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INFLUENCE OF MAGNETIC FIELD ON THE PERFORMANCE OF THE TRIBOELECTRIC NANOGENERATOR

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ABSTRACT
The present study aims to develop the performance of the triboelectric nanogenerator (TENG) based on triboelectrification and magnetic field. PP and steel sheets of different thicknesses were inserted between the contact area and the magnets to investigate the effect of the distance separating them on the generated voltage.

It was found that the generated voltage drastically decreased with increasing PP sheet thickness. Besides, position of the magnets relative to the contact area has insignificant effect on the generated voltage. In sliding, voltage showed higher values than that observed for contact-separation. While voltage significantly increased with increasing the thickness of steel sheet. Longitudinal sliding produced higher voltage values than transverse sliding and contact-separation. Finally, it is proposed to use steel sheet to induce an extra magnetic field to increase the external voltage. In condition of using nonmagnetic material such as PP, the distance between the magnet and the contact area increases then the magnetic field lines become larger and consequently the number of magnetic field lines passing through the contact area decreases leading to the decrease of the magnetic field.

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

INTRODUCTION
It was known that the position of the permanent magnets relative to the triboelectrified area for the triboelectric nanogenerator (TENG) based on triboelectrification and magnetic field influences its performance, [1 – 6]. It was observed that voltage increased when the electrode cut the lines of a magnetic field. It was recommended to harvest the highest voltage values by selecting the proper position of the magnet relative to the contact area. Besides, PMMA and steel sheets

were between the permanent magnets and the triboelectrified area to control the flow of the lines of magnetic field. It was found that the steel sheets of different thickness redirected the flux lines of the permanent magnet and provided an extra magnetic field.

ESC is generated from contact-separation and sliding of two dissimilar materials. Then triboelectrification of the contact surfaces results from the transfer of ESC from one surface to another, [7 - 11]. The magnitude and sign of ESC is specified by the triboelectric series that classifies the materials based on their gaining positive or negative ESC after contact-separation and sliding, [12 - 15].

The drawbacks of triboelectrification are fires, [16, 17], and destruction of electronics, [18, 19]. It was found that, blending two materials having different charge in one surface can reduce that effect, [20 - 22]. In addition to that, it can be used to defeat viruses, [23 - 27], and develop the triboelectric nanogenerator (TENG), [28 - 30]. Triboelectrification supported by electrostatic induction were applied in TENG to generate voltage difference between two electrodes such as energy harvesters, [31 - 34], and self-powered sensors, [35 - 37]. Electromagnetic induction is applied to make hybrid electromagnetic-TENG, [39 - 43].

The present study aims to inspect the influence of inserting PP and steel sheets of different thicknesses between the contact area and the magnets on the performance of the TENG.

