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Performance Assessment of Contact Separation Triboelectric Generators (CS-TEGs) under various contact frequencies and electrode layers.

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Abstract: Triboelectric generators (TEGs) are classified as a novel approach for harvesting energy from small-scale mechanical motions. This work is concerned with improving the performance and output energy from contact separation triboelectric generator (CS-TEG) by using different electrodes under variable contact-separation frequencies. Aluminum or Copper layers were proposed as electrodes for PTFE/PVC, PTFE/Kapton, and Kapton/PVC CS – TEGs. Three contact frequencies were applied for the proposed TEGs for each electrode type under the constant contact load and separating distance of 2N and 0.5mm respectively. Aluminum electrodes that were used for Kapton/PVC CS – TEGs under high contact frequency show significantly improved performance of TEG.

Keywords: Triboelectric generators (TEG), friction energy, contact separation mode, PTFE, PVC, and Kapton TEGs.

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تأثير المواد المستخدمة في صناعة الاقطاب الموصلة وكذلك معدل الاتصال والانفصال بين الطبقات العازلة علي اداء المولد الكهربي الاحتكاكي

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المستخلص: تتزايد الجهود البحثية والمحاولات التقنية في الآونة الاخيرة للبحث عن مصادر نظيفة ومتجدده للطاقة وذلك للمساهمة في توفير طاقة بديلة امنة بيئيا ومنخفضة التكاليف وايضا تعتمد علي المصادر الطبيعية والموارد البيئية المتاحة. تعتبر المولدات الكهربية الاحتكاكية (Triboelectric Generators "TEGs") – التي تعتمد علي تحويل الشحنات الكهروستاتيكية الناتجة عن احتكاك المواد المختلفة معا الي طاقة كهربية- من التطبيقات الهندسية الحديثة والتي تهدف الي الاستفادة من الحركات البسيطة لتوليد وتجميع الشحنات الكهربية التي يمكن استخدامها في العديد من التطبيقات الصناعية والطبية. تهدف الدراسة الحالية الي تحسين اداء المولد الكهرو احتكاكي الذي يعتمد علي الية الاتصال والانفصال (Contact-Separation TEG) وذلك من خلال استخدام مواد مختلفة في صناعة الاقطاب الموصلة (Electrodes) مثل النحاس والالومنيوم وايضا الطبقات العازلة مثل PVC، PTFE، Kapton بمعدلات مختلفة لعملية الاتصال والانفصال بين اجزاء المولد. لذلك تم تصميم عدد 6 مولدات كهرو احتكاكية وبناء دائرة كهربية لقياس كميات الطاقة الكهربية الناتجة عن كل منها. اظهرت النتائج تحسن ملحوظ في اداء المولدات التي تكونت من استخدام اقطاب الالومنيوم مع طبقات Kapton/PVC تحت معدلات اتصال وانفصال مرتفعة (3Hz) مقارنة بالمولدات الأخرى، مما يعزز التوصية باستخدام هذه المواد في صناعة المولدات الكهرو احتكاكية التي تعتمد في عملها علي الية الاتصال والانفصال مثل قطرات المطر وحركة الاشخاص اليومية علي الطرقات وغيرها من الحركات الميكانيكية البسيطة.

الكلمات المفتاحية: المولدات الكهربية الاحتكاكية TEGs ، طاقة الاحتكاك، ميكانيزم الاتصال والانفصال C-S mode، البوليمرات المولدة للطاقة

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1. INTRODUCTION

In recent years, looking for clean and renewable energies has remarkably increased and occupied scientists' minds and attention. Energy harvesting techniques from small-scale mechanical actions such as human daily motion, raindrops, and low-vibration movements were introduced as a novel energy solution (Nguyen, et al. 2023). With the increasing popularity of portable and efficient electronic devices, like those utilized on the Internet of Things (IoT), the demand for consistent, reliable, and mobile power sources has become a pressing concern (Raj & Steingart 2018; Xu, Song & Han 2021). This has led to the exploration of energy harvesting methods as a feasible solution for powering these types of devices (Zhang et al. 2021). Triboelectric generators (TEGs) are energy harvesting devices (Chu & Majumdar 2012; Maria et al. 2018; Ibrahem 2022) that can convert mechanical energy from various sources into electrical energy using the triboelectric effect. TEGs operate based on the coupling of triboelectric charges and electrostatic induction, which allows them to generate an output voltage and current (Zhou, Wang, Liu & Zhong 2020). TEGs can operate in several fundamental modes (Niu 2013; Niu & Wang 2015); vertical contact-separation mode - in this mode- the two materials in the TEG move vertically relative to each other, creating a contact and separation cycle (Luo, Jianjun, Wang & Zhong. 2020). This mode is typically used in applications where the two materials are fixed to a substrate and experience a periodic mechanical force, such as in footwear or ocean wave energy harvesting (Luo, Gao & Wang, 2021; Wu 2018). The resulting triboelectric charges generated during the contact and separation cycle are collected by *electrodes and used to generate electrical power. The present work is based on the contact-separation mode.*

