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Development of Hybrid Contact Mode Triboelectric and Electromagnetic Energy Harvester

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***Abstract:** The aim of this study is to harvest sufficient amount of power to power up the low power sensor node by using vibration mechanism. The hybrid triboelectric (TENG) and electromagnetic (EMG) nanogenerator is needed to sustain the unlimited usage of energy.The testing for the TENG consisting of varying the air gap distance between the dielectric and the electrode, surface area of the triboelectric layers into a large and smaller surface. Whilst for the EMG, the testing is varying the number of coil turns for each big and small magnet size.At the frequency of 11Hz with the acceleration of* $0.69ms^{-2}$*, the optimum opened-circuit voltage,* V_{OC} *produced for TENG is 3.97V while for the EMG is 1.85V. The hybrid nanogenerator produced 2.071mW of power with a resistance of* $1k\Omega$*. The power density obtained from the prototype is* $2.6059Wm^{-3}$ *which is enough to power up the low power sensor node.*

***Keywords:** TENG, Sensor Node, Energy Harvester*

I. INTRODUCTION

Energy harvester is the process of storing energy for a certain time and to be used in wide applications such as medical equipment, electronic devices and other devices. Typically, gadgets, materials or sensors used AC control supplies or batteries to harvest electrical voltages and streams such as piezoelectric generators (PZT) [1], solar powered photograph voltaic cells [2], thermo electric generators (TEGs) [3] and electromagnetic generators [4]. These materials produce an extensive variety of yield voltage and streams [5]. Triboelectric commonly being labeled as a bad side effects of the daily life due to past incidents, i.e. car explosions at petrol stations, the electrostatic induction can be caused by so many reasons such as the rubbing of a silk with a ruler will attract small pieces of papers and also the building up charges in the human bodies through walking or running and can be transferred to another person when the skin comes into contact and causes the tingling sensation. For many years triboelectrification has been neglected because of its dark incidents, but then scientists and fellow researchers have ta from the process, which results in the development of triboelectric nanogenerators and since then lots of efforts have been done in order to improve the output for the betterment of the world's energy sustainability.

The electromagnetic generator in the other hand has been used widely in the industry to reduce the cost by lowering the industrial electricity usage, with just a very strong magnet moves back and forth in a solenoid wires (copper coils), ken the initiatives to study the benefits that can be gained electricity is produced. This application was first discovered by Michael Faraday when he moved a bar magnet through an electric curl. He saw an adjustment in voltage of the circuit. He later reasoned the elements that could impact the electromagnetic acceptance as the quantity of curls, the quality of the magnet, the changing attractive fields and the speed of relative movement between loop and magnet. Noteworthy points made was, the higher the number of coil turns and the faster the relative motion of the magnet with the coil turns, the higher the incited voltage will be. Theoretically, by combining the triboelectric and the electromagnetic into one nanogenerator, the output will be better than ever. The need of this is what leads to this project which is an extension to study the characteristics of triboelectric and electromagnetic from Li et al [6] works. Their work was creating a hybridized nanogenerator of triboelectric and electromagnetic nanogenerator using the contact mode and it was a handmade product. Developed a new prototype to further improvise the triboelectric and electromagnetic output by further investigate the factors affecting the output, experiments were carried out to find out what can boost the results. The expected outcome of the product was aimed to be a low power output with the range of 1 mW to 4 mW which is enough to power up a low power sensor nodedue to the past research states that only 100µW is needed to operate a low power wireless sensor node[7].

II. EXPERIMENTAL SETUP

There is a few electrode arrangements and this prototype uses dielectric-to-electrode type with tapping mode. It consists of two sections as shown in Fig. 1, the top hanging part and the base bottom part. At the top part a magnet is hanging and being supported by three supporting springs, underneath the magnet a few films are attached in the order of Kapton film, Copper film which functions as an electrode and lastly the system's dielectric layer, Polytetrafluoroethylene (PTFE).

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The base part houses copper coils and two films on top of it, first the Kapton film and the Copper film next. When the whole prototype vibrates, the PTFE film from the top part will constantly tap the Copper film which explains the dielectric-to-electrode type, by PTFE being the dielectric and the Copper being the electrode. At the same time, the magnet will move towards and away from the copper coils and this theoretically creates electromotive force (e.m.f.).

