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Feasibility Studies of Piezoelectric as a Source for Street Lighting

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Abstract: Piezoelectric is a device that has been widely used in this few years. Environmental energy such as piezoelectric begins to take place over the usage of power supply to generate a voltage, for any electronic devices and applications. This device was used to generate electrical power while the vehicles drive over the piezoelectric device. The wasted energy from vehicles movement also can be used by scavenging this energy using piezoelectric generator. Piezoelectric generator is the conversion of mechanical energy into electrical energy. In this research, the feasibility and capability of piezoelectric for street lighting has been experimented. Piezoceramic materials used are PZT5A1 navy type II from Morgan Technical Ceramics Piezoelectric (ring). The test results are given for this system is based on the voltage from the outer radius, inner radius and thickness of piezoelectric ceramic crystal. This research aimed to produce voltage output more than $24V_{dc}$ for the usage of battery bank of the Light Emitting Diode (LED) street lighting. MATLAB software is used to simulate and develop each of the subsystems in this research.

Key words: Piezoelectric · LED street lighting · MATLAB software · Morgan Technical Ceramic

INTRODUCTION

The piezoelectric effect was discovered by Curie's brothers in 1880. They were observed that this effect can transform mechanical energy into electrical energy. The potential of piezoelectric material as a transducer was recognized in early 1917. The ideas of piezoelectric energy are well known for wasted energy can be scavenged by using piezoelectric operation. Piezoelectric sensor is based on the principle of electromechanical energy conversion [1]. When the pressure was applied to a specific material, it will give an electrical output. The electric field is generated when a stress is applied, otherwise when there is no stress applied, positive and negative charges will be at natural condition and there will be no potential differences. By using piezoelectric technology, the street lighting can be rechargeable and the energy demand can be reduced.

However, the output voltage produced by piezoelectric was alternating current (AC). Thus rectifiers are required to convert the AC into DC output [2]. Piezoelectric principle has experienced a constant growth in many applications and appliance such as in aerospace, medical and nuclear instrumentation.

Piezoelectricity means "electricity by pressure". An electric field is generated when the material is mechanically imperfect. When a piezoelectric materials is to be strain, it will be polarizes and will create an electric field. Figure 1 shows how the polarization of the material occurs.

As the material is compressed, the symmetry of the atomic structure is disrupted, resulting in poles occurring in atoms of the material. These poles lead to the creation of the electric field. The converse effect works in much the same way. When an electric field is applied across the material, it will cause polarization of the material, which in turn will deform it [3].

Matlab/Simulink software was used for simulation and analysis each outer radius, inner radius and thickness of piezoelectric ceramic crystal. Morgan Technical Ceramics (MTC) Navy type II characteristic has been used as the piezoelectric ceramics crystal while modelling

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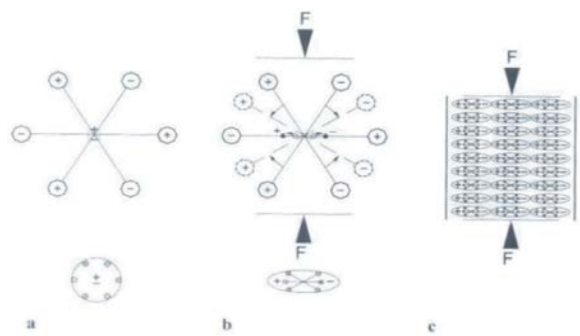

Fig. 1: Atomic distortion of piezoelectric material

the piezoelectric element using Matlab using this specification [3]. The result for this research is to produce an output voltage more than $24V_{dc}$ to charge battery bank of street lighting. This research also produces continuous power supply for the battery to support the street lighting to operate continuously.

Methodology

Pulse Generator: Pulse Generator block generates a square wave pulse at regular intervals. Parameter block wave, amplitude, pulse width, period and delayed phase. It also determines the output waveform. Pulse Generator block outputs real signals of any type of numerical data that supports Simulink, including fixed point data types. Output signal data type is the same as the amplitude parameter. In this research also, pulse generator have been chosen because the input given to the system is dynamic input since electricity is generated when the vehicles are driving through the road.

The amplitude in this source block was set as gravity acceleration which is at $9.81m^2/s$ and the period (sec) was set at 0.3s considering the mean numbers of car in 10 minutes. Thus, every 0.3s there will be an input given to the system in acceleration of $9.81m^2/s$.