Lateral sliding mode- in this mode; two materials in the TEG slide laterally relative to each other, generating triboelectric charges through friction. This mode is typically used in applications where the two materials experience a sliding or rubbing motion, such as touchscreens or self-powered sensors. The triboelectric charges are collected by electrodes and used to generate electrical power (Wang et al. 2016).

Single-electrode mode: In this mode, a single electrode is used to collect the triboelectric charges generated by the contact and separation of two materials (Fan et al. 2012). The single-electrode mode is used in applications where only one electrode is accessible, such as in wearable electronics. This mode can also be used to reduce the complexity and cost of TEGs by eliminating the need for multiple electrodes.

Freestanding mode: In this mode, the two materials in the TEG are not fixed to a substrate, allowing them to move freely and generate triboelectric charges through vibrations or other mechanical motions. This mode is typically used in applications where the TEG must be sensitive to small mechanical motions, such as in self-powered sensors or environmental monitoring. The freestanding mode can also be combined with other modes to enhance the performance of TENGs (Wang et al. 2015).

2. EXPERIMENTS WORK

To investigate the performance of a triboelectric generator based on contact separation mode, test samples were designed in the form of a triboelectric generator that consists of different non-conductor layers as well as different electrode layers. The electrode layers that are used for this work are aluminum or copper film in the form of rectangular layer (12mm x 7mm) with a 0.2mm thickness. Three different triboelectric layers were used for this design; Kapton, PTFE, and PVC in a rectangular form (10mm x 5mm) with a 0.5mm thickness. Triboelectric generators based on contact separation mode are shown in Fig.1. Separating distance of 0.5mm between the contact layers allows the electrons that generate from contact between different materials to transfer from one electrode to another. The present design for TEG is also concerned with the frequency of contact and separation between layers, which also affect the amount of output voltage.

To evaluate the TEGs performance based on different electrodes and different nonconductors; electrical circuits were designed using external load with 10 Ω and 16mf capacitance. The output voltage was measured instantaneously through millimeters under three values of contact separation frequencies 1Hz, 2Hz, and 3Hz.

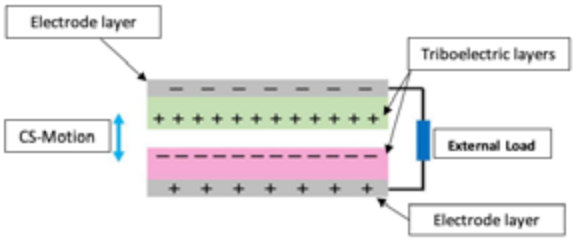

Fig.1 Contact-Separation TEG

3. RESULTS AND DISCUSSION

The triboelectric performance of the proposed contact-separation TEG was investigated through generated voltage. After building Triboelectric generators from the proposed materials for the three models each generator was subjected to repeated press and release of constant load 2N for 60 seconds then the output voltage was measured continuously, each type of CS-TEG was tested three times, and the average result was recorded.

3.1 Effect of aluminum electrodes

Figure 2 shows the output values of the generated voltage on the vertical axis during the time of the test for different contact separation frequencies for CS-TEG that consist of Kapton and PTFE as triboelectric layers and Aluminum Electrode, the average values of the electric voltage from this generator increases with time under high contact-separation frequencies. The output voltage exceeds 104 mV after 30 sec. of the 3Hz contact separation mechanism. The generated voltage for other frequencies also increases with time. In comparison with Figure 3 which explains the effect of using other triboelectric layers (PVC) with Kapton on the same Aluminum electrode; the output voltage increases at high frequencies with time, but the overall performance slightly decreases to 75mV. Figure 4 shows the effect of an aluminum electrode on the generated voltage of PTFE/ PVC CS-TEG, the output voltage increases under high frequency to 68mV, low frequencies contact separation shows low values of the generated voltage in comparison with other types of triboelectric layers on the same aluminum electrode.

