Proceedings of the 2nd International Conference on Computing Innovation and Applied Physics (CONF-CIAP 2023)
DOI: 10.54254/2753-8818/5/20230618

Study of the Physical Mechanism of Power Generation with Wheels

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Abstract. It is known well that electricity is an important part of our life and most of it is wasted. However, the natural resources of energy are being wasted and reduced. To utilize the mechanical energy of rotating wheels, in this research report, the device structure of generating electricity voltage is designed, and the relations between the voltage generated by rotating wheels and the geometry and physical parameters of the structures are derived, and the effects of the geometry and physical parameters on the voltage are analyzed. The theoretical results show that the voltages are in proportion to the weight and speed of rotating wheels. The experiments with piezoelectric film and wheels are used to verify the theoretical analysis. The experimental results show that the theoretical analysis is in good agreement with measured results.

Keywords: piezoelectricity, force, transportation

1. Introduction

Within two hundred years since people discovered and became adept at using electricity, our lives have changed dramatically. Now, electricity has become an indispensable part of our daily life. In the face of the increasingly severe greenhouse effect. In terms of environmental protection can achieve energy recovery and reuse? Piezoelectricity is a fascinating phenomenon in which certain materials generate an electric charge when subjected to mechanical force or pressure[1]. The theoretical results show that the voltages are in proportion to the weight and speed of rotating wheels[2].This property of piezoelectric materials has found a wide range of applications, including sensors, actuators, energy harvesters, and medical devices[3]. Materials with piezoelectric effects can produce electricity under force. Human being live in a world where force is everywhere. For example, when a car is driving on a highway, its wheels exert force on the highway; when a high-speed railway runs at a high speed, its wheels exert great force on the track, and so on. This research report will study the influence of vehicle load weight and driving speed on voltage generation during vehicle wheel running.

This project firstly conducts a theoretical analysis of the force and voltage generation generated by vehicle wheels including piezoelectric film, establishes the theoretical model of the influence of vehicle load weight and wheel speed on voltage generation, and then builds an experimental system for experimental verification on this basis.

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2. Literature review

The platform we used in our daily life and work is called the Internet of Things (IoT), and it connects the whole world to the internet. Sensors are essential input devices for remote monitoring. In order for the Internet of Things to perform properly, we need a vast number of sensors dispersed across the whole system. In order for the sensor to work, it needs a power source that is both compact and sustainable, and that can create electricity by capturing energy from its surroundings. The world took notice, and soon people were developing nanogenerators and other forms of self-sustaining energy. However, even though nanogenerators were initially considered as a source of power, they also have the potential to be self-powered sensors. Vibration is a prevalent sort of mechanical motion that may be found in a number of forms and sizes in people's everyday lives. Vibrational energy may be found in a variety of natural and man-made sources, including raindrops, winds, ocean waves, and human movement. Because the vibration frequency is so low, present technologies cannot extract this energy because the frequency fluctuates with time. In recent years, researchers have been working to harness this vibrational energy for self-powering devices. Nanogenerators are energy converters that use displacement current to transform mechanical energy into electrical energy[3]. Nanogenerators do not need the presence of nanoparticles, despite their name (Brahmadutta).

The world is facing a growing demand for clean and sustainable sources of energy. The traditional sources of energy, such as fossil fuels, are finite, non-renewable, and have a significant impact on the environment[4]. The search for alternative sources of energy has led to the development of piezoelectricity as a potential solution. Piezoelectricity is a unique phenomenon that allows the generation of electricity from mechanical force or pressure. This makes it an ideal source of energy for various applications, especially in situations where traditional energy sources are not feasible. Piezoelectric materials can generate electricity from a wide range of sources, including human motion, wind, and water.[5] One of the most exciting applications of piezoelectricity is in the field of energy harvesting. Energy harvesters are devices that convert mechanical energy into electrical energy, which can be stored and used to power electronic devices. Piezoelectric energy harvesters can be used to power small electronic devices, such as sensors and wearable devices, which can significantly reduce the dependence on traditional energy sources and batteries[3]. Another promising application of piezoelectricity is in the field of sustainable transportation. Piezoelectric materials can be integrated into the suspension systems of vehicles to generate electricity from the motion of the vehicle[6]. This can help to reduce the dependence on fuel and batteries and make transportation more sustainable. Piezoelectricity also holds great promise for the future of smart cities. Smart cities are designed to be more energy-efficient, sustainable, and resilient[7]. Piezoelectric materials can be integrated into the infrastructure of smart cities to generate electricity from various sources, such as foot traffic, wind, and water. This can help to reduce the demand for traditional energy sources and make cities more sustainable[8].

The experiment was divided into the following sections：

Section 3 will discuss the theoretical analysis that revolves around the generation of electricity. Section 4 will base on the experiment. This section will be divided into 3 parts. The first part will describe the equipment used in the experiment and the second part will talk about the schedule. How are we going to conduct the experiment? The last part will be the result with detailed calculations. Section 5 will be the conclusion, containing specific analysis and personal ideas. Other details and background will be summarized in Section 6.

3. Theoretical framework

3.1. The relation between voltage and structure parameters

The diagram of device structures with piezoelectric film PZT designed in this research project is shown in Figure 1, where (A) is side view, and (B) is top view of the structures.

Figure 2 is the variation of electrical protentional, charge distribution (Q+,Q-) of surface of the piezoelectric film PZT with position R.