Dynamic Input For The System: For better accurate training input, the data was taken from the vehicles which are driving through the road near the main entrance at National Defence University of Malaysia. This data collection was held during the peak hours which are between 12 pm to 2 pm. The time constant is 10 minutes and each reading was recorded for 10 times in between that period. The numbers of vehicle are than to be counted in 10 minutes and the numbers are different for the each time it was recorded. Table 1 shows data taken from the experiment which were conducted at National Defence University of Malaysia.

Table 1: Data for Vehicles in 100 minutes

Periods (10 Minutes)	Number Of Vehicles
1	15
2	18
3	19
4	16
5	20
6	17
7	15
8	21
9	22
10	17

As shown in Table 1, it shows that the number of vehicles driving through the road is different for each time it was recorded. Time of each reading from the number of vehicle was divided by 600 (sec) to obtain the average time result from the data taken. The time frame for each reading was between 0.25s – 0.37s and the average was 0.3s. It is found out that the dynamic force input for the system was triggered every 0.3s since this project focuses on the scavenging energy to charge battery bank of LED street lighting from the vehicles movement on the road.

Resonator: The type of piezoelectric used are Navy type 2 consist of piezoelectric ceramic crystal from Morgan Technical Ceramics specification [3]. The shape used was piezoelectric ring. The force is applied to the generator in parallel with the poled direction of the PZ material.

Next, the mechanical system can be modelled with bulk elements, depending on the transient nature of the applied forces. The bulk element model is suitable for this investigation because shock waves are not generated in the PZ material that would warrant the use of the distributed model [3]. The bulk element model of the PZ material is also conceptually simpler to understand than a distributed model. The applied force is assumed to be instantly and uniformly distributed throughout the device, which allows the simple mass-spring system of Figure 2 to be used [3].

Resonator in this research act as a spring which produces continues output to the system and oscillating waveform for piezoelectric. Resonator also helps the voltage and current output produced to be higher. In the analyzing the value of mass for the resonator is the mass of the spring and not the mass of vehicle due to when a vehicle move only resonator will vibrate along with the spring.

The spring will provide continuous vibration, while the mass of vehicle will act as the force to the system. The value of mass in this model set at 0.05kg and the coefficient of spring (k) set at 2000000. Lastly, the value of

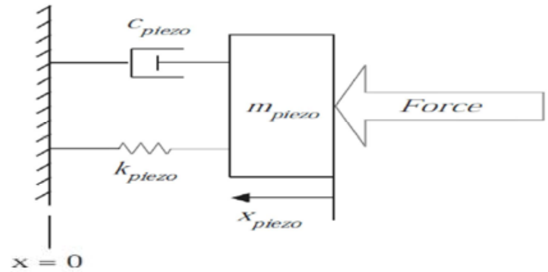

Fig. 2: Mechanical part which is the resonator

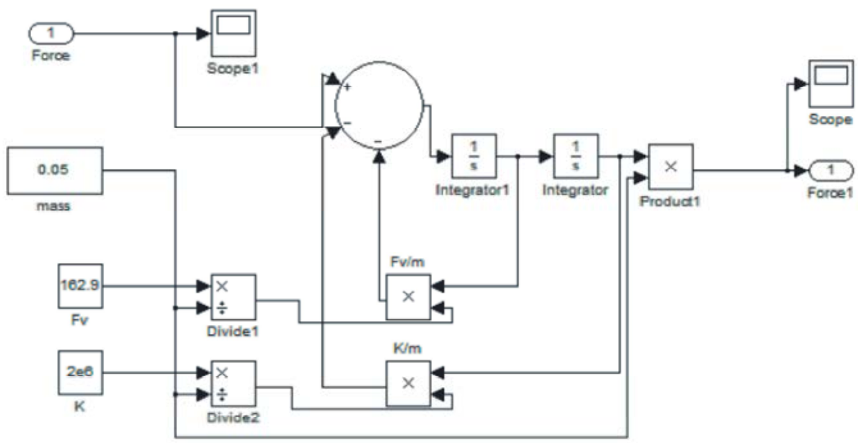

Fig. 3: Resonator of the system

damper (Fv) set at 162.9 and these values kept constant for this type of spring [2]. Figure 3 shows the output waveform of a resonator.

