

Analysis of Triboelectric Tile for Energy Harvesting from Walking

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Abstract- Harvesting mechanical energy from human walking by triboelectric tile is an effective approach for a sustainable, maintenance free, and green power source. The triboelectric tile is capable of harvesting vibrational energy. In this paper, a simplified model of triboelectric tile system using simple coupling of commercial polyvinyl fluoride (PVDF) with a thin copper film is presented. Based on the simplified model, Real-time output characteristics of triboelectric tile at different values of resistance are derived. The output characteristics of triboelectric tile are validated with the existing literature.

Keywords: Triboelectric mechanism, Energy harvesting, Contact electrification, Electrostatic induction.

I. INTRODUCTION

Now a day, the tremendous increase in popularity of small handheld electronics like cell phones, robots, navigation, motion and biological sensors require very small power. These small electronics need a battery to operate, but sometimes it is difficult to replace/charge the battery. Energy harvesting devices have emerged as one of the most promising solutions to serve smaller energy needs, e.g. powering low power electronic devices and wireless sensors. Researchers have used piezoelectric, electromagnetic and electrostatic mechanisms to harvest mechanical energy from vibrating and pressure available in the environment. In the past few years, the triboelectric mechanism has also been used for harvesting mechanical energy.

II. LITERATURE REVIEW

The triboelectric mechanism is based on the principles of contact electrification and electrostatic induction. Feng-Ru Fan¹ (2012) published first paper on triboelectric energy harvesting. They fabricated the triboelectric energy harvester (TEH) by stacking two polymer sheets made of materials having distinctly different triboelectric characteristics, with metal films deposited on the top and bottom of the assembled structure. Surface topography plays a vital role as it decides the effective contact area between the triboelectric layers. Fan et. al.² demonstrated that patterned films have a

significantly higher performance than unpatterned films. The patterning of triboelectric layers is known to improve the performance of triboelectric nanogenerators (TEG). Guang Zhu et. al.³ (2013) fabricated a triboelectric nanogenerator (TEG) that has not only much-simplified structure but also substantially higher power output enabled by nanoparticle-based surface modification. Simiao Niu et. al.⁴ developed a theoretical model for contact-mode TEG and experiments were performed to verify these theoretical results.

Danial Sharifi Kia et. al.⁵ have been performed on the systematical numerical simulations on the adhesive contact behavior of the macro/nanostructures at the TEG interface. An interaction potential has been used to represent the adhesive interactions while surface deformations are coupled using half-space Green's function. Simiao Niu et. al.⁶ demonstrated the first equivalent circuit model was proposed and the first integrated simulator for triboelectric nanogenerator systems is built from this equivalent circuit model and validated through comparison with the analytical results. Mohammad S. Rasel et. al.⁷ demonstrated a human skin based triboelectric generator consisting of human skin, a polydimethylsiloxane (PDMS) film with micro-structured surface, a Cu electrode connected with a ground, and Polyurethane (PU) as the substrate material. In this paper, a triboelectric tile is proposed to harvest the energy from walking. A simplified model of tile has been analyzed, and results have been compared with published one.

III. MATHEMATICAL MODELLING

Triboelectric tile is shown in figure 1. When people walk on the tile, then it vibrates. During the vibration PVDF (triboelectric) layer makes intermittent contact with a bottom copper layer that results in an electrical voltage difference between both layers. A simplified model of the tile is shown in figure 2.

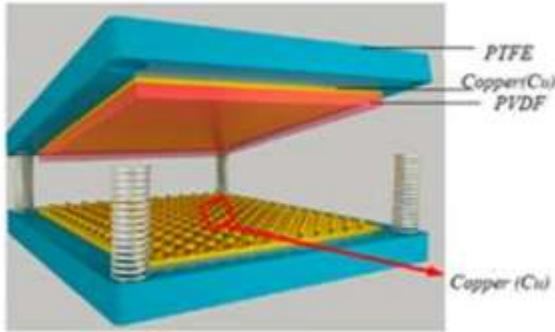


Figure 1: Triboelectric tile

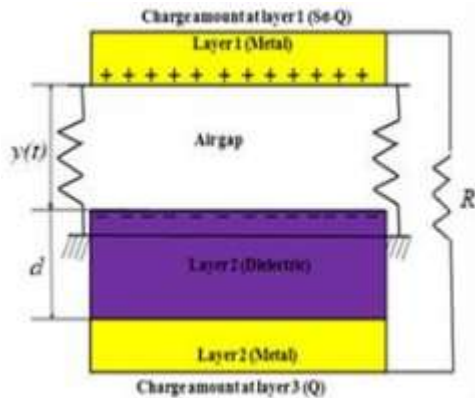


Figure 2: Simplified Model of tile

The inner surfaces of these two layers will have opposite static charges (tribocharges) with an equal amount and opposite charge density (σ), as a result of contact electrification. When the two-layers start to separate from each other with increasing separation a potential difference (V) between the two electrodes will be induced.

For the insulator (layer 2) it is reasonable to assume that the tribocharges are uniformly distributed at the surface with negligible decay. So the total charge in layer 1 has two parts: one is triboelectric ($S\sigma$) charge, the other is the transferred charge between the two electrodes ($-Q$). This charge flows through an

external resistance (R). Thus, the total charge in layer 1 is ($S\sigma - Q$).