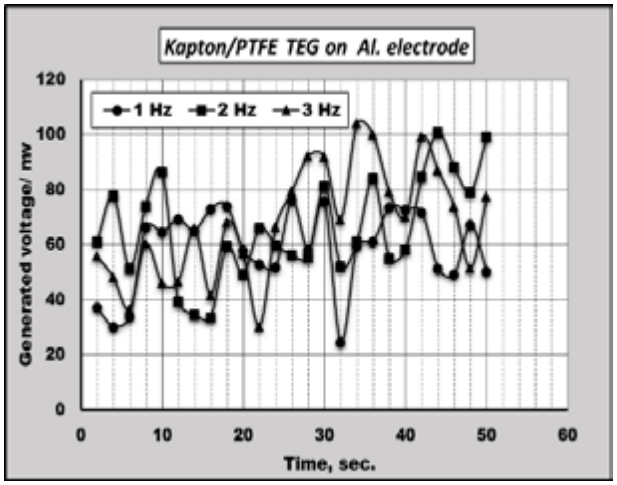

Fig.2 Effect of Al. electrode on the output voltage of Kapton/PTFE CS-TEG

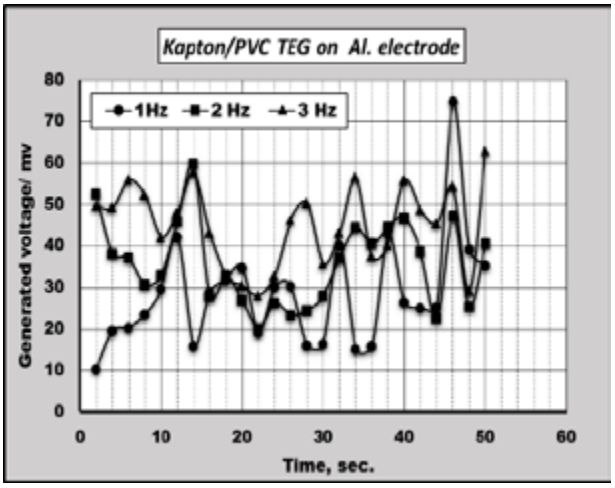

Fig.3 Effect of Al. electrode on the output voltage of Kapton/PVC CS-TEG

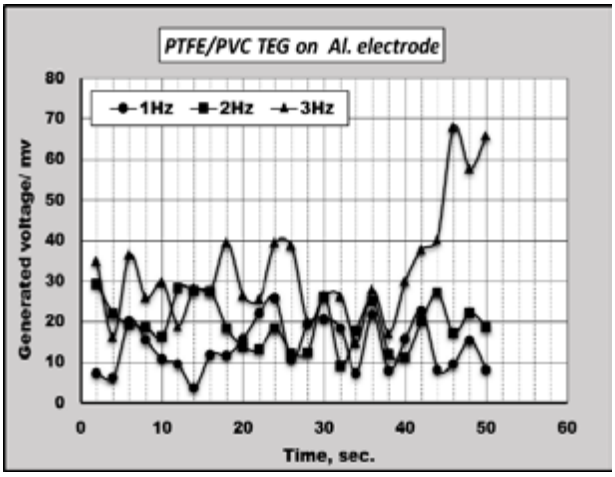

Fig.4 Effect of Al. electrode on the output voltage of PTFE/ PVC CS-TEG

3.2 Effect of copper electrodes

To obtain the effect of the copper electrode on the generated energy from CS-TEG, a single-layer Kapton/ PTFE TEG was tested under different contact separation frequencies. Figure 5 shows that the value of the output voltage slightly increases with time, as well as contact frequency. At a contact separation frequency of 3 Hz, the output voltage was achieved at 43mV after 42 sec. A triboelectric generator that consists of Kapton/PVC dielectric layers on a copper electrode. Figure 6 shows a small rise in voltage compared with Kapton/PTFE CS-TEG on the same electrodes. Figure 7 explains the effect of using PTFE and PVC as triboelectric layers for CS-TEG with copper electrode, as shown in the figure; the generated voltage remains constant between 10 and 25mV for low and medium frequencies, but remarkably increases to 45mV after 50 seconds at high

contact separation frequencies. The overall discussion of the observed results shows that of aluminum electrodes increases the output voltage of CS-TEG in comparison with that of copper electrodes; beside the TEG that consists of Kapton /PTFE dielectric layers shows remarkably improvement of the generated voltage which recommended these TEG to be used for industrial and medical applications (Yuan et al. 2022).