The mechanical system in Figure 3 is described by equation below:

$$F = m_{piezo}x''_{piezo}+c_{piezo}x'_{piezo}+k_{piezo}x_{piezo} \quad (1)$$

where m_{piezo} is mass, c_{piezo} is damping constant, k_{piezo} is the spring constant and x_{piezo} is the compression distance of piezoelectric material [3].

For a given displacement, the mechanical compression energy is given by [3]:

$$W_{mech}=Fx_{piezo} \quad (2)$$

Relating (2) to Young's modulus, Y, the mechanical energy expression becomes [3]:

$$Wmech= (1/2)(F^2h_{piezo}/YA) \quad (3)$$

where h_{piezo} is thickness of piezoelectric material and A is it cross-sectional area of piezoelectric ring.

Piezoelectric Element: Matlab/Simulink software was used for simulation and analysis each outer radius, inner radius and thickness of piezoelectric ceramic crystal. Morgan Technical Ceramics (MTC) Navy type II characteristic has been used as the piezoelectric ceramics crystal while modeling the piezoelectric element using Matlab using this specification [3].

The result for this research, it was to produce an output voltage more than 24VDC to charge battery bank of street lighting. This research also produces continuous power supply for the battery to support the street lighting to operate continuously.

For this research, three variables have been used which is outer radius, inner radius and the thickness of the piezoelectric ceramic crystal to determine the voltage of the system, so it can be used to charge the battery bank of street lighting. Figure 4 shown piezoelectric elements of the system.

As a rule, loss resistance is relatively small and the leakage resistance is high, this value is depending on the thickness of the material. Loss resistance represents the losses from the current travelling across the surface of the material to the electrical leads. Leakage resistance represents the losses as current travel through the material [4].

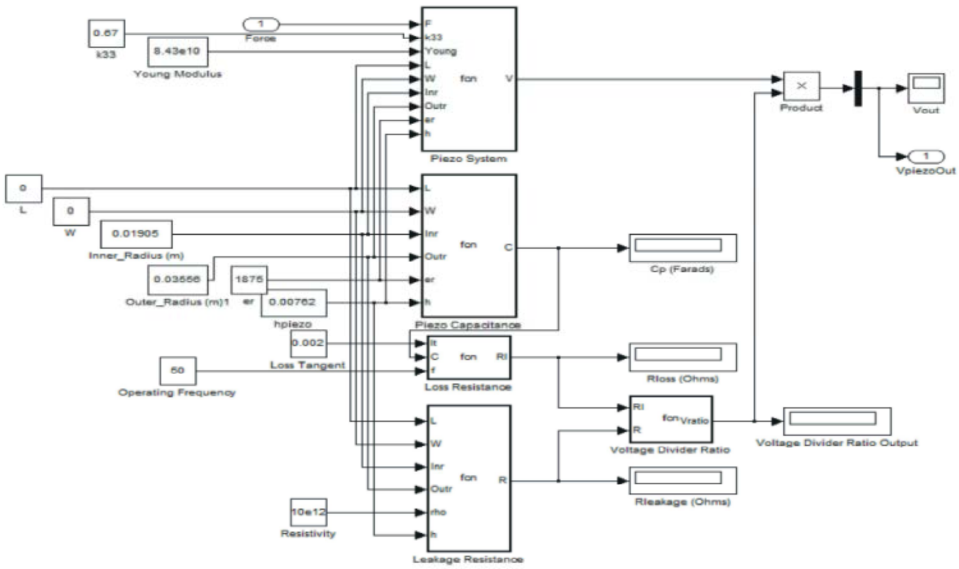

Fig. 4: Piezoelectric Element

Fig. 5: Examples of shape and sizes for piezoelectric type ring

Table 2: Common shapes and sizes of piezoelectric ceramic crystal

Property	Values For PZT5A
Relative permittivity	1875
Dielectric Loss	0.002
Coupling Factors (k33)	0.67
Resistivity (at 25°)	1012
Frequency Constants (Hz)	50
Young modulus	8.53e10

Table 3: Property and value of piezoelectric element

Variables	Outer Diameter	Inner Diameter	Thickness
Ranges (inch)	0.250"- 2.000"	0.070"- 0.750"	0.008"-0.400"
Description		Depending on outer diameter and thickness	Depending on material

There are a lot common shapes and sizes for piezoelectric ceramic crystal, but this thesis will be using piezoelectric rings as the piezoelectric element since it is very suitable to generate electricity while walking and this piezoelectric ceramic crystal also are very suitable for the usage of this project. Table 2 shown common shapes and sizes for piezoelectric ring, but this research uses outer diameter from 1.400”-2.000” only in this research [3].

