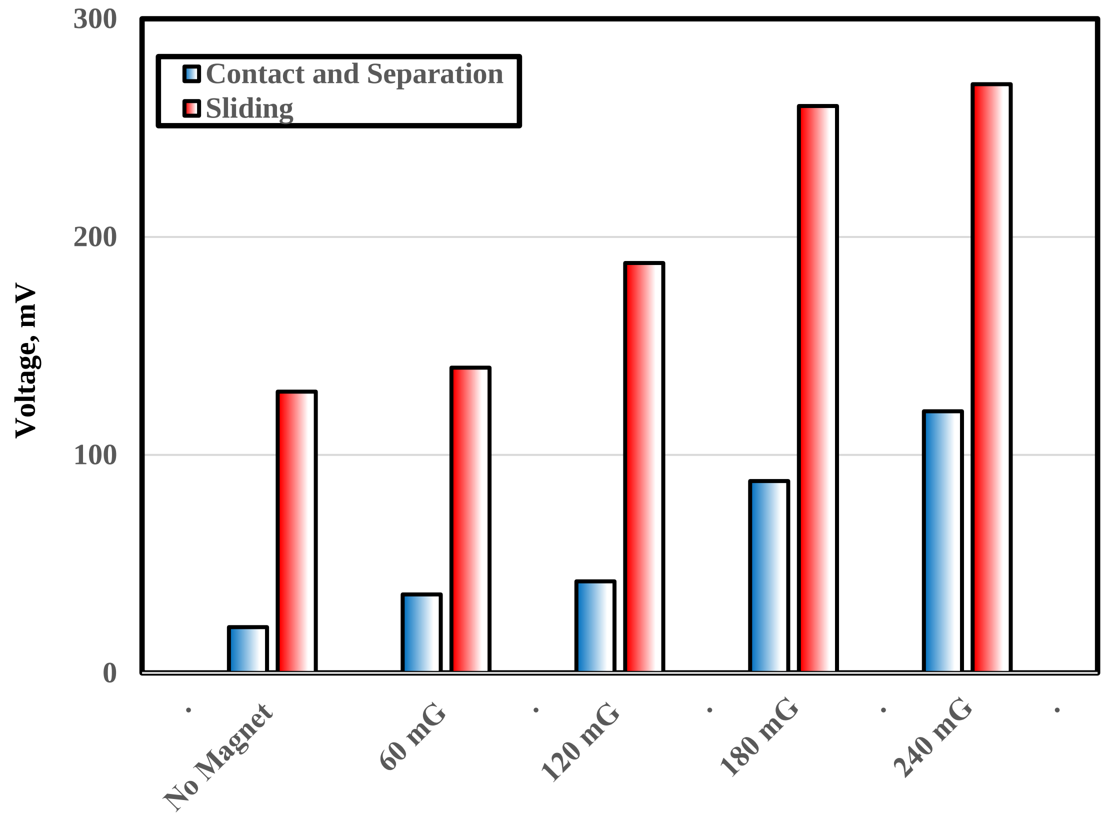


Fig. 3 Voltage generated from contact-separation and sliding between PTFE and PA when magnets are placed under the PMMA sheet.

After determining the proper position of the permanent magnet relative to the friction surface, experiments were carried out to investigate the effect of replacing the PMMA sheet by steel sheet on voltage generated from contact-separation and sliding. Figure 4 shows the relationship between voltage difference between PTFE and PA at 60 mG magnet intensity and the thickness of the steel sheet. Voltage significantly increased with increasing steel thickness for both contact-separation and sliding. To explain that observation, it is thought that magnetic shielding made by the steel sheet redirected the lines of flux and provided easier path for the flow of the lines of flux. The lines flow out from the pole of the magnet into the steel then to the air and get back to the other pole of the magnet. It can be imagine that the steel sheet concentrates the field lines on the triboelectrified area. The thickness of the steel shield influences the flow of the lines of the flux. Thin steel sheet becomes saturated and its ability to hold more lines of flux increases, while thick steel can hold higher magnetic flux. It seems that the steel sheet becomes an extra magnet, where its magnetic strength is imposed on the strength of the permanent magnets. As the steel thickness increased the held magnetic flux increased and the steel sheet became relatively stronger magnet affecting the triboelectrified area. As result of that, the resultant magnetic field strength increased. It is clearly seen that voltage difference generated from by sliding displayed higher values than that observed for contact-separation. The highest voltage values recorded at 11.1 mm steel thickness for contact-separation and sliding were 105 and 430 mV respectively. It seems that the double layer of ESC generated

on the contact surfaces induced extra electric field on the sliding surfaces leading to the voltage increase.