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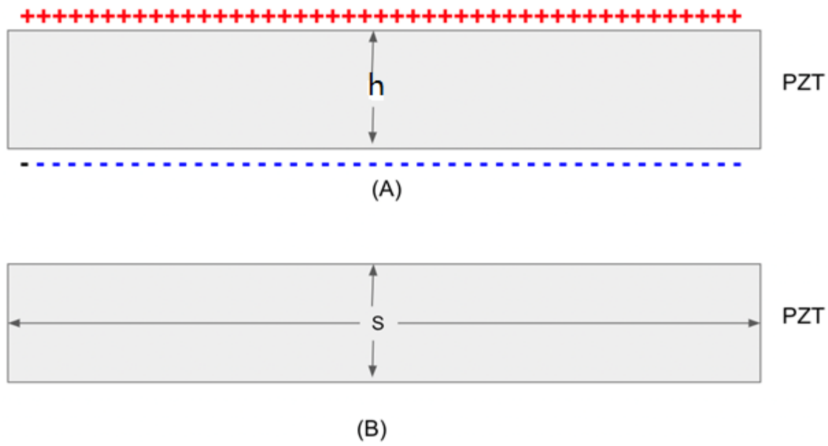

Figure 1. The diagram of device structures designed in this research project, (A) is side view, and (B) is top view of the structures with piezoelectric film PZT.

The difference between the pole spacing L and the deformation of the piezoelectric material is 6 orders of magnitude. So $L \ll R, R_1, R_2$ Where, R, R1 and R2 are the distances from a point on the surface of the piezoelectric film to the center of positive and negative charge and the center of the pole respectively.

According to the electric potential formula

$$\varphi = k\frac{Q}{R} \tag{1}$$

for the point A on the electrodes at both ends of the piezoelectric film, there are positive potential

$$\varphi^+ = k\frac{Q}{R_1} \tag{2}$$

and negative potential

$$\varphi^- = -k\frac{Q}{R_2} \tag{3}$$

The sum of potential at point A should be the sum of positive and negative potential, so:

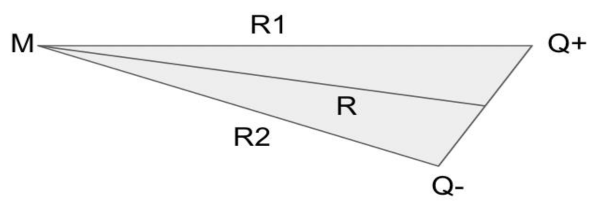

Figure 2 The variation of electrical protentional, charge distribution (Q+,Q-) of surface of the piezoelectric film PZT with position R

$$\boldsymbol{\varphi_A = \varphi^+ + \varphi^-}$$

$$\boldsymbol{= k\frac{Q}{R_1} - k\frac{Q}{R_2}}$$

$$\boldsymbol{= kQ\frac{R_2 - R_1}{R_1 R_2}} \tag{4}$$

And because$R_1 \gg L, R_2 \gg L$, there are

$$\boldsymbol{R_1 \approx R - \frac{L}{2}\cos\theta} \tag{5}$$

$$\boldsymbol{R_2 \approx R + \frac{L}{2}\cos\theta} \tag{6}$$

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$$\boldsymbol{R_2 - R_{1=} = L\cos\theta} \tag{7}$$

$$\boldsymbol{R_1 R_2 = R^2} \tag{8}$$

By substituting the numerator and denominator in formula (1) with formula (2) and (3), it can be obtained

$$\varphi_A = kQ\frac{L\cos\theta}{R^2} \tag{9}$$

Now to put point A right above the charge r units away, $\theta_A = 0^o$; The addition point B is r units directly below the charge, so $\theta_B = 180^o$. At this point, the values in formula (4) can be substituted into the calculation:

When $\theta = \theta_A = 0^o$,

$$\varphi_A = kQ\frac{L\cos 0^o}{R^2} = kQ\frac{L}{R^2} \tag{10}$$

When$\theta = \theta_B = 180^o$,

$$\varphi_B = kQ\frac{L\cos 180^o}{R^2} = -kQ\frac{L}{R^2} \tag{11}$$

The potential difference can be obtained by subtracting equation (5) and equation (6) :

$$\varphi = \varphi_A - \varphi_B = 2kQ\frac{L}{R^2} \tag{12}$$

From the final derivation (7), it can be seen that the potential difference is proportional to the pole spacing L and inversely proportional to the distance from the point to the pole squared R^2.

In order to determine the relationship between the potential difference and pole distance, the square of the distance from point to the pole was set as $R^2 = 10 \times 10^{-3}$meters, pole distance L was regarded as a variable, and then the images of potential difference and pole distance were drawn using MATLAB. (Q is proportional to the velocity)

Combining the couple equations and finishing the final calculations the process of it will be listed as follow:

$$n = m/N_A \tag{13}$$

To take Barium Titanate as a sample (BaTiO3) and need to find out its molar mass.

So after inserting the data into the equation the molecule number is 233 besides taking volume and length

$$E = \frac{E/S}{dL/L} \tag{14}$$

into consideration and

The final equation will be :

$$\varphi = \frac{kFLh^2}{2SE(h - \frac{hF/S}{E})^2} \tag{15}$$

Because measuring the voltage at different speeds of wheel. Then the speed will also affect the voltage measurement. Not considering the ideal case, due to the influence of air resistance. According to the formula:$F_D = \frac{1}{2}\mathrm{Clav}^2$

At this point considered the lift coefficient of the car, for the convenience of the research. The rough calculation of the vehicle lift coefficient used in the experiment will be listed below. It's going to take the lift coefficient of a normal car into the calculation and can find out the greater the velocity the greater the pressure on the surface, also know that voltage is proportional to velocity.