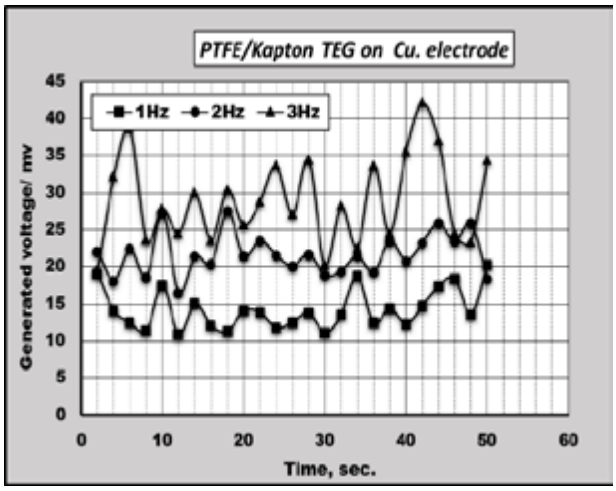

Fig.5 Effect of Cu. electrode on the output voltage of Kapton/PTFE CS-TEG

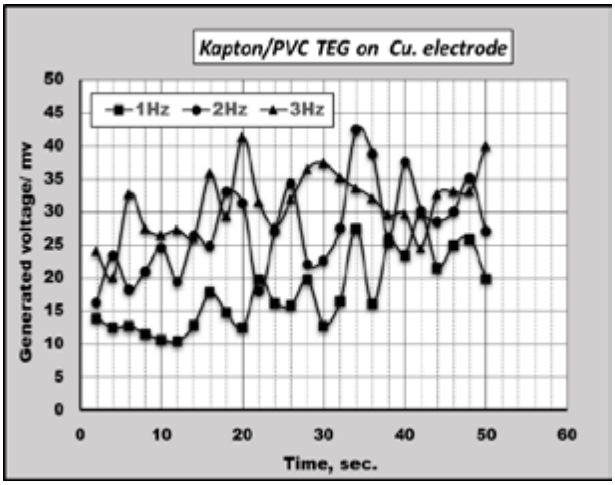

Fig.6 Effect of Cu. electrode on the output voltage of Kapton/PVC CS-TEG

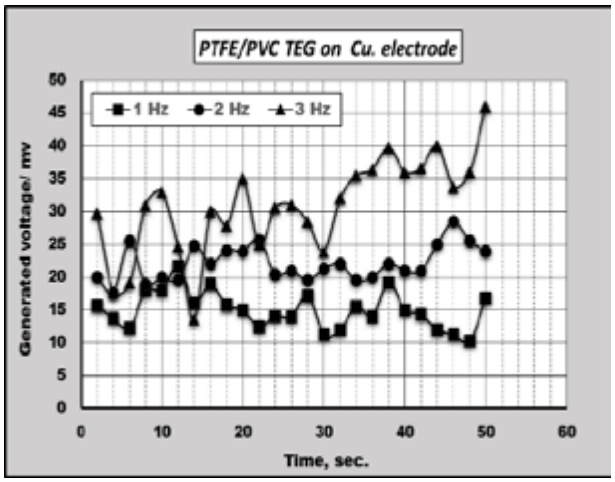

Fig.7 Effect of Cu. electrode on the output voltage of PTFE/ PVC CS-TEG

Table 1: Summary & comparison of the study results

Triboelectric layer for TEG	Cont. Freq. & Electrode Type (mv after 50 sec.)						Max. output
	Low freq. 1Hz		**Med. Freq. 2Hz**		**High freq. 3Hz**		
	AL	Cu	AL	Cu	AL	Cu	
Kapton/PTFE	38	27	40	20	62	40	**62mv**. On Al. under 3Hz
PTFE/PVC	8	24	20	18	65	46	**65mv.** On Al. under 3Hz
Kapton/PVC	45	18	100	20	80	34	**100mv.** On Al. under 2Hz

4. CONCLUSION

a. The triboelectric performance of TEG consists of Kapton and PTFE as triboelectric layers significantly enhanced by means of aluminum film as electrodes for electron transfer.

b. TEG that consists of Kapton/PTFE on AL electrodes shows high output values of voltage from 80 to 100 mv under high contact frequency after 50 sec. also, the generated voltage decreases under low contact separation frequency.

c. The use of PTFE/PVC as triboelectric layers for TEG on AL electrodes shows low values of output voltage in comparison with the other types of TEG in this study.

d. Using copper film as an electrode layer for TEGs that consist of Kapton/PTFE triboelectric layers slightly increases the output voltage to 45mv under high contact separation frequencies after 50 sec.

e. For all proposed TEGs the generated voltage increases with an increase in contact separation frequency.

f. It can be recommended that the proposed TEGs be a sustainable source of electrical energy on the roads that afford continuous contact-separation mechanisms.

Future work: a wide range of engineering materials will be proposed as triboelectric layers for different contact mechanisms to enhance the generated energy gained by TEG.

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