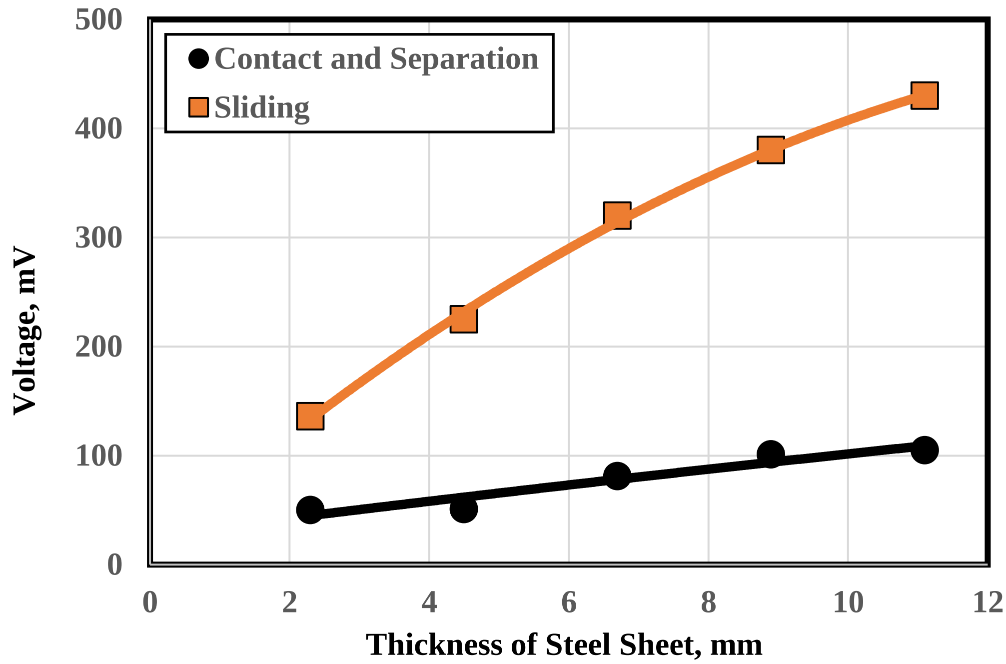


Fig. 4 Voltage difference between PTFE and PA at 60 mG magnet intensity placed above steel surface.

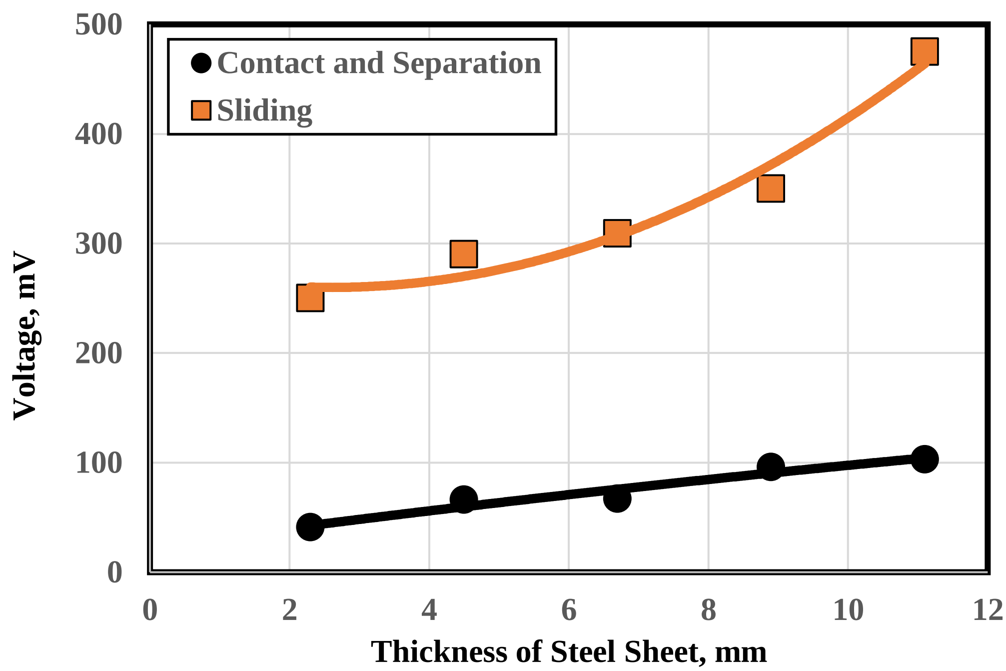


Fig. 5 Voltage difference between PTFE and PA at 120 mG magnet intensity placed above steel surface.