Finally, the equation can also be simplified as:

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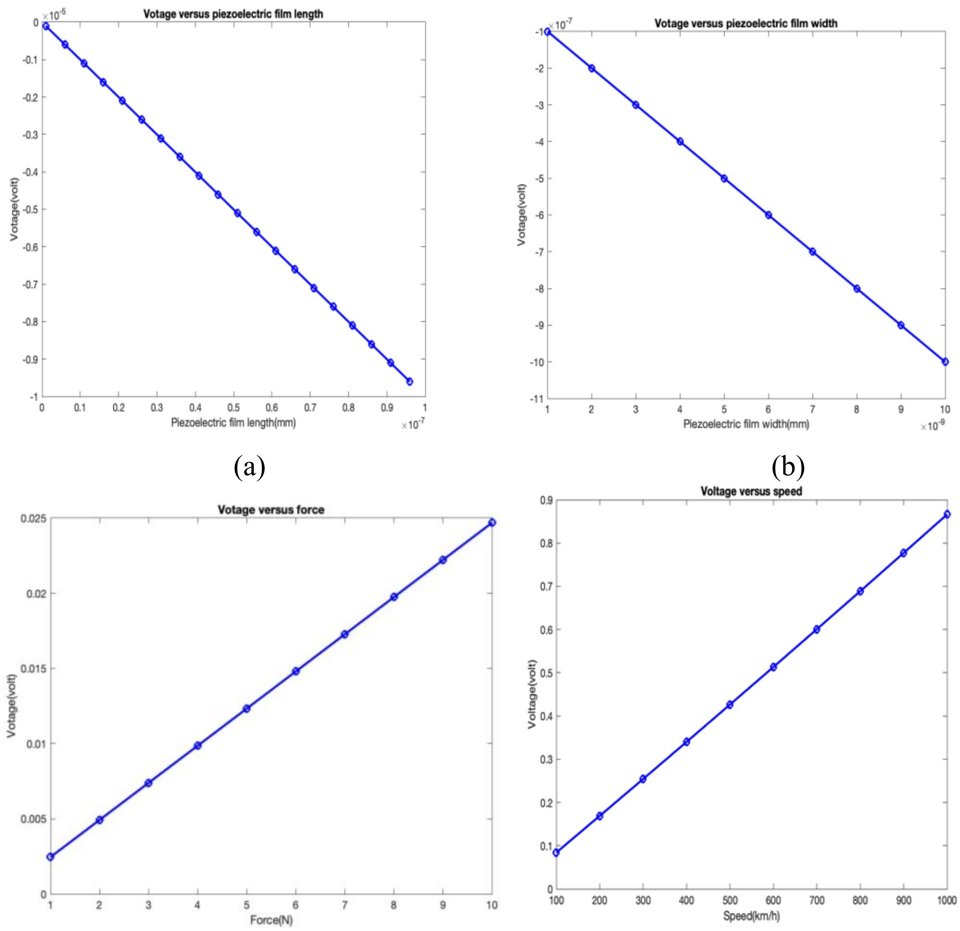
$$\varphi = \frac{kFL}{(2SE - \frac{F/S}{E})^{2}} \tag{16}$$

3.2. The effect of structure parameters on voltage

The variation of voltage with the structure parameters of PZT film is shown in figure 3. Where (a),(b),(c),(d) are voltage versus the film length, voltage versus the film width, voltage versus the film pressure, voltage versus the speed of wheel.A subsubsection. The paragraph text follows on from the subsubsection heading but should not be in italic.

It is shown from the figure 3 that with fixed pressure or weight on the film, when film length and film width increase, the voltage or potential difference between the two surfaces of the film decrease nearly.

With fixed structure parameters of the film, when the pressure and speed of the wheel increase, the voltage or potential difference between the two surfaces of the film increase nearly.



(a) (b)

(c) (d)

Figure 3. Voltage versus the structure and other parameters of PZT film: (a) film length (b) film width (c) film pressure (d) wheel speed.

4. Experimental process

First analyzed the theoretical knowledge. Then, applied different forces on the piezoelectric film to explore the relationship between the force and electricity generation. Then, under the same force, applied the force to the different position of the film and the electricity generation. After completing these two

DOI: 10.54254/2753-8818/5/20230618

steps, the variation of voltage with the structure parameters is analyzed. Finally, a tire power generation experiment will be carried out.