EXPERIMENTAL

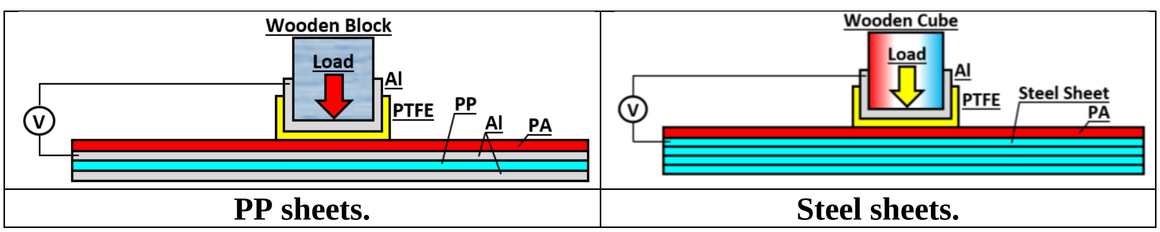
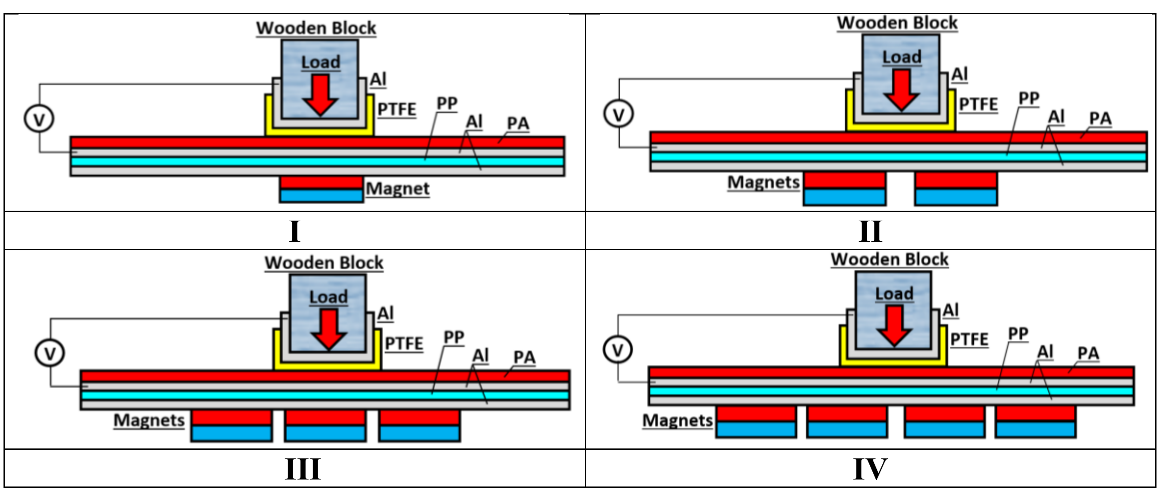


Fig. 1 Arrangement of the test procedure.



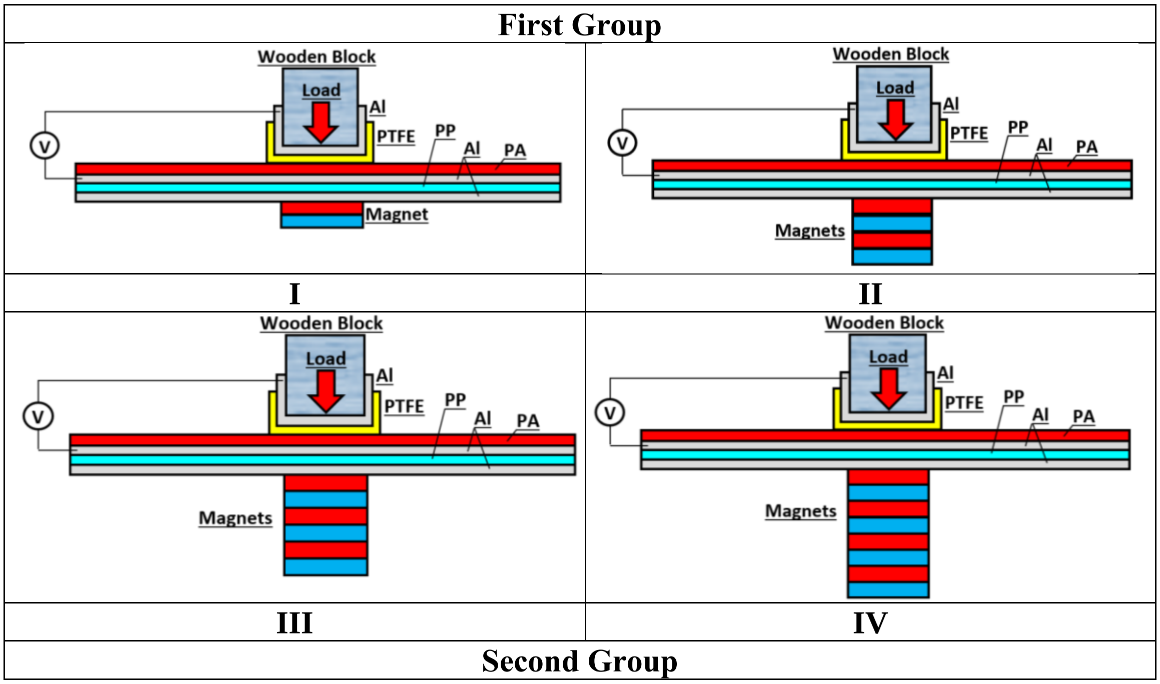


Fig. 2 Arrangements of the permanent magnets for PP sheets.