From the Gauss theorem, the electric field strength in dielectric layer and air gap is given by:

$$E_{air} = -\frac{Q}{S\epsilon_0\epsilon_{r1}}$$

Inside the air gap:

$$E_{air} = -\frac{Q}{S} + \sigma(t)$$

The voltage between the two electrodes can be given by:

$$V = E_1d + E_{air}y(t)$$

Substituting equation (1) and (2) into equation (3)

$$V = -\frac{Q}{S\epsilon_0}(d_0 + y(t)) + \frac{\sigma y(t)}{\epsilon_0}$$

The output properties can be estimated by combining equation (4) with Ohm's law:

$$V = IR = R\frac{dQ}{dt}$$

Merging equation (4) and equation (5)

$$R\frac{dQ}{dt} = -\frac{Q}{S\epsilon_0}(d_0 + y(t)) + \frac{\sigma y(t)}{\epsilon_0}$$

Then equation (6) can be solved analytically as

$$Q(t) = \sigma S - \sigma S \exp\left[-\int_0^t \frac{(d_0 + y(t))}{RS\epsilon_0} dt\right] - \frac{\sigma d_0}{R\epsilon_0}$$

$$\exp\left[-\int_0^t \frac{(d_0 + y(t))}{RS\epsilon_0} dt\right] \int_0^t \exp\left[\int_0^t \frac{(d_0 + y(t))}{RS\epsilon_0} dt\right] dt$$

Where,

$$Q = 0 \quad \text{at} \quad t = 0$$

$$y(t) = vt, \quad v \text{ is constant velocity.}$$

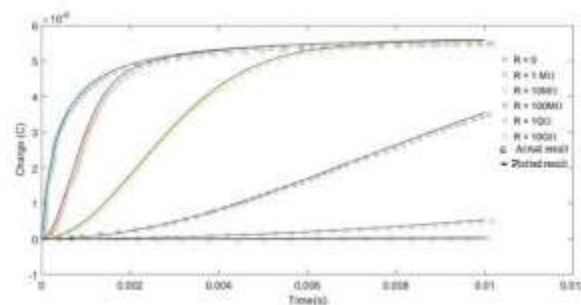


Figure 3: Real Time transferred charge time relationships at different load resistance

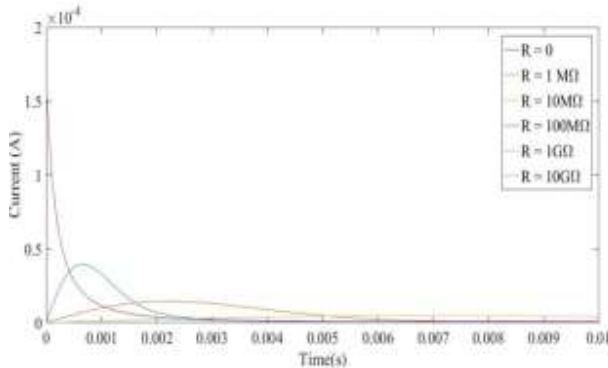


Figure 4: Real Time current - time relationships at different load resistances

Table - 1: Parameters utilized in the constant velocity theoretical calculation [8]

Dielectric	$d = 125\mu\text{m}$, $\epsilon_r = 3.4$
Area size of the Dielectrics (S)	$S = 58.0644 * 10^{-4} \text{ m}^2$
Tribo-charge surface density (σ)	$\sigma = 10\mu\text{Cm}^{-2}$
Maximum separation distance (y_{max})	$y_{\text{max}} = 0.001 \text{ m}$
Average velocity (v)	$v = 0.1 \text{ ms}^{-1}$

IV. RESULT AND CONCLUSION

Now a Based on the analytical Modeling, a code is developed in MATLAB. The top plate of the tile is vibrated with a constant average velocity of 0.1 m/s and generated charge, current and voltage are calculated from equation (7) at different values of resistance. Geometric and material properties are given in Table 1. The calculated charge has been compared with existing results8 as shown in figure 3.

Figure depicts that calculate charge matches well with published results9, 10.

Further it can be noted that, for a relatively small R, Q can still get its saturation value when the top electrode stops moving (t = 10 ms). However, when R is more than 100 MΩ, at t = 10 ms, the charge cannot get saturated due to the limit charge transfer

rate by the resistor, resulting in the unstopped charge transfer from Metal 1 to Metal 2 after t = 10 ms. Therefore, the current is a peak-shape when R is small while the current continues increasing during the plate movement when R is large. The voltage has the same profile with the current, but a different trend in magnitude. The peak of current and voltage on different values of resistance are displayed in Fig. 4-5.

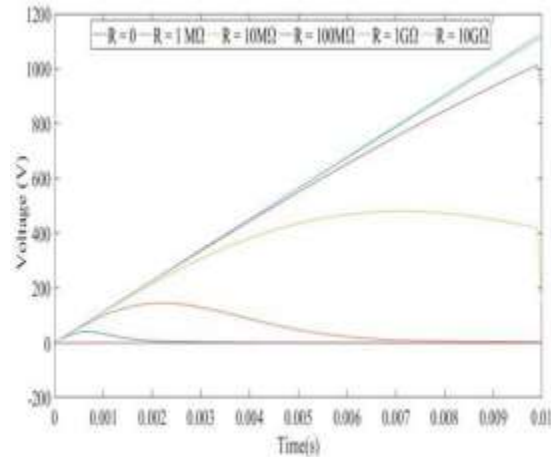


Figure 5: Real-time voltage - time relationship at different

Conclusion

In summary, a simplified model for triboelectric tile is presented in this work. Tile has been modeled under theoretical contact mode of the triboelectric harvester. An explicit expression for the output charge has been presented for a triboelectric tile with an external load of resistance. Based on a simplified model, the electrical output achieved a peak voltage of 1129 V and current of 15.9 μA. The simplified model would be a potent tool to guide the design of the device structure and selection of materials for triboelectric tile. Future works will concentrate on modeling and simulating an optimal triboelectric tile by selecting optimal material pairs from triboelectric series.

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