4.1. Elements and equipment

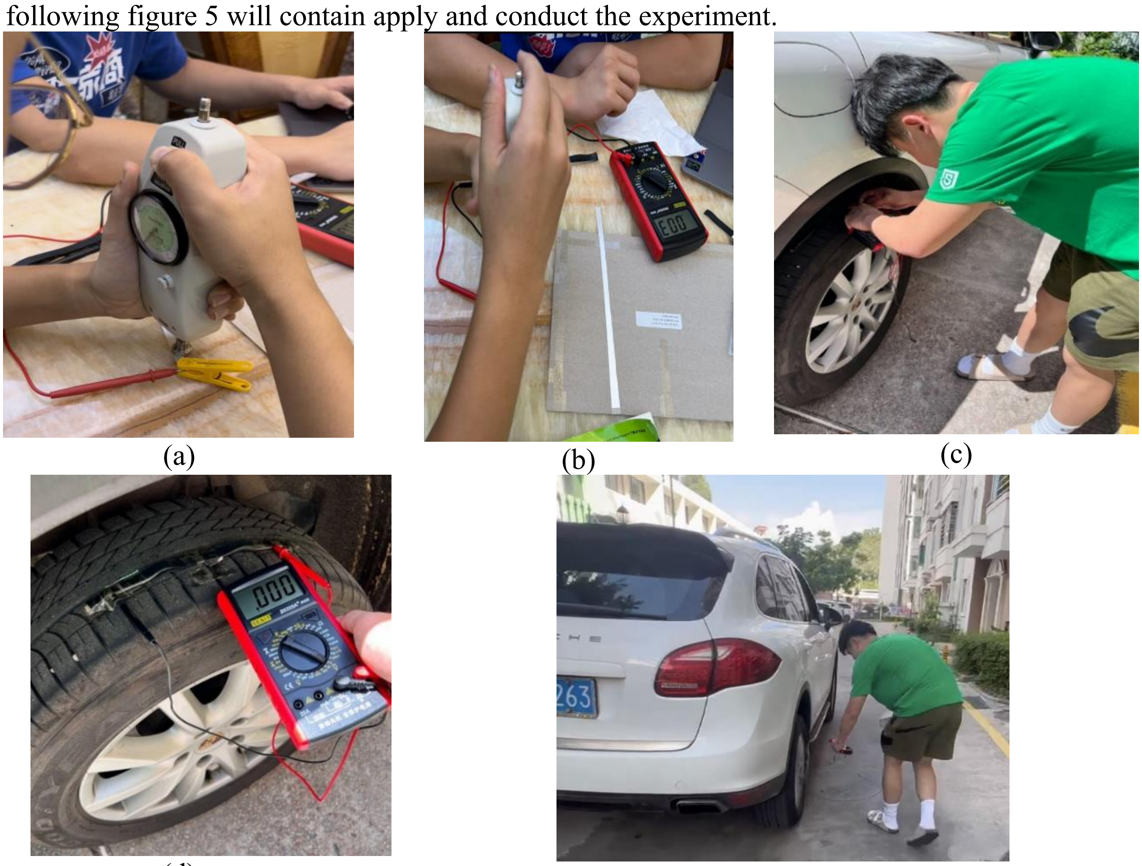
The following figure 4 contains the experimental equipment.

(a) (b)

Figure 4. the demonstration of experimental equipment: (a) PZT Piezoelectric film (b) A multimeter and a manometer and a whole piezoelectric film.

4.2. Experiment schedule

The following figure 5 will contain apply and conduct the experiment.



(a) (b) (c)

(d) (e)

Figure 5. The demonstration of apply and conduct the experiment: (a) Apply 60N force on the piezoelectric film (b) Collect and confirm the data (c) Installing experimental instruments (d) Installation of the instrument (e) Measuring the data.

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4.3. Experiment result

Figure 6 is the voltage versus force with different position from monitoring point). Figure 7 is the voltage versus force with elastic band at different position from monitoring point. Figure 8 is the voltage at different position from monitoring with different pressure. Figure 9 is the voltage of film with elastic band at different position from monitoring with different. Figure 10 show the relationship between voltage of film and speed of wheel.

Through the experimental data of table 1 and table 2 experimental data obtained, it is shown that the greater the force applied, the greater the voltage measured by the multimeter. And when clipping the piezoelectric film between the elastic bands, the voltage is slightly less than the voltage measured without the elastic band.

After preliminary exploration of the piezoelectric effect. And what are going to do is to go to take the piezoelectric effect and to apply it to the tire, and to use the force on the tire to generate electricity. At this time, use five sets of data, which are the voltage values measured at different speeds. Through the experimental data drawing analysis, it is show that the faster the speed, the higher the voltage. Thus, the velocity is proportional to the voltage.

Table 1. Experiment data.

length	full length:21.2	5	10	15	20	
Force		20	40	60	80	100
Data	5	0/0.01/0.03	0/0.03/0.02	0.01/0.02/0.02	0.02/0.11/0.08	0.2/0.09/0.16
	10	0.02/0.01/0.00	0/0.05/0.00	0.01/0.04/0.07	0.05/0.00/0.06	0.05/0.00/0.09
	15	0.02/0.00/0.00	0.07/0.00/0.02	0.04/0.03/0.03	0.03/0.06/0.07	0.03/0.07/0.10
	20	0.00/0.00/0.02	0.00/0.02/0.03	0.01/0.02/0.02	0.02/0.04/0.06	0.03/0.06/0.15
with elastic band	5	0.00/0.01/0.00	0.00/0.01/0.03	0.00/0.03/0.04	0.04/0.03/0.10	0.04/0.08/0.12
	10	0.02/0.01/0.01	0.0/0.00/0.04	0.02/0.05/0.08	0.03/0.06/0.10	0.09/0.10/0.08
	15	0.01/0.01/0.02	0.01/0.01/0.03	0.02/0.03/0.07	0.03/0.06/0.11	0.10/0.12/0.09
	20	0.01/0.03/0.03	0.02/0.03/0.03	0.02/0.03/0.04	0.02/0.03/0.04	0.10/0.09/0.09

Table 2. Generated Voltage at Different Speed.