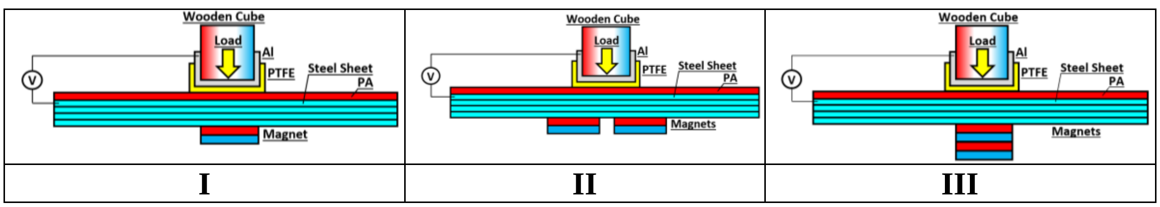


Fig. 3 Arrangements of the permanent magnets for steel sheets.

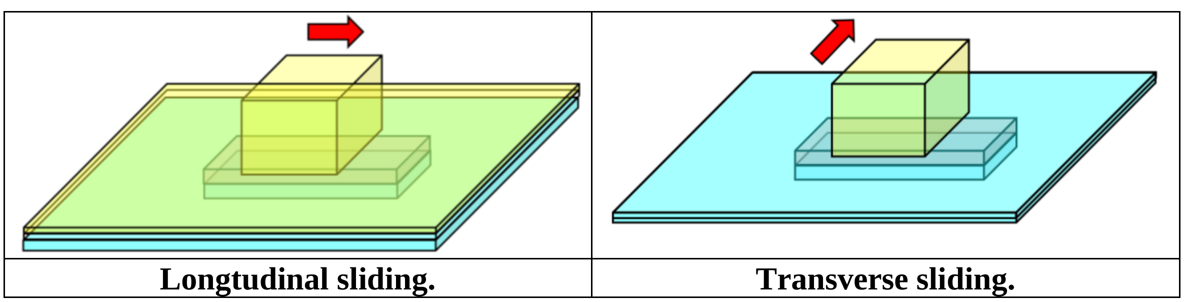


Fig. 4 Direction of sliding relative to the direction of the lines of magnetic field, [1].

The test specimens consisted of polytetrafluoroethylene (PTFE) film representing the first dielectric of 0.04 mm thickness sliding on polyamide (PA) textile of 0.15 mm thickness (the second dielectric). PTFE was adhered to wooden cube of 40 × 40 × 40 mm^3 through Al film of 0.01 mm thickness as the first electrode. While PA was adhered to polypropylene (PP) sheet of 0.1 mm wrapped by two layers of Al film to function as second electrode, Fig. 1. The thickness of PP was controlled by using multiThe voltage difference between the two contacted surfaces was measured by digital voltmeter. Multi layers of PP film were used to control the distance from the

permanent magnets of 60, 120, 180 and 240 mG field strength used in the test. The permanent magnets were installed in two group as illustrated in Fig. 2. The load value was (0.35 N). The test procedure was contact-separation as well as sliding. Steel sheets of thickness ranging from 0.3, 2.6, 4.9 and 7.2 mm were replaced PP sheets, where permanent magnets were installed in three groups as illustrated in Fig. 3. The direction of sliding is shown in Fig. 4.

RESULTS AND DISCUSSION

Figure 5 shows the relationship between voltage generated from contact-separation of PTFE and PA when PP sheet of different thickness is inserted between the permanent magnets and the contact area. The permanent magnet was installed as shown in Fig. 1, first group. It is noticed that voltage slightly increased with the increase of the magnetic field. While the voltage drastically decreased with increasing the thickness of the PP sheet.