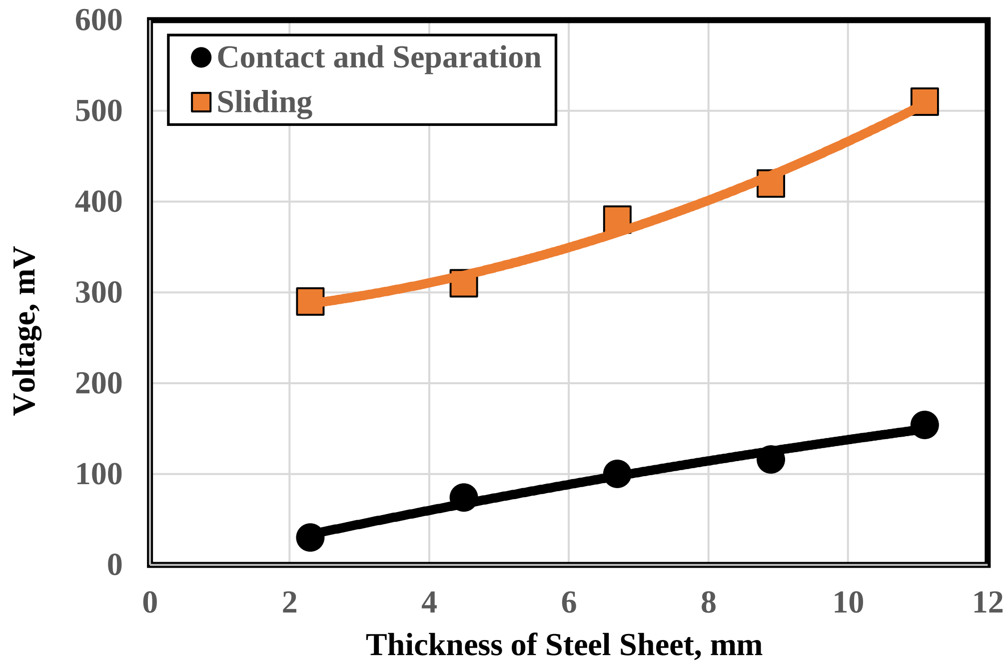


Fig. 6 Voltage difference between PTFE and PA at 180 mG magnet intensity placed above steel surface.

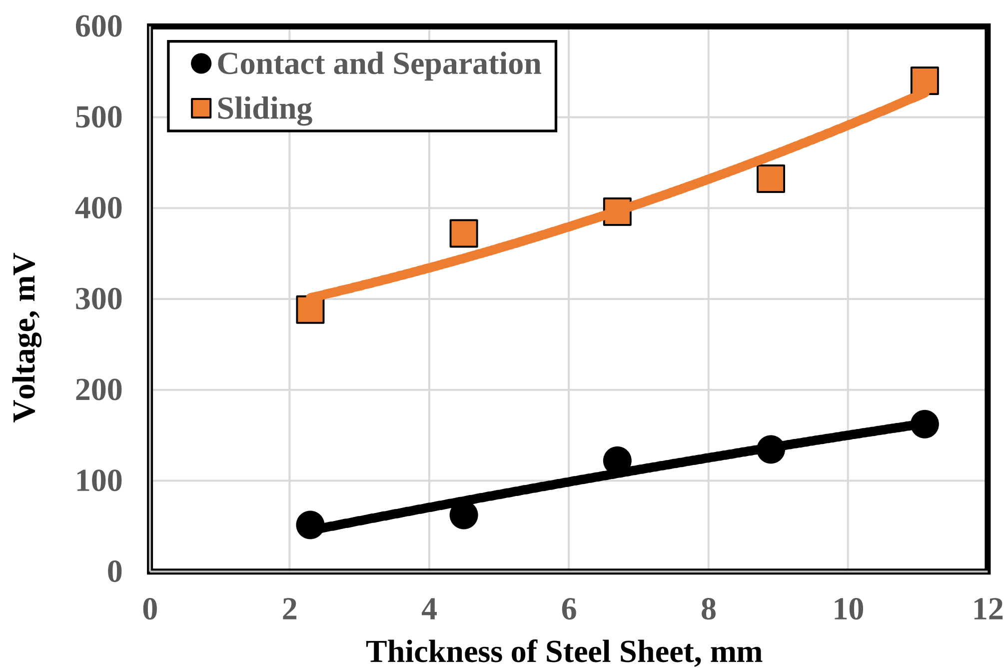


Fig. 7 Voltage difference between PTFE and PA at 240 mG magnet intensity placed above steel surface.

Increasing the magnetic strength to 120 mG increased the voltage difference between PTFE and PA for sliding to 475 mV at 11.1 mm steel sheet thickness, Fig. 5. The same trend was observed for 180 and 240 mG field strength, Figs. 6 and 7 respectively with relatively higher voltage. It is known that magnetic shielding does not block the magnetic field but it can redirect the lines of flux and homogeneously distribute the magnetic field on the friction surface. The presence of PMMA sheet allows the lines of magnetic field to flow from one pole of the magnet to the other with the same intensity, while steel sheet reflects the field lines to the friction area. It can be concluded that the voltage increase may be from the effect of the permanent magnets and the extra magnetic field supplied by the steel sheet as well as the double layer of ESC generated from friction that provides the surface by an electric field. All those, magnetic and electric fields are responsible for the increase of the voltage.

CONCLUSIONS

1. The effect of the magnets depends on their position relative to the friction surface.
2. Slight voltage decrease was observed when the magnets were placed under friction surface.
3. Voltage significantly increased as the steel thickness increased for contact-separation and sliding.
4. The flow of the lines of the flux is influenced by the thickness of the steel shield. As the thickness of steel sheet increased magnetic field increased. Then, the steel sheet represents an extra magnet.
5. Voltage generated from sliding is higher than that generated from contact-separation.

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