There are three types of variable was develop and one analysis to determine the voltage of the system, so it can be used to produced electrical DC output for LED street lighting. These variable needs to be set, to analyze the voltage output for this system.

There are a lot common shapes and sizes for piezoelectric ceramic crystal, but this research uses piezoelectric type rings as the piezoelectric element since it is very suitable to generate electricity while the vehicle pass through on the material. For that, this piezoelectric ceramic crystal also is very suitable for the usage of this research. Figure 5 shown example shape and sizes for the research.

Resistance leakage must be greater than resistance loss for high voltage on Voltage Output as described in the journal “Electrical Power Generation Generator Characteristic of Piezoelectric under Quasi-Static and Dynamic Stress Condition” [5].

The value was taken from Morgan Technical Ceramics which has constant values for piezoelectric ceramic crystal. Table 3 shown property and value for each constant value [3].

Rectifier Circuit: The piezoelectric element prove that it produces AC output based on the journal article that title “Analysis of power output for piezoelectric energy harvesting systems” written by Y C Shu et and Ic Lien [2]. Rectifier is used to convert AC to DC output. This rectifier is also used to reduce the distortion and noise of the systems [6]. Since battery of street lighting needs DC output, RC-filter rectifier had been choosing as the type of rectifier for this research.

Table 4: Outer radius of piezoelectric element 2.0”-1.40”

Or (m)	Or (Inch)	Ir (m)	Ir (Inch)	hpiezo (m)	hpiezo (Inch)	Vpeak (V)
0.0508	2	0.75	0.01905	0.0102	0.4	16.4
0.04699	1.85	0.75	0.01905	0.0102	0.4	18.5
0.04445	1.75	0.75	0.01905	0.0102	0.4	21.4
0.04191	1.65	0.75	0.01905	0.0102	0.4	25.0
0.03937	1.55	0.75	0.01905	0.0102	0.4	29.4

Table 5: Output from thickness 0.4”

Or (m)	Or (Inch)	Ir (m)	Ir (Inch)	hpiezo (m)	hpiezo (Inch)	Vpeak (V)
0.0508	2	0.01905	0.75	0.0102	0.4	16.4
0.0508	2	0.01778	0.70	0.0102	0.4	16.2
0.0508	2	0.01651	0.65	0.0102	0.4	16.0
0.0508	2	0.015240	0.60	0.0102	0.4	14.5
0.0508	2	0.01397	0.55	0.0102	0.4	13.2
0.0508	2	0.01905	0.75	0.00762	0.3	11.0
0.0508	2	0.01905	0.75	0.0058	0.2	7.70
0.04699	1.85	0.01905	0.75	0.0102	0.4	18.5
0.04699	1.85	0.01905	0.75	0.00762	0.3	15.0
0.04445	1.75	0.01905	0.75	0.0102	0.4	21.4
0.04445	1.75	0.01905	0.75	0.0072	0.3	15.9
0.04445	1.75	0.01905	0.75	0.0058	0.2	10.0
0.04191	1.65	0.01905	0.75	0.0102	0.4	25.0
0.04191	1.65	0.01905	0.75	0.00762	0.3	20.0
0.04064	1.60	0.01905	0.75	0.0058	0.2	15.0
0.03937	1.55	0.01905	0.75	0.0102	0.4	29.4
0.03937	1.55	0.01905	0.75	0.00762	0.3	22.0
0.0381	1.50	0.01905	0.75	0.00762	0.3	23.8
0.0381	1.50	0.01905	0.75	0.0058	0.2	16.0
0.03556	1.40	0.01905	0.75	0.00762	0.3	31.5
0.03556	1.40	0.01905	0.75	0.0058	0.2	20.0

Table 6: Output from thickness 0.3”

Or (m)	Or (Inch)	Ir (m)	Ir (Inch)	hpiezo (m)	hpiezo (Inch)	Vpeak (V)
0.0508	2.0	0.75	0.01905	0.00762	0.3	11.1
0.04445	1.75	0.75	0.01905	0.00762	0.3	15.9
0.04064	1.6	0.75	0.01905	0.00762	0.3	22.0
0.0381	1.5	0.75	0.01905	0.00762	0.3	23.8
0.03556	1.4	0.75	0.01905	0.00762	0.3	31.5

RESULT AND DISCUSSION

Simulation Task: This section presents the simulation relating to the outer radius of piezoelectric elements and its thickness. From Table 4 shown the outer radius range of 2.000”-1.400” with different value of inner radius and thickness to indicate the voltage output produce for the system.