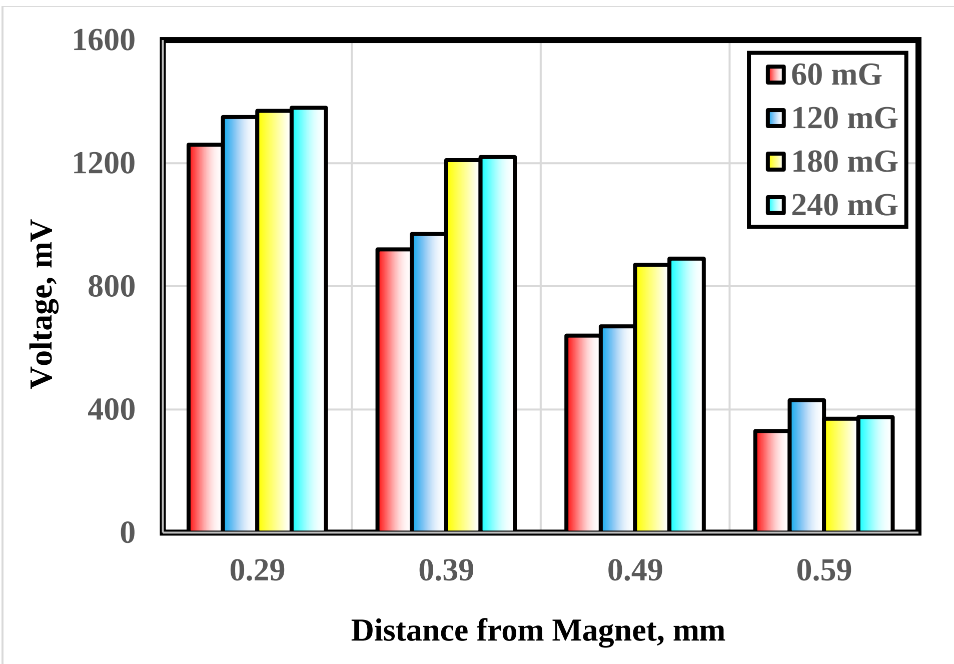


Fig. 5 Voltage difference between PTFE and PA after contact-separation as function of the distance from the permanent magnets of the first group.

When the magnets were installed in the order as shown in Fig. 2, second group, slight voltage decrease was observed, Fig. 6. It seems that the distribution of the permanent magnets relative to the contact area has insignificant effect. It seems that the lines of the magnetic field were concentrated in smaller contact area compared to the magnet distribution in the first group. Because the generated voltage depends on the number of lines of the magnetic field cut by the moving electrode (Al film), it can be seen that the first group of distribution was more efficient.