Speed:	5km/h	10km/h	15km/h	20km/h	25km/h
Voltage:	10.44	32.24	29.12	44.3	50.01
	16.89	47.32	41.13	47.23	72.1
	10.79	32.46	37.7	37.13	59.92
	11.84	36.24	38.36	44.12	62.12

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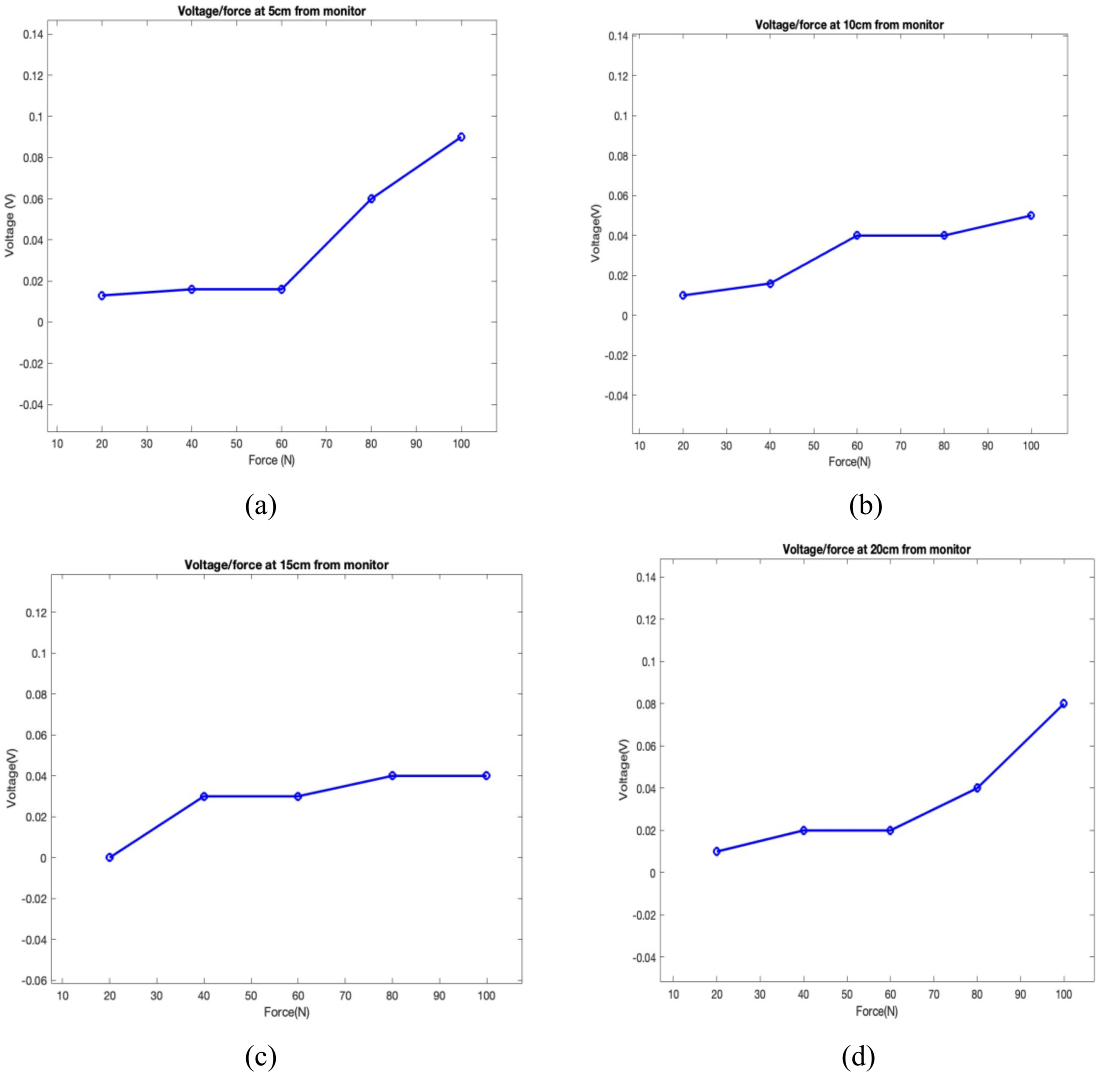

Figure 6. The voltage versus force with different position from monitoring point: (a) 5 cm (b) 10 cm (c) 15 cm (d) 20cm.