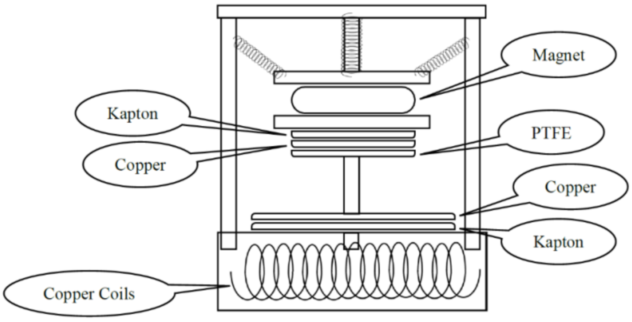

Fig. 1 Schematic Diagram of the Prototype

Testing Setup

The experiment was done inside the lab by using few reliable equipment, the main usage of the equipment is to give consistent input into the prototype in term of vibration motion in a more accurate adjustable frequency and acceleration.

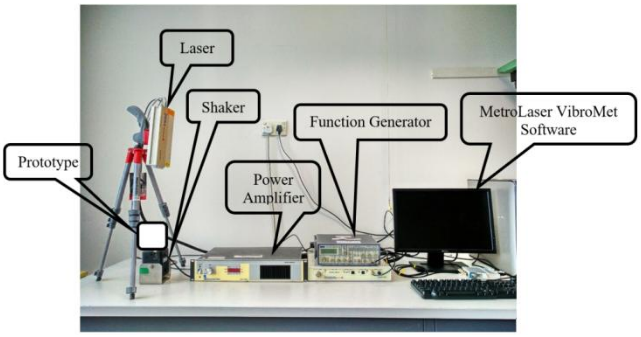

Fig. 2 Testing Setup of the Experiment

Figure 2 shows the setup of the experiment. The software inside the computer called, “Metro Laser Vibro Met” is used to obtain the reading received by the laser sensor, mainly the frequency and the acceleration of the prototype. The laser is fixed to be right above the prototype and is used to determine the frequency and the acceleration of the prototype. The prototype was mounted on the shaker and the Function Generator can be used to control and adjust the frequency of the shaker in order to find the prototype’s resonance frequency. Once the shaker’s frequency has been set, the laser will be used to identify the prototype’s acceleration since in the industry, 0.25g is set to be a safe limit for a working machine. Power Amplifier was used to control and adjust the acceleration of the shaker itself. Next, the same resonance frequency and acceleration was fixated throughout the experiment to achieve results with consistent input.

Testing the Parameters

To test the triboelectric part of the prototype, several factors were chosen, and the factors are the surface area and the air gap distance between tapping distance. There were two experiments involved, one to check the effect done on voltage by the triboelectric surface area and the one to check the effect done on voltage by the air gap distance between the tapping distances. Figure 3 shows the inner side between the triboelectric layers.

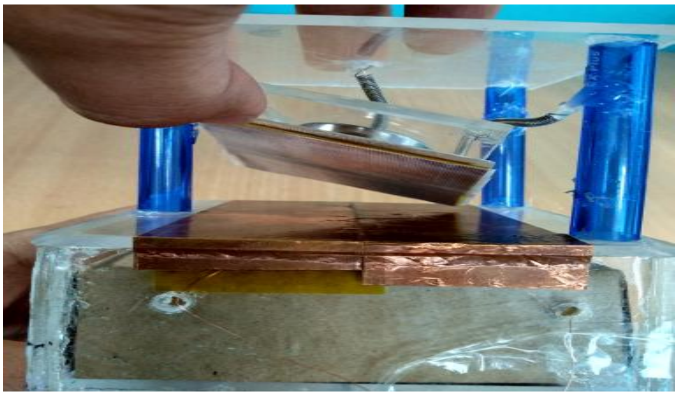

Fig. 3 Inner side between triboelectric layers

Based on the factors chosen, the testing was conducted while varying the parameters. The area of the surface is 3600 mm^2 for bigger area and 1600 mm^2 for smaller area whilst the distance of air gap is 5 mm to 25 mm in the multiple of five. First and foremost, the output voltage was obtained by varying the distance of air gap on the big surface area, then the same method applied to the smaller area. The results obtained are for both areas with varied length of air gap.