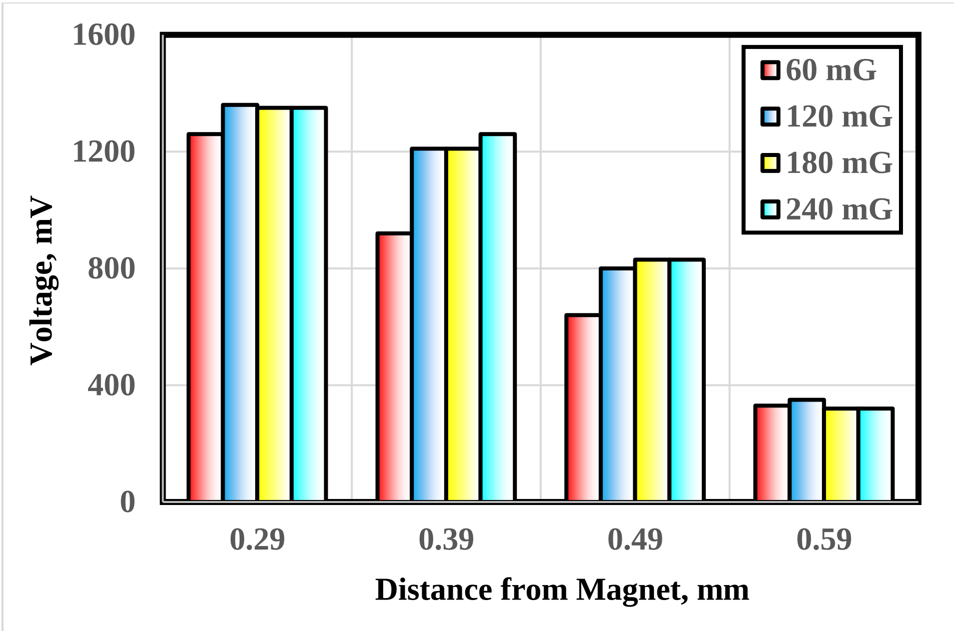


Fig. 6 Voltage difference between PTFE and PA after contact-separation as function of the distance from the permanent magnets of the second group.

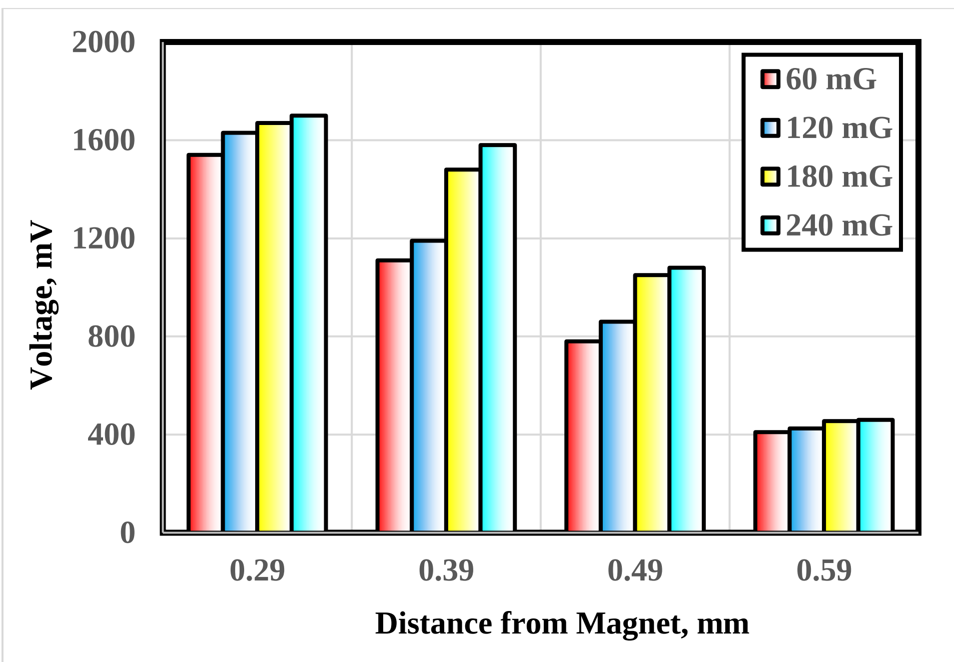


Fig. 7 Voltage difference between PTFE and PA after sliding as function of the distance from the permanent magnets of the first group.

Because magnetic field lines are inversely proportional to distance. This behavior is attributed to the fact that magnetic field lines become larger and larger indicating the decreasing the strength of the magnetic field. Then, the number of magnetic field lines passing through the friction area decreases. The closer the distance between the

magnet and friction area, the stronger the magnetic field will be. It was observed that the field strength decreases as the distance between the magnet and the friction area increases. This can be explained as the number of magnetic field lines passing through the contact area decreases.