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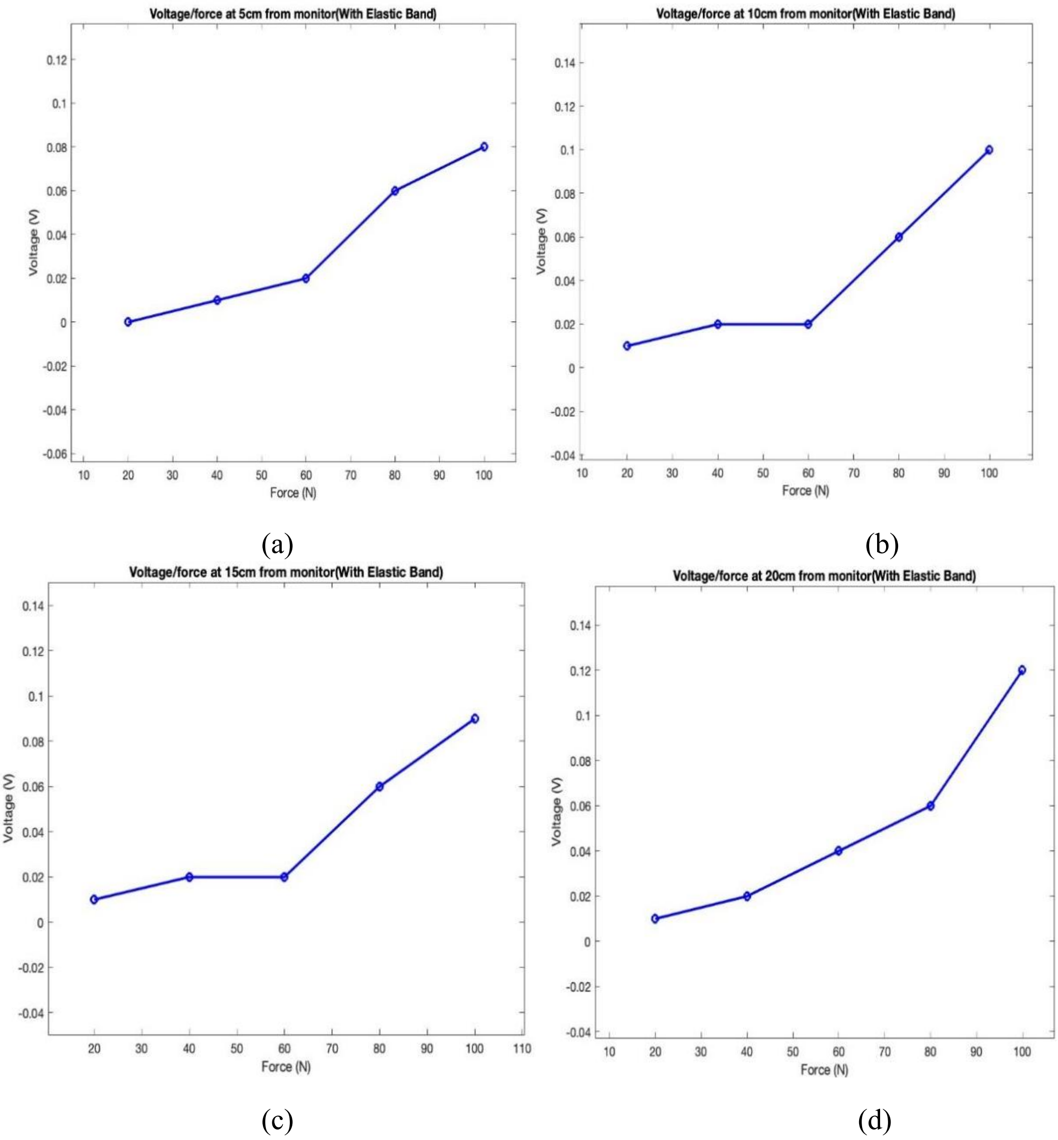

Figure 7. The voltage versus force with elastic band at different position from monitoring point: (a) 5 cm (b) 10 cm (c) 15 cm (d) 20cm.