From Table 4 also prove that the smaller outer radius, thicker piezoelectric ceramic crystal yields a higher voltage.

Figure 6 shows the output voltage of the system and have V_{peak} at 16.4V_{dc}. The outer radius for this piezoelectric is 2.0” and the thickness is 0.4”. The outer radius and the thickness of the piezoelectric is the largest and thickest piezoelectric element for the system.

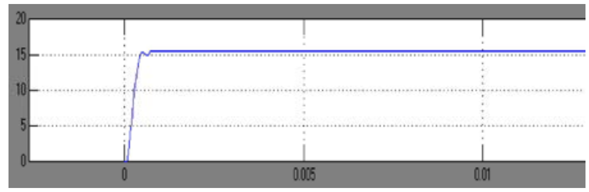

Fig. 6: Voltage output of the system (16.4V_{dc})

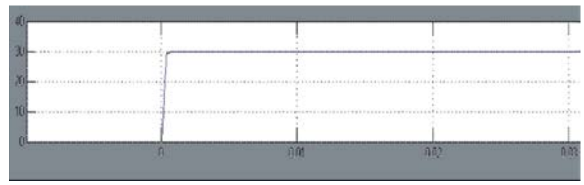

Fig. 7: Voltage output of the system (29.4V_{dc})

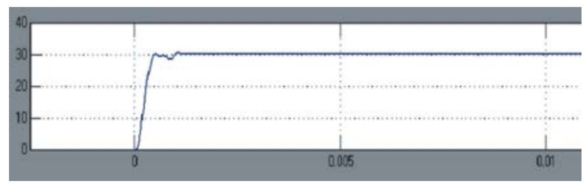

Fig. 8: Voltage output of the system (31.5V_{dc})

Table 5 summarized the effect of voltage output and power delivered when the inner radius and thickness kept constant at 0.75” and 0.4” respectively while the outer radius varied. It is found that for outer radius 1.55”, 29.4V_{dc} being produced and all the voltage output produced stable in nature.

From Figure 7 it shown that the output of the waveform is at 29.4V_{dc}. The output also trigger up every 0.3s due to footsteps per seconds. The Outer radius for this output is 1.55”, inner radius is 0.75” and the thickness is 0.4”.

Table 6 summarized the voltage output produced for outer radius 2.0” until 1.4” while the inner radius and thickness kept constant at 0.75” and 0.3” respectively for the piezoelectric element. It also indicates the decreasing value of outer radius while causing the voltage output to be higher.

From Figure 8 it shows that the output of the waveform is at 31.5V_{dc}. The output also trigger up every 0.3s due to footsteps per seconds. The outer radius for this output is 1.4”, inner radius is 0.75” and the thickness is 0.3”.

All result obtained are depict that the comparison of output when outer radius, inner radius and thickness varied. From results, it is learned that the more thickly a piezoelectric combine with smaller outer radius produced higher voltage output.

CONCLUSION

From the results obtained, this research has made the street lighting rechargeable and reducing the energy demand. The simulation results shows that the piezoelectric navy type II from Morgan Technical Ceramics thickness of 0.4 inch, with outer radius of 1.65 inch and inner radius of 0.75 inch is feasible of charging battery for street lighting and the voltage output produce are more than $24V_{dc}$.

Under dynamic stress, the piezoelectric power generator also produces a bidirectional output which is positive and negative peak [7]. Other than that resonator in this research also help to produce oscillating output waveform for the system. Resonator used as to improve the output of the system, since resonator acts as a spring for this research.

From analysis and simulations it is found that the smaller outer radius with the thickest piezoelectric element of piezoelectric to yield a higher voltage output. Analysis also shows that the smaller outer radius and thicker piezoelectric ceramic crystal produce high voltage output by the system. As stated before, the objective of this research is to produce voltage output more than $24V_{dc}$. Thus, from the simulation and analysis it shows that all the objectives of the research have been achieved.

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