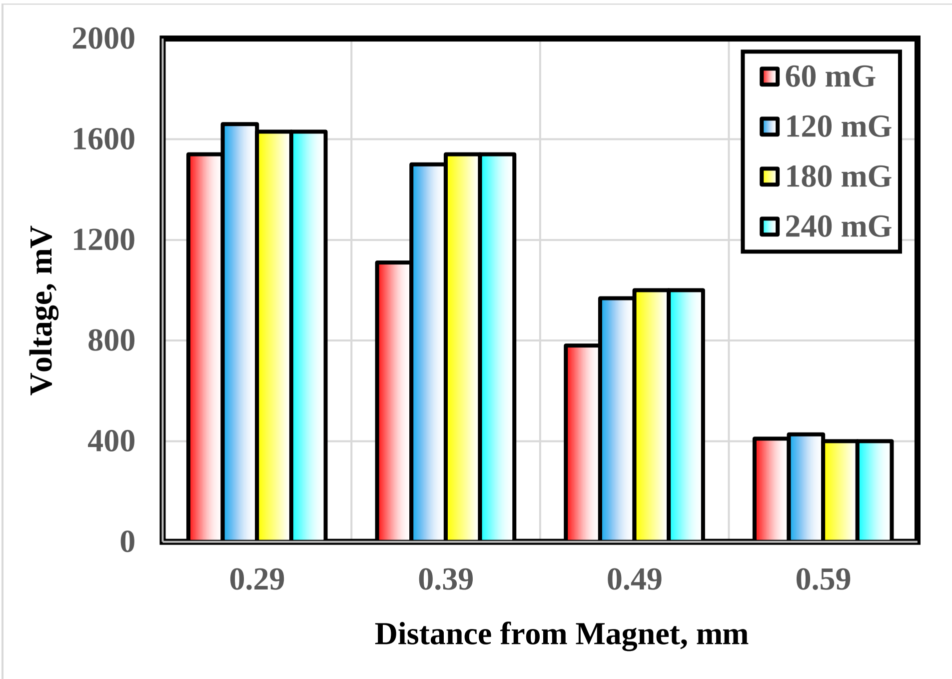


Fig. 8 Voltage difference between PTFE and PA after sliding as function of the distance from the permanent magnets of the second group.

The voltage difference between the contacting surfaces after sliding is illustrated in Figs. 7 and 8 for the first and second groups respectively. Values of voltage displayed relatively higher values than that observed for contact-separation where the highest values were 1380 and 1700 mV at 240 mG magnetic strength for contact-separation and sliding respectively. The arrangement of the magnets displayed insignificant effect on voltage values. The drastic voltage decrease was observed too in sliding condition. According to that observation, it is clearly shown that the voltage values were much influenced by the distance from the friction surface.

The experiments carried out to investigate the effect of replacing the PP sheets of different thicknesses by steel sheets on the generated voltage illustrated that the voltage difference between PTFE and PA at 60 mG magnet strength as function of the thickness of the steel sheet significantly increased with increasing steel thickness for contact-separation, longitudinal and transverse sliding, Fig. 9. It was found that longitudinal sliding displayed the highest voltage values followed by transverse sliding and contact-separation. It seems that longitudinal sliding cut more lines of magnetic field than Increasing the magnetic field strength into 120 mG, Figs. 10 and 11, increased the voltage, where voltage values were 2210 and 2170 for the II and III arrangements illustrated in Fig. 2, respectively.

The enhancement in the values of voltage with increase of the steel sheet is attributed to that the steel sheet redirected the lines of flux of the permanent magnet and provided easier path for the flow of the lines, where they flow out from the pole of the magnet into the steel that concentrated the field lines on the contact area. Based on the experimental observations, the thickness of the steel sheet influences the flow of the lines of the flux. When the thickness is thin, it can hold limited lines of flux. While thicker sheet can hold more lines of flux. Multiple layers of steel can be used to increase its ability to hold more lines of flux instead of travelling through the air. It is thought that steel sheet becomes an extra magnet imposed on the permanent magnet strength. Consequently, the magnetic field strength increased.