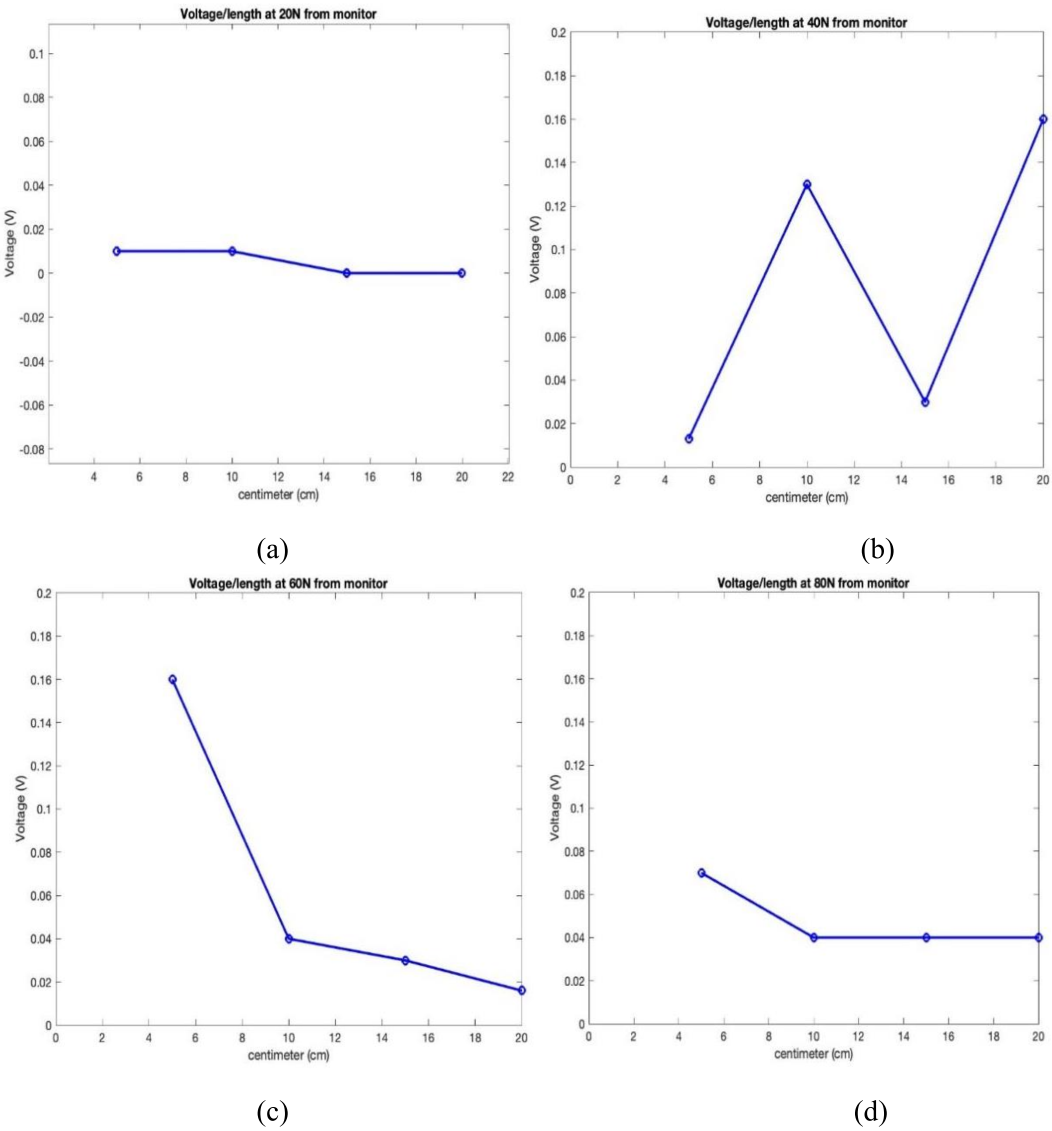

Figure 8. The voltage at different position from monitoring with different pressure: (a) 20N (b) 40N (c) 60N (d) 80N.

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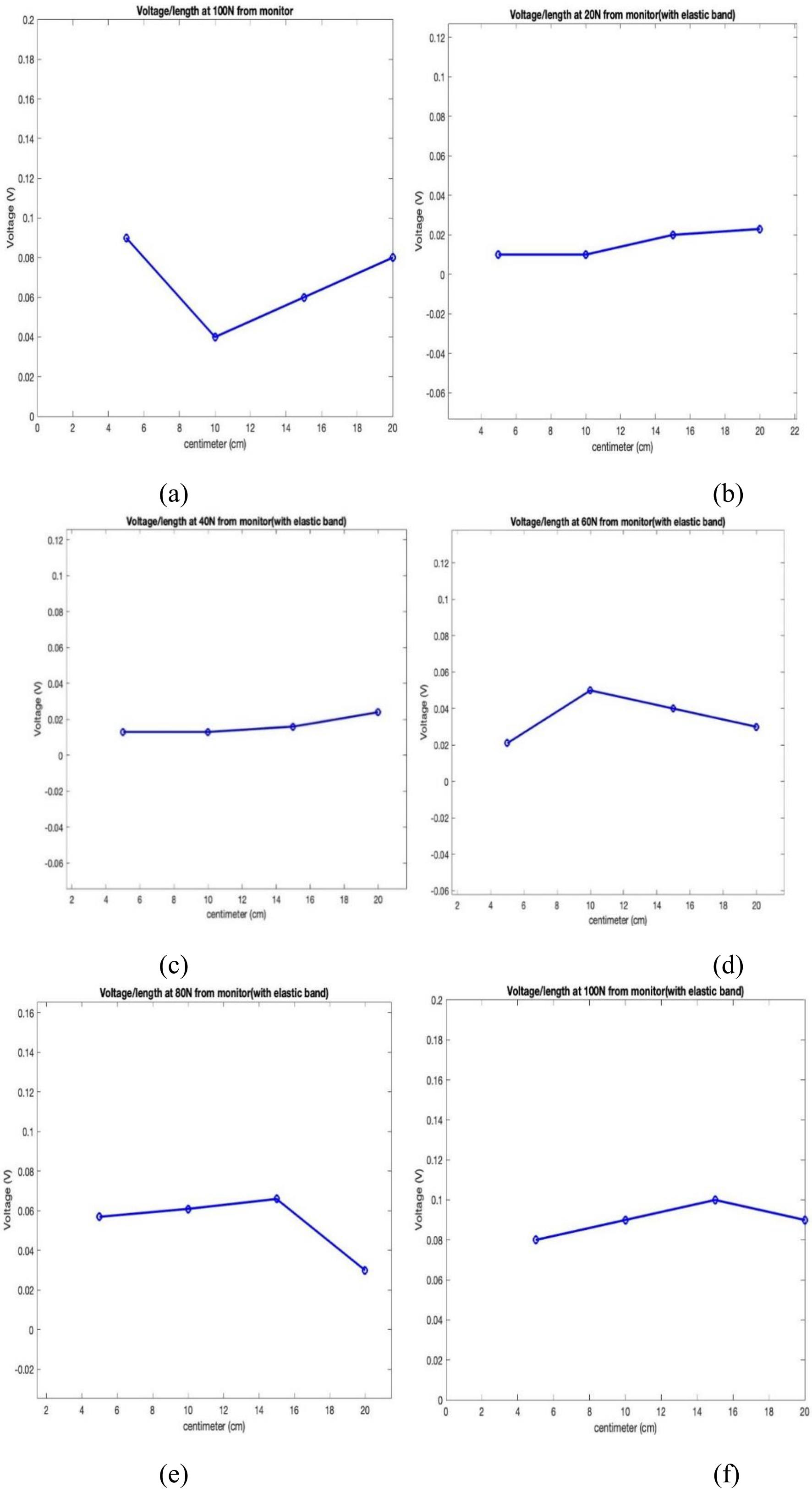

Figure 9. The voltage of film with elastic band at different position from monitoring with different pressure: (a) 100N (b) 20N (c) 40N (d) 60N (e) 80 N (f) 100 N.