On electromagnetic part, the factors chosen were the magnet strength and the number of coil turns to study the effect of output voltage produced by varying those factors. There were two testing conducted, one to check the effect of magnet strength on output voltage and another one was to check the effect of the number of coil turns on the output voltage. Figure 4 and Fig.5 show the shape of the coil turns and the relative magnet sizes respectively.

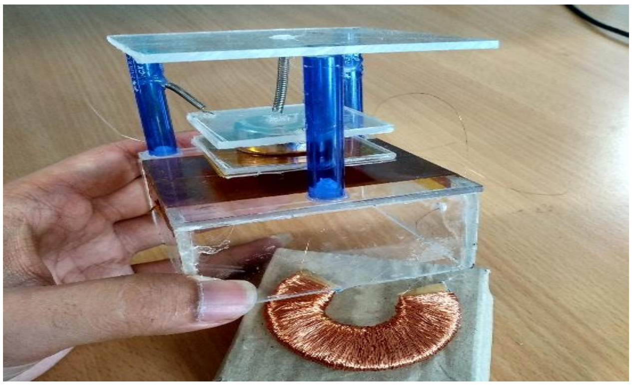

Fig. 4 Coil turns in ‘O’ shape

Fig. 5 Magnet Sizes

Based from the factors chosen as the parameter, there are two types of magnet, Ø25 x 8mm for smaller magnet and Ø30 x 8mm for bigger magnet as shown in Fig. 5. The testing was conducted by varying the number of coil turns from Fig. 4 from 200, 500, 1000, 1600 to 2303 turns on both magnet sizes to obtain the open circuit output voltage. The results obtained were from both magnet sizes with varied number of coil turns.

III. RESULTS AND DISCUSSIONS

Working Mechanism

Based on the working mechanism of the prototype in Fig. 6, there are four stages of load work. First, the top part holds by the spring of tapping mechanism makes a contact with the bottom part. At this stage, the triboelectric charges produced on the surface due to its difference of polarity. No electron flows between the TENG and EMG. Then, the top part makes a gap in between and the electron started to flow. This is because the electrostatic induction produced output voltage and current from the triboelectric. On the third stage, the electron changes through coil and the magnet, the EMG can produce an output voltage and current. The electron flows from TENG and EMG can flow till it reaches to maximum. Lastly, the reversed current produced when the top part came into a contact the bottom part and generates the alternating current in both nanogenerators.

Fig. 6 Completed prototype

Parameters Results

The expected outcome of the triboelectric part supposedly shows that the larger the surface area and the longer the length of air gap, it will produce the higher output voltage. The conclusion can be drawn same for electromagnetic part, the stronger the magnet with greater number of coil turns will produce much more higher output voltage. Table 1 shows the experimental result based on the surface area and air gap distance.

Table. 1 Effect of surface area and air gap distance on output voltage

Surface area (mm^2)	Distance (mm)	Output voltage (V_{oc})
Small Area (1600)	5	1.432
	10	1.661
	15	2.614
	20	1.853
	25	1.612
Big Area (3600)	5	2.549
	10	2.985
	15	3.743
	20	3.97
	25	2.534

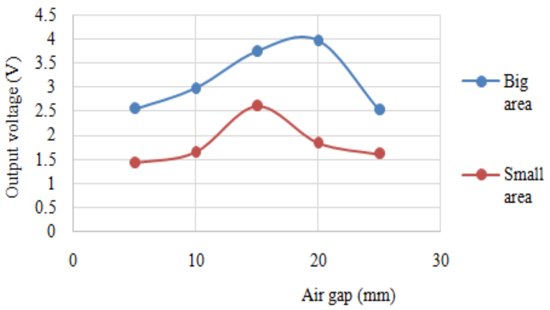

Fig. 7 Comparison between the effect of surface area and distance of air gap

Bigger area with a longer distance of air gap produced higher output voltage than smaller area with longer distance of air gap. This result from Fig. 7shows that the longer distance of air gap will produce the higher output voltage. This was shown in previous study about the air gap distance stated that the longer the distance, it will produce higher voltage [8]. The value increased gradually from 5 mm to 15mm for smaller area and 5 mm to 20 mm for bigger area. This shows that the optimum distance of air gap should be ranging around 15 mm to 20 mm.

The effect of magnet strength and number of coil turns on the output voltage is given in Table 2. From the Fig. 8it is shown that a bigger magnet with a greater number of coil turns have higher output voltage compared to smaller magnet with greater number of coil turns. This result shows that the higher number of coil turns and the stronger magnet Will produce the higher output voltage.

The voltage increased gradually when the higher number of coil turns paired with a stronger magnet which evidently shows that the stronger magnet will produce a better output. This was shown in previous study about the number of coil turns stated that the greater number of turns will produce higher voltage [9].

As stated in the above statement, stronger magnet with larger number of coil turns will produce more output voltage.

Table. 2 Effect of magnet strength and number of coil turns on output voltage

Magnets' size (mm)	No. of coil turns (n)	Output voltage (V_{oc})
Small Magnet (Ø25 x 8mm)	200	0.067
	500	0.181
	1000	0.462
	1600	0.875
	2303	0.964
Big Magnet (Ø30 x 8mm)	200	0.386
	500	0.944
	1000	1.215
	1600	1.756
	2303	1.85

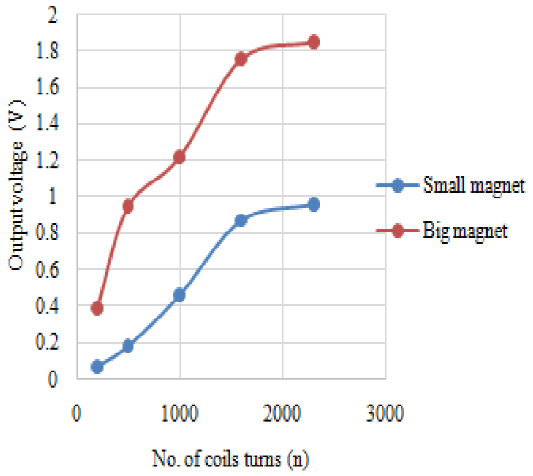

Fig. 8 Comparison between the effect of strength of magnet and number of coil turns

Power Results

Figure 9 shows the varied values of load resistance with its corresponding voltage and power values. Theoretically, the optimum power occurred when the load resistance is equivalent with the internal resistance of the source [10]. Thus, the resistance of this prototype is 1kΩ for an optimum power of 2.071mW from Table 3.

Table. 3 Effect of resistance on power.

Resistance (Ω)	Voltage (V)	Power (mW)
0.2	0	0
100	0.255	0.650
300	0.527	0.926
500	0.864	1.493
800	1.146	1.642
1000	**1.439**	**2.071**
2000	1.901	1.807
5000	2.046	0.837
10 000	2.874	0.826
40 000	4.811	0.579
60 000	3.977	0.264
100 000	3.861	0.149
200 000	3.343	0.056

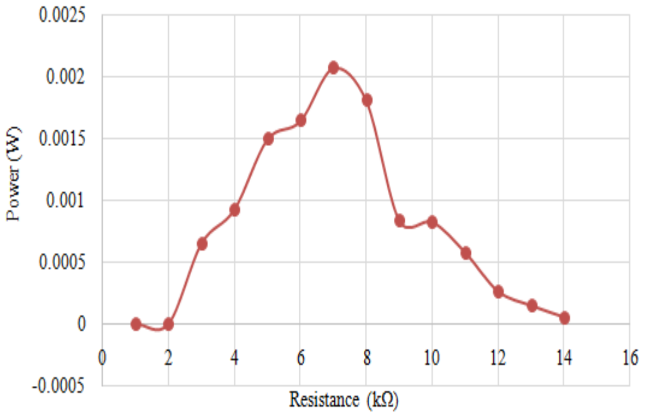

Fig. 9 Effect of resistance on power

IV. CONCLUSIONS

The design of the hybrid triboelectric and electromagnetic nanogenerator can be fabricated using several components such as acrylic substrate, copper coils, Polytetrafluoroethane (PTFE) tape and magnet. From the result achieved for TENG, the larger surface area with a longer distance of air gap produced a higher output open circuit voltage. Meanwhile for EMG, the stronger magnet strength with a greater number of coils turns produced more output open circuit voltage. The objective to power up the low power wireless sensor node is achieved when the result of the power output is 2.071mW due to the past research states that only 100µW is needed to operate a low power wireless sensor node.

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