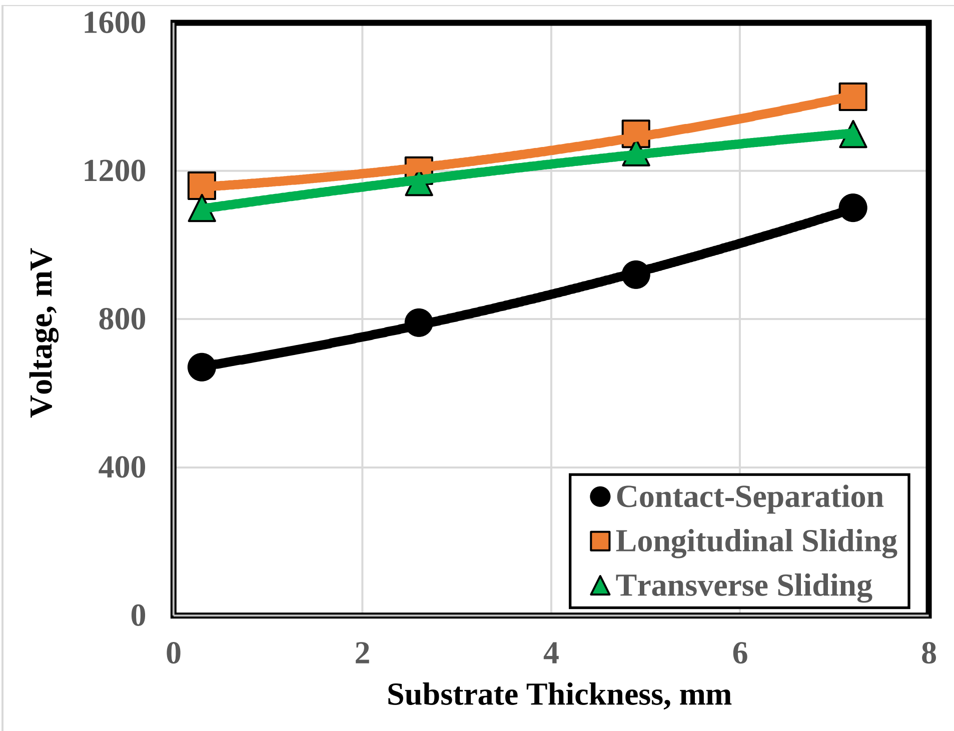


Fig. 9 Voltage difference between PTFE and PA as function of the distance from one permanent magnets (I) when steel sheets replaced PP sheets.

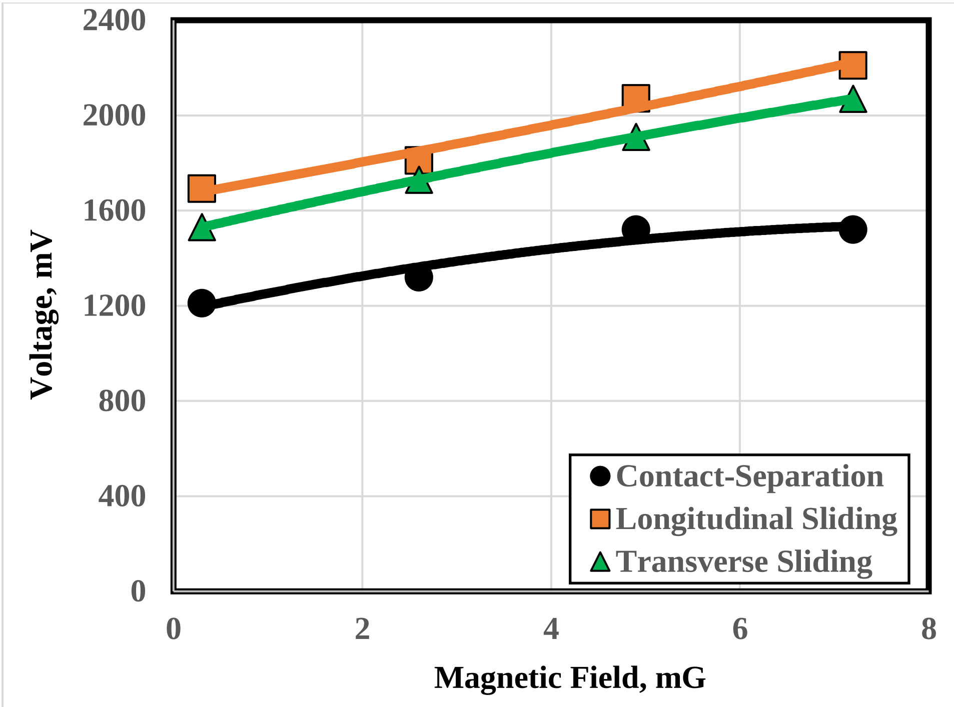


Fig. 10 Voltage difference between PTFE and PA as function of the distance from two permanent magnets (II) when steel sheets replaced PP sheets.