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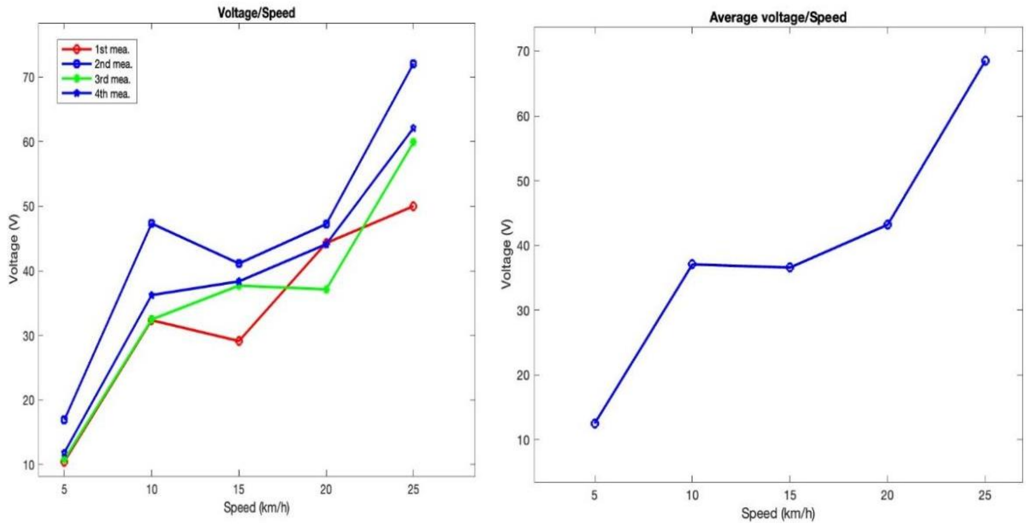

(a) (b)

Figure 10. Relationship between (a) voltage and speed with four measurements and (b) averaging value.

5. Result and discussion

The calculated and measured values of the relationship between voltage and pressure are illustrated in figure 11. It is shown from the comparing that with increasing pressure, the voltages increase, indicating that the theoretical model is in qualitative agreement with experiment results.

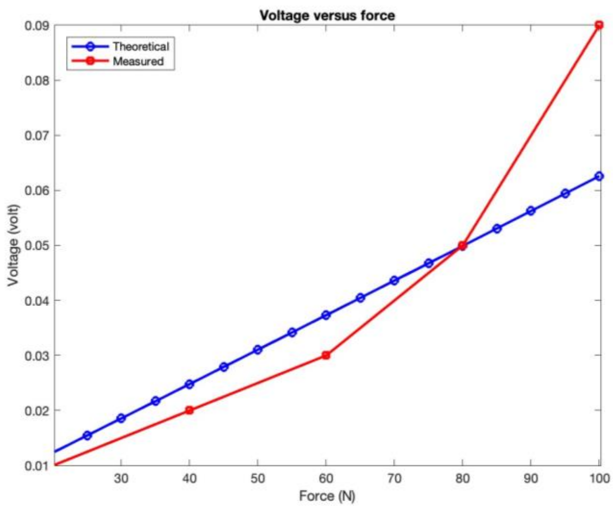

Figure 11. The comparing of calculated and measured values of voltages with increasing pressure.

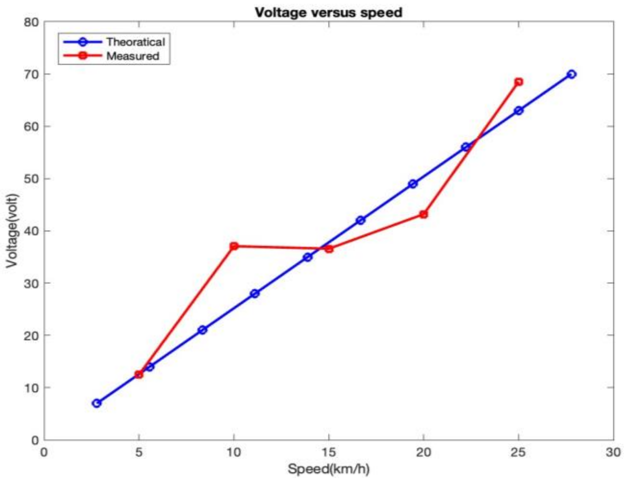

Figure 12. The comparing of the calculated and measured values of voltages with increasing speed.

Figure 12 illustrates the comparing of the calculated and measured voltages with increase speed of wheel. It is shown from the comparing that with increasing speed of wheel, the voltages increase, indicating that the theoretical model is in qualitative agreement with experiment results.

6. Conclusion

Through data analysis and experiments, it is shown that generating power by rotating wheels is feasible. By controlling for different variables, someone initially measured the relationship between the force and the voltage and applied the same force to the piezoelectric film at different distances to prepare for later experiments. After the analysis. it helps figured out the relationship between them. And then what is going to do the power generation experiments on tires. After repeated measurement, the voltage generated by the film device at different speeds was simulated and measured. Five experiments was conducted at each speed, then calculated the resulting data and averaged them. These average values were then plotted to obtain the relationship between the velocity and the generated voltage.

As a summary, in this research report, the device structure of generating electricity voltage was designed, and the relations between the voltage generated by rotating wheels and the geometry and physical parameters of the structures were derived, and the effects of the geometry and physical parameters on the voltage were analyzed. The theoretical results showed that the voltages were in proportion to the pressure and speed of rotating wheels. The experiments with piezoelectric film and wheels were used to verify the theoretical analysis. The experimental results showed that the theoretical analysis was in good agreement with measured result. Piezoelectricity is a fascinating phenomenon with a wide range of applications. The versatility of piezoelectric materials has made them an essential part of modern technology. With ongoing research and development, the future of piezoelectricity looks bright, and we can expect to see even more exciting applications in the years to come.

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