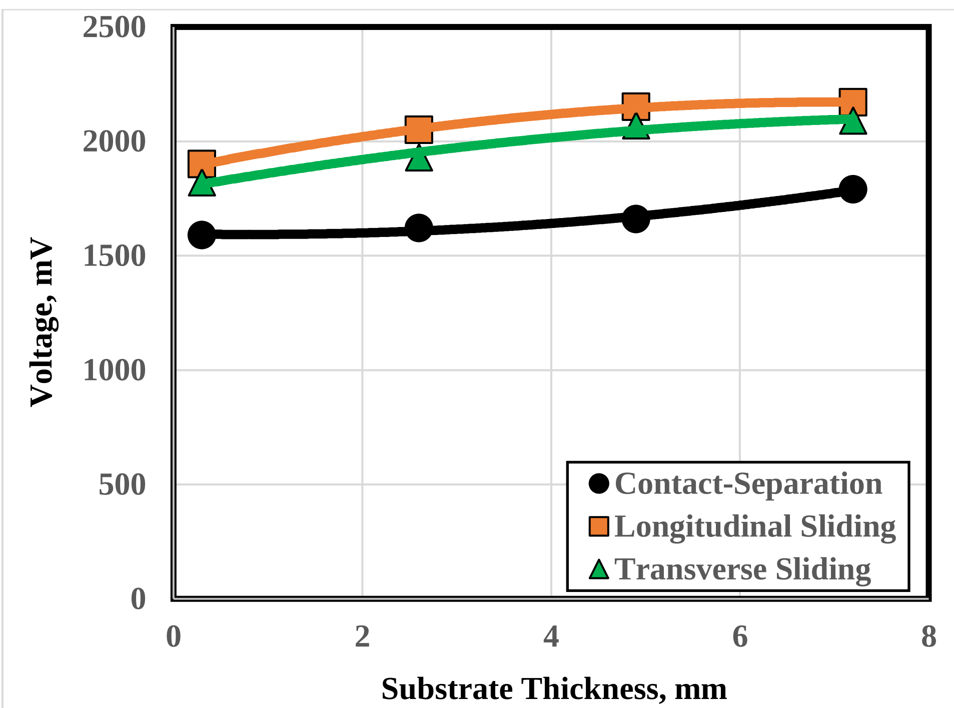


Fig. 11 Voltage difference between PTFE and PA as function of the distance from two permanent magnets (III) when steel sheets replaced PP sheets.

Based on the experimental results it can noticed that PP sheets increased the distance between the magnets and the contact area although they allowed the lines of magnetic field to flow from one pole of the magnet to the other with the same intensity. In contradiction to that, steel sheet redirected the field lines to the contact area. It is proposed to use steel sheet to increase the voltage by the extra magnetic field added to the ESC double layer generated from friction that provides the surface by an electric field.

CONCLUSIONS

1. Voltage slightly increased with the increase of the magnetic field, while drastically decreased with increasing the thickness of the PP sheet.
2. Position of the permanent magnets relative to the contact area has insignificant effect on the generated voltage.
3. Field strength decreases as the distance between the magnet and the friction area increases in the presence of PP sheets.
4. Voltage displayed relatively higher values for sliding than that observed for contact-separation
5. Voltage significantly increased with increasing steel thickness for contact-separation, longitudinal and transverse sliding.
6. Longitudinal sliding displayed higher voltage values than that observed for transverse sliding and contact-separation.
7. It is recommended to replace PP sheets that decreased the magnetic field strength by steel sheets due to their ability to redirecting the field lines to the